

## **Nutritional and technological aspects of vegetable oils that stand out for the prevalence of medium-chain triacylglycerides: A review**

**Aspectos nutricionais e tecnológicos de óleos vegetais com predominância de triacilgliceróis de cadeia média: Uma revisão**

**Aspectos nutricionales y tecnológicos de los aceites vegetales con un contenido predominante de triglicéridos de cadena media: Una revisión**

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### **Abstract**

The nature of the fatty acid presented in each type of vegetable oil will determine the oil's characteristic. The purpose of this review is to describe the medium chain fatty acids present in vegetable oils absorption mechanism and their benefits for human body, combined with technological advantages in the preparation of food formulations. Highlighting how the source of the raw material and the extraction method interfere with the concentration of fatty acids present in the oils. It is a review of narrative literature, which used as a theoretical framework recent scientific articles in the English language. Oils derived from coconut, palm kernel, and babassu, for example, have a solid or semi-solid characteristic at room temperature. This happens due to the presence of saturated fatty acids with medium-length carbon chains, that is from 6 to 12 carbons. Although medium-chain fatty acids are saturated, they present characteristics that are different from other long-chain saturated fatty acids. They are quickly digested by the body, which favors the absorption and the using of these nutrients, leading an impact on diseases' control, such as obesity, diabetes and hypertension. In addition, due to their chemical structure, medium chain fatty acids can be used in the food industry as a substitute for animal fat, combining their nutritional benefits with technological advantage, being used in food preparations to impact texture, flavor, stabilize emulsions, and improve the rheological characteristics of the product.

**Keywords:** Obesity; Coconut oil; Kernel palm oil; Babassu oil; Medium-chain fatty acid.

### **Resumo**

A natureza do ácido graxo presente em cada tipo de óleo vegetal, irá determinar a característica desse óleo. O objetivo do estudo foi descrever o mecanismo de absorção dos ácidos graxos de cadeia média presentes em óleos vegetais e seus benefícios ao organismo humano, aliado aos benefícios tecnológicos no preparo de formulações alimentícias. Destacando como a fonte da matéria-prima e o método de extração interferem na concentração dos ácidos graxos presentes nos óleos. Trata-se de uma revisão de literatura narrativa, que utilizou como referencial teórico artigos

científicos recentes na língua inglesa. Óleos derivados do coco, palmiste e babaçu por exemplo, apresentam característica de sólido ou semissólido em temperatura ambiente. Isso acontece devido à presença predominante de ácidos graxos saturados com cadeias carbônicas de comprimento médio, ou seja, de 6 a 12 carbonos. Os ácidos graxos de cadeia média apresentam características distintas dos outros ácidos graxos saturados de cadeia longa, são rapidamente digeridos pelo organismo o que favorece a absorção e utilização desses nutrientes, exercendo impacto no controle de doenças como obesidade, diabetes e hipertensão. Além disso, devido a sua estrutura química os ácidos graxos de cadeia média podem ser utilizados na indústria de alimentos como substituto de gordura animal, aliando seus benefícios nutricionais aos benefícios tecnológicos, sendo empregado em preparações alimentícias para conferir textura, sabor, estabilizar emulsões e melhorar as características reológicas do produto.

**Palavras-chave:** Obesidade; Óleo de coco; Óleo de palmiste; Óleo de babaçu; Ácido graxo de cadeia média.

### Resumen

La naturaleza de los ácidos grasos presentes en cada tipo de aceite vegetal determina sus propiedades. El propósito de esta revisión es describir el mecanismo de absorción de los ácidos grasos de cadena media presentes en los aceites vegetales y sus beneficios para el cuerpo humano, además de los beneficios tecnológicos en la preparación de formulaciones alimentarias. Destacando la manera en que la fuente de la materia prima y el método de extracción interfieren con la concentración de ácidos grasos presentes en los aceites. Se trata de una revisión de la literatura narrativa, que utilizó como marco teórico artículos científicos recientes en lengua inglesa. Los aceites derivados de coco, palmiste y babasú, por ejemplo, son sólidos o semisólidos a temperatura ambiente. Lo anterior se puede deber a la predominar presencia de ácidos grasos saturados de longitud media, es decir de 6 a 12 carbonos. Aunque los ácidos grasos de cadena media son saturados, presentan características (propiedades) diferentes a otros ácidos grasos saturados de cadena más larga, pues son rápidamente absorbidos y digeridos en el organismo, lo que favorece el aprovechamiento de estos nutrientes, influyendo en el control de enfermedades como la obesidad, diabetes e hipertensión. Adicionalmente, por su estructura química, los ácidos grasos de cadena media pueden ser utilizados en la industria alimentaria como sustitutos de grasa animal, combinando sus beneficios nutricionales con beneficios tecnológicos al ser incluidos en preparaciones alimentarias con el fin de impartir textura, sabor, estabilizar emulsiones y mejorar las características reológicas del producto.

**Palabras clave:** Obesidad; Aceite de coco; Aceite de palmiste; Aceite de babasú; Ácidos grasos de cadena media.

## 1. Introduction

Vegetable oils can be extracted from vegetable raw materials such as grains, seeds, cereals, fruits and other food types (Costa et al., 2019). The main component of oils are lipids that account for different functions in the body, such as providing energy, contributing to hormone formation and producing satiety; in addition, they are of great importance for the food industry since they can change the flavour and texture of processed food. Lipids found in oils are mostly composed of both triacylglycerols and small amounts of mono and diacylglycerols (Kumar & Krishna, 2015).

