Journal Homepage: -www.journalijar.com
INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)
Article DOI:10.21474/IJAR01/7775
DOI URL: http://dx.doi.org/10.21474/IJAR01/7775
ISSN NO. 2320-5407

RESEARCH ARTICLE

LITERATURE REVIEW ON STRUCTURED LIPIDS AS A HEALTHY ALTERNATE FOR THE CLASSICAL COOKING OILS.

Montaser. A. Mohamed, Shahat saber and Salma FoadGomaa.
Innovation – R&D center- Savola Foods Company, Cairo, Egypt.

Manuscript Info

Manuscript History

Received: 26 July 2018
Final Accepted: 01 September 2018
Published: September 2018

Keywords:-
Medium-chain triglycerides oil (MCT), Medium-Long chain triacylglycerils, (MLCT) , Structured oils , Dietitian , low calories oil.

Abstract

Structured triacylglycerolsLipids differ from conventional triacylglycerols, becausethe medium-chain fatty acids (MCT) esterified to the glycerol skeleton of Long chain triglycerides (LCT) to yield a new oil called medium –long chain tri glycerides (MCLT). MLCT oils are absorbed inthe intestines via portal blood as free fatty acids; absorption pathways arealso conventional with long-chain triacylglycerols.

Medium- and long-chain triacylglycerol (MLCT) is a modified lipid containing medium- chain (C6-C12) and long-chain fatty acids (C14-C24) in the same triacylglycerol (TAG) molecule. It can be produced either through enzymatic (with 1,3 specific or nonspecific enzyme) or chemical methods. The specialty of this structured lipid is that itis metabolized differently compared to conventional fats and oils, which can lead to a reduction of fat accumulation in the body. Therefore, it can be used for obesity management. It also contains nutritional properties that can be used to treat metabolic problems. (1)This review will discuss on the previous research and applied work done on the synthesis and application of MLCT, its production methods especially viaenzymatic inter-estrification processes and its applications in food industriesThe MLCT .oil which is addressed in this thesis is coming under the edible oils & fats categories called **structured lipids .**

Introduction:-

Structured lipids

Structured lipid is a lipid that has been modified from its nativeform either biologically with enzymes such as lipase or chemically with sodium methoxide as catalyst. These modifications will result in changes in fatty acid composition, fatty acid position in a TAG molecule, physicochemical properties such as melting properties, solid fat content (SFC), oxidative stability, iodine value, viscosity, and saponification number to enhance its functionality.Sometimes, structured lipid with nutritional value can alsobe obtained through these modifications. Modification of lipidcan also be done to produce either zero or low calories lipid tocater for the growing consumers' interest for healthier food andto control the worldwide obesity problem.

In other context (7) ,Memorial University of NewfoundlandThe term ''structured lipid'' (SL), very broadly defined, refers to acylglycerolswhose fatty acid composition or distribution has been altered by enzymatic or nonenzymatic catalysis, or any of a number of biological or physical methods (8). The products of acidolysis and

Corresponding Author:- Montaser. A. Mohamed.
Address:- Innovation – R&D center- Savola Foods Company, Cairo, Egypt.

transesterification are thus structured lipids. More specifically, this term is often applied to acylglycerols in which some of the long-chain fatty acids at the sn-1 and -3 positions have been replaced by medium-chain length ones, generally caprylic acid (8:0) or capric acid (10:0). In these positions, medium chain fatty acids are readily released from fats and oils in the gut by the action of (1,3-positionally specific) pancreatic lipase and absorbed. Medium-chain fatty acids are directly metabolized for energy rather than deposited as depot fat. Thus, structured lipids containing them provide readily available energy and have a reduced tendency to foster obesity. They are desirable dietary components for those requiring high-density energy sources, such as athletes and individuals recuperating from burns. The presence of some degree of long-chain fatty acid content in SLs is desirable to provide a source of essential fatty acids, especially linoleic acid (18:2). Substantial work has been conduced to investigate and optimize SL production from vegetable oils. Animal fats have also been shown to be substrates for SL production. Thus, the introduction of caprylic acid into the sn-1 and sn-3 positions of an unsaturate-rich fraction of tallow (9),(10) and of unfractionated chicken fat have been described(11)

A structured, lipid-containing dairy fat is covered by aU.S. patent (12) .

The invention relates to a trans-esterification product of a mixture of fatty acids and triglycerides, including milk fat, in the form of cream or butter as the main component. The product has nutritional applications and may also be used as an enteral or parenteral supplement.
Other than MCT oils as an example of structured lipids , the common scientific terminology of Structured lipids means to any TAG in which specific fatty acids have been placed at specific positions on the glycerol backbone of the TAG.(6). This is done in order to confer specific functional, nutritional or medicalProperties.

FAO/WHO definition of structured lipids:
Structured lipids (SL) or structured triacylglycerols (ST) may be broadly defined as triacylglycerols that have been altered or restructured using natural oils and fats. The earliest example of ST is the development of medium chain triglycerides (MCT). Using coconut and palm kernel oil, caprylic acid C8:0 and capric C10:0 are liberated. MCT are produced by esterification of these fatty acids with glycerol. The most widely available MCT have a C8:0:C10:0 ratio of 10:30. MCT also have the trade name Captrin®. One of the earliest uses of SL was in enteral and parenteral nutrition, followed by its application in a range of clinical settings including prevention of thrombosis, improved nitrogen balance, and enhanced immune (19) as per FAO foods and nutrition .

How structured lipids (SL) are manufactured ?
Structured lipids can be produced by interesterifying a mixture of conventional fats and oils of interest using chemical or enzymatic methods. Chemical methods provide random distribution of different fatty acids on the glycerol backbone, whereas enzymatic reactions could be position specific, affording controlled production of triacylglycerols with desired configuration (6)

Interesterification involves rearrangement or randomization of acyl residues in triacylglycerols with the fats and oils taking on new properties. 'Tailored fats' (fats with specific nutritional or textural properties) are easily obtained during this phase. The raw materials and processing conditions can be controlled or manipulated to produce a fat that has specific desired characteristics. The most widely used class of interesterification in the food industry is trans-esterification, where the ester bonds linking the fatty acids to the glycerol molecule are broken to release the fatty acids. The liberated fatty acids are then randomly shuffled in a fatty acid pool and re-esterified in new positions, either in the same or in a different glycerol molecule.(8)

Applications of structured lipids :
(Geoff Talbot-Oxford brookes university – School of life science) (6)
• Functional uses
• Margarine fats
• Plastic fats for margarine bases
• Hardstocks to structure margarine
• Cocoa butter equivalents
• StOSt TAG
• Nutritional uses
• Enteral and parenteral nutrition
• Combinations of medium chain and long chain fatty acids

• Infant nutrition
• TAG with C16:0 in the sn-2 position to mimic breast milk
• Weight loss – or weight management(2)

Medium chain fatty acids (MCFA):
Medium-chain fatty acids (MCFA) with C6-C12 carbon chain length is more rapidly metabolized than LCFA.Due to its small sizeand greater solubility compared to long-chain fatty acid (LCFA),MCFA is transported directly to the liver via portal vein to undergo beta oxidation process producing ketones, thus providing a rapid source of energy. MCFA also causes an increase in the diet-induced thermogenesis and satiety(2), (23).

In contrast, LFCA needs to be cycled back into the intestinal lymphatic ducts and transportedas chylomicron to the throracic ducts into the systematic circulationand deposited in the body as fat. As such, medium-chaintriglyceride (MCT) has been used for years to treat patients with malabsorption of fat problems and provide instant energy to the athletes. However, as MCT contain solely of MCFA, it lacks essential fatty acid. Besides, MCT is also not suitable to be used for cooking purposes such as frying oil due to foam formation.

