J Food Sci Technol (August 2023) 60(8):2143–2152
https://doi.org/10.1007/s13197-022-05499-w

REVIEW ARTICLE

Triglycerides of medium-chain fatty acids: a concise review

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Revised: 19 April 2022 / Accepted: 21 May 2022 / Published online: 22 June 2022

Abstract Medium-chain triglycerides contain medium-chain fatty acid esterified to the glycerol backbone. These MCFA have a shorter chain length and are quickly metabolized in the body serving as an immediate energy source. They are known to have good physiological as well as functional characteristics which help in treating various health disorders. Naturally, they are found in coconut oil, milk fat, and palm kernel oil, and they are synthetically produced by esterification and interesterification reactions. Due to their numerous health benefits, MCT is used as a functional or nutraceutical oil in various food and pharmaceutical formulations. To increase their nutraceutical benefits and food applications MCFA can be used along with polyunsaturated fatty acids in the synthesis of structured lipids. This review aims to provide information about triglycerides of MCFA, structure, metabolism, properties, synthetic routes, intensified synthesis approaches, health benefits, application, and safety of use of MCT in the diet.

Keywords Medium-chain triglyceride · Medium-chain fatty acid · Nutraceutical · Esterification · Interesterification · Coconut oil

Abbreviations

MCT	Medium-chain triglycerides
MCFA	Medium-chain fatty acids
MUFA	Monounsaturated fatty acids
PUFA	Polyunsaturated fatty acids
EFA	Essential fatty acids
SFA	Saturated fatty acids
LCPFA	Long-chain polyunsaturated fatty acids
LCT	Long-chain triglycerides
LCFA	Long-chain fatty acids
USFDA	United States Food & Drug Administration
GRAS	Generally Recognized as Safe

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Introduction

Lipids are considered one of the major food constituents required for the normal functioning and growth of the human body. Lipids are required by human beings from all age groups starting from infants till old age people. They serve as the source of essential fatty acids in the human diet and also serve as a concentrated source of energy-giving 9 kcal/g. Most lipids in the diet are in the form of triglycerides, in which three different fatty acids are esterified to the glycerol backbone, these fatty acids can be SFA, MUFA, and, PUFA. Each fatty acid has its own chemical and physical characteristics and is metabolized and absorbed by the body depending on its chain length. The fatty acid composition of triglyceride is largely decided by its source which can be a plant source or animal source. Triglycerides from plant sources are generally liquid at room temperature because they contain MUFA/PUFA. But, triglycerides from animal sources are generally solid at room temperature because they contain SFA (Dorni et al. 2018). Food processing industries make use of fat/oil for making processed food and even at home cooking is done using fat/oil. These dietary fats used at home or in industry contains LCFA. A diet containing a high amount of dietary fat or excess intake of these dietary fats is related to various diseases like cardiovascular

diseases, obesity, cancer, and increased health issues which are mostly seen in the developed countries (Liu et al. 2020). Consumer across the globe needs a better alternative that will be healthier and beyond that, a 'Nutraceutical' MCT emerged as a 'Nutraceutical fat' having many health benefits (St-Onge and Jones 2002). MCT contains all three positions on the glycerol backbone occupied by medium chain-fatty acids. MCFA includes caprylic acid (C8:0), capric acid (C10:0) and lauric acid (C12:0) (Table 1). There are limited natural sources that contain medium-chain triglycerides which include coconut oil, palm kernel oil,and bovine milk (Jensen 2002). Synthetically MCT are synthesized by an esterification reaction between MCFA and glycerol (Jadhav and Annapure 2021a; Jadhav et al. 2021a). In comparison with long-chain saturated triglycerides, the MCT give less calorie i.e., 8.4 kcal/g are liquid at ambient temperature, and has a shorter chain length (Fig. 1) (Ingle et al. 1999). These unique properties of MCT make it an ideal choice for health-conscious consumer and because of such unique physicochemical properties, MCT are metabolized in different ways unlike long-chain triglycerides (Babayan 1968; Rial et al. 2020). MCTs were launched as an exceptional source of energy for various clinical nutrition like malabsorption of fat, atherosclerosis, obesity, parenteral nutrition, severe hyperchylomicronemia etc., and they were also used in infant formulations (Bach et al. 1996; Carlson et al. 2015; Zhang et al. 2016; Augustin et al. 2018; Hollis et al. 2018; Avgerinos et al. 2020; Izgelov et al. 2020; Ashton et al. 2021). US FDA has assigned GRAS status to the use of MCT in food products (Traul et al. 2000). In spite of having so many good physicochemical properties which make it superior to other fats, MCT has certain limitations in food applications. A diet containing only MCT can make human body to have deficiencies of essential fatty acids since MCT lack essential fatty acids and PUFA. This can be overcome by making designer lipid having MCFA at *sn*-1,3 position and EFA or PUFA at *sn*-2 position on the same glycerol backbone, thus providing the nutrition from both the fatty acids. Japan was the first country to use designer lipid (Jadhav and Annapure 2021b) (Fig. 1) as a healthy cooking oil which does not result in fat accumulation when taken into diet. These are available as cooking oil under the brand name Resetta in Japan since 2000. This review aims to highlight medium chain triglyceride which has many benefits over