The physical, chemical and nutritional properties of oils depend on the nature of fatty acids found in them, which, in their turn, are influenced by the source of oil's raw material. The raw material for oils can be influenced by the variety and maturation stage of the fruits, climate where it was cultivated other factors capable of interfering with the features of the vegetable raw material (Maruyama et al.2014).

Each fatty acid has a different feature, i.e., number of carbons in the chain, degree of saturation, which determines the chemical behaviour of this oil and its stability in the face of changes in temperature, storage and other factors (Dhamodharan & Bakthavatsalam, 2020).

Among saturated fatty acids, we can highlight those of medium-chain, which are found at high concentration in the composition of some vegetable oils such as coconut, babassu and kernel palm oil. The presence of medium chain fatty acids has straight impact on the absorption of these oils by the body, a fact that means several benefits to consumers' health (Figure 1). In addition to the nutritional aspects, the chemical structure of these fatty acids presents technological features such as low melting point, which cause these oils to solidify at temperatures below 25°C and to return to the liquid state when the room temperature increases – this process does not make these oils lose any technological or nutritional property(Kumar & Krishna, 2015) (Figure 1).This phenomenon results from the prevalence of medium-chain fatty acids( MCFA) in the composition of

these oils (Jeyarani et al., 2009).

The aim of the present review is to address vegetable oils that have high concentrations of medium-chain fatty acids (MCAF) in their composition, the features of these fatty acids and how they influence the physical-chemical properties of oils, as well as their nutritional impact on and health benefits to consumers.

**Figure 1:** Overview on the technological and nutritional features of medium-chain fatty acids extracted from vegetable oils.



Source: Authors.

Figure 1 presents a graphic summary of all issues covered in the review. The figure illustrates the main sources of raw materials used for oil extraction with medium-chain fatty acids (MCFAs) predominance, highlighting the nutritional and technological benefits associated with MCFAs use.

## 2. Methodology

A narrative review was carried out (Sant'Anna Ramos Vosgerau & Paulin Romanowski, 2014), through bibliographic research in different indexing bases, on topics related to the nutritional and technological properties of oils with predominance of medium chain fatty acids. In the search for scientific articles, the keywords "vegetable oils", "metabolic syndrome", "fatty acid nutrition and metabolism", "functional fatty acids", "medium chain fatty acid rheology" and "technological properties" were used of medium chain fatty acids".

In order to obtain reliable information on the topic, only scientific articles were searched in electronic databases such as: Scopus, Scielo, Science Direct, Web of Science and Wiley Online Library. The criteria adopted for the selection of articles included publications in the English language, preferably between the years 2015 to 2021, relevant and recent research in the nutritional and technological area on the use of medium-chain fatty acids.

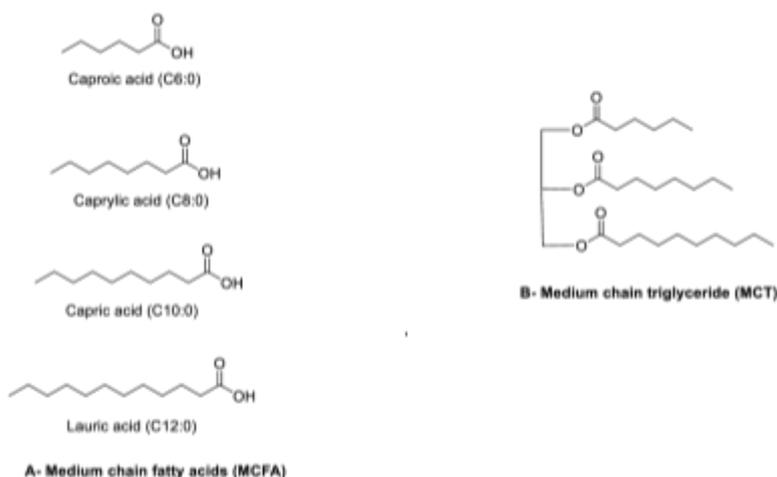
## 3. Results and Discussion

### 3.1 General aspects

Vegetable oils consist of triacylglycerides extracted from plant that present glycerol molecules linked to three fatty

acid molecules (Figure 2). Some oils, such as coconut, kernel palm and babassu oil, are mainly composed of medium-chain triglycerides such as caproic acid (C6:0) caprylic acid (C8:0), capric acid (C10:0) and lauric acid (C12:0), which are saturated fatty acids presenting carbon chains ranging from six to twelve carbons (Figure 2) (Norizzah et al., 2018).

**Figure 2:** Chemical structure of medium-chain fatty acids (A). Chemical structure of a medium-chain triacylglycerol (B).



Source: Authors.

Figure 2 shows the structural formula of medium-chain fatty acids, followed by the structure of a triacylglycerol composed of medium-chain fatty acids. Fatty acid structure influences directly its solubility, melting point, absorption, and other functions. Medium-chain fatty acids have low water solubility, which is a factor related to the presence of a hydrocarbon chain, increase in acyl chain and to less double bonds. It is also associated with the presence of the carboxylic acid group, which is polar and ionized at neutral pH (Ratnayake et al., 2001).

