Chapter 3
Fats and Oils for Health and Longevity

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Abstract Fats and oils are one of the three primary nutritional components, and they deliver essential fatty acids and lipids vitally important for the normal biological structure and functions. The physiological functions of lipids include storing and providing energy, acting as inter- and intra-cellular signaling molecules, dissolving some vitamins to make them bioavailable, and acting as the crucial structural components of the cell membranes. This article provides an overview of the chemical nature and composition of fats and oils, their biological functions, their metabolic pathways of synthesis and catabolism, and dietary guidelines for their consumption for a healthy and possibly a longer life.

Keywords Animal fats · Plant oils · Health · Signaling · Cell membrane · Lipidome · Vitamins

3.1 Introduction

Fats and oils are the third primary nutritional component after proteins and carbohydrates, and they deliver essential fatty acids (FA) vitally important for the normal biological structure and physiological functions. Fats have the highest caloric density among foodstuffs (9 kcal/g), and are also the solubilizers and carriers of vitamins A, D, E and K. Our intake of oils and fats is largely through cooking- and salad-oils; butter, margarines and other spreads; baked and fried products; dairy-products including milk, cheese, desserts, chocolate and sugar confectionery; and through culinary applications, such as mayonnaise and other dressings. Fats are also consumed as a part of the animal-based foods. All these sources make up a complex matrix

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of various visible and invisible oils and fats that end up in our body (Bhattacharya 2006).

Oils and fats contribute to both the textural-structural properties of the food, and organoleptic aspects including flavor, mouthfeel, palatability and appearance. Food additives such as emulsifiers and hydrocolloids play an ever-increasing role in providing the structural integrity in processed foods to deliver lubrication, enhance and stabilization of aeration, crumb structure etc., and also contribute to the shelf-life of such foods (Bhattacharya 2006).

The aim of this article is to provide an overview of the chemical nature and composition of fats and oils, their biological functions, their metabolic pathways of synthesis and catabolism, and dietary guidelines for their consumption for a healthy and possibly a longer life.

3.2 Terminology and Chemical Composition of Fats and Oils

Before describing the chemical nature and composition of fats and oils, it may be useful to clarify some terminology. FA are the basic unit of all fats and oils. Lipids are the compounds based on fatty acids or on closely related compounds, such as the corresponding alcohols or the sphingosine base, and are mainly, but not entirely, mixtures of triacylglycerols (often termed triglycerides). Collectively, these are known as oils or fats, depending on whether, at a room temperature of about 24 °C, they are liquid or solid, respectively. Often these terms are used interchangeably, and so one should be cautiously aware and precise about these.

The broad group of lipids can be subdivided into classes based on their chemical structure, for example diacylglycerols, phosphatidylethanolamines, ceramides and others. They can be further separated into individual molecular species based on their acyl groups. Fats and oils of animal and plant origin consist almost exclusively of triglycerides, which consist of a glycerol moiety with each hydroxyl group esterified to a fatty acid. Triacylglycerols are synthesized by enzyme systems, which determine that a centre of asymmetry is created about carbon-2 of the glycerol backbone, so they exist in enantiomeric forms, that is with different fatty acids in each position. The positions of the fatty acids in the glycerol backbone are denoted by sn-1 or sn-3, the two terminal positions and sn-2, the middle position. (The abbreviation 'sn' stands for 'stereospecific numbering'). The naturally occurring fatty acids are mainly straight-chain compounds containing an even number of carbon atoms, and can be grouped into three classes, (i) saturated; (ii) monounsaturated and polyunsaturated; and (iii) branched chain. Unsaturated fatty acids may contain one or more double or triple bonds and can be classified as monounsaturated, polyunsaturated, and acetylenic. FA composition and distribution of triacylglycerols can be altered via a process called interesterification for a specific ratio of n-3, n-6, n-9 and saturated FA (SFAs), which play an important role in lowering cholesterol and blood lipid levels leading (Akoh 2002).

3.2.1 Saturated Fatty Acids (SFA)

SFA are composed of straight-chain FA esterified to the glycerol backbone. Among the most common and commercially available vegetable oils, such as coconut oil, palm kernel oil and palm oil, the most common SFA are lauric (C12), myristic (C14), palmitic (C16) FA. Presence of stearic acid (C18) is quite low (often below 5%) in common vegetable oils and fats. Dairy fats contain C4 to C10 FA while longer chain SFA up to C38 are found in waxes (Bhattacharya and Rattan 2006).

3.2.2 Monounsaturated Fatty Acids (MUFA)

The most abundant MUFA in common liquid vegetable oils such as olive, canola, sunflower, peanut, and safflower is oleic acid, a FA with one unsaturation or one double bond at the 9th carbon atom from the methyl end. Oleic acid is the precursor of biosynthesis of omega-9 class of FA. There are also high oleic varieties of sunflower, canola and soybean oil developed via selective breeding and genetic modification techniques (Kristott 2003).