Hence, LCFA is incorporated in the MCT molecule to overcomethese weaknesses. This has led to the development of a new typeof structured lipid, called medium-and long-chain triacylglycerol(MLCT).
In MLCT, each individual triacylglycerol (TAG) molecule contains.both the MCFA and LCFA. This can either be producedvia lipase-catalyzed reaction of acidolysis, esterification, or interesterification(3) ,(20), (33).
Lipase, which is nonspecific,will give randomly structured MLCT consisting of 6 configurations,which are MLM, MML, LLM, LML, LLL, and MMM(Figure 1). However, when 1,3 specific enzyme is used, it will give
the desired structured MLCT (4).

In the individualMLCT TAG molecule, the LCFA is usually contributedby the common vegetable oil (such as canola, soybean, cottonseed,sunflower, peanut, olive, corn, safflower seed, rice bran, andsesame seed oil) while MCFA is contributed either by mediumchain triglyceride (MCT) (such as coconut or palm kernel) or fattyacids such as caprylic acid, respectively. The presence of LCFA helpto increase the smoke point of the MCT, making it feasible forfrying purposes (5) .

Medium-chain fatty acids (MCFA), mainly C8 and C10, obtained by hydrolysis ofcoconut oil, is re-esterified with glycerol to form a mixture of randomized medium-chaintriglyceride (MCT) through a method developed by Babayan (13). MCTs areabsorbed and oxidized rapidly with an energy rated at 34.7 kJ/g. A number of medicaland infant food formulations have MCTs as the principal source of fat supplementedwith polyunsaturates(14)
In a field study by Intengan et al. (15).

Astructured (interesterified) 75 coconut oil–25 corn oil preparation gave betterweight gain and nutritional recovery, vis-a´-vis a polyunsaturated vegetable oil,when given to malnourished children as supplemental fat source in their diet.

Another area of current research is development of structured lipids where GLAis combined with a fatty acid of omega-3 family, preferably EPA or DHA, intoone triacylglycerol molecule. Structured lipids can be produced by interesterifyinga mixture of conventional fats and oils of interest using chemical or enzymaticmethods. Chemical methods provide random distribution of different fatty acidson the glycerol backbone, whereas enzymatic reactions could be position specific,affording controlled production of triacylglycerols with desired configuration (16).
Interesterification using the chemical method usually involves a reaction betweentwo oils using metal alkoxide (sodium methoxide) as a catalyst. The unreacted fattyacids are removed by vacuum distillation. The alternative and more researched processinvolves acidolysis using lipases. In this process, either pure fatty acid is reactedwith a triacylglycerol molecule or relatively rich fraction of fatty acid of interestis taken/prepared before acidolysis reaction.The structured lipids have unique chemical, physical, or physiologic propertiesthat are not observed by simply blending mixtures of the starting fats and oils (17).

Structured lipids containing both omega3long-chain PUFAs, possibly from seal blubber oil, or their omega 3 concentrates, andmedium-chain fatty acids (MCFAs), which are saturated fatty acids with 6–12carbon atoms, have been produced. Enzyme-catalyzed synthesis of structured lipidshas been proposed, with commercial lipase

preparations . The final products,with reduced calorie, exhibit the combined health benefits of long-chain PUFAsand MCFAs, which are believed to possess many unique nutritional and metabolic characteristics(18).

Reduced- calories structured lipids are functioning as fat substitutes .For several years, structured lipids with less than 9 kcal/g have been on the market.These engineered lipid molecules contain fatty acids that are less digestible tocreate a reduced-calorie content. These low-calorie TAGs are characterized bythe presence of short-chain fatty acids (SCFAs) or medium-chain fatty acids(MCFAs) and long-chain fatty acids (LCFAs) in a single TAG structure. The caloriccontent of constituent SCFAs is lower compared with that of their LCFA counterparts.

The products have all the functional properties of full-calorie fats, includingtheir ability to act as carriers for fat-soluble ingredients. Reduced-calorie structuredlipids are intended for use in baking chips, coatings, dips, bakery and dairy products,or as cocoa butter substitutes.

Medium-Chain Triacylglycerols (MCTs)

Medium-chain triacylglycerols (MCTs) contain predominantly 8-carbon (caprylic)and 10-carbon (capric) saturated fatty acids esterified to the glycerol backbone ofTAGs. The primary sources for MCTs are fractions of coconut and palm kerneloils. Hence, MCTs are manufactured from these oils via hydrolysis followed byfractionation of the resulting fatty acids to concentrate caprylic and capric acids,and re-esterification with glycerol to form new TAGs (73, 74).Caprylic and capricacids comprise more than 96% of the fatty acids in MCT preparations. MCTs arereadily hydrolyzed by digestive enzymes,to produce MCFAs. The fatty acid end products are rapidlyabsorbed into the bloodstream (75). MCFAs do not require carnitine to cross thedouble mitochondrial membrane of the hepatocyte, thus they quickly enter the mitochondriaand undergo rapid b-oxidation. Hence, MCFAs are used as immediatesources of energy by the liver, yielding fewer calories per gram than LCFAs. Thegross energy content of MCTs is 8.3 kcal/g vs 9 kcal/g for fat or LCTs. However,the net caloric energy value of MCT preparation is 6.8 kcal/g (76). MCTs arerelatively stable at high temperatures and are less susceptible to oxidation (77).MCTs are much more soluble in water than LCTs. MCTs are a translucent andodorless liquid at room temperature. Although completely saturated, it is not solidin consistency like other saturated fats, because of the shorter chain lengths of thefatty acids within the oil.MCTs were originally developed for therapeutic purposes to provide a source ofenergy for individuals with compromised gastrointestinal systems; thus, they arebeneficial for AIDS and cancer patients, premature infants, burn victims, and individualswith shortened bowel syndrome. MCTs have been used extensively in themanufacture of parenteral and enteral nutrition formulations. MCTs are beneficialfor such applications because they are more readily hydrolyzed and metabolizedmuch more rapidly than LCTs. MCTs have specific nutritional applications suchas infant formulas, energy bars and drinks, geriatric preparations, and sports nutritionproducts. In addition, they are used as carriers for colors, flavors, and vitaminsand provide gloss and prevent sticking on confectionery products. It is reported thatfeeding diets, wherein a fat source of LCTs was replaced with MCTs, to laboratoryanimals and humans resulted in decreased body weight gain and reduced fat deposition(78, 79). Such results have led to the suggestion that replacing conventionalsource of dietary fat, which composed primarily of LCTs, with MCTs may yieldfood with lower caloric content. In the sports world, MCTs have been positionedas an easily absorbed and oxidized fuel source and have been marketed to bodybuilders and athletes as a fat source that is less likely to deposit as body fat.

Safety of MCTsin direct food application:

The safety of mediumchaintriacylglycerol (MCTs) in dietary oil has been debated, and associated effectson cholesterol metabolism remain unclear. Although some studies have shown that MCTs are essentially nontoxic, noncarcinogenic, and nonmutagenic for human consumptionwith a safety level up to 1 g/kg (58), other studies have indicated that MCToil-containing diets can increase blood cholesterol levels (59). MCTs, on a percent energy basis, have half the potency of palmitic acid (C16:0) in raising plasmacholesterol(59). Palmitic acid (C16:0) can lead to increases in blood cholesterol levels; however, when ingested in a diet that contains a recommended intake of C18:2,n-6, the effect on both total and LDL cholesterol levels are minimized(60). This has been shown with fat blends, such that hypercholesterolemia was not observed in animals fed either butter or tallow fat sources that were blended with soybean oil in a low-cholesterol-containing diet (61, 62). In gerbils and monkeys, the relative ratio between C14:0 to C18:2 n-6 fatty acids as well as dietary cholesterol are important factors in modulating increases in serum cholesterol levels (63, 64).