The melting point is also influenced by the length and degree of hydrocarbon chain unsaturation. Saturated fatty acids presenting from 12: 0 to 24: 0 carbons have wax consistency at room temperature (25 °C), whereas unsaturated fatty acids (at the same length) are oily liquids. Coconut oil has melting point close to 22.3 °C (Dhamodharan & Bakthavatsalam, 2020), Kernel palm oil presents melting point at approximately 28.2 °C and babassu oil has melting point ranging from 24 °C to 26°C. Soybean oil, which is composed of long chain unsaturated fatty acids, has melting point of -20 °C. This difference in melting points results from different fatty acid-molecule packaging degrees (Norizzah et al., 2018).

Carbon chain packaging is possible due to chain flexibility. Completely saturated compounds account for great hydrocarbon chain flexibility as rotation of the hydrocarbons is free around each carbon-carbon bond. The linear conformation is the most stable one, and it minimizes the steric impedance of neighbouring atoms. These molecules can group into almost crystalline arrangements - atoms along their entire length are at Van der Waals interaction with atoms of neighbouring molecules.

The double cis bond forces the hydrocarbon chain to fold in unsaturated fatty acids. Fatty acids with one or more of these folds cannot clump as tightly as fully saturated fatty acids, fact that makes interactions between them weaker. Since less thermal energy is needed to clutter these poorly ordered arrangements of unsaturated fatty acids, they have considerably lower melting points than saturated fatty acids presenting the same chain length (Heil et al., 2019).

### 3.1.1 Extraction method

Vegetable oil is extracted through different ways, the main extractions are artisanal, mechanical and made with solvent. Based on the artisanal extraction method, the fruit pulp is subjected to intensive cooking in container filled with water. After boiling the mixture, the supernatant oil is separated from the aqueous part. Then, the oil is left to dry over low heat until it loses opacity, the oil is filtered. The artisanal method has some drawbacks, such as low yield, product with opaque aspect and high humidity. Artisanal coconut oil must be centrifuged to allow better oil phase separation and waste extraction in order to avoid the oxidation process within few days (De Pinho & Souza, 2018).

Mechanical extraction can be carried out by using the pressing technique, without solvents; thus, the obtained product maintains its natural properties. However, as the result from its lower efficiency in removing oil from the fruit or seed, this extraction method can be combined to solvent extraction in order to increase yield. Press extraction does not generate oil and cake heating, since it only requires a press and an extractor cylinder (Bhatnagar et al., 2009; De Pinho & Souza, 2018).

Solvent extraction consists of putting an organic solvent in direct contact with the plant matrix. The oil derives from the evaporation of the solvent used in the liquid phase. This methodology is recommended for very unstable oils that do not handle temperature increase. Hexane, benzene, methanol, ethanol, propanol, acetone, pentane and several chlorinated solvents are the organic solvents mostly used in this process for oil extraction purposes. The difficulty in removing all residual solvent and non-volatile compounds that remain in the oil after extraction is one of the negative effects of using organic solvents (Nik Norulaini et al., 2009; Santos et al., 2013).

Virgin coconut oil, which is extracted from fresh coconut pulp. Coconut oil extraction process does not use heat treatment or food preservatives. It can also be called cold extraction, as the oil does not reach temperatures higher than 40 °C. Coconut milk is left to stand for 20–24 h, under favourable conditions (35–40 °C, 75% relative humidity). Autochthonous lactic acid bacteria, which have the ability to break protein bonds, act in the coconut milk mix by causing the separation of virgin coconut oil. The separated oil is filtered through sterile paper filter placed in a large funnel. Refined and deodorized coconut oil derives from the extraction of dehydrated copra oil – this process is followed by alkali refining, bleaching and deodorization (Kumar & Krishna, 2015).

Extraction can still be done by using the supercritical fluid method. Carbon dioxide is the most used solvent, mainly by the food industry, as it is not toxic, not combustible, available at high purity rates and at low cost, has low critical temperature (31°C) and critical pressure (74 bars) ‘which are advantages when it comes to the required energy and to the conservation of thermolabile substances’ has low boiling point, does not leave solvent waste in the extracted material and accounts for good extraction yield. When this method is used to purify edible oils, it presents high solvation power and does not have its properties changed (Nik Norulaini et al., 2009).

In Table 1, it is possible to observe that fatty acids are present in vegetable oils and also products of animal origin, in lower concentrations although. The vegetal source influences fatty acids composition and determines the physical characteristics of oil, for example, solidification temperature. The fatty acids concentrations in the oils do not present sudden variations when they are subjected to different extraction methods; however, the adopted method can influence the phytochemical compounds found in plants, which are transferred to the oil and can be lost after extraction (Srivastava et al., 2016). These compounds can also influence oil solubility depending on the applied temperature and pressure (Soares et al., 2007).