Table 1 General information of medium chain fatty acids

Medium chain fatty acid	Number of carbons	Molecular formula	Structural formula	Systematic name	Molecular weight (g/mol)
Caproic acid	C6:0	$C_6H_{12}O_2$	$CH_3(CH_2)_4COOH$	Hexanoic acid	116.15
Caprylic acid	C8:0	$C_8H_{16}O_2$	$CH_3(CH_2)_6COOH$	Octanoic acid	144.21
Capric acid	C10:0	$C_{10}H_{20}O_2$	$CH_3(CH_2)_8COOH$	Decanoic acid	172.26
Lauric acid	C12:0	$C_{12}H_{24}O_2$	$CH_3(CH_2)_{10}COOH$	Dodecanoic acid	200.31

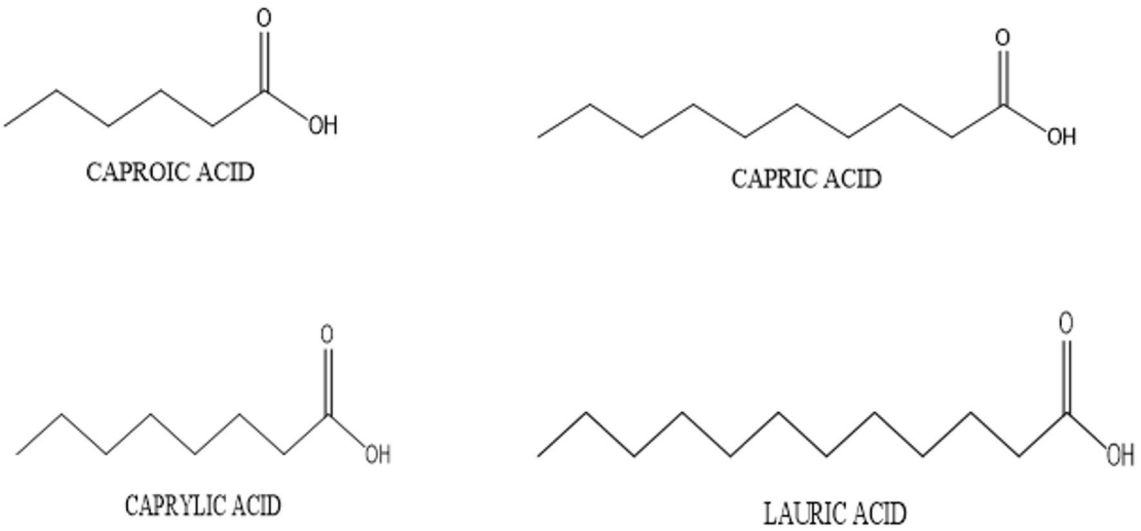

Fig. 1 Chemical structure of medium chain fatty acids

traditional fat. This review also covers various sources and synthetic routes to produce medium chain triglycerides, intensification approaches to get maximum yield in less time, health benefits of MCT, application and safety of MCT. MCT has been a research topic of great interest lately, hence this review will be of great interest to food scientists and technologists across the globe.

