

FOOD SCIENTIST'S GUIDE TO FATS AND OILS FOR MARGARINE AND SPREADS
DEVELOPMENT

by

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Abstract

Fats and oils are an important topic in the margarine and spreads industry. The selection of these ingredients can be based on many factors including flavor, functionality, cost, and health aspects. In general, fat is an important component of a healthy diet. Fat or oil provides nine calories per gram of energy, transports essential vitamins, and is necessary in cellular structure. Major shifts in consumption of fats and oils through history have been driven by consumer demand. An example is the decline in animal fat consumption due to consumers' concern over saturated fats. Also, consumers' concern over the obesity epidemic and coronary heart disease has driven demand for new, lower calorie, nutrient-rich spreads products.

Fats and oils can be separated into many different subgroups. "Fats" generally refer to lipids that are solid at room temperature while "oils" refer to those that are liquid. Fatty acids can be either saturated or unsaturated. If they are unsaturated, they can be either mono-, di-, or poly-unsaturated. Also, unsaturated bonds can be in the *cis* or *trans* conformation. A triglyceride, which is three fatty acids esterified to a glycerol backbone, can have any combination of saturated and unsaturated fatty acids. Triglycerides are the primary components of animal and vegetable fats and oils. The ratio of saturated to unsaturated fatty acids in these fats and oils has a great impact on their functionality.

Common fats and oils include butterfat, beef tallow, fish oils, soybean oil, rapeseed (canola) oil, corn oil, cottonseed oil, olive oil, sunflower oil, palm oil, palm kernel oil, coconut oil, linseed (flax) oil, and safflower oil. Typical fat and oil modification techniques include hydrogenation, interesterification, alternative hydrogenation, fractionation, blending, farm/field practices and genetic modification, and the use of fat replacers. There are many processing techniques that can be utilized in margarine and spreads production. The process can be optimized for each margarine or spreads product.

There are many fats and oils in margarine and spreads formulations. Familiarity with commonly used fats and oils in regards to availability, cost, nutrition, chemistry, and functionality are important when creating a cost-effective, functional margarine or spreads product.

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Dedication

I dedicate this paper to my wonderful husband, Ryan. He was there for me every step of the way. From encouraging me to follow my dream and apply to Kansas State University three and a half years ago, to taking care of the house so I would have more time to work on this paper. I don't think I could have done it without him.

I would also like to thank my parents for their love and encouragement throughout my academic career. From an early age I was told to follow my dreams and that sometimes choosing the difficult path over the easy path is necessary to obtain these dreams. I lead my life by their example and am so grateful for everything they have done for me.

I am so blessed in my life and would like to thank God for the many gifts he has given to me.

- Katy Morlok

Preface

The purpose of this review is to provide the reader with a basic understanding of lipid chemistry and functionality as well as review common fats and oils used in margarine and spreads development with respect to their history, availability, cost, functionality, and nutrition. Food scientists must have a clear understanding of various common fats and oils used in the development of margarine and spreads, as well as a firm grasp on lipid chemistry in regards to functionality in order to create desirable products. By understanding how each fat or oil functions and why, as well as cost, nutrition, and availability, food scientists can develop products that meet consumer needs while maintaining profitability.

A thorough coverage of all aspects of fats and oils, their chemistry, and functionality, as well as complex and minute details of margarine and spread formulations and processing, is beyond the scope of this report. However, this report can be considered an up-to-date review of fats and oils in margarine and spreads products.

CHAPTER 1 - History of Fats and Oils

Importance of Fat in the Diet

Fat is a very important component in a balanced, nutritious diet. Often the term “fat” is used in conjunction with terms such as “obesity” and “coronary heart disease” in the media, without proper discussion about the importance of fat in the diet and the many critical roles fat plays in food and health.

Fat is a vital component in cellular membranes, functions in biochemical regulation, is a source of vitamins A, D, E, and K, and is an important source of linoleic and linolenic acids (Strayer and others 2006), both of which are essential fatty acids. Essential fatty acids must be consumed in the diet as the human body cannot synthesize them on its own (Strayer and others 2006).

Fats are the most energy-rich molecules in the diet. Compared to proteins and carbohydrates, which each contain roughly four calories per gram, fat contributes nine calories per gram in the diet (Stauffer 1996). This gives fat the advantage of providing a lot of energy in a small quantity. However, this aspect of fat, coupled with the human evolutionary drive to consume it, leads to excessive consumption (Lichtenstein 1999). Excess calories (more calories are consumed than can be burned) are stored as body fat.

Apart from nutrition, fats and oils play important functional roles in food products. They contribute to the characteristic flavor and texture of many foods, aid in processing, and can contribute to the shelf life stability of foods.

Fat Consumption through History

Fat and oil consumption has been steadily increasing since the end of the 19th century. Since that period consumer incomes have increased, oil refining capabilities have advanced, and global trade has expanded to allow for a greater availability of oils throughout the world (Grigg 1999). The percentage of fat in the diet rose to more than 40% in many Western countries by the late 1940's. In the U.S. this percentage decreased by 5% in the 1980's (Garn 1997). This dip might have been caused by a large campaign during this period to reduce fat consumption and thereby, reduce body weight and intake of saturated fat that could lead to related health

conditions. The food industry played a key role in this initiative by reformulating many products to meet the claims of “low-fat” or “fat-free” (Garn 1997). These claims are defined by the Food and Drug Administration (FDA). For example, fat-free products must contain less than five calories per reference amount customarily consumed (RACC), less than 0.5 g fat per RACC, and cannot contain any ingredient known to contain fat (FDA 2006).