3.2.3 Polyunsaturated Fatty Acids (PUFA)

FA with two or more unsaturation or double bonds in the carbon chain are known as PUFA, and the two major PUFA families are linoleic acid (delta-9,12–18:2 omega-6), and alpha-linolenic acid (delta-9,12,15–18:3 omega-3). These two class of PUFA are considered as essential FA as they cannot be synthesized *in vivo* by humans, and so the dietary intake of linolenic and linoleic acids is commonly via canola, soybean, sunflower, flaxseed and corn oils. Once linoleic and linolenic acids are consumed, they undergo elongation and desaturation via enzymatic pathways into higher monologues such as arachidonic acid (AA, 20:4, omega-6), eicosapentaenoic acid (EPA, 20:5, omega-3) and docosahexaenoic acid (DHA, 22:6, omega-3). EPA and DHA are the most bioavailable forms of omega-3 for humans. (Murphy and Howe 2008).

3.2.4 Trans Fatty Acids (TFA)

Various health-detrimental effects of TFA have been extensively documented over the last two decades. The double-bond geometry of TFA is in the trans (E) configuration as the hydrogen atoms are placed on the opposite sides of the double bond (Hunter 1992; Hastert 1996). While dairy fats contain small amounts of naturally occurring

TFA, it is the industrially-produced TFA during the process of partial hydrogenation that has been studied the most. However, fully hydrogenated oils have less than 2% TFA and are often considered as zero trans. The use of partially hydrogenated oils have also been removed from food application in most parts of the world.

3.3 Physiological Functions of Fats and Oils

The physiological functions of lipids include storing energy, inter- and intra-cellular signaling, and being the structural components of the cell membranes, and are briefly discussed below. In addition, some vitamins, for example vitamins A, D, E and K, require fats for getting dissolved and becoming bioavailable as essential micronutrients stored in the liver and other fatty tissues. The major sources of energy storage in adipose tissue, both in animals and plants, are triglycerides. Lipases in the body regularly synthesize and break down the adipocytes or fat cells, and oxidation of FA provides high caloric content (about 9 kcal/g or 38 kJ/g), compared with 4 kcal/g or 17 kJ/g obtained from the breakdown of carbohydrates and proteins.

The role of FA in the composition of eukaryotic cell membranes is crucial. In animal cells, the intracellular components are physically separated from the extracellular environment by the plasma membrane. The main structural components of the cellular plasma membrane and the intracellular membranes of organelles are glycerophospholipids along with non-glyceride lipid components namely, sphingomyelin and sterols (Stryer et al 2007). It is often considered that the formation of lipids into protocell membranes was a key step in the origin of life (Segré et al 2001).

Another important physiological function of FA is the lipid-based signaling in cellular functioning (Wang 2004). Lipid signaling is initiated by the activation of G protein-coupled nuclear receptors, and several different lipid categories are identified as the signaling molecules acting as the messengers (Eyster 2007). Such signaling molecules include ceraminde-derived sphingosine-1-phosphate, which is involved in the regulation of calcium mobilization (Hinkovska-Galcheva et al 2008), cell growth, and apoptosis. Other examples of signaling molecules are diacylglycerols (DAG), phosphatidylinositol phosphates, prostaglandins and phosphatidylserines involved in the signaling for the phagocytosis of apoptotic cells or other broken components of cells (Saddoughi et al 2008).

3.4 Lipid Metabolism

Triglycerides, sterols and phospholipids from animals and plants are the main dietary sources. Lipid metabolism includes the production and the degradation of lipids inside the cells both for the production of energy and for the synthesis of structural and functional lipids. However, unlike long chain-PUFAs, very long chain PUFAs are generally not obtained from the ordinary dietary sources, and therefore need to be synthesized *in situ* from shorter FA precursors.

Lipids being hydrophobic molecules, require solubilization before being metabolised. In comparison, PUFA are more readily mobilized and oxidized than other fats. PUFA also have an influence on gene expression and appetite-controlling peptides, providing some protective value against obesity. The initial step of lipid metabolism is enzymatic hydrolysis of the triglycerides into its constituent FA in the digestive system. This is followed by the absorption of the FA into the epithelial cells of the intestinal wall where FA are packaged and transported to the rest of the body.

The processes of lipid digestion begin with lingual lipases starting the breakdown of dietary fats in the mouth. However, cholesterols from the food are not broken down by the lipases and generally remain intact until they reach the epithelium of the small intestine. The chemical digestion of fats continues by gastric lipases and the mechanical digestion, peristalsis, begins. In the small intestine, pancreatic lipases and bile salt-dependent lipases help breakdown the triglycerides along with further mechanical digestion. Triglycerides are finally converted into individual FA units and are absorbed into the small intestine's cells (Voet et al 2013).