**Table 1:** Composition of fatty acids from different food sources.

Food Source	Extraction method	C6:0%	C8:0 %	C10:0 %	C12:0%	C14:0 %	C16:0 %	C18:0%	C18:1 %	C18:2 %	Reference
Coconut oil	solvent	0.35	7.87	6.07	49.55	17.03	8.02	2.71	7.01	1.39	Srivastava et al., 2016
		48.03	6.27	7.64	0.64	16.23	8.40	3.46	5.80	0.90	Marina et al., 2009
Coconut oil	Virgin	48.08	6.48	6.01	-	17.72	7.79	6.94	0.85	1.61	Zicker et al., 2019
		50.00	5.55	7.10	0.45	18.1	7.05	2.42	7.26	1.66	Srivastava et al., 2016
Coconut oil	Refined	47.42	6.53	8.24	0.63	18.26	9.33	2.68	5.25	1.57	Marina et al., 2009
		-	7.24	5.25	50.90	21.38	9.22	0.38	4.81	0.81	kumar & krishna 2015
Coconut oil	Supercritical fluid	42-47	8-10	10-12	-	21-23	7-9	1-2	3-5	0.5-1.5	Norulaine et al., 2009
Babassu oil	Cold Press	42.79	5.21	4.77	0.27	14.11	8.85	3.57	17.48	2.88	Ferrari & Soler 2015
Babassu oil	Solvent extraction	48.93	7.99	4.54	-	15.64	7.46	1.65	10.55	3.24	Santos et al., 2013
		47.42	6.46	8.06	-	15.47	7.60	2.81	10.28	1.90	D'Anton et al., 2011
		-	-	4.1	36.1	19.4	12.3	5.8	19.4	2.8	Oliveira et al., 2019
Kernel palm oil	Solvent extraction	0.32	3.24	3.6	47.73	15.91	8.25	2.45	15.18	3.22	Kiliç & Özer.,2019
palm oil	extraction	0.20	3.13	3.18	45.51	15.64	9.48	2.55	16.90	2.64	Rodrigues, 2010
		-	4.45	-	49.1	17.00	10.0	2.30	11.00	1.60	Halim et al., 2019
		-	3.01	3.06	47.85	17.25	10.31	2.63	14.43	1.19	Costa et al.,2019

Kernel palm oil	Supercritical fluid	-	2.33-4.34	2.56-4.37	39.4-45.5	15.9-17.25	9.44-10.31	1.14-3.35	17.9-24.3	0.9-4.36	Costa et al. 2019
Kernel palm oil	Inter esterified	0.17	7.06	7.97	39.97	12.46	7.52	1.31	13.84	8.17	Kiliç & özer, 2019
Cow milk	-	0.92	0.62	1.47	1.71	6.44	29.13	9.13	20.89	1.78	Rennó et al., 2013
Human milk	-	-	0.17-0.22	1.46- 2.00	4.24- 5.86	4.91- 6.80	18.60- 22.59	5.77- 6.25	-	-	Yuhās et al., 2006
Ghee Buffalo	-	1.02	0.47	0.97	1.55	9.64	33.13	13.07	22.49	0.67	Ali et al., 2020
Ghee Bovine	-	1.01	0.61	1.37	1.79	7.89	29.76	13.18	28.76	0.62	Ali et al., 2020
Anhydrous fat milk	-	1.76	1.28	2.91	4.89	13.00	35.20	10.24	-	1.51	Neves et al.,2020

Wherein: C6: 0- caproic acid, C8: 0- caprylic acid, C10: 0- capric acid, C12: 0- lauric acid, C14: 0- myristic acid, C16: 0 –palmitic acid, C18: 0- stearic acid, C18: 1-oleic acid, C18: 2-linoleic acid.  
 Source: Authors.

In addition to the extraction method, the variety of the raw material and the place of origin can influence the characteristics of these oils. Ferreira et al. (2019) and Kumar & Krishna (2015) evaluated the lipid profile of different varieties of coconut (*Cocos nucifera L.*) and observed that the composition of fatty acids in the triacylglycerol chains was not the same for all varieties. These variations in the concentration of fatty acids can also be seen in Table 1.

The composition of triacylglycerols has an impact on their molar mass, density, melting point, solubility, a fact that has a direct influence on the stability of oils against oxidative rancidity. This stability allows the use of these oils in confectionery products due to the increased shelf life of products without trans fatty acids (Jeyarani et al., 2009).

According to (Azeez 2007), the fatty acid profile of coconut oil can change depending on the season and the maturation of the nut, as well as the differences between the cultivars. Fatty acid rates can increase or decrease from small to medium cadence due to the maturity of the nut and the concentration of unsaturated fatty acids (Ferreira et al., 2019).

### 3.2 Nutritional Aspects

Closer attention has been paid to the role of fats and oils in modern diet in recent decades due to their high caloric contribution to the diet itself and to health issues associated with the growing concern about obesity. However, studies show that some specific saturated fatty acids account for a wide spectrum of critical functions in physiological activities, depending on the unsaturation length and degree of the hydrocarbon chains. Fatty acids are not only essential nutrients, but they can also modulate many human diseases and conditions (Legrand & Rioux, 2015; H. Lu et al., 2020).

#### 3.2.1 Absorption of medium-chain triglycerides

Lipid catabolism coordinates lipolysis, which is the hydrolysis of triacylglycerides into free fatty acids, which account for the peroxisomal and mitochondrial  $\beta$ -oxidation of fatty acids to produce chemical energy (ATP) and heat (Rial et al., 2020).