Overall, the quantity of fats and oils consumed per capita has dramatically increased since the 1950’s (Grigg 1999). Table 1.1 illustrates this point. Since 1961, daily per capita consumption has increased more than 2.5 times. This could be attributed to population growth and the availability of fats and oils to areas that previously did not have access to them (Grigg 1999). Furthermore, fat as a percentage of total caloric intake has also increased. Many factors contribute to the decision-making process of what humans eat. Health considerations often lose out to flavor and cost. It is commonly understood that many low-cost, tasty, and flavorful foods (such as deep-fried foods) contain high percentages of fat.

Table 1.1–U.S. population and vegetable oil consumption over four decades.

Year	Estimated Population (in millions)	Fat Supply Quantity (g/capita/day)
1961	183.7	31.16
1965	194.3	34.83
1970	205.1	44.54
1975	216.0	45.82
1980	227.2	53.86
1985	237.9	61.19
1990	249.5	62.03
1995	262.8	62.08
2000	282.2	70.89
2005	296.4	80.85

This data was adapted from the Food and Agriculture Organization of the United Nations and the U.S. Census Bureau (FAO 2009, U.S. Census Bureau 2010).

Evolution of Fat Consumption

Prior to the Stone Age, genetic selection and adaptation were largely influenced by the available food supply. During this period mankind experienced “feast or famine” in regards to eating. When there would be food, there would be a lot of food (e.g. killing a large animal). The limited capabilities for storing excess food contributed to periods where man would starve. This fluctuation encouraged the selection for fat storage capabilities in man to provide energy during periods of famine. According to scholars, genetic selection stopped about 40,000 years ago. During this period *Homo sapiens* were consuming approximately 50% lean animal meat and 50% plant-based food (Lichtenstein 1999). However, the food supply has experienced many changes since this time.

The modern day food supply, which includes a high percentage of fat as well as the inclusion of many saturated and *trans* fats, may not be optimal to the genetic selection that has been set since the Stone Age (Lichtenstein 1999). Most of the population does not encounter “feast or famine” scenarios in modern times. This again leads into the push toward fat reduction and healthier fat consumption in order to combat obesity and coronary heart disease.

The Decline of Animal Fat Consumption

The decline in animal fat consumption coincides with the dramatic rise in the consumption of vegetable oils. In the late 1800’s and early 1900’s, animal fats such as butter, lard, and tallow were used for cooking, baking, and spreading. In fact, according to the Agricultural and Economic Report No. 138, “Food Consumption, Prices, Expenditures,” published in 1968, it was estimated that about 2/3 of available food fat came from animal sources while the other 1/3 came from vegetable sources during the 1940’s. Inventions of margarine and the technique of partial hydrogenation coupled with soaring butter prices led to the decline of animal fat consumption (Table 1.2) (Grigg 1999). By 1950, butter consumption had decreased from about eighteen pounds per capita at the turn of the century to just over ten, while margarine rose from two pounds per capita to around eight. During this same period, vegetable oil consumption increased dramatically from three pounds per capita to more than ten. An increased decline in animal fat consumption since the 1950’s can be linked to growing awareness of

coronary heart disease, which by 1950 was the leading cause of death in the U.S. (Enig and Fallon 1999). In 1968, the American Heart Association published eight dietary guidelines that became known as the ‘Prudent Diet.’ These guidelines encouraged the public to reduce animal fat consumption, decrease saturated fats while increasing unsaturated fats, and to decrease cholesterol (Kritchevsky 1998).

Vegetable oils have risen in popularity since the days of the ‘Prudent Diet’ - low in saturated fats and relatively high in polyunsaturated fatty acids. Many food companies began reformulating their products to remove the saturate-rich animal fats. Therefore, vegetable oils were used as a replacement since they provided many benefits including: low cost compared to animal fats, neutral color and flavor, oxidative stability when hydrogenated, and relatively high levels of beneficial unsaturated fatty acids (Grigg 1999).

Table 1.2–World usage of fats and oils – average annual production of the major commodity oils and fats in the five-year periods 1958-1962 and 1996-2001.

Source	1958-1962		1996-2001	
	Rank	Million Metric Tons	Rank	Million Metric Tons
Animal	37%	–	19%	–
Vegetable	63%	–	81%	–
Butter	1	4.21	7	5.75
Tallow	2	3.39	5	7.65
Soybean Oil	3	3.20	1	22.84
Lard	4	3.19	6	6.21
Olive Oil	9	1.30	11	2.42
Palm Oil	10	1.26	2	17.93
Canola Oil	11	1.13	3	12.56

This data was adapted from the 14th Biennial Sunflower Association conference proceedings (Aldersey 2003).