Sources of medium chain triglycerides

Naturally MCT are found in coconut oil, palm kernel oil, and also in milk fat. Coconut oil contains a larger fraction of lauric acid than other MCFA. Specifically, in bovine milk caproic, caprylic and capric constitute about 4–12% of total fatty acids whereas lauric acid constitutes about 3–5%. These MCT from natural sources are hydrolysed to obtain MCFA which are then again esterified to obtain MCT. In case of coconut oil, copra is obtained by sun drying, this copra is pressed using a solvent to obtain the oil. The obtained oil is referred to as virgin coconut oil, this oil is then subjected to a refining process, which can be used for food and nutraceutical application. This oil is known as Refined, bleached and deodorized (RBD) oil. The oil obtained from coconut contains about 46–54% lauric acid, 5–10% caprylic acid and 5–8% capric acid. Similarly, oil obtained from palm kernel contains 45–50% lauric acid, 3–5% caprylic acid, 3–4% capric acid and 0.1–0.5% caproic acid. The amount of MCFA present in milk fat is very low i.e., lauric acid, capric acid, caprylic acid, caproic acid constitute about 2.5–4%, 1.5–3.5%, 0.5–1.6%, 0.5–3.0% respectively (Ransom-Painter et al. 1997; Ibrahim et al. 2003).

Synthetic routes

Since the natural sources of MCT are limited and demand is increasing, hence MCT is obtained through a synthetic route by the esterification reaction between alcohol (glycerol) and fatty acids (MCFAs) using an enzyme or chemical catalyst. The enzymatic esterification process for the synthesis of MCT uses lipases from various sources like animals, plants, and microorganisms (Mehta et al. 2021), these lipases are specific to the fatty acid, i.e., they can be stereospecific or regiospecific. Lipases that are specific to fatty acid will tend to have an affinity for that particular fatty acid regardless of their position on the glycerol backbone. For example, lipase from *Penicillium rocquefortii* shows a higher affinity towards SCFA, lipase from *Geotrichum candidum* shows more affinity towards a fatty acid that contains unsaturation at the *cis*-9 position (Jensen 1983; Mase et al. 1995). Stereospecific lipases are specific to positions on glycerol backbone. They are specific to *sn*-1 and *sn*-3 position on the glycerol backbone. Their specificity varies at *sn*-1 and *sn*-3 positions, for example, lipase from *Candida antarctica B* is specific to *sn*-3 position whereas lipase from *Pseudomonas fluorescens* is specific to the *sn*-1 position (Jensen et al. 1982; Lavayre et al. 1982; Uzawa et al. 1990; Rogalska et al. 1993). Regiospecific lipase has an affinity towards position *sn*-1,3 and *sn*-2. Lipase from *Aspergillus niger* has affinity towards the *sn*-1,3 position and cannot act on *sn*-2 position because of steric hindrance and lipase from *Candida parapsilosis* shows more affinity towards *sn*-2 position than *sn*-1,3 position (Riaublanc et al. 1993). There are non-specific lipases that do not have an affinity for specificity for a particular position on the glycerol backbone, they interact with fatty acid regardless of their position and produces triglyceride with a random distribution of fatty acid to the glycerol backbone. For example, lipase from *Candida cylindraceae* is not specific to any position, and also lipase from *Staphylococcus aureus* is also non-specific (Macrae 1983). These specific and non-specific enzymes are used for attachment of fatty acid on glycerol backbone and even hydrolysis of fatty acid from the glycerol backbone. As it is done when oil is extracted from natural sources like coconut oil, the triglycerides are first hydrolyzed and then re-esterified to get MCT. Enzymatic esterification process has many advantages over chemical esterification process, as chemical esterification reactions are carried out at higher temperature using acid catalyst, there is formation of many unwanted by-products, and quality of triglyceride is also low as compared with one formed from enzymatic processes. In chemical esterification additional processes like washing, bleaching, deodorization, and purification is required (Sivakanthan and Madhujith 2020). The chemical catalyst used are very reactive and they should be handled carefully for large-scale production of triglycerides. The acid catalyst may lead to an explosion when it comes in contact with water. Since enzymes are very specific to the position, the enzymatic synthesis does not form any undesirable by-products. The enzymatic esterification reaction is generally carried out at a moderate temperature below 50 °C, thus posing less harm and enzymes are not toxic like a chemical catalyst. The chemical or enzymatic esterification reaction (Fig. 2) forms water as a by-product, this water should be continuously removed from the reaction mixture, so that reaction proceeds in the forward direction. Esterification reaction for synthesis of the triglycerides is highly reversible in presence of water. Table 2 shows comparison between chemical and enzymatic esterification process. There are many studies reported in the literature for synthesis of MCT using either chemical or enzymatic routes. Boulos (2013) reported synthesis of MCT using metal catalyst. The author reported maximum yield of triglycerides of caproic acid as 85% with use of tungsten oxide as catalyst, whereas triglyceride of caprylic acid gave maximum yield of 93% with tungsten oxide and triglyceride of capric acid