Fat absorption is the next step in lipid metabolism. The triglycerides moieties FA and glycerol along with cholesterol, aggregate into colloidal structures (micelles) before diffusing across the membrane to enter the intestinal epithelial cells. Monoglycerides and FA resynthesize triglycerides in the cytosol of epithelial cells, forming clusters of bigger particles called chylomicrons which are amphipathic structures that transport digested lipids as they travel through the bloodstream to enter adipose and other tissues in the body (Jo et al 2016).

Transportation of lipids between organs in an aqueous environment is facilitated by lipoproteins, which are complexes of lipids with specific apoproteins. Such transportation process through blood is necessary because of the hydrophobic character of membrane lipids, triglycerides and cholesterols. The lipoprotein lipase breaks down the lipoproteins in the luminal surface of endothelial cells in capillaries, and triglycerides are released, which are then next split into FA and glycerol before entering the cells, and the remaining cholesterol travels through the blood to the liver. The glycerol is converted to glyceraldehyde 3-phosphate, and is subsequently oxidized for production of energy while long chain FA are converted to fatty acyl-CoA in order to pass across the mitochondria membrane (Feingold and Grunfeld 2000).

Triglyerides, membrane lipids and cholesterols can also be synthesized by the organisms through various pathways. Biosynthesis of glycerophospholipids and sphingolipids, the two main classes of membrane lipids occurs in the endoplasmic reticulum membrane. The first step is synthesis of sphingosine or glycerol as the backbone followed by the esterification of fatty acids to the backbone to make phosphatidic acid, which is further altered with the attachment of different hydrophilic head groups to the backbone (Gault et al 2010; Choe et al 2016). Triglyceride biosynthesis occurs in the cytosol via phosphatidic acid which acts as a precursor (Lok et al 1976). Cholesterol biosynthesis occurs in the cytosol of liver cells from acetyl-CoA through a multiple-step pathway known as isoprenoid pathway.

3.4.1 Sources of Lipids – Natural and Prepared Foods

Oils extracted from crops such as soybean, canola, sunflower, safflower, corn, palm, palm kernel, coconut, etc. are widely used in food items, including baked and fried products, margarines and spreads, chocolate and various other confectionery products, ice creams, salad dressings and mayonnaise. Individual oils may be used in these applications, or two or more oils may be blended in defined proportions with or without modification. Such wide array of oils and fats provide us with a diverse range of FA which fall into the categories as mentioned earlier.

Table 3.1 gives a comparative list of FA composition of common vegetable oils. Only by understanding the relative importance and the health-beneficial or health-damaging effects of various FA, one can choose among various sources according to one's needs and preferences.

3.5 Guidelines for Fat Intake

With the globalization of internet and social media, the way consumers obtain nutrition information has changed dramatically. This has also vastly contributed to conflicting information of uncertain and variable quality leading to confusion in many cases. One prominent example is the erroneous understanding and belief about dietary fats leading to its general avoidance.

For years, an emphasis of nutrition communication was to balance calorie intake and energy expenditure, and to decrease dietary fat intake. Reductions in total dietary fat were recommended to reduce saturated fat, trans fat with the overall aim of reducing calorie consumption. However, this resulted in an unintentional negative

Table 3.1 Typical major fatty acid composition of common vegetable oils

Plant source	C12:0 Lauric acid	C16:0 Palmitic acid	C18:0 Stearic acid	C18:1 Oleic acid	C18:2 Linoleic acid	C18:3 Linolenic acid
Coconut	46.5	9.2	2.9	6.9	1.7	
Palm oil	1	43.5	4.5	38.8	9.5	0.3
Sunflower		6	4.6	15.7	71.4	0.6
Canola		4.5	1.8	58	21	9.9
Cottonseed		22.9	2.5	17.5	54.5	0.5
Soybean		10.3	3.9	22.2	54.3	8.5
Olive		11	3	75	9.5	0.5
Safflower		6	4.6	15.7	71.4	0.6
Rice bran		20	2	42.5	31.5	
Corn		9.9	2	28.7	56.9	1.1

health consequences. Reduction of fat in industrially produced food often led to its substitution with refined carbohydrates and added sugars, which led to significant increases in total energy intake and obesity rates (Liu et al 2017). In addition, it led to avoidance of nutrient-dense foods rich in healthy unsaturated fats such as nuts, seeds, avocados and vegetable oils.

3.5.1 Current Recommendations for Dietary Fat Intake

Various national and international health organizations have put forward guidelines on dietary fat intake, as summarized in Tables 3.2 and 3.3. Dietary guidelines from the World Health Organization and other health organizations recommend a total fat intake between 20 and 35% of total calories. The minimum of 20% is to ensure adequate consumption of total energy, essential fatty acids, and fat-soluble vitamins and prevent atherogenic dyslipidemia which occurs with low-fat, high carbohydrate diets and increases risk of coronary heart disease. Table 3.2 shows the recommended percent of energy from fats as recommended by various organizations and institutions; and Table 3.3 lists the recommended levels of n-3 LC-PUFA as per various international organizations. These guidelines are as per 2017 (Liu et al 2017).