Beginnings of Butter and Spreads Usage

For over 5,000 years, butter has been an important food product in cultures throughout the world (Robinson 2005a). This energy-rich dairy product provides functionality and flavor in many baking, cooking, and spreading applications. For those not living on farms however, butter was expensive and sometimes hard to get.

In 1870, Hippolyte Mège-Mouriez, a French chemist, invented margarine. Margarine, made of non-dairy fats, presented a lower cost alternative to butter. This invention was in response to a challenge by Emperor Louis Napoleon III to create a butter substitute that would be more affordable to the working class (List 2006).

Competition was beginning to put pressure on the butter industry in the U.S. by the end of the 1870's. This can be attributed to a U.S. patent issued to Mège-Mouriez for margarine in 1873 (List 2006). Several dairy-producing states had enacted legislation to try to slow the growth of margarine in the marketplace (Robinson 2005b). In 1886, Congress passed the Margarine Act which imposed two cents per pound tax on margarine and also required expensive licenses to make, distribute, or sell margarine. With margarine still increasing its share of the butter market, amendments to the Margarine Act of 1886 increased taxes on colored margarines by five-fold. These measures successfully stifled the margarine industry in the U.S. temporarily. Eventually, increases in dairy prices and consumer demand for lower priced alternatives pushed margarine back into the public light. Consumer pressure eventually led to the end of the margarine taxes as well as other bans, restrictions, and fees enacted by the states (Young 2002). In the ten year period between 1960 and 1970, margarine consumption nearly doubled and overtook butter (J Am Oil Chem Soc 1977).

The rise of margarine consumption naturally corresponded with the decline in butter sales. Over the years, technology related to margarine development and processing has yielded a product that closely resembles butter in both flavor and functionality, and is substantially cheaper than butter. Thus, consumers may purchase margarine for cost-savings reasons.

Butter and margarine both have specific standards of identity set by the federal government. These include specific fat content and limitations on ingredient usage. These restrictions have preserved the identity of these products but have given rise to a new broad category called 'spreads.'

21 U.S.C. 321a Butter

“The food product usually known as butter, and which is made exclusively from milk or cream, or both, with or without common salt, and with or without additional coloring matter, and containing not less than 80 per centum by weight of milk fat, all tolerances having been allowed for.” 21U.S.C. 321a

21 CFR 166.110 Margarine

“Margarine (or oleomargarine) is the food in plastic form or liquid emulsion, containing not less than 80 percent fat determined by the method prescribed in “Official Methods of Analysis of the Association of Official Analytical Chemists,” 13th Ed. (1980), section 16.206, “Indirect Method,” under the heading “Fat (47) –Official Final Action,” which is incorporated by reference.” ... “It is produced from one or more of the optional ingredients in paragraph (a) (1) of this section, and one or more of the optional ingredients in paragraph (a) (2) of this section, to which may be added one or more of the optional ingredients in paragraph (b) of this section. Margarine contains vitamin A as provided for in paragraph (a) (3) of this section.”

“(1) Edible fats and/or oils, or mixtures of these, whose origin is vegetable or rendered animal carcass fats, or any form of oil from a marine species that has been affirmed as GRAS or listed as a food additive for this use, any or all of which may have been subjected to an accepted process of physico-chemical modification. They may contain small amounts of other lipids, such as phosphatides or unsaponifiable constituents, and of free fatty acids naturally present in the fat or oil.” ... 21CFR166

The spreads category has been evolving since the early 1970's. The products are usually packaged in tubs and are spreadable right from the refrigerator. Spreads are not confined to strict standards like butter and margarine and can be formulated to meet consumer's changing demands. In recent years, the spreads category has expanded significantly; offering spreads from reduced calories and fat, improved functionality, to other health benefits such as addition of omega-3 fatty acids, vitamins, plant sterols, and fiber. These spreads products have confused consumer's minds about the definition of margarine. To the consumer, the term 'margarine' is now used to refer to any non-butter spreads.

CHAPTER 2 - Overview of Fats and Oils Chemistry

Definitions

Fats

In food sources, fats are generally triesters of glycerol and fatty acids that are soluble in organic solvents and insoluble in water. Typically, the term ‘fat’ is used to refer to those whose triglycerides (or mixtures of triglycerides) are in the solid or semi-solid state at room temperature (Strayer and others 2006).

Oils

The terms ‘oils’ and ‘fats’ generally refer to the same group of compounds and can be used interchangeably. However, the term ‘oil’ is used when the lipid is liquid at room temperature (Strayer and others 2006).

Lipid

This term can be used to describe either a fat or oil but does not imply its physical state at room temperature. ‘Lipid’ is a more general classification and has a less clear definition (Strayer and others 2006). According to Christie (2010), editor-in-chief of the AOCS Lipid Library, lipids are defined as “fatty acids and their derivatives, and substances related biosynthetically or functionally to these compounds.”

Triglyceride

A triglyceride consists of a glycerol backbone that is esterified with three fatty acids (Figure 2.1). The triglyceride’s composition, as well as the position of the fatty acids, has an impact on its functionality. Triglycerides are the predominant components of animal and vegetable fats and oils (Strayer and others 2006).