Intake of saturated fat sources has also been associated with insulin resistance,leading to altered glucose metabolism, type II diabetes, and impaired glucosetolerance(65). Comparatively, saturated fat has a more deleterious effect on fat-induced insulin sensitivity than both mono- and polyunsaturated fat sources (65).Higher intakes of saturated fat and trans-fat adversely affect glucose metabolism and insulin resistance, whereas higher intakes of polyunsaturated fat and possiblylong-chain n-3 fatty acids are beneficial (66). Within the category of saturated fats, dietary saturated, short-chain, and o6 fatty acids have been found to have the most deleterious effects on insulin action associated with insulin sensitivity, asopposed to medium- and long-chain fatty acids and o3 fatty acids (67). Intramuscular triacylglycerol (MTG) and elevated plasma free fatty acid (FFA) levels also have roles in insulin-mediated glucose uptake, reflecting a pivotal role of the high saturated fatty acid content in the MTG (68). Changing dietary fat quality by substituting saturated for monounsaturated fat can impair insulin sensitivity, as saturated fat has a greater deleterious impact on insulin sensitivity (69). For example, substituting a monounsaturated fatty acid diet (MUFA diet) for a saturated

fatty acid diet (SAFA diet) has been shown to be favorable for only those subjects that had a lower-than-average total fat intake. This intervention improved insulin sensitivity, but had no effect on insulin secretion. Notably, the addition of n-3 fatty acids to MUFA and SAFA diets affected neither insulin secretion nor insulin sensitivity (69).

Food applications of MCFA/MCT :

Medical and Infant Food Formulations:

Medium-chain fatty acids (MCFA), mainly C8 and C10, obtained by hydrolysis ofcoconut oil, is re-esterified with glycerol to form a mixture of randomized mediumchaintriglyceride (MCT) through a method developed by Babayan(70). MCTs areabsorbed and oxidized rapidly with an energy rated at 34.7 kJ/g. A number of medicaland infant food formulations have MCTs as the principal source of fat supplementedwith polyunsaturates(71). In a field study by Intengan et al. (72) astructured (interesterified) 75 coconut oil–25 corn oil preparation gave betterweight gain and nutritional recovery, vis-a´-vis a polyunsaturated vegetable oil,when given to malnourished children as supplemental fat source in their diet.

Medium –long chain triglycerides (MLCT)Oils :

MLCT oils is an abbreviation for medium long chains fatty acids triglycerides .Medium-chain fatty acids (MCFA) with C6-C12 carbon chainlength is more rapidly metabolized than long chain fatty acids LCFA ,due to its small sizeand greater solubility compared to LCFA , MCFA is transported directly to the liver via portal vein to undergo beta oxidation process producing ketones, thus providing a rapid source of energy. MCFA also causes an increaseindiet-induced thermogenesis and satiety (2).In contrast, LFCA needs to becycled back into the intestinal lymphatic ducts and transportedas chylomicron to the throracic ducts into the systematic circulationand deposited inthe body as fat. As such, medium-chaintriglyceride (MCT) has been used for years to treat patients withmalabsorption of fat problems and provide instant energy to theathletes. However, as MCT contain solely of MCFA, it lacks essentialfatty acid. Besides, MCT is also not suitable to be used for cooking purposes such as frying oil due to foam formation.

Hence, LCFA is incorporated in the MCT molecule to overcome these weaknesses. This has led to the development of a new type of structured lipid, called **medium-and long-chain triacylglycerol (MLCT).**

In **MLCT**, each individual triacylglycerol (TAG) molecule containsboth the MCFA and LCFA. This can either be produced via lipase-catalyzed reaction of acidolysis, esterification, or interesterification(3);(21); (20). Lipase, which is nonspecific, will give randomly structured MLCT consisting of 6 configurations, which are MLM, MML, LLM, LML, LLL, and MMM.

However, when 1,3 specific enzyme is used, it will give the desired structured MLCT (4).

In the individual **MLCT** TAG molecule, the LCFA is usually contributedby the common vegetable oil (such as canola, soybean, cottonseed, sunflower, peanut, olive, corn, safflower seed, rice bran, and sesame seed oil) while MCFA is contributed either by medium chain triglyceride (MCT) (such as coconut or palm kernel) or fatty acids such as caprylic acid, respectively.

The presence of LCFA help to increase the smoke point of the MCT, making it feasible for frying purposes .

Numerous studies reported that this MLCT can restrain the accumulation of body fat, reduce cholesterol, and bloodtriglyceride upon consumption (22);(36);(37);(38).

MLCT oil also has myriads of applications in the food industry as home cooking oil, salad dressing, vegetable-oil spreads, dietary supplement, and frozen dinner.(1)

Synthesis of MLCT oil as a structured food:
MLCT is synthetized through an enzymatic reaction or chemical inter-esterification .
Various lipase-catalyzed enzymatic approaches have been studied to determine the best method of getting high MLCT yield. MLCT can be produced via enzymatic process in 3 routes:
(1) Interesterification
(2) Acidolysis
(3) Esterification

Small scale and large scale production of it have also been studiedto find out the optimum conditions for producing best yield of MLCT, thus providing useful information for MLCT productionto the industries.

Interesterification
Interesterification is the reaction between esters or TAG molecules. Not much research has been reported on MLCT production via interesterification reaction. For MLCT production, interesterification often involved the coconut oil or palm kernel oil or saturated TAG such as tricaprylin that will provide theMCFA. LCFA part in MLCT is contributed by the vegetable oil such as soybean oil, rapeseed oil (Fomuso and Akoh 1998; Lopez-Hernandez and others 2005; Adhikari and others 2011b)(24&3 & 25).

The progress of the interesterification reaction is measured by the changes in the TAG composition before and after the reaction .

For interesterification, substrate ratio is an important parameterthat will affect the desirable yield. For example: substrate moleratio of trilinolein to tricaproin from 1 : 1 to 1 : 4, the mole ratioof 1 : 2 gave the highest yield of 50.7% dicaproyllinolein (ECN 33)and 23.6% monocaproyldilinolein (ECN 45) (Fomuso and Akoh1998)(24).

Acidolysis:
Acidolysis involved the exchange reaction between acyl moietyofacylglycerol and a free carboxylic acid. For MLCT productionviaacidolysis reaction, the acylglycerol mostly came from nativeoils such as soybean oil, canola oil, lard, fish oil, sesame oil, borageoil, menhaden oil, and chicken fat (Lee and others 1999(4) Xu and others 2000, Kawashima and others 2001, 2002; Kim andAkoh 2006; Zhao and others 2007; Li and others 2008; Shuangand others 2009)(27-33). These native oils were used in acidolysis asit contained essential fatty acids like, linoleic acid (LA), alphalinoleicacid (ALA), eicosapentanoic acid (EPA), docosahexanoicacid (DHA), and y-linolenic acid (GLA) that impart good health toour body. However, tripalmitin, tristearin, and triolein also can beused as the acyglycerol for this reaction (Sellappan and Akoh 2000;
Yankah and Akoh 2000).(34);(39).

As for the free carboxylic acid, the most commonly used is the caprylicacid (CA). Little has been done on capric or lauric acid (Sellappan and Akoh2000;(34)Nunes andothers 2011)(35). Summary of research done on MLCT production via acidolysis issummarized byYee-Ying Lee, Teck-Kim Tang, and Oi-Ming Lai.(1) , in their excellent review summary of MLCT in food applications .

Literature shows that parameters such as substrate ratio, residencetime, temperature, enzyme load, water content have to be takeninto consideration when producing MLCT -Kim and Akoh 2006;(30),Zhao and others 2007;(31),Li and others 2008;(32)Shuang and others2009;(33)Nunes and others 2011)(35). These parameters are not only
important to be considered when running in flasks for small scaleexperimental purposes, but also for large scale production in eitherpacked bed reactor or stirred tank reactor (Xu and others 2000;(27)Kawashima and others 2002)(29).

Besides, choosing the right type of enzyme is importantwhen running acidolysis reaction as different types of enzymewill affect the yield of MLCT. For acidolysis reaction to produceMLCT, 1,3 specific immobilized enzyme Rhizomucormeihei(RM IM) (Novozyme, Bagsvard, Denmark) lipase is commonlyused compared to 1,3 specific enzyme TLIM thoughsometimes nonspecific enzymes such as Rhizopusoryzae and Rhizopus

delemar lipase may be used. 1, 3 specific enzymes willmake sure that the essential fatty acid is maintained in thesn2 position, creating the desired structured type of MLCT(Sellappan and Akoh2000;(34)Yankah and Akoh 2000; (39)Foresti andFerreira 2010;(40)Nunes and others 2011)(35).