Table 3.2 Recommended percent of energy from fats and oils

Organization	Recommended percent of energy				
	Total	Saturated fats	Trans fats	n-6 PUFA	n-3 PUFA
World Health Organization	20–35%	< 10%	< 1%	2.5–9%	0.5–2%
Food and Nutrition Board, Institute of Medicine, WHERE?	20–35%	Limit	Limit	5–10%	0.6–1.2%
United States Department of Health and Human Services and United States Department of Agriculture		< 10%	Limit		
American Heart Association/American College of Cardiology		5–6%	Limit		

Adapted from (Liu et al 2017)

Table 3.3 Recommended n-3 LC-PUFA from various organizations

Organisation	n-3 LC-PUFA mg/day
UK Committee on Medical Aspects of Food Policy, 1994	200
British Nutrition Foundation, 1992	400–1000
American Heart Association, 2002	400–500
ISSFAL, 2004	500
North Atlantic Treaty Organization	800
Japanese Ministry of Health, Labor and Welfare, 1999	1600
France, CNERNA-CNRA; AFSSA, 2001	400–500
National Heart Foundation of Australia, 2008	500
Health Council of Netherlands, 2001	200

Adapted from (Murphy and Howe 2008)

3.6 Lipidome During Aging

More than 75% of the human metabolome is represented by lipids, and the complete set of all biological lipids is called lipidome (Ejsing et al 2009; Psychogios et al 2011). The plasma lipidome consists of thousands of lipids performing different functions and having different structures (Almeida et al 2021). Changes in dietary lipid intake during aging would influence the plasma or serum lipidome. For example, there is a correlation between the FA ingested in the diet and the phospholipids of the cell membranes and the TG of the adipose tissue and plasma (Abbott et al 2012). These studies also showed that whereas dietary SFA, MUFA and PUFA did not significantly influence membrane lipids, the composition of TG in adipose tissue and plasma appeared to be influenced in accordance with the dietary FA (Almeida et al 2021).

During ageing, there is a gradual decrease in the total intake of lipids. More specifically, there is an increase in the intake of SFA and a decrease in the intake of MUFA and PUFA (Almeida et al 2021). With regard to PUFAs, there appears to be a deficit in the intake of omega-3-PUFA, such as α-linoleic acid, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in the elderly (Carrière et al 2007). This specific group of PUFA is extremely important as it has numerous benefits. For example, omega3-PUFA are associated with the maintenance of bone health and muscle tone, inhibition of TG synthesis in the liver, decrease of the inflammatory processes, and decrease in the cognitive performance decline associated with aging (Almeida et al 2021).v

Due to the central role that lipids play in the body, changes in their metabolic pathways can lead to the development of diseases, such as atherosclerosis, DM2, arterial hypertension, dyslipidemia, cardiovascular, and neurodegenerative diseases.

A comprehensive description of the age-related changes in the lipid profiles during normal ageing and pathological situations in old age is available in Almeida et al (2021). Currently, there are several dietary supplements marketed with the claims of increasing the plasma levels of omega3-PUFA (mainly EPA and DHA); and often, these omega3-PUFA used in supplements are derived from fish oils (Almeida et al 2021). However, to what extent such food supplements can slow down or reverse age-related changes in lipidome is presently not well demonstrated.

3.7 Conclusion

Our daily diet is made up of a complex mix of oils and fats from both vegetable, animal and marine sources. Fats and oils are essential for our health and survival at all ages, and no single category of FA can be labelled as good or bad in its entirety. Of course, any imbalance between the amounts of FA and the physiological requirements of the body can lead to health problems and several diseases. Therefore, a focus should be maintained on consumption of balanced intake between saturated, monounsaturated and polyunsaturated rich oils in accordance with the needs of the body at different stages of life. In future, more focus will be put on personalized diet that fits the individual blood lipid profiling (Almeida et al 2021).

In case of industrially-produced food products, the consumer has only a limited say in deciding the oils and fats used in the application. Selection of these oils and fats is based on their contribution to the texture, structure and organoleptic properties of the food item. Declaration on the nutritional labels and guideline recommendations as mentioned in the above tables could be useful. One should also consider proper protection of mono- and polyunsaturated oils against oxidation. Consumption of recommended calories from carbohydrates, proteins and oils and fats, regular physical activity, maintenance of proper food safety and personal hygiene all contribute to health and longevity.

Compliance with Ethical Standards

Conflict of Interest All authors declare they have no conflict of interest.

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