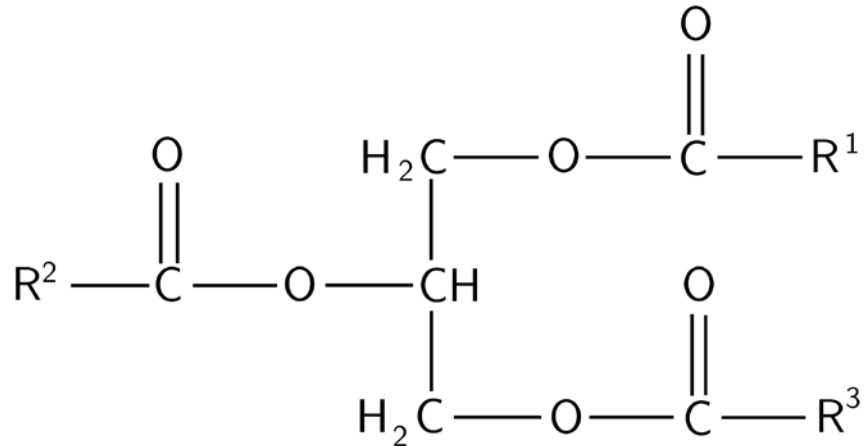


Figure 2.1–Simple triglyceride structure.

Fatty Acids

Fatty acids are carboxylic acids with long, unbranched aliphatic tails (Figure 2.2). Most natural fatty acids have an even number of carbon atoms. This is due to their biosynthesis involving acetyl-CoA which is a coenzyme that carries a two-carbon atom group. Fatty acids have different functional properties based on their chain length, saturation or degree of unsaturation, and their conformation (*cis* or *trans*) when they are unsaturated (Stauffer 1996).

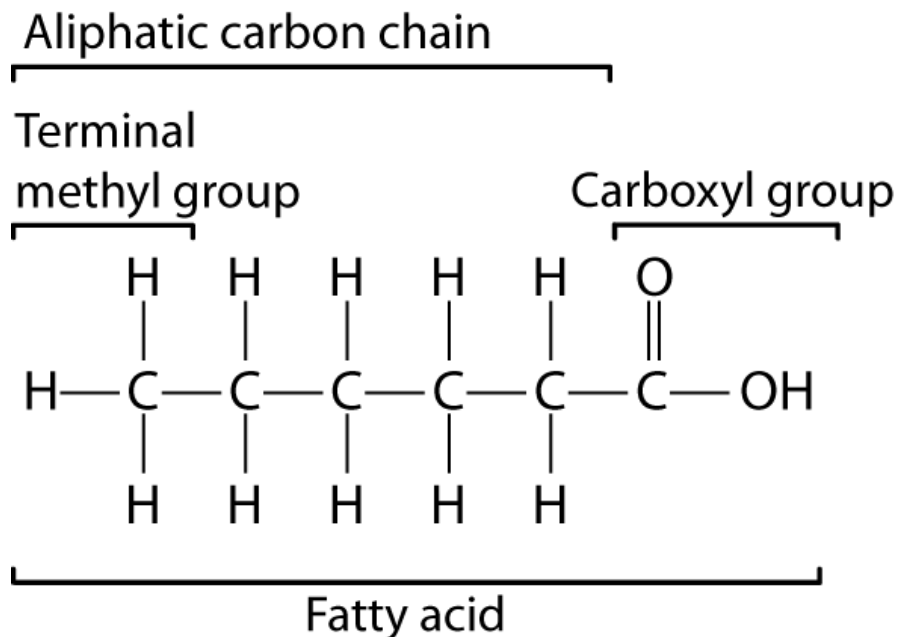
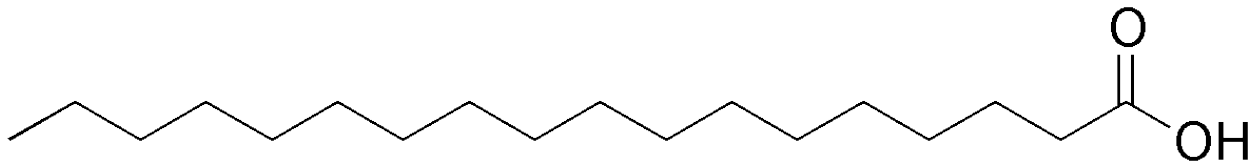


Figure 2.2–Fatty acid structure.

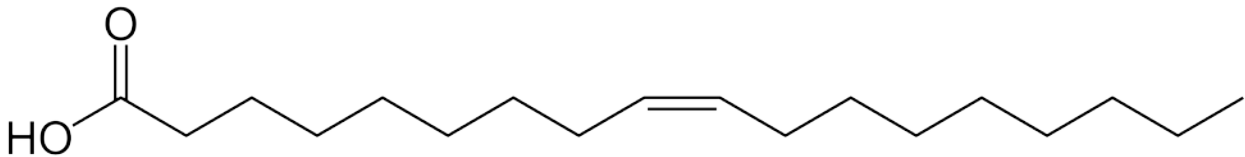
This figure was adapted from Fats and Oils (Stauffer 1996).