When RM IM enzymeis utilized for acidolysis reaction, it normally gives around 40 to50 mol% of CA incorporation at reaction times of around 20 to24 h (Akoh and Moussata2001;(41) Kim and Akoh 2006;(30) Li and others 2008; (32)Shuang and others 2009)(33).
As for Thermomyceslanguninosa(TLIM) (Novozyme, Bagsvard, Denmark) enzyme at thesame duration time, 20 h, and only 27.01 mol% of CA can beincorporated into soybean oil. However, when organic solventsuch has hexane and isooctane is added in the reaction, TLIMwill give a 50.14% of CA incorporation (Zhao and others 2007)(31).
The enzyme load that was normally used is in between 5% and10% (w/w). At least 24 h of residence time were required for amaximum CA incorporation.Besides 1-step acidolysis reaction discussed previously, there is a2-step enzymatic process for MLCT production. For this method,the 1st step involved the production of TriPUFA from EPA,DHA, and AA via esterification with glycerol at 3 : 1 mol/molusing Candida antratica (Novozyme, Bagsvard, Denmark) enzymefor 24 h. The TriPUFA of the following (1) 89% of y-linolenicacid (GLA), (2) 89% of archidonic acid (AA), (3) 88% ofecosapentaenoic acid (EPA), and (4) 83% of docosahexanoic acid(DHA) then undergone acidolysis with caprylic acid via Rhizopusndelemar lipase (Ta-lipase Tanabe Seiyala Co. Ltd., Osaka, Japan) for48 h producing acylglycerol containing CA. This 24-h acidolysisstep was carried out consecutively for 3 cycles to increase theincorporation of CA. The repeated acidolysis reaction managed toincrease the amount of CA incorporated in each of the TriPUFAwith TriE 66%, TriA 63.8%, TriG 52.6%, and TriD 31.1%. MLMtype structured lipid also increased with the 3 repeating acidolysissteps (diCA 86.5%, dice 85.7%, diCD 62.6%, and diCE32.3%).

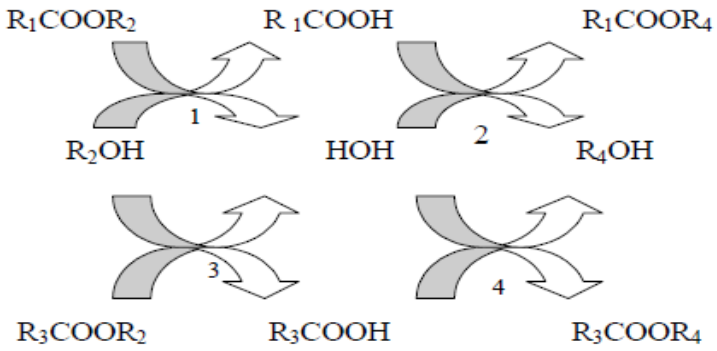
This process gives the highest yield of MLCT among all the otheracidolysis methods carried out by other researchers. In this study,the enzyme can be reused up to 10 cycles in esterification step and20 cycles in acidolysis step, respectively, reducing the cost of operation(Kawashima and others 2001)(28). However,the concern aboutthis method is that it is time consuming compared to the normal 1-step acidolysis method in which the first esterification step needed24 h and the 3 consecutive acidolysis steps each required 48 h to becarried out.Substrate mole ratio of fatty acid/glycerol also significantlyaffects the CA incorporation. Increase in the amount of fattyacid will lead to an increase in the CA incorporation (Li andothers 2008)(32). However, too much of the fatty acids will make themedium too acidic, thus inactivating theenzyme. Furthermore,the use of higher amounts of fatty acids will also incur higher costof production. Thus, it is important get the optimum substratemole ratio for acidolysis reaction to obtain a high yield of MLCT.Temperature is a crucial parameter as it will affect the activityof enzyme, solubility and viscosity of the substrate. Temperaturefor acidolysis reaction normally falls in the rangeof 40 to 65 ◦C. However, recently, novel cold active lipasefrom Pichialynferdii NRRL Y-7223, (culture collection of NationalCentre for Agricultural Utilization Research, Peoria IL,USA) was found to have comparable activity with RMIM at20 ◦C. This Pichialynferdii NRRL Y-7223 cold lipase gives 47.5%of CA incorporation on the borage oil at 20 ◦C, which is comparableto the RMIM with 45.7% incorporation at 40 ◦C (Kim andothers 2010).(42) Lower temperature for acidolysis reaction is preferableespecially for structured lipid that contained PUFA such asfish oil, borage oil, GLA from evening primrose oil, which issusceptible to oxidation. Hence, it is necessary to maintain thetemperature as low as possible during storage or reaction. Besides,lower temperature uses less energyconsumption. However, this isnot suitable to be applied to TAG production that has higher meltingpoints such as palm kernel olein as this TAG will crystallizeduring the reaction.

The drawback of this acidolysis reaction is that a high ratioof fatty acids especially short chain and MCFA, which are easilysoluble will create acidic condition in the reaction. This will inactivatehe enzyme and restrict its reaction, leading to a low yield of MLCT.

Esterification
Esterification is another alternative in the synthesis of MLCT.However, not much research has been done on the esterificationreaction of MLCT production due to the high cost of fatty acidsand glycerol. In esterification process, the desired fatty acid (such asoleic acid, stearic acid, capric acid, and so on) is made to react withglycerol in the presence of the enzyme lipase. To drive the reactionforward towards synthesis, vacuum pump or nitrogen gas purgingis used to remove the water formed during the esterification reaction.Esterification process is a much more preferable methodto produce a higher concentration of MLCT as it gives a highpurity of MLCT and few

unnecessary TAG, FFA, and MAG ascompared to acidolysis. However, the drawback from this methodis that it does not contain any
residualnatural antioxidants. Thus, naturalantioxidants such as rosemary extract, sage extract, or chemicalantioxidant such as tert–butyl hydroquinone (TBHQ), butylatedhydroxyanisole (BHA) has to be added to increase the oxidativestability of this oil (Koh and others 2009)(43).

Koh and others (2010)(20) and Arifin and others (2011a, 2012)(44-46) managedto produceMLCT oil via esterification reaction. Both studiesuse the same RMIM enzyme and same MCFA (capric acid) butdifferent LCFA, with the former using oleic acid and the latter usingstearic acid as their substrate. Both studies optimized the conditionsfor MLCT production using response surface methodology.Koh and others (2010)(20) managed to get 58 wt% ofMLCT oil underoptimized conditions of 13.6 to 14 h reaction time, 7.9% to 8%for enzyme load, and 3 : 1 for fatty acid/glycerol molar ratio. Thisis comparable to that reported by (Arifin and others 2011a, 2012)(44-46)who obtained 59.76 wt% of MLCT oil with 10% enzyme load,70 ◦C reaction temperature, 14 h reaction time, and 3.5 : 1 substratemole ratio.Purity of MLCT increases after undergoing refining process.Refining will remove the unnecessary matters like free fatty acids,andunsaponified matter (Kawashima and others 2001; Koh andothers 2010; (20)Arifin and others 2011a)(44). For example, after refined,bleached, and deodorization (RBD) processes,theMLCT contentincreased from to 59.76% to 76% (Koh and others 2010)(20).Here after , the schematic illustration of Lipase reaction with triacylglycerolsin different reaction mechanisms .



1: Hydrolysis
2: Ester synthesis
1+2: Alcoholysis
1+3: Acidolysis
1+2+3+4: Transesterification

Figure 2.3. Schematic illustration of lipase reactions (Balcao et al., 1996).

Structured oils based on MLCT application in Food Industries

Fats and oils give palatability to a food product and cannot betotally eliminated in our food. As some foods are high in fat,consumption of it can be detrimental to health. As such, MLCTis seen to have potential to prevent body weight gain and body fataccumulation when used to replace the conventional fats/oils forfood production especially those that required high amount of fat.There are several studies that tested on the application of MLCTin food products.