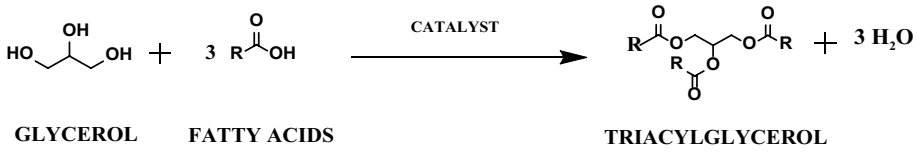

Fig. 2 General esterification reaction for synthesis of triglycerides

Table 2 Points of comparison between chemical and enzymatic esterification reaction

Characteristics	Chemical	Enzymatic
Type of catalyst	Chemical catalyst like sulphuric acid, hydrochloric acid, sodium methoxide, para-toluene sulphonic acid etc	Lipases from animal, plant and microorganisms
Temperature	Reaction is usually carried out at higher temperature (150–200 °C)	Reaction is carried out at moderate temperature below 50 °C
Bi-product formation	Many undesirable by-products are formed and hence product needs purification	Insignificant or no by-products are formed
Eco-friendly	No, since it produces many by-products which are toxic in nature	Yes, it is cleaner and eco-friendly
Challenges	It produces toxic products and final product is dark in color hence processes like bleaching, deodorization, purification is necessary	Little change in temperature, pH of reaction medium affects the activity of enzyme
Rate of reaction	Rate of reaction is faster; hence less time is required for completion of reaction	Rate of reaction is very slow; hence more time is required for completion of reaction
Economical aspect	Chemical catalyst are inexpensive, hence the process is economical as compared with enzymatic process	Enzymes are very expensive, which increases the cost of production

gave highest yield of 93%, 92%, 91%, 90% with tungsten oxide, tungsten chloride, calcium oxide, zinc chloride respectively. Triglycerides of lauric acid gave highest yield (%) of 78% with calcium oxide as catalyst. Author reported different yield with use of different catalyst at 160–180 °C in 22–24 h. Thus, in esterification reaction the yield of final triglyceride will depend on the type of catalyst used and activity of catalyst will be dependent on the substrate of reaction. The chemical esterification reaction gives yield more than 90% at higher temperature with reaction time of more than 20 h. In order to reduce this reaction time and increase the yield there is recent advancement in the synthesis of MCT with application of microwave and or ultrasound irradiation technology (Table 3). In recent study MCT (tricaprylin) was synthesized using amberlyst – 15 which is an acid resin catalyst with application of microwave. The authors reported conversion (%) of more than 95% in just 16 min (Jadhav and Annapure 2021a). Microwave was used as an intensified approach for synthesis of triglyceride. In microwave the microwave energy is directly coupled with the reaction mixture and there is formation of hotspots which results in enhanced rate of heat and mass transfer (Fig. 3) (Surat et al. 2012). Another approach for intensified synthesis is with use of sonication process. In ultrasonication there is formation, growth and collapse of cavities which results in generation of shock wave which travels through the reaction mixture and creates turbulence which increases rate of mass transfer thus achieving intensified yield of product in short reaction time (Gharat and Rathod 2020). There are many recently published studies on ultrasound assisted synthesis of MCT. Mohod et al. (2018) reported intensified synthesis of MCT using chemical catalyst in presence of ultrasound. The authors reported yield (%) of 77.8% in 5 h of ultrasound irradiation at 90 °C. In order to highlight the intensification approach by ultrasound and microwave Mohod et al. (2017) reported synthesis of medium chain triglyceride using microwave, ultrasound and conventional approaches. The authors reported that microwave assisted synthesis gave 97.8% yield in 20 min, ultrasound gave 97.3% yield in 120 min whereas conventional process gave only 40% yield in 180 min. Similar studies using chemical catalyst and intensification approach were reported by Deshmane et al. (Deshmane et al. 2008; Jadhav and Annapure 2021c). Langone et al. (2002) reported synthesis of MCT with use of immobilized lipase. The authors reported that higher selectivity of lipase was observed at 5–9% concentration and at different temperature i.e., 70 °C for capric acid, 80 °C for lauric acid and 90 °C for myristic acid. Further the authors reported 50%, 70% and 70% as yield (%) of triglycerides of capric acid, lauric and myristic acid respectively. The difference in the yield (%) is due to affinity of lipases towards the particular substrate. The enzymatic synthesis is time consuming; the enzymatic process requires around 48 h for completion because in enzyme catalysed reaction the rate of mass transfer is very slow, however this can be overcomed with use of newer synthetic technologies like ultrasound,