Saturated Fatty Acids

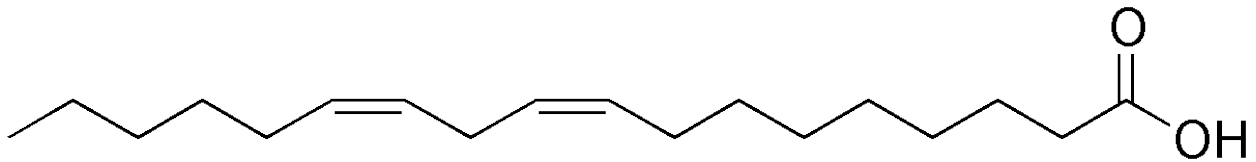
Saturated fatty acids are long-chain carboxylic acids generally consisting of 12-24 carbon atoms and no double bonds (Figure 2.3 and 2.4) (Christie 2009b). The term ‘saturated’ refers to the fact that the acid is ‘saturated’ with hydrogen atoms, these fatty acids are straight or linear, without any kinks in their molecular structure. Examples of saturated fatty acids include butyric, lauric, myristic, palmitic and arachidic acids.



Saturated Fatty Acid (Stearic acid)



Monounsaturated Fatty Acid (Oleic acid)



Polyunsaturated Fatty Acid (Linoleic acid)

Figure 2.3–Saturated, monounsaturated, and polyunsaturated fatty acid structures.

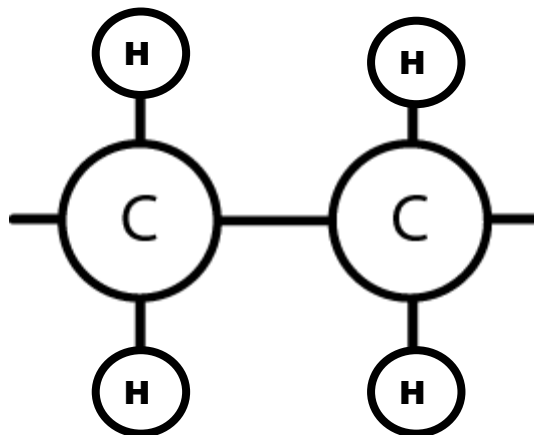


Figure 2.4–Saturated bond structure.

Unsaturated Fatty Acids

Unsaturated fatty acids are long-chain carboxylic acids that contain one or more double bonds (Figure 2.3 and 2.5) (Christie 2009a). If it contains one double bond it is called ‘monounsaturated’ and if it contains two or more double bonds it is termed ‘polyunsaturated’ (Figure 2.3). The degree of unsaturation, chain length, conformation (*cis* or *trans*), and position of the double bond affects the functionality of the fat (Strayer and others 2006). Examples of unsaturated fatty acids include oleic, linoleic, linolenic and arachidonic acids. Unsaturated fatty acids can be in the *cis* or *trans* conformations.

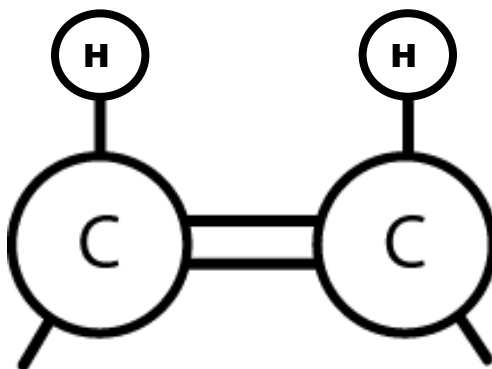


Figure 2.5–Unsaturated bond structure.

Cis Unsaturated Fatty Acids

In the *cis* conformation the carbon chains are on the same side across the double bond. In the E, Z system of naming, the *cis* conformation is designated 'Z' for *zusammen* which is Greek for 'together' (Figure 2.6). This results in a bent shape to the fatty acid (Stauffer 1996).

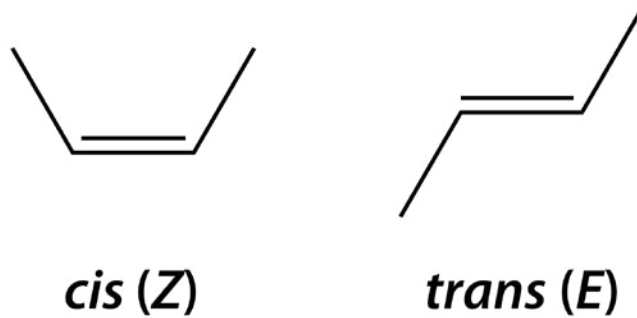


Figure 2.6– Fatty acids in the *cis* (Z) and *trans* (E) conformations.

Trans Unsaturated Fatty Acids

In the *trans* conformation, the carbon chains are on the opposite side across the double bond. In the E, Z system of naming, the *trans* conformation is designated 'E' for *entgegen* which is Greek for 'opposite' (Figure 2.6) resulting in a straight shape similar to that of a saturated fatty acid. Most *trans* fatty acids are a result of processing and are not predominantly found in nature. The *trans* formation results in higher melting points than the *cis* formation (Stauffer 1996).