The digestive bioavailability of medium-chain triacylglycerides (MCT) is greater than that of long-chain triacylglycerides (LCT). The comparison between MCT and LCT has shown that MCT hydrolysis, which starts in the stomach, is faster and more complete than that of LCT, as well as its gastrointestinal transit speed is faster and its absorption occurs in the proximal portion of the small intestine, a fact that makes it faster and more efficient (Ferreira et al., 2003).

Fatty acids undergo different metabolic pathways depending on their saturation degree and on chain length. Medium-chain saturated fatty acids (carbon chains presenting up to 12 carbons) can be transported right to the mitochondria without the aid of membrane transporters. They are promptly absorbed by the enterocytes and transported directly to the liver by the blood in order to produce energy. On the other hand, long-chain fatty acids travel through the lymphatic system via chylomicrons to extrahepatic tissues where they can be stored in the form of triglycerides (Heil et al., 2019).

The transport of lipids in the body is overall described in the exogenous and endogenous metabolic pathways. The exogenous pathway represents the transport of dietary lipids from the intestine to the liver. The endogenous pathway describes the transport of lipoproteins synthesized in hepatocytes from the liver to peripheral tissues. Medium-chain fatty acids are easily transported in the plasma since they bind to albumin during the post-absorptive phase; they also take the portal vein and quickly reach the liver (Montgomery et al., 2019).

Approximately 80% to 100% of medium-chain fatty acid (MCFAs) found in the entire portal flow are captured by the liver and the remaining portion of them flows through the bloodstream and becomes available to peripheral tissues (Ronis et al., 2013; X. Lu, Chen, et al., 2019a). MCFAs are partially converted into ketone bodies and released into the blood due to fast metabolism of MCT in the liver. Approximately 10% of ingested MCFAs are detected as chylomicrons in postprandial venous blood (Ronis et al., 2013; Wang et al., 2016) and it turns medium-chain fatty acids into a fast source of energy (Yoshihara et

al., 2020).

The high intake of medium-chain fatty acids rich in triglycerides leads to the significant intracellular incorporation of them into chylomicrons (in the resynthesized triacylglycerol form). This incorporation likely depends on the consumed amount and distribution of medium-chain fatty acids in the ingested triacylglycerides (Heil et al., 2019).

### **3.2.2 Medium-chain fatty acid in lipid oxidation**

Mitochondria are important sites for lipid oxidation. Several mitochondrial metabolism markers are used to determine whether intracellular lipid levels can be related to differences in fatty acids size of the chain. Diets high in fat and MCFAs increase mitochondrial biogenesis in skeletal muscle (Ishizawa et al., 2015; Montgomery et al., 2019). In addition to the postprandial absorption pathway, MCFA effects on muscle mitochondrial biogenesis are affected by metabolic degradation of the liver (Thevenet et al., 2016). MCFAs induce much greater increase in the activity of the muscle oxidative enzyme (Montgomery et al., 2019) (Thevenet et al., 2016). A study carried out with sedentary individuals in the age group 40 and 60 years who received a diet rich in medium-chain fatty acids showed that exercising increases and improves the aerobic capacity in terms of oxygen transport and cardiac output capacity (Nosaka et al., 2020).

High fat-based MCFA diet increases the activity of the Citrate Synthase (CS) mitochondrial oxidative enzyme in both fast and slow skeletal muscle contractions (Ishizawa et al. 2015). However, based on the current results, MCFA-based diets increased the activity of the mitochondrial oxidative enzyme in slow muscle contraction. The ability of the muscle to increase mitochondrial concentration, density and oxidative enzymatic activity (e.g., CS activity) is an important muscle adaptation to resistance exercises. Oxidative enzyme activity, in its turn, is associated with significant mitochondrial biogenesis stimulation (Ströher et al., 2020).

### **3.2.3 Medium-chain fatty acid in obesity control**

Some studies have suggested that medium chain fatty acids are potential obesity control factors (Assunção et al., 2009; Zhou et al., 2017). Studies with humans and rodents have shown that MCFA induces higher energy expenditure than LCFA, but such an outcome has also been associated with lower adipose tissue accumulation (Ishizawa et al., 2015).

A study carried out with rats fed on diet rich in MCFA has evidenced that rats' body weight was lower when they fed on diet rich in MCFA than that of rats who did not. Rats who fed on long-chain fatty acids (LCFA), even at equal energy value, have shown that diets rich in MCFA can reduce fat accumulation. Plasma glucose concentrations were significantly higher in the LCFA group than in the MCFA group (Ishizawa et al., 2015; Turner et al., 2009). Such features are indicative that MCFA can be recommended as dietary supplement to prevent obesity and high fat diet-related diseases.

### **3.2.4 Medium-chain fatty acid for diabetes control**

Resistance to insulin is defined as the reduced ability of insulin to regulate the metabolism of carbohydrates and lipids in target tissues. It is one of the main metabolic obesity and type 2 diabetes issues.

Diets rich in MCFA reduce plasma glucose levels and improve insulin sensitivity in comparison to diets rich in LCFA (Ferreira et al., 2019; Turner et al., 2009). A study based on coconut oil addition to the diet showed increased fatty acids and triglycerides availability, and it may have changed glucose using in oxidative mitochondrial metabolism (Yoshihara et al., 2020), since metabolic changes related to glucose metabolism and resistance to insulin are closely associated with increased dietary fat intake.