Table 3 Synthetic routes for synthesis of medium chain triglycerides

Reaction	Substrate	Catalyst/enzyme	Reaction temp (°C) and time	Intensification approach	Yield (%)	References
Esterification	Caproic acid, caprylic acid, capric acid, lauric acid and glycerol	Tungsten oxide, calcium oxide, tungsten chloride	160–180 °C in 22–24 h	Conventional reaction	90–93%	Boulos (2013)
	Caprylic acid and glycerol	Amberlyst-15	80 °C in 16 min	Microwave assisted synthesis	99.7%	Jadhav and Annapure (2021a)
	Lauric acid and glycerol	Sulphuric acid	90 °C in 300 min	Ultrasound assisted synthesis	77.8%	Mohod and Gogate (2018)
	Lauric acid and glycerol	Sulphuric acid	90 °C in 1. 20 min 2. 120 min 3. 180 min	1.Microwave assisted 2.Ultrasound assisted 3.Conventional synthesis	1. 99.7% 2. 97.5% 3. 40%	Mohod and Gogate (2017)
	Caprylic acid (60.35%), Capric acid (38.11%), lauric acid (1.15%) and glycerol	Sulphuric acid	90 °C in 300 min	Ultrasound assisted synthesis	98.5%	Deshmane et al. (2008)
	Caprylic acid and glycerol	Sulphuric acid, hydrochloric acid, PTSA, Sodium methoxide	170 °C in 9 h	Ultrasound assisted synthesis (More et al. 2017a)	96.6%	More et al. (2017a)
	Capric acid, lauric acid, myristic acid and glycerol	Immobilized lipase (Lipozyme IM 20)	60–90 °C in 26 h	Conventional synthesis	50%-Tricaprin 70%- Trilaurin 70%-Trimyristin	Langone and Sant'Anna (2002); Langone et al. (2002)
	Caprylic acid and glycerol	Novozyme 435, Lipozyme IM RM	50 °C in 6 h	Supercritical CO_2 Technology	97.3%	More et al. (2018)
	Caprylic acid and glycerol	Novozyme 435 and Lipozyme RM IM	50 °C in 7 h	Ultrasound assisted synthesis	94.8%	More et al. (2017b)
Interesterification	Medium chain triglycerides and soyabean oil	Lipozyme 435	90 °C in 300 min	Conventional synthesis	74.9%	Lu et al. (2017)
	Coconut oil	Potassium methoxide	40–60 °C in 12 h	Conventional synthesis	24%	Nugrahini and Soerawidjaja (2015)

supercritical carbondioxide. One such recent study by More et al. (2018) reported that with the use of supercritical carbondioxide at 100 bar pressure for 60 min at 50 °C has been shown to intensify yield (%) of triglyceride of caprylic acid by enzymatic esterification using immobilized enzymes. The authors reported intensified yield of 97.3% in 6 h of reaction time. The supercritical carbondioxide increases the diffusivity of the enzyme, which result in increase in rate of mass transfer, thus the reaction is pulled in forward direction and supercritical CO_2 is a green alternative to organic solvents usually used in enzymatic synthesis. Similarly, ultrasound is also used to intensify the yield of MCT in less reaction time. More et al. (2017b) reported intensified synthesis of triglyceride of caprylic acid by enzymatic esterification using Novozyme 435 and Lipozyme IM RM with 70%ultrasound duty cycle at 50 °C. Author reported maximum yield (%) of 94.8% in 420 min. MCT can also be synthesized by interesterification reaction between two triglycerides. In interesterification the fatty acids may change position on same glyceride molecule or there may be interchange of fatty acid between two triglyceride molecules (Sivakanthan and Madhujith 2020). These reactions are also catalysed by enzyme or chemical catalyst, mostly alkali metals are used for chemical interesterification reaction (Pires et al. 2008). But here also enzymatic process is preferred for synthesis if end application is meant for food or nutraceutical products.