Fatty Acids Common in Spreads Products

The most common and predominant fatty acids in butter and spreads will be discussed in this section. These include the saturated fatty acids butyric (C4:0), lauric (C12:0), myristic (C14:0), palmitic (C16:0), stearic (C18:0), and arachidic (C20:0) as well as the unsaturated fatty acids oleic (C18:1), linoleic (C18:2), linolenic (C18:3), and arachidonic (C20:4). Table 2.1 identifies the common name of these fatty acids as well as their systematic names, common nomenclature, carbon chain lengths, number of double bonds, melting points and fat sources where they are commonly found.

Table 2.1–Predominant fatty acids found in animal and vegetable fats and oils.

Systematic Name^a	Common Name	Nomenclature^b	# of Carbon	# Double Bonds	Melting Point°C	Typical Fat Source
Butanoic	Butyric	C4:0	4	0	-7.9	Butterfat
Dodecanoic	Lauric	C12:0	12	0	44.2	Coconut oil Palm kernel oil
Tetradecanoic	Myristic	C14:0	14	0	54.4	Butterfat Coconut oil
Hexadecanoic	Palmitic	C16:0	16	0	62.9	Most edible fats and oils
Octadecanoic	Stearic	C18:0	18	0	69.6	Most edible fats and oils
Eicosanoic	Arachidic	C20:0	20	0	75.4	Peanut oil Butterfat
9-Octadecenoic	Oleic	C18:1	18	1	16.3	Most edible fats and oils
9,12-Octadecadienoic	Linoleic	C18:2	18	2	-6.5	Most vegetable oils
9,12,15-Octadecatrienoic	Linolenic	C18:3	18	3	-12.8	Soybean oil Canola oil
5,8,11,14-Eicosatetraenoic	Arachidonic	C20:4	20	4	-49.5	Some fish oils
5,8,11,14,17-Eicopentaenoic	EPA	C20:5	20	5	-53.5	Some fish oils
4,7,10,13,16,19-Docosahexenoic	DHA	C22:6	22	6	NA	Some fish oils

^a These numbers indicate the location (carbon number) of the double bonds in the molecule.

^b The nomenclature “C##:##” refers to the number of carbons in the fatty acid chain (the number directly following the C) and the number of double bonds it contains; its degree of unsaturation (the number following the colon).

This data was adapted from the Food Fats and Oils published by the Institute of Shortening and Edible Oils in 2006 (Strayer and others 2006).

Butterfat, coconut oil, and a few other edible fats contain notable amounts of fatty acids with carbon chain-lengths of less than twelve. In general, most natural fats and oils primarily consist of fatty acids larger than twelve carbons in chain-length. Thus, the focus of this next section will be on the higher molecular weight fatty acids commonly found in margarine and spreads formulations.

Saturated Fatty Acids

Saturated fatty acids do not contain any carbon-carbon double bonds and are fully saturated with hydrogen atoms. These fatty acids are more stable to changes and less chemically reactive than unsaturated fatty acids. The greater the chain length of the saturated fatty acid, the higher its melting point. Saturated fatty acids greater than or equal to ten carbons in chain length are solid at room temperature (Strayer and others 2006).

Butyric Acid (C4:0)

Butyric acid is a short-chain saturated fatty acid consisting of a four-carbon chain. Butyric acid, also referred to as butanoic acid, is not found in significant quantities in many fats or oils. Of commonly eaten fats, butterfat contains the highest butyric acid concentration at approximately 4% of total fatty acids (Fallon 1996). Short-chain fatty acids such as butyric acid are digested faster than medium- and long-chain fatty acids. This makes them quickly available as sources of energy (Bell and others 1997).

Lauric Acid (C12:0)

Lauric acid is a major component of both coconut and palm kernel oil (41-56% and 41-55%, respectively) (Gunstone and others 1994). Lauric acid is a medium-chain fatty acid not typically found in high concentrations in animal or vegetable fats and oils with the exceptions of palm kernel and coconut oil (Christie 2009b).

Myristic Acid (C14:0)

Myristic acid is also an important component in coconut and palm kernel oil (13-23% and 14-20%, respectively) (Gunstone and others 1994). Myristic acid is found in butterfat and is a minor component of other animal fats. Myristic acid is found in most living organisms but usually at levels of 1-2% or less (Christie 2009b).

Palmitic Acid (C16:0)

Palmitic acid is one of the most commonly found saturated fatty acids in nature although not in large amounts. It is a major component of cottonseed oil (17-31%) and palm oil (32-59%). Palmitic acid is present in almost every animal and vegetable fat and oil. Animal fats from pig, sheep, and cattle can contain 20-37% palmitic acid (Gunstone and others 1994).

Stearic Acid (C18:0)

Stearic acid is found in many ruminant animal fats (tallows contain 5-40%). It can be obtained through complete hydrogenation of unsaturated C18 fatty acids. Stearic acid is less common than palmitic acid although it is a component of most vegetable fats. There are significant levels in cocoa and shea butters which are not used in the spreads industry (Gunstone and others 1994). Apart from palmitic acid, stearic acid is the second most prevalent saturated fatty acid found in natural fats and oils (Christie 2009b). From a health standpoint, it has been found to have a neutral effect on serum cholesterol levels when compared to other saturated fatty acids (Bonanome and Grundy 1988).