Cooking oil

The first commercialized MLCT was produced by Nisshin OillioGroup Ltd. (Japan) and are sold widely as cooking oil inJapan and United States with the name Resetta. It is stable for30 min in 200 ◦C. Koh and others (2009)(43) found that MLCTwhen blended with soybean or palm olein, can be used for cookingpurposes especially frying. This

is because, the presence oflong chain fatty acid from soybean oil and palm olein such asoleic acid (C18), linoleic acid (C18:1), and linolenic acid (C18:3)increases the blended MLCT oil's smoke point. For example,the smoke point of MLCT blended with palm olein (225 ±1.41 ◦C) and soybean oil (229 ± 1.41 ◦C) at ratio 1 : 1 weremuch higher compared to the control, which is the unblendedMLCT oil (210 ± 0 ◦C). Apart from increasing the smoke point,blending with soybean or palm olein also helped to reduce the productioncost of MLCT. Koh and others (2011) (5)also demonstratedthat the MLCT added with antioxidants has a higher thermal resistantoxidative strength (above 180 ◦C) than RBD palm olein,lighter in color and lower free fatty acid content, thus having the characteristic required for deep frying oil. Sensory test showedthat there is no difference in term of taste and rancidity assessmentin potato chip fried with MLCT oil and those with palm olein.Jennings and others (2010) (47)reported that rice bran oil structuredlipid (RBOSL) consisting primarily of CA at the sn-1,3 positionand oleic and linoleic acid at the sn-2 position can be used infrying sweet potato chip (SPC) at 165 to 185 ◦C for 20 to 60 s.The color variable, smoke point, foaming ability, and γ -oryzanolconcentration showed no significant difference between RBOSLand RBO after frying. However, RBOSL tend to have a lowerviscosity and oil uptake compared to RBO after frying.

Energy bars

Jennings and others (2010)(47) also used 13.27% of the RBOSL tomake energy bar (EB), whichwas baked at 176 ◦Cfor 30 to 40 min.Sensory evaluation showed a significant difference in energy barprepared with RBOSL and RBO. RBO EB has a softer texturecompared to RBOSL EB. In addition, the willingness to purchase(WTP) of EB made from RBOSL was 60% indicating that 60% ofthe consumers accepted the RBOSL EB. This indicates that theproduct prepared with SL has a bright future to be commercialized
(Jennings and others 2010).(47)

Butter fat

MLCT made via Rhizomucormeihei lipase trans-esterification of57.7% of capric acid and canola oil when blended with butterfat improved the cold spreadability of the pure butter. Triangletest showed that 23 out of the 30 panelists were able to detectthe difference between the pure butter and blended butter due tothe cold spreadability between samples. In terms of flavor, there isnot much difference between both pure butter and butter blendedwith structured blended butter fat. Structured blended butter fatalso has a higher antherogenic index than pure butter (0.07),which can counterbalance the attribute of hypercholesterolemicof pure butter. As such, MLCT showed potential to be used assubstitute for canola oil in making cold spreadable butter (Kim andAkoh 2006).(30).

Margarine and shortening

Both margarine and shortening are visco-elastic semi solid foodproducts. Margarine is water in fat emulsion, which consists of80% fat and 20% water. In contrast, shortening is any fat that issolid at room temperature and used to shorten baked products suchas making crumbly pastry. Palm stearin is hardstock that is usuallyblended with soft oils such as soybean oil, canola oil, sunflower oil,and cotton seed oil through enzymatic interesterification processto produce trans free plastic fats as well as to improve the SFCof the product. The presence of palm stearin help to enhancethe plasticity and maintain the shape and structure of the productto withstand temperature fluctuation (Nor Aini and Miskandar2007).(48)MLCT can be used to prepare shortening and margarine. Arifinand others (2011b)(45) showed that MLCT produced from lipase esterificationof stearic acid, capric acid, and glycerol at 3 : 1 for fattyacid/glycerol molar ratio is suitable to be a functional hard stock inshortening and**margarine that can be used forobesity management**purposes as it has a high SFC at 25 ◦C. Besides, MLCT producedfrominteresterification between a hard stock (fully hydrogenatedsoybean oil) and soft oil (rice bran oil, coconut oil) give the newlyformed oil plasticity property suitable to be made into margarineand shortening (Adhikari and others 2011a).(26) Similarly, (Zhang anothers 2010)(38) studied the production of margarine using LipozymeIM lipase-catalyzed interesterification of palm stearin and coconutoil (75/25, w/w) in 1 kg batch stirred tank reactor.For baking purposes, shortening should have a SFC of 15%to 25%at ambient temperature (25 C). Arifin and others (2011a) (44)carried out a study on thebinary (MLCT: palm stearin) and ternary (MLCT: palm stearin:palmolein) blends of MLCT to be used as shortening for baking.Blending with other oils will help to reduce the production cost ofMLCT. From the study, increasing the MLCT from 40% to 90%causes a reduction in the SFC of theMLCT-enriched formulation.All these shortenings have melting points of 55 ◦C. Binary blends of MLCT and palm stearin in the ratio 70 : 30, 80 : 20, 90 : 10and ternary blends of MLCT, palm stearin, and palm olein withratio 40 : 40 : 20, 50 : 40 : 10, 50 : 30 : 20 fulfill the 15% to25% SFC requirement for shortening at 25 ◦C. Therefore, they aresuitable to be used as shortening for baking purposes. Quantitativedescriptive analysis (QAD) showed that Madeira cakes made from

these MLCT have better taste and aroma than the commercialshortening. The acceptability test in terms of taste, texture, andoverall acceptability showed a higher degree of liking for Madeiracakes made of 50 : 30 : 20 ratio of MLCT, palm stearin, andpalmolein. MLCT-enriched shortening also has a higher SFCcompared to local commercial shortenings made from soybean,sunflower, and hydrogenated palm oil.

Beverages

Canola oil is commonly used in preparing beverages. Canolaoil-based structured lipid is of importance so that the manufacturerdoes not need to change the formulation when replacingcanola oil with canola oil-structured lipid. Triangle test showedthat 23 out of 38 participants managed to distinguish the differencebetween the chocolate beverages made of canola oil-basedstructured lipid and chocolate beverages made of canola oil. Structuredlipid beverage is sweeter (2 times sweetness intensity) and hasless bubble formation than the canola oil-beverages. However, notmuch difference was observed in terms of other attributes suchtexture, aroma, aftertaste, and color (Osborn and others 2003).(49)The presence of CA acts as flavor carrier that helps in transportingthe flavor component. This increases the sweet taste in the SL
containing chocolate beverages. This beverage is useful for thosewho require a rapid source of energy. It can also provide essentialfatty acids.

Coating lipid

In the food industry, coating a layer of polysaccharides, protein,or lipid on to a food product is important to prolong the storagelifespan and maintain the quality of the products as it preventsthe diffusion of moisture, air, and aroma to enter or escape fromthe food. Lipid with its hydrophobic property and giving a glossyappearance is most preferred compared to protein and polysaccharidesas coating material. Acidolysis of the tristearin with lauricacid and oleic acid in substrate ratio of 1 : 4 : 1 using RMIM lipasewas better in inhibiting moisture than cocoa butter when appliedon cracker. This may be due to the compactness and rigidity of thestructured lipids. This structured lipid has a sharp melting pointof 31.4 ◦C. Addition of lauric acid and oleic acid will help toregulate the melting profile of tristearin to be in the range of 30to 37 ◦C, which is suitable for coating applications (Sellappan andAkoh 2000).(34)

Nutrient admixtures

MLCT oil can be used in nutrient admixtures. It helps to increase the storage stability of the nutrient admixtures. When 20%soybean oil was replaced with 20% MLCT oil in nutrient admixtures,kinetic stability test showed that the mean droplet size (300to 400 nm), surface tension value remained unchanged forMLCToil throughout the 10 d of storage period at both 2 to 7 ◦C and37 ◦C. However, soybean oil nutrient admixtures stability starts todeteriorate starting Day 4 (Balogh and others 2005).(50).