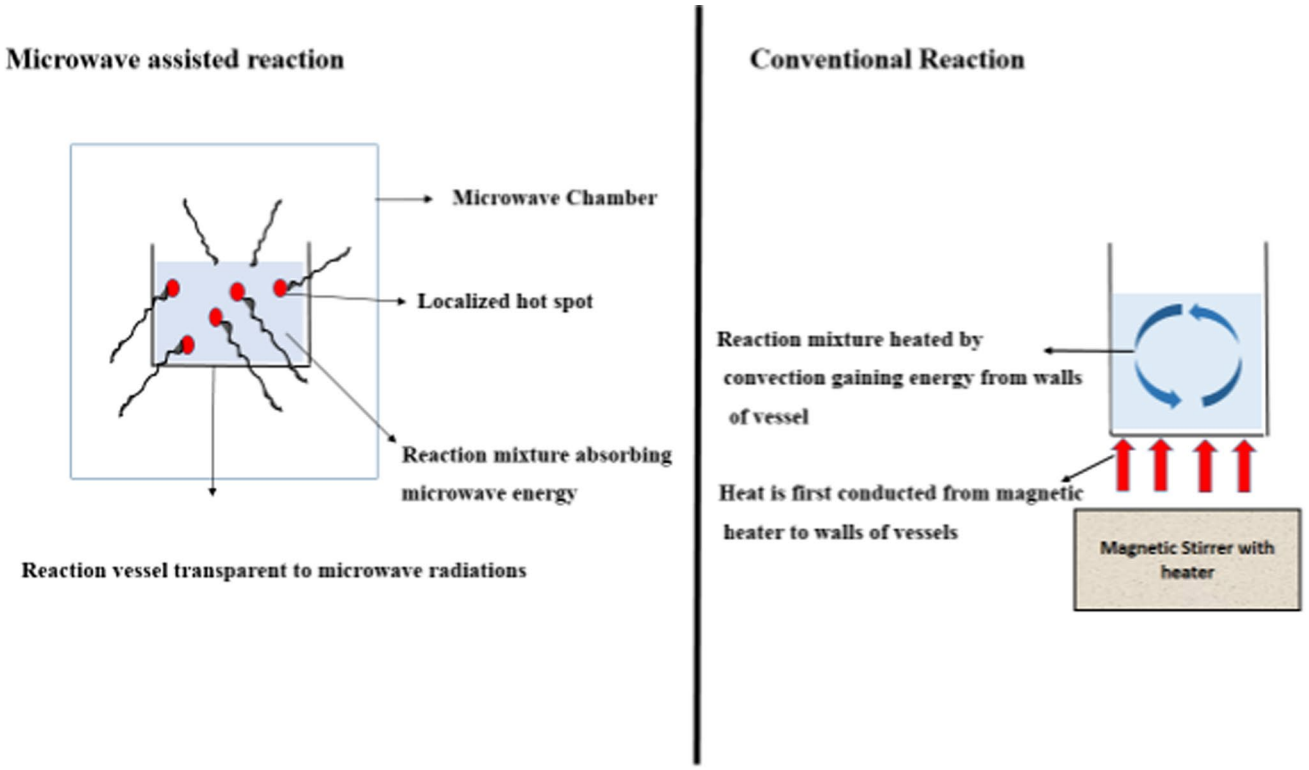

Fig. 3 Figure representing comparison between microwave and conventional reaction

Lu et al. (2017) reported synthesis of MCT by interesterification reaction between MCT and soyabean oil using Lipozyme 435. The authors reported yield (%) of 74.9% at 90 °C in 300 min of reaction time. The interesterification reaction may produce triglyceride molecule enriched in MCFA with one LCFA. Interesterification of coconut oil produced a triglyceride containing MCFA, this chemical interesterification reaction resulted in reshuffling or exchange of fatty acid with on the glyceride of coconut oil, thus giving a new triglyceride molecule with different fatty acid composition (Nugrahini and Soerawidjaja 2015).