Arachidic Acid (C20:0)

Arachidic acid is found at low levels in most animal and vegetable fats and oils. Peanut oil contains a relatively high concentration of arachidic acid at 1.1-1.7% (O'Brien 2009). This fatty acid is a precursor to arachidonic acid (an omega-6 fatty acid) (Christie 2010).

Unsaturated Fatty Acids

Unsaturated fatty acids contain one or more double bonds between carbon atoms. Generally, when the degree of unsaturation is increased, the reactivity of the compound will also be increased (Strayer 2006). Unsaturated fatty acids commonly found in vegetable and animal fats and oils have low melting points and are generally liquid at room temperature.

Oleic Acid (C18:1)

Oleic acid contains one double bond (monounsaturated) in the *cis* formation. It is the most commonly found fatty acid in nature and is found in almost all animal and vegetable fats and oils (Gunstone and others 1994). Most seed oils, such as soybean and canola, contain 20-80% oleic acid while olive oil contains up to 78%. Oleic acid in the *trans* conformation is not

normally seen in nature but is regularly observed in hydrogenated oils as a byproduct of the hydrogenation process (Christie 2010).

Linoleic Acid (C18:2, omega-6)

Linoleic acid contains two double bonds in the *cis* formation. Thus, it is a polyunsaturated fatty acid (PUFA). Linoleic acid is not synthesized in the body and must be consumed in the diet making it an essential fatty acid. Linoleic acid is present in most vegetable oils and can be found in all commercial seed oils. Corn, sunflower, and soybean oils can contain over 50% linoleic acid while safflower oil can contain up to 75% (Christie 2009a).

α-Linolenic Acid (C18:3, omega-3)

Linolenic acid has three double bonds. It is also a PUFA, an essential fatty acid, and an omega-3 fatty acid. A deficiency in α-linolenic acid has been shown to lead to poor growth and neurological problems in infants (Strayer and others 2006). Linolenic acid is found in fairly high concentrations in photosynthetic plants. In linseed oil, it can be as much as 65% of total fatty acids. Soybean and canola oils can have up to 7% linolenic acid (Christie 2009a). This fatty acid is relatively susceptible to oxidation and thus oils containing lower levels of linolenic acid are more desirable for food applications.

Arachidonic Acid (C20:4, omega-6)

Arachidonic acid is a long-chain, omega-6 essential fatty acid. It is found in animal fat such as red meat and eggs but is not present in vegetable fats and oils. Linoleic acid and arachidic acids can be converted to arachidonic acid in the body. Arachidonic acid is a precursor to important pro-inflammatory compounds such as eicosanoids (Gerster 1997).

Omega Fatty Acids

Another class of fatty acids is the omega group. These are currently a popular addition to many varied food products as well as spreads. The ‘omega’ system of naming simply refers to the location of the carbon double bond that is closest to the methyl group at the end of the chain (Figure 2.7) (Strayer and others 2006). In the omega family, there are omega-3, omega-6, and omega-9 fatty acids. The most notable, omega-3 fatty acids, are α-linolenic acid (ALA), 5,8,11,14,17-eicosapentaenoic acid (EPA) and 4,7,10,13,16,19-docosahexaenoic acid (DHA). Stearidonic acid (SDA) is also an omega-3 fatty acid but is not widely used at this time. The

most notable omega-6 fatty acid is linoleic acid. Unlike omega -3 and -6, omega-9 fatty acids are not essential fatty acids. This category contains oleic and erucic acids which can be synthesized in the body. The ratio of omega-6:omega-3 may play a role in health (Prybylski and McDonald 1995). This will be discussed further in the Health Concerns and Consumer Trends section.

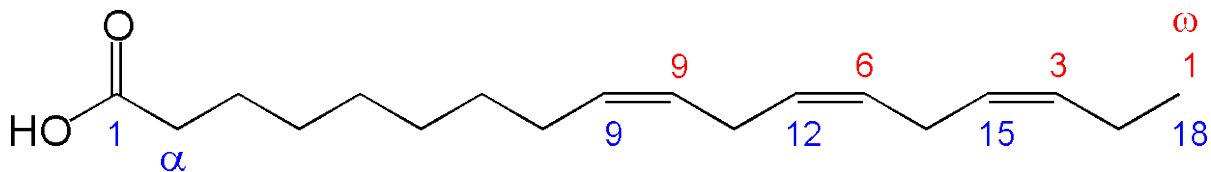


Figure 2.7–Structure of the omega-3 α -linolenic acid (ALA) with numbering.

α -Linolenic acid (ALA) (C18:3, n-3)

ALA is found in many common vegetable oils. Soybean, canola, and linseed (flax) oil contain the highest concentrations at approximately 7, 7, and 65%, respectively. ALA by itself is not known to have positive health effects but can be synthesized into EPA and DHA in the body (Christie 2009a). Thus, it would seem more efficient to consume larger quantities of EPA and DHA rather than ALA. However, ALA is readily available in the diet and present in more common food products.

Stearidonic acid (SDA) (C18:4, n-3)

SDA, omega-3 fatty acid is not as common as ALA, EPA, or DHA but interest is growing into potentially using stearidonic acid as an alternative to EPA in the diet. SDA is a component of fish oil and other seafood. It can be used as an alternative to fish oils when it is expressed in other vegetable oils, such as soybean and canola, through genetic modification. Canola oil has been modified to contain as much as 23% of total fatty acids as stearidonic acid. SDA is a metabolic intermediate to EPA and thus results in the same documented health benefits as EPA (Whelan 2008).