Progressive resistance to insulin and the subsequent hyperglycaemia caused by high-fructose intake diet leads to

symptoms similar to those of hepatic steatosis, in rats (De Moura et al., 2008). Coconut oil supplementation reversed the hepatic steatosis condition in addition to having better resistance to insulin, lower glucose levels, higher HDLc levels and lower levels of total cholesterol and triacylglycerols. These outcomes are attributed to improvement in the hepatic steatosis-associated dyslipidemic condition (Narayanankutty et al., 2018).

Other studies have reported that diets rich in coconut oil have hypolipidemic activity mediated by its effect on lipid metabolism; they also have antidiabetic activity in diabetic models due to high fructose and fast MCFA absorption and metabolism. Narayanankutty et al. (2018) observed that diets rich in coconut oil have shown that MCFA improves fat's beta oxidation and protects individuals from liver disease caused by excess of fat (Ronis et al., 2013). MCFA markedly decreased the percentage of apoptotic and late cells necrosis in comparison to the long-chain fatty acid. Moreover, it did not induce apoptosis, oxidative stress and chronic inflammatory responses in liver cells of individuals with steatosis. (Wang et al., 2016).

### **3.2.5 Medium-chain fatty acid to control cardiovascular diseases**

Postprandial triglycerides (TG) are among factors accounting for the development of cardiovascular diseases (Jackson et al., 2012). TG levels reflect the presence of remaining lipoproteins that can cause atherosclerosis (Austin et al., 2020). MCFA reduced postprandial TG levels since it was transported through portal circulation and was little incorporated to chylomicrons. MCAF fast beta oxidation in the liver results in decreased TG synthesis (Jackson et al., 2012). There was significant reduction in serum TG levels due to MCFA diet intake in comparison to the LCFA diet.

The MCFA diet did not affect the total levels of free fatty acids. Postprandial hypertriglyceridemia appeared to be related to fasting atherogenic dyslipidaemia, increased stress oxidation and impaired haemostasis. All together, these factors can contribute to impair the vascular function and to the development of atherosclerotic cardiovascular disease. Thus, MCFA oil consumption can limit the entry of circulating chylomicron-TG and, consequently, reduce the residence time of remaining lipoproteins rich in atherogenic TG (Lee et al., 2019). However, the study by Austin et al. (2020) did not demonstrate any beneficial effect of MCFA-rich diets on postprandial TG reduction. These effects were only observed when MCFA was combined to fish oil.

The Table 2 shows clinical studies *in vivo* and *in vitro* on the use of triglycerides in the diet. Featuring type of used oil, dosage administered and observed benefits.

**Table 2:** Physiological effects of dietary MCFA / MCT observed in clinical studies.

Assessed Component	Declared Composition	Dosage/ period	Assessed Individual	Observed Effect	Reference
MCFA	C8:0- C18:3	45% to 60% calories of diet / 21 days	Mice	Adiposity reduction and glucose intolerance improvement.	Turner et al.,2009
MCFA	MCFA-rich oil	60% of calories of diet/ 4 weeks	5-week-old male Wistar rats	Increases the activity of the mitochondrial oxidative enzyme	Ishizawa et al.,2015
MCFA	C8:0- C18:3	45% of calories of diet/ 8 weeks	Mice (absence of Gpr84 protein)	Mitochondrial regulation, insulin response	Montgomery et al., 2019
MCT	Nestle Nutrition (82%MCT /18% Bovine tallow)	20%, 35%, 50%, 65% for 21 days	Male rats	Metabolic syndrome, hepatic steatosis	Ronis et al., 2013
MCT	FA C8:0	12 months	Mice	Treatment for Acil -CoA dehydrogenase deficiency	Tucci et al., 2015
MCT	FA C8:0, C10:0	10%, 20%, 30% p/p	Mice	Obesity control, body weight reduction	Zhou et al., 2017
MCT	40:60 ratio of MCT C8:10	5% of diet	Wistar rats	Social behaviour	Hollis et al., 2018
MCT	C8:0, C10:0 –Nestlé Switzerland	30g/ 2.000kcal	18-65 year old individuals BMI $\leq 5.0 \text{ kg / m}^2$	Glucose and insulin metabolism	Thomas et al., 2019
MCT	FA C8:0, C10:00	6g/ day	40–60 year old sedentary individuals	Increased aerobic capacity, oxygen transport and cardiac output capacity	Nosaka et al., 2020
MCT	Dermol M-5 (ALZO international )	45kcal (40%MCT - 60%C:8 and C:10/ 5% TCL-Soy)	Mice	Hepatic thermogenesis	Rial et al., 2020
Coconut oil	Virgin commercialisation	5% and 15% of basal diet- 10 days	Wistar rats	Antioxidant and hepatoprotective	Famurewa et al., 2017

Coconut oil	Santa Cruz Biotechnology, TX, USA	4.5g/Kg- 180 days	Wistar rats	Hypertrophy	Quitete et al., 2019
Coconut oil	Organic commercialisation	1.3 and 9 g/kg- 12 weeks	Mice	Inflammatory and metabolic dysfunction	Zicker et al., 2019
Coconut oil	Virgin	2ml/kg -30 days	Rats	Metabolic changes due to lipid accumulation in the liver	Ströher et al., 2020

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Wherein: MCFA: medium chain fatty acid, MCT: medium chain triacylglycerol, FA: fatty acid. Source: Authors.