Metabolism of medium chain triglyceride

MCT contain MCFA attached to glycerol molecule. The metabolism, digestion and absorption of MCT is different than that of LCT. Human endogenous enzyme lipase brings about hydrolysis of MCT. After hydrolysis the MCFA are released from glycerol backbone and because of its hydrophilic nature and shorten carbon chain these MCFA are directly transported via hepatic portal vein to liver. These fatty acids undergo β-oxidation process. This quick metabolism of MCFA results in formation of ketones body. These ketone body act as an immediate energy source to body. The hydrolysed medium chain fatty acid does not go to lymphatic system for re-synthesis of triglyceride molecule which has ability to be stored in the form of adipose tissue as fat, leading to obesity (Babayan 1968).

Health benefits of medium chain triglycerides

MCT were first launched as a source of energy in 1950. Since MCT are metabolized in different way they provide immediate energy and can be used to control obesity. MCT has high satiety value, which prevents over consumption of food (Kinsella et al. 2017). Zhang et al. (2015) reported that diet rich in MCT can lead to increase in fat oxidation and increase in energy expenditure in healthy adults fed with 2% MCT in diet for 3 months. MCT serve as an immediate energy source for sports person, athletes and also for humans having inability in metabolizing sugar due to old age. Consumption of MCT is diet is related to increase psychological health by boosting memory. A recent study on rats showed that diet rich in MCT can reduces anxiety and leads to improve social behaviour in rats (Hollis et al. 2018; Ashton et al. 2021). These effects are closely related to metabolism of MCT which generates ketone body namely β-hydroxybutyrate. Increase in formation of this ketone body results in such positive effects (Reger et al. 2004). MCT is very effective in managing epilepsy. The ketone bodies

generated after metabolism of MCT are transported to brain cell shows good results in reduction of seizures as compared to ketone bodies generated by glucose metabolism. MCT is also found to be effective against SARS Coronavirus-2. MCT is able to change the metabolism of lipids in virus. Virus replicates quickly and for this replication energy is needed which is extracted from long chain fatty acids. Long chain fatty acids are also needed for attachment of virus envelope with the host. MCT decreases formation of long chain fatty acid thereby making it unavailable to virus, leading to death of virus. MCFA released from glycerol backbone after lipase hydrolysis are believed to have antimicrobial properties. MCFA destroys the bacterial colony in intestinal tract by decreasing the pH. Recent research reported that 3% MCT supplement results in decreasing the total coliform bacteria present in rectum and colon. MCT can also be used as an effective antibiotics against the bacterial growth (Yen et al. 2015). But to use MCT as antibiotics needs further study as this is just a single study reported in literature for MCFA as potential antimicrobial agent.

Application

MCT is available in the market in the form of liquid oil (Table 4) which is largely used for therapeutic purpose and as a potential agent against obesity. MCT is also used as a salad dressing oil, it is used in yogurt, shakes, smoothies etc. MCT is also used as a cooking oil, there are certain brands available in market like Viola oil which is a blend containing about 65–70% MCT along with small amount of plant sterols, Delta oil which is a blend of MCT and canola oil with plant sterols. The physical blend of MCT along with other oil and plant sterol will give additional benefits of fatty acids from both the oil and the plant sterols will regulate the level of cholesterol in human body. MCT are also converted in to powdered form by spray drying for their better application in food products. Interesterified designer lipids produced contains medium chain fatty acid at *sn*-1, 3 position and long chain fatty acid at *sn*-2 position (Jadhav et al. 2021c). Such modification of triglyceride molecule produces a new triglyceride enriched in MCFA which can be used in confectionaries, bakery, as a better substitute to plastic fats (Heydinger and Nakhasi 1996). The di and monoglycerides of MCFA are also a good emulsifiers and can be used in making flavour emulsion having higher stability and these flavour emulsion can be used in bakery and beverage industries (Jadhav et al. 2021b). Since, MCT provides immediate energy when taken in diet, MCT can be added to food like cookies, biscuits, jellies, puff pastries for the patients suffering from critical illness and cannot metabolize carbohydrates easily. MCFA can be incorporated in designer lipid along with EFA and can be used for patients having cardiovascular problem, obesity, cancer, inflammation etc. MCT are hydrophilic as compared with LCT; hence they can be effective solvent to dissolve food colour, flavour etc. Thera are studies which have shown that the MCT show anti-bacterial activity and are even active against viruses. Malaysian palm oil board have recently notified that they will be making palm oil MCT based anti-viral drug against covid-19. Even Philippines which are largest producer of coconut have initiated their clinical trials to see effectiveness of virgin coconut oil against covid-19. Thus, MCT is an excellent lipid which can be used in formulation of