Parenteral nutrition

Structolipid 20% is a parenteral type structured fat emulsionthat was produced from Pharmacia/Upjohn, Uppsala, Sweden. Itis made up of soybean oil and purified coconut oilin ratio 36 : 64,w/w, that was interesterified. Study revealed that this structolipidhas similar properties as the control, which was LCT (Intralipid20%) of soybean oil triglyceride. For example, no difference wasobserved in the plasma lipid (triglyceride, total and free cholesterol,phospholipid, free fatty acid) between those subject consumingLCT and structolipid as well as on its clinical safety. Besides,structolipid 20% showed possible reduction in liver dysfunctionas the liver problem in 2 patient revolved after switching to thestructolipid 20%. The presence of soybean oil in the structuredlipid will provide essential fatty acids, not seen in the commonlyused MCT parenteral (Rubin and others 2000).(52)

Health benefits of MCT &MLCT in dietary food application

Medium-chain fatty acids (MCFAs) comprise saturated fatty acids with 6–10 carbons. Besides synthetic medium-chain triglyceride(MCT) oils there are natural sources, like coconut oil and dairy fat. Compared with long-chain fatty acids (LCFAs), the chemical andphysical properties of MCFAs show substantial metabolic differences. MCFAs do not require binding to proteins such as fatty-acidbinding protein, fatty acid transport protein, and/or fatty acid translocase (FAT, homolog to human platelet CD36). MCFAs are apreferred source of energy (b-oxidation). MCFAs are also incorporated into adipose tissue triglycerides, and may nfluence adipose tissueand other systemic functions more substantially than previously assumed. MCTs reduce fat mass, through down-regulation ofadipogenic genes as well as peroxisome proliferator activated receptor-g. Recent studies confirmed the potential of MCFAs to reducebody weight and particularly body fat. This effect was not transient. MCFAs reduce lipoprotein secretion and attenuate postprandialtriglyceride response. It was, however, frequently observed that MCTs increase fasting cholesterol and triglyceride levels. But, given inmoderate amounts, in diets with moderate fat supply,

MCFAs may actually reduce fasting lipid levels more than oils rich in mono- orpolyunsaturated fatty acids. The same is true for glucose levels. MCTs improved several features contributing to enhanced insulinsensitivity. Under certain in vitro conditions, MCTs exert proinflammatory effects, but in vivo MCTs may reduce intestinal injury and protect from hepatotoxicity.BeritMarten,et al.(80)

Antiobesity Effect of MLCT

The benefits of MLCT oil is that it can act as functional oilthat can prevent fat accumulation in our body. Various clinicaland preclinical studies have been carried out so far regarding theantiobesity effects of MLCT and this will be discussed here.Most animal and human trials on MLCT were based on theeffect of Nisshin Ollio Group's MLCT oil, a randomly structuredMLCT made by interesterification of MCT and soybean oil tosuppress body fat and body weight (Matsuo and others 2001;(52)Kasai and others 2003; (22)Matsuo and Takeuchi 2004;(36),Shinohara andothers 2005; Shinohara and others 2006).(53-54)Regarding the body composition, MLCT when tested on human,was shown to be able to reduce the body weight and body fataccumulation (Matsuo and others 2001; (52)Kasai and others 2003)(22).For example: consumption of 200 g of MLCT (10% w/w ofMCFA) containing liquid diet twice daily for 12 wk in 13 healthyhuman male subjects aged 18 to 20 y caused a lower mean weightgain and body fat percentage (0.91 kg and 2.16%) compared tothose consuming soybean (1.83 kg and 4.30%) (Matsuo and others2001)(52). A thorough study demonstrated that reduction of body fat(either subcutaneous or visceral) can be seen particularly in thewaist circumference (4.6% loss), hip circumference (2% loss), aswell as body weight (6.1% loss) when MLCT isconsumed. Thisstudy is performed under strict calories diet on 82 healthy humansubjects of 21 to 59 y for 12 wk when 14 g MLCT (12%, w/w, of MCFA) is consumed at breakfast (Kasai and others 2003).(22)Overweightand obese Chinese human subjects when consumed 25to 30 g/d of MLCT (13% w/w of MCFA) for 28 d under strictdiet regime showed significant decrease in their body fat. Overweightpeople with body mass index (BMI) of 24 to 28 has moresignificant decrease compared to obese people with BMI morethan 28 (Zhang and others 2010).(38) In another study, MLCT uponconsumption for 8 wk at 25 to 30 g (13%, w/w, MCFA) daily inChinese hypertriglycerideamic (1.7 to 4.5 mmol/L) subjects withages less than 60, showed the ability to lower the body weight andbody fat accumulation. However, MLCT was shown to have noeffect on subjects that are more than 60 y old (Xue and others2009).(55)As for rats, the outcome on the effect of MLCT in reducingbody fat and weight vary among studies. When 48 male Wistarrats (Japan SLC Inc., Shizuoka) fed ad libitum with MLCT in theamount of 150 and 200 g/kg diet (20% of MCFA) for 8 wk,they were found to have a lower body weight and total intraabdominaladipose tissue. However, MLCT in the amount of 50or 100 g/kg diet was not able to decrease the body weight gain orbody fat (Matsuo and Takeuchi 2004).(36).Also, MLCT in 70 g/kgdiet (12% MCFA) showed no effect on reducing both the bodyweight and total intra abdominal tissue in Sprague–Dawley rats(Japan SLC Inc., Shizuoka) for a duration of either 2 or 4 wk(Shinohara and others 2005).(53) The previous studies reported weretested using Nisshin Ollio Group's MLCT oil. Besides, the NisshinOllio Group's MLCT,MLCT that has been incorporated with fishoil was also shown to have lower body weight gain in ICR mice(Harlan Sprague Dawley, Indianapolis, IN) compared to controlgroup fed with soybean oil with the former having gain of 5.8% and latter of 11.4%, respectively (Lee and others 1999).(4)Besides the previously mentioned studies, there were also studiesrelated to the enzymes that are involved in the metabolismof fatty acids and these were conducted on animal models consumingMLCT. It is shown that 30 min after administrationof MLCT and LCT, Wistar rats (Japan SLC Inc., Shizuoka)fed with MLCT have a higher activityof the hepatic fattyacid oxidation enzyme than those fed with LCT, demonstratingthat MLCT is oxidized more rapidly than LCT in the liver(Shinohara and others 2002). Examples of such enzymes includeshort chain acyl coA dehydrogenase, medium chain acyl coA dehydrogenase(ACAD), citrate synthase, cytochrome oxidase, carnitinepalmitoyltransferase (CPT). Meanwhile, the activity of lipogenicenzyme is not affected by MLCT (Lee and others 1999;Shinohara and others 2002, 2005, 2006;(57) ,(53-54) Matsuo and Takeuchi2004).(36) It was found that no caprylic acid is detected in the liver ofthe group of mice fed with MLCT for 21 d, further supportingthat the incorporation of MCFA will provide a quick source ofenergy as they are rapidly metabolized (Lee and others 1999)(4). Also,diet induced thermogenesis (DIT) of MLCT in 21 adults humanshowed that 6 h after taking a diet consisting of MLCT, energyexpenditure increased by 14 kcal (Ogawa and others 2007).(57)Safety evaluation also showed that acute dosage of MLCT at5000 mg/kg and subchronic study for 6 wk at 3500 mg/kg showedno signs of toxicity of MLCT in Wistar rats (Japan SLC Co.Ltd., Hammamatsu). MLCT is also non-mutagenic when tested(Matulka and others 2006).(37)Numerous studies have been done on the effect of MLCT onthe blood composition of either rats or humans.(Table 1)To sum it up, most of the studies clearly showed that MLCToil consumption can help to reduce body fat accumulation andbody weight gain. Nonetheless, MLCT was found to be moreeffective as anti-obesity functional oil on humans as compared to animals. This may be due to the short duration of the preclinicalstudies that were unable to show the effect of MLCT. MLCTeffect on blood parameters on human and animal's studies werealso not consistent. Some were found

to improve the blood lipidand blood cholesterol levels while others did not. As such, the effect of MLCT on blood lipid and cholesterol level still remainedunclear.