Table 2 shows some *in vivo* and *in vitro* clinical studies about MCFAs use in diet and its benefits. From these studies was highlighted the type of MCFAs applied, whether it was pure or associated with other oils, and its necessary period of use. Studies show a range of benefits associated with MCFAs use, better insulin response, better obesity control, better arterial blood pressure, being used isolated or mixed in high concentration in oil.

### 3.3 Technological Aspects

The concern of consumers to have a healthier life shows the search for products with less fats, mainly of animal origin (Kiliç & Özer 2019). In order to meet consumer demands, there is a growing interest in studying vegetable oils to partially or totally replace animal fat in order to improve the textural quality, appearance and oxidation stability of products (Goibier et al., 2020; Nguyen et al., 2021)

#### 3.3.1 Application of the MCFA in food formulations

Bhatnagar et al., (2009) tested blends of vegetable oils such as flaxseed, rice, sunflower and soy added with coconut oil. They evaluated the oxidative stability of mixes and observed that blends with coconut oil showed greater oxidative stability because it is less likely to form peroxide due to the presence of medium chains.

Coconut oil was also used by Szafrńska (2020) in cheese sauce formulations to replace anhydrous milk fat. Visually the sauces with milk fat and the sauce with coconut oil showed differences, however the technological characteristics such as stability, viscosity, water activity of the coconut oil made it a good alternative for the production of analogues to the cheese sauce (Szafrńska et al., 2020).

Ali (2020) showed used coconut oil in vegetable meat formulations as ingredient added to unsaturated oil in order to add texture and sensory aspect similar to that of beef. Saturated and unsaturated oils are mixed to form white dots in hamburgers and vegetable sausages, and to simulate animal fat (Chatterjee et al., 2020; Guimarães et al., 2007).

Kiliç et al. (2019) assessed animal fat replacement by kernel palm oil in sausages, which showed excellent sensory results and no significant differences between treatments focused on colour, odour, flavour, juiciness, texture and general acceptance. Kiliç et al. (2017) also assessed animal fat replacement by kernel palm oil in sausage and found that bovine fat replacement by kernel palm oil can be a strategy to improve nutritional quality without having negative effect on quality features. In addition, meat fat replacement by kernel palm oil has not significantly contributed to lipid oxidation development (Kiliç & Özer 2017, 2019).

Goibier (2020) used triacylglycerides that crystallize at 20 °C, such as coconut oil, as a stabilizer for a double (W1 / O / W2) emulsion. Emulsions are complex liquid dispersions of oil globules containing small aqueous droplets. These systems have great potential to arrest and control the release of aroma and flavor in the field of food production, to protect and arrest probiotics, to mask flavor and to reduce the fat content in foods. Initially obtained emulsions were relatively fluid, but after a few hours at 20°C, they presented considerable yield, strength and firmness. As crystallization proceeded, solid bridges formed between aggregated crystals that further strengthened the network. The W/O emulsion obtained was stabilized only by triglycerides; it did not demand the addition of surfactants, resisted osmotic shocks and was not subjected to coalescence under storage conditions, at room temperature (Goibier et al., 2020).

#### 3.3.2 Stability of oil-in-water emulsion systems

Most industrialized foods are oil-in-water emulsions, such as beverages, sauces and ice cream, and are also used in the pharmaceutical, cosmetic and oil industries. Naturally, this system does not remain stable, making them dependent on the use

of emulsifiers (H. Lu et al., 2020).

Many emulsions based on coconut oil and water as vegetable drinks are being introduced to the market, it is necessary that this emulsion remains stable. Emulsification is characterized by the dispersion of immiscible liquid in other liquids based on the use of high shear energy. Requires the use of an emulsifying agent to avoid separation of the subsequent phase (Ramisetty et al., 2015). In addition to the type of emulsifier, the mixing method, pressure of homogenization influences the stability of the emulsion, as shown in table 3.

In general, the mixing process is one of the most important unit operations that influence the size of the drops and the stability of the emulsion. Studies have already shown the effect of different homogenization pressures and their response to the stability of the emulsion (Cheng et al., 2020; Matsuura et al., 2015). Other types of processing have been used to prepare ultrasonic emulsions that have shown excellent results in reducing particle size and excellent morphologies: particles of uniform size that favor emulsions and, consequently, avoid coalescence (Gulão et al., 2018; X. Lu, Su, et al., 2019b; Ramisetty et al., 2015; Saricaoglu et al., 2018). The final average size of the drops and their distribution depend on the dissipation of energy, which, in turn, depends on the intensity of the cavitation (Lu et al., 2020).

Emulsifying agents are responsible for the development of bonds between two immiscible liquids, acting as a surface-acting agent. The hydrophilic head of the emulsifying agent has a good connection with the aqueous phase and the lipophilic tail connects with the oil phase to bring these two liquids together. The lipophilic tips of the tail move towards the center of the oil drop and the hydrophilic layer goes to the emulsifying agent around the surface of the spherical oil droplets which prevent the oil droplets from coalescing and stabilize the emulsion. (Ramisetty et al., 2015). Therefore, using sufficient amount of emulsifying agent allows the emulsion to be made more stable for long periods of time (Table 3).