Table 4 Commercially available MCT products in market

MCT oil brand	Application	Producer
MCT oil	Act as a fuel to brain and body	Nature way, USA
Powdered MCT Oil	Ketogenic diet	Quest Nutrition USA
MCT Oil (mixture of C8 and C10)	Food applications like bakery and confectionary	AAK Kamani, India
Joymix MCT Oil	For weight management	Malaysia
Keto products	Source of energy	360 Nutrition, USA
Keto organic MCT Oil	Used for weight loss	Ancient Nutrition, USA
MCT powder	Help to control cardiovascular diseases	Ogranika, Canada
Liquid MCT Oil	Supplement to be used in food formulation	Supplement manufacturer, UK
Spring valley oil	Management of weight and for athletes	Spring valley, USA
Soft gel (MCT Oil)	Improved fat metabolism	Carlson Lab, USA
Melrose MCT powder and MCT oil	Energy for brain and body	Melrose, Australia
MCT Oil	Source of energy	Bioglan, Australia
Max-C8	Proper metabolism, digestion, energy, weight management	Zenwise health, Germany
Pure tricaprylin oil	Weight management	Weight world, UK
Diet MCT Oil	Nutraceutical fat and source of energy	Diet works, USA

various food products; thus, consumer will get processed food with added benefits of MCT in it.

Safety of medium chain triglyceride

MCT has been the interested area of research for food scientist. But there is lack of knowledge about the dosage and ill effect of MCT on human body. Safety and toxicity of MCT still remains an unexplored area. There is one study reported in literature which demonstrates that the designer lipids with 30% MCFA can help in reducing weight without any adverse effect on the body of mice. There are some reports available in literature demonstrating the effect of MCFA on increasing high density lipoprotein but the research lack in providing evidences of effect of these fatty acid on the level of low-density lipoprotein and on level of total cholesterol. Food Scientist should carry out extensive research in this area to find out how MCFA effects total cholesterol level in body. MCT cannot be used as a single substitute for traditional cooking oil. MCT need to blended in certain amount with other edible oil and then it can be used for cooking and frying food because it generates higher amount of smoke when heated due to presence of MCFA and they easily form foams. This can be overcomed by designing of designer lipid having combination of MCFA and PUFA attached to single glycerol backbone.

Conclusion

MCT are lipids with multiple health benefits owing to its fatty acid composition which are metabolized in such a manner that it produces ketone bodies which serves as a quick energy source and there is no reformation of triglyceride which accumulate as a fat. These MCFA are found in coconut oil, milkfat and palm kernel oil only. Due to limited natural sources and increasing demand, these are synthetically made by esterification and interesterification reaction using enzyme or chemical catalyst. Use of MCT in to foods like confectionary, cookies, biscuits, plastic fats etc. reduces the calorific value of food thereby managing diseases like obesity. The application of MCT in cooking and frying can be increased by synthesis of designer lipid having MCFA and PUFA or essential fatty acid esterified on same glycerol backbone. So, that the nutrition of PUFA and MCFA can be enjoyed in a single triglyceride molecule and also the problem of foam formation and low smoke point in frying will be overcomed. Still, there need to extensive research in the area to know the exact effect of MCFA on the total cholesterol level in body and what ill effect does MCFA cause to body when taken in high amount because of their saturation. Thus, by overcoming these lacunas, food processing industries will be able to serve the consumer with processed food containing functional or nutraceutical MCT.

Acknowledgements Author is thankful to Department of Science and technology, Government of India for providing DST- Inspire fellowship for doing doctoral research.

Author contributions H.B.J.: Conceived, did the critical review of literature and wrote manuscript. U.S.A.: Supervision, Proof reading.

Funding Author is thankful to Department of Science and technology, Government of India for providing DST- Inspire fellowship for doing doctoral research.

Data availability Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest The authors confirm that they have no conflicts of interest with respect to the work described in this manuscript.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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