Conclusions:-

From the health benefits point of view, MLCT not only canprovide us with nutritional properties from the essential fatty acidsIncorporated, but most importantly it can also help to reduce bodyweight and body fat accumulation in the body. However, at least12% of MCFA must be present in the product to see the beneficialeffects. As such, including MLCT into our diet is 1 way to curbthe increasing rise of worldwide obesity. As for the enzymaticproduction, among the 3 enzymatic processes discussed,(interesterification,esterification, and acidolysis), esterification gave thehighest yield of MLCT though it may be costly when produced in large scale due to the substrates used. More studies need tobe carried out to find more MLCT application in the food andindustries. MLCT as functional lipids is gaining its momentumin recent fats and oils industries. It may be the next generation"potion" to be included to our diet

References:-

1. A review of Health Benefits, Enzymatic Production,and Application of Medium- and Long-ChainTriacylglycerol (MLCT) in Food Industries:
2. Vol. 77, Nr. 8, 2012 Journal of Food Science.
3. Yee-Ying Lee, Teck-Kim Tang, and Oi-Ming Lai.
4. Aoyama T, Nosaka N, Kasai M. 2007. Research on the nutritional characteristics of mediumchainfatty acids. J Med Invest 54(3,4):385–8).
5. Lopez-Hernandez A, Garcia HS, Hill CG. 2005. Lipase-catalyzed transesterification of mediumchaintriacylglycerols and a fully hydrogenated soybean oil. J Food Sci 70(6):c365–72.
6. Lee KT, Akoh CC, Dawe DL. 1999. Effects of structured lipid containing omega-3 and mediumchain fatty acids on serum lipids and immunological variables in mice. J Food Biochem23(2):197–208.
7. Koh S, Arifin N, Tan C, Yusoff M, Long K, Lai O. 2011. Deep frying performance of enzymaticallysynthesized palm-based medium- and long-chain triacylglycerols (Mlct) oil blends.Food BioprocTechnol 4(1):124–35.
8. Structured lipids for weigh loss – Geoff Talbot-Oxford brookes university – School of life science .
9. BAILEY'S INDUSTRIALOIL AND FATPRODUCTS-sixth edition
10. Part 1- page 191 ,Edited by :FereidoonShahidi ,Memorial University of Newfoundland.Copyright # 2005 John Wiley & Sons, Inc.503.
11. F. D. Gunstone, ed., Structured and Modified Lipids, Marcel Dekker, New York, 2001.K. T. Lee, T. A. Foglia, and M. J. Oh, J. Food Sci., 67, 1016–1020 (2002).
12. K.-T. Lee and T. A. Foglia, J. Food Sci., 65, 826–831 (2000).
13. K.-T. Lee and T. A. Foglia, J. Amer. Oil Chem. Soc., 77, 1027– 1034 (2000).
14. V. K. Babayan, G. L. Blackbrun, and B. R. Bistrian(to N.E. Decaness Hospital), U.S.Patent 4,952,606, 1990.
15. V. K. Babayan, JAOCS, 45, 23–25 (1968).C. Dayrit et al., Phil. J. Coconut Studies, XVII(2), 15–17(1992).
16. C. Intengan et al., Phil. J. Coconut Studies, XVII(2), 11–14 (1992).
17. S. P. Senanayake and F. Shahidi, J. Agric. Food Chem., 50(3), 477–483 (2002).
18. K. T. Mok, A. Maiz, K. Yamazaki, J. Sobrado, V. K. Babayan, L. L. Moldawer, B. R.Bistrian, and G. L. Blackburn, Metabolism, 33(10), 910–915 (1984).
19. S. P. J. N. Senanayake and F. Shahidi, Food Res. Int., 35, 745–752 (2002).FAO Foods and nutrition paper 91-Chapter 14.
20. Koh S, Tan C, Lai O, Arifin N, Yusoff M, Long K. 2010. Food BioprocTechnol 3(2):288–99.
21. Shuang D, Jiang-Ke Y, Yun-Jun YAN. 2009. J Food Biochem 33(3):442–52.
22. Papamandjaris and others1998; Aoyama and others 2007
23. Fomuso L, Akoh C. 1998.J Am Oil ChemSoc 75(3):405–10.
24. Lopez-Hernandez A, Garcia HS, Hill CG. 2005. J Food Sci70(6):c365–72
25. Adhikari P, Shin JA, Lee JH, Kim HR, Kim IH, Hong ST, Lee
26. KT. 2011b. FoodBioprocTechnol 1–14.
27. Xu X, Fomuso L, Akoh C. 2000. JAm Oil ChemSoc77(2):171–6.
28. Kawashima A, Shimada Y, Yamamoto M, Sugihara A, Nagao T,Komemushi S, Tominaga Y.2001. Enzymatic synthesis ofhigh-purity structured lipids with caprylic acid at 1,3-positionsand polyunsaturated fatty acid at 2-position. J Am Oil ChemSoc
29. 78(6):611–6.