**Table 3:** Coconut oil-in-water-type emulsions stabilized with different types of emulsifiers.

Emulsifying agent	Source of emulsifying agent	Emulsifier dosage	Formulation of the assessed emulsion	Mechanical process applied to emulsion	Effect observed in the emulsion	Reference
Lactoferrin	Bovine milk	3% p/v	10% coconut oil/ 90% water	Ultrasound 30 KHz/3min-25°	Emulsion stability during 7-day storage.	Gulão et al., 2018
Albumin and Globulin	Coconut pulp	1% p/p	1:9 coconut milk/ water	Homogenizer 3000psi- 2x	The globulin fraction is more effective in stabilizing the emulsion.	Patil & Benjakul, 2017
Pre-gelatinized Rice Starch	Rice	5% to 7%	10% coconut oil	Ultra-Turrax at 8.000, 11.000, and 15.000 rpm/ Calorimetry 30°c and 50°C	It showed better results in both heating and stirring conditions than the other oil.	Yulianingsih & Gohtani, 2020
Egg yolk	Egg	6% w/w	Coconut oil + Palm oil diaglycerol (0%, 10%, 20% ,30%)	Agitator 12.500rpm/6min	Samples with coconut oil alone were more stable for 30 days.	Ng et al., 2014
Tween 80 and Span 80	-	0.02, 0.04, 0.05, 0.07, 0.09, 0.11 and 0.12w/w	0.1%, 0.2%, 0.3% and 0.4 % of coconut oil.	Ultrasound Processor -20 KHz and 750W -20 KHz 1500W -20 KHz 1000W	The greater the power of the processor, the smaller the size of fat droplets, the better the stability of the emulsion.	Ramisetty et al., 2015
WPC 80%	Whey	2%, 3%, 4%, 5%, 6%, 7%, 8 %	10% Anhydrous milk fat 10% milk and coconut oil	Agitator 10.000rpm / 2min 80°C	Both are efficient in producing cheese sauce.	Szafrańska et al., 2020
Sucrose esters (SE)	Sucrose	0.25% in oil weight	5% oil in coconut milk	Agitator 11.200rpm / 3min	Emulsions with sucrose esters were thermally more stable than emulsions with Tween 60.	Ariyaprakai et al., 2013
Glyceryl monostearate (GME)	Fat	0-0.40%	10% coconut oil 4% protein 14% sucrose 0.25% carboxymethylcellulose	Pasteurization 65 ° Homogenizer of 2 pistons 20 Mpa in the first stage and 4 Mpa in the second stage.	GME reduced fat cell deformation and inhibited partial coalescence	Cheng et al., 2020

Corn grain and starch with different amylose levels	Corn	0.3 to 0.5g/L	6% Coconut cream (30.8% fat, 3.9 protein)	Mixer 13,500rpm / 3 minutes - sterilization after filling 115 ° C / 20 min	The higher the amylose content, the higher the viscosity and the better the thermal stability.	M. Lu et al., 2020
Glyceryl monostearate (GME) Waxy Starch	Fat and corn	0.3 to 0.5g/L	6% Coconut cream (30.8% fat, 3.9 protein)	20KHz high intensity ultrasound	Ultrasonic treatment resulted in particle size reduction to monomodal size distribution.	X. Lu, Chen, et al., 2019a
Dextrose (DE) and Maltodextrose (MC)	-	27.5% p/p- (2,10,25 DE)	20% w/w coconut oil	High pressure homogenizer - 60Mpa in the 1st stage and 40Mpa in the 2nd stage	The best results were obtained by using 10% dextrose associated with sugar stearic acid esters	Matsuura et al., 2015

Wherein: w / v- weight / volume ratio, w / w: weight / weight ratio. Source: Authors.

The substitution of animal fat for vegetable oils such as coconut oil and palm kernel oil in food products can present some difficulties because vegetable oils have different characteristics from animal fats and present differences in the homogenization of the mixture. Table 3 provides a compilation of scientific studies on the total or partial replacement of vegetable oils in food emulsions. Highlighting the type of emulsifier used, the dosage needed to stabilize the emulsions, the physical homogenization treatments, and the effects observed in the emulsion.

#### 4. Conclusion

This review explored the technological and nutritional functions of vegetable oils that have medium-chain fatty acids in their composition. Fatty acids can be free or observed in their triacylglycerol form. They are intrinsically connected to the control of some diet-related diseases and to their technological applications in the food industry. Experimental studies have shown that dietary MCFA suppresses fat deposition through thermogenesis and fat oxidation both in animals and humans. In addition, several reports have suggested that MCFA has the therapeutic advantage of preserving insulin sensitivity in type 2 diabetes' animal and human models. MCTs enable technological benefits for the food industry, since they provide texture and flavour to products.

Further long-term studies are needed to test the cumulative effects of MCFA as a source of dietary lipids. Long-term tests can clarify whether continued use of MCFA maintains the nutritional benefits found and whether they are viable, comparing to daily consumption of other triglycerides such as long-chain fatty acids or unsaturated fatty acids.

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