30. Kawashima A, Shimada Y, Nagao T, Ohara A, Matsuhisa T, Sugihara A, Tominaga Y. 2002.Production of structured tag rich in 1,3-dicapryloyl-2-linolenoyl glycerol from borage oil.J Am Oil ChemSoc 79(9):871–7.
31. Kim BH, Akoh CC. 2006. Characteristics of structured lipidprepared by lipase-catalyzed acidolysisof roasted sesame oil andcaprylic acid in a bench-scale continuous packed bed reactor.J Agric Food Chem 54(14):5132–41.
32. Zhao H, Lu Z, Bie X, Lu F, Liu Z. 2007. Lipase catalyzed acidolysis of lard with capric acid inorganic solvent. J Food Engineer 78(1):41–6.
33. Li L, Ping L, Linyuan L, Junshe S. 2008. Production of structured lipids by enzymatic incorporationof caprylic acid into soybean oil. ICBBE 2008. The 2nd Intl. conference onbioinformatics and biomedical engineering, 2008. p. 1033–7.
34. Shuang D, Jiang-Ke Y, Yun-Jun YAN. 2009. Optimization of lipase-catalyzedacidolysis ofsoybean oil to produce structured lipids. J Food Biochem 33(3):442–52.
35. Sellappan S, Akoh C. 2000. Enzymatic acidolysis of tristearinwithlauric and oleic acids toproduce coating lipids. J Am Oil ChemSoc 77(11):1127–34.
36. Nunes P, Pires-Cabral P, Guill´en M, Valero F, Luna D,Ferreira-Dias S. 2011. Productionof Mlm-type structured lipids catalyzed by immobilized heterologous ≪I≫RhizopusOryzae≪/I≫ lipase. J Am Oil ChemSoc 88(4):473–80.
37. Matsuo T, Takeuchi H. 2004. Effects of structured medium- and long-chain triacylglycerols indiets with various levels of faton body fat accumulation in rats. Brit J Nutri 91(02):219–25.
38. Matulka RA, Noguchi O, Nosaka N. 2006. Safety evaluation of a medium- and long-chaintriacylglycerol oil produced frommedium-chaintriacylglycerols and edible vegetable oil.Food Chemical Toxicol 44(9):1530–8.
39. Zhang Y, Liu Y, Wang J, Zhang R, Jing H, Yu X, Zhang Y, XuQ, Zhang J, Zheng Z, NosakaN, Arai C, KasaiM, Aoyama T,Wu J, Xue C. 2010. Medium- and long-chain triacylglycerolsreduce body fat and blood triacylglycerolshypertriacylglycerolemic,overweight but notobese, chinese individuals. Lipids 45(6):501–10.
40. Yankah V, Akoh C. 2000. Lipase-catalyzed acidolysis of tristearin with oleic or caprylic acids toproduce structured
41. lipids. J Am Oil ChemSoc 77(5):495–500.
42. Foresti ML, Ferreira ML. 2010. Lipase-catalyzed acidolysis of tripalmitin with capric acid inorganic solvent medium: analysisof the effect of experimental conditions through factorialdesign and analysis of multiple responses. EnzyMicrobTechnol46(6):419–29.
43. Akoh C, Moussata C. 2001. Characterization and oxidative stability of enzymatically producedfish and canola oil-based structured lipids. J Am Oil ChemSoc 78(1):25–30.
44. Kim HR, Hou CT, Lee KT, Kim BH, Kim I-H. 2010. Enzymatic synthesis of structured lipidsusing a novel cold-active lipase from pichialynferdiinrrl Y-7723. Food Chem122(3):846–9.
45. **d lipids forweig3**Geoff TalbotKoh SP, Arifin N, Lai OM, Yusoff MSA, Long K, Tan CP. 2009. Oxidative stability of palmandsoybean-based medium- and long-chain triacylglycerol (Mlct) Oil blends. J Sci FoodAgric 89(3):455–62.
46. Arifin N, Cheong LZ, Koh SP, Long K, Tan CP, Yusoff MSA, Nor Aini I, Lo SK, LaiOM. 2011a. Physicochemical properties and sensory attributes of medium- and long-chaintriacylglycerols(Mlct)-enriched bakery shortening. Food BioprocTechnol 4(4):587–96.
47. Arifin N, Soo-Peng K, Long K, Chin-Ping T, Yusoff M, Oi-Ming L. 2011b. Modeling andoptimization of lipozymeRmIm-catalyzed esterification of medium- and long-chain Triacyglycerols(Mlct) using response surface methodology. Food BioprocTechnol 1–10.
48. Arifin N, Soo-Peng K, Long K, Chin-Ping T, Yusoff M, Oi-Ming L. 2012. Modeling andoptimization of lipozymeRmIm-catalyzed esterification of medium- and long-chain triacyglycerols(Mlct) using response surface methodology. Food BioprocTechnol 1–10.
49. Jennings BH, Shewfelt RL, Akoh CC. 2010. Food applicationsof a rice bran oil structured lipidin fried sweet potato chips and an energy bar. J Food Qual 33(6):679–92.
50. Nor Aini I, Miskandar MS. 2007. Utilization of palm oil andpalm products in shortenings andmargarines. Euro J Lipid SciTechnol 109(4):422–32.
51. Osborn H, Shewfelt R, Akoh C. 2003. Sensory evaluation of a nutritional beverage containingcanola oil/caprylic acid structured lipid. J Am Oil ChemSoc 80(4):357–60.
52. Balogh J, Bubenik J, Dred´an J, Csempesz F, Kiss D, Zelk´o R. 2005. The effect of structuredtriglycerides on the kinetic stability of total nutrient admixtures. J Pharm PharmSci8(3):552–7.Rubin M, Moser A, Vaserberg N, Greig F, Levy Y, Spivak H, Ziv Y, Lelcuk S. 2000.Structured triacylglycerol emulsion, containing both

medium- and long-chain fatty acids,in long-term home parenteral nutrition: a double-blind randomized cross-over study. Nutrition16(2):95–100.
53. Matsuo T, Matsuo M, KasaiM, Takeuchi H. 2001. Effects ofa liquid diet supplement containingstructured medium and long chaintriacylglycerols on bodyfat accumulation in healthy youngsubjects. Asia Pacific J Clinic Nutr 10(1):46–50.
54. Shinohara H, Ogawa A, Kasai M, Aoyama T. 2005. Effect of randomlyinteresterifiedtriacylglycerolscontaining medium- and long-chain fatty acids on energy expenditure and hepaticfatty acid metabolism in rats. BiosciBiotechnolBiochem69(10):1811–8.
55. Shinohara H, Wu J, Kasai M, Aoyama T. 2006. Randomly interesterified triacylglycerol containingmedium- and long-chain fatty acids stimulates fatty acid metabolism in white adiposetissue of rats. BiosciBiotechnolBiochem70(12):2919–26.
56. Xue C, Liu Y,Wang J, Zhang R, Zhang Y, Zhang J, Zheng Z, Yu X, Jing H, Nosaka N, Arai C,Kasai M, Aoyama T, Wu J. 2009.Consumption of medium- and long-chain triacylglycerolsdecreases body fat and blood triglyceride in Chinese hyper - triglyceridemic subjects. Eur J ClinNutr 63(7):879–86.
57. Shinohara H, Shimada H, Noguchi O, Kubota F, Aoyama T. 2002. Effect of medium-chainfatty acids-containing dietary oil on hepatic fatty acid oxidation enzyme activity in rats. J OleoSci 51(10):621–6.
58. Ogawa A, Nosaka N, Kasai M, Aoyama T, Okazaki M, Igarashi O, Kondo K. 2007. Dietary medium- and long-chain triacylglycerols accelerate diet-induced thermogenesis inhumans. J Oleo Sci 56(6):283–7.
59. K. Traul, A. Driedger, D. Ingle, and D. Nakhasi, Food Chem. Toxicol., 38, 29 (2000). N. B. Cater, Food Chem. Toxicol., 35, 428 (1997).
60. Y. Tsai, S. Park, J. Kovacic, and J. Snook, Lipids, 34, 895 (1999).
    A. Lichtenstein, and U. Schwab, Atherosclerosis, 150, 227 (2000).
61. Y. V. Yuan, D. D. Kitts, and D. V. Godin, J. Nutr., 128, 1620 (1998).
62. Y. V. Yuan and D. D. Kitts, J. Nutr., 133, 679 (2003).
63. P. Khosla and K. C. Hayes, Biochem. Biophys. Acta., 1210, 13 (1993).
    A. Pronczuk, P. Khosla, and K. C. Hayes, FASEB J., 8, 1191 (1994).
64. F. Hu, R. van Dam, and S. Liu, Diabetologia, 44, 805 (2001).
65. J. Lovejoy, Current Atheroscler. Rep., 1, 215 (1999).
66. M. Manco, G. Mingrone, A. Greco, E. Capristo, D. Gniuli, A. De Gaetano, andG. Gasbarrini, Metabolism, 49, 220 (2000).
67. B. Vessby, M. Uusitupa, K. Hermansen, G. Riccardi, A. Rivellese, L. Tapsell, C. Nalsen,L. Berglund, A. Louheranta, B. Rasmussen, G. Calvert, A. Maffetone, E. Pederen,I. Gustafsson, and L. Storlien, Diabetologia, 44, 312 (2001).
68. J. Kanagaratnam, A. L. Lai, K. H. Lim, and B. J. Wood, Proc. of Nat. Workshop on Oil Palm By-Product Utilization, 1981, pp. 16–23.
69. C. H. Lim, T. C. Ping, K. W. Chan, and S. Y. Chooi, Proc. of Land Application of Palm Oil and Rubber Factory Effluent, Malaysia Society of Soil Science, 1983, pp. 71–89.
70. K. H. Yeow and Gurmit Singh. MOPGC/TRC Internal Report, 1983.
71. V. K. Babayan, Lipids, 22, 417 (1987).C. Bach, Y. Ingenbleek, and A. Frey, J. Lipid Res., 37, 708 (1996).
72. V. K. Babayan, J. Amer. Oil Chem. Soc., 51, 260 (1974).
73. D. L. Ingle, A. Driedger, K. A. Traul, and D. K. Nakhasi, J. Food Sci., 64, 960 (1999).
74. V. K. Babayan and J. R. Rosenau, Food Technol., 45, 111 (1991).
75. N. Baba, E. F. Brace, and S. A. Hashim, Amer. J. Clin. Nutr., 35, 678 (1982).C. Bach and V. K. Babayan, Amer. J. Clin. Nutr., 36, 950 (1982).International Dairy Journal 16 (2006) 1374–1382(Review on Medium-chain triglycerides) – Berit Marten, Maria Pfeuffer, Ju¨ rgenSchrezenmeir.