Eicosapentaenoic acid (EPA) (C20:5, n-3)

EPA, an omega-3 fatty acid is commonly found in fish oils (such as herring, pilchard and menhaden). This polyunsaturated fatty acid (Figure 2.8) is an important component of

phospholipids and is known to have anti-inflammatory properties as well as other beneficial neurological effects. The omega-3 fatty acid, EPA, can also be found in algae (Christie 2009a).

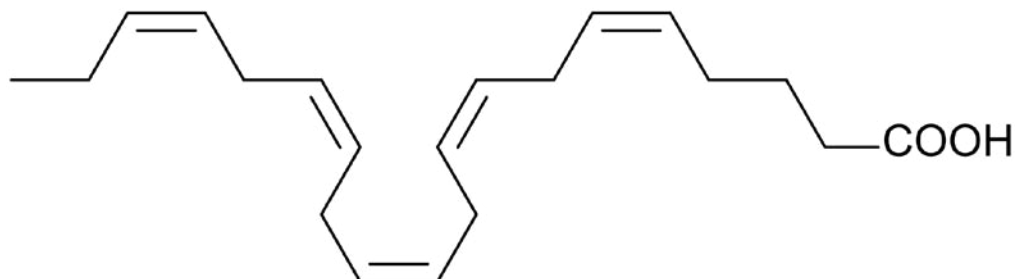


Figure 2.8–Structure of eicosapentaenoic acid (EPA).

4,7,10,13,16,19-Docosahexaenoic acid (DHA) (C₂₂:6, n-3)

DHA (Figure 2.9) is found in high concentrations in fish oils (such as herring, pilchard, and menhaden) and algae but is not present in higher plants (such as soybean, rapeseed, corn, or palm). Consumption of DHA has been correlated with behavioral and neurological development in babies. Other studies have shown that consumption of DHA can have positive effects on inflammation and immuno-regulatory systems. In addition, DHA may play a role in the retina where it is a major structural component (Christie 2009a). This is further discussed in the Health Concerns and Consumer Trends section.

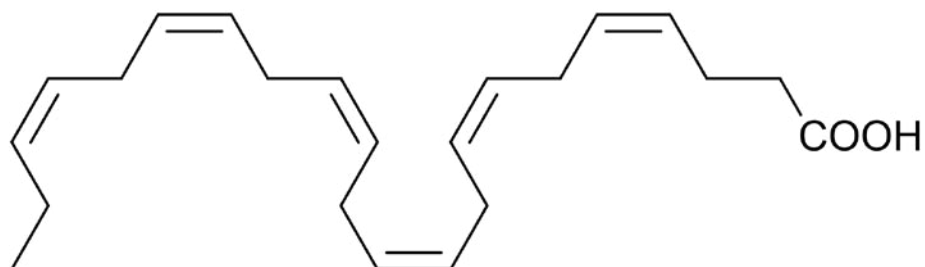


Figure 2.9–Structure of docosahexaenoic acid (DHA).

Linoleic acid (C18:2, n-6)

Linoleic acid is found in most natural fats and oils. The largest concentrations can be found in soybean oil, corn oil, and sunflower oil, each containing over 50% linoleic acid. Linoleic acid is an essential fatty acid. It is converted into arachidonic acid in the body which has been shown to be involved in cellular signaling and inflammatory responses (Christie 2009a).

Functionality

Overview

When developing a spreads product, a few key desirable qualities need to be kept in mind. Consumers expect spreads to be spreadable from the fridge, smooth, melt away quickly in the mouth, and have a relatively long shelf life before the product develops rancidity. These qualities, among others such as flavor and visual appeal, are a direct result of the fats and/or oils used in development.

As food scientists, it is important to understand the reasons behind the functionality and characteristics of commonly used fat and oil ingredients. Properties such as oxidative stability, melting properties, and crystallization and polymorphism explain why fats and oils behave the way they do in spreads products. It is also important to understand why these properties and functionality characteristics occur. Thus, it is necessary to look at the length and degree of unsaturation of the fatty acids, the isomeric form of the fatty acids, and the fatty acid position on the triglyceride. All of these factors influence the physical characteristics of a fat or oil.

Certain natural fats will contain desirable characteristics while others need to be modified before use in food applications. Chemical and physical processing techniques allow for the modification of fats and oils to meet specific needs such as functionality, nutrition, and/or cost.

Melting Properties

The melting properties of a fat or oil can be influenced by the following:

- Chain-length of the fatty acids (increase in chain-length corresponds to an increase in melting point);

- Saturation or degree of unsaturation of the fatty acids (increase in saturation corresponds with an increase in melting point);
- Isomerization of double bond(s) in unsaturated fatty acids (*cis* to *trans* increases melting point);
- Position of double bonds in unsaturated fatty acids (conjugated double bonds – double bonds separated by a single bond – corresponds to an increase in melting point);
- Position and identity of fatty acids on the triglyceride molecule (simple homogeneous triglycerides will have sharper melting curves than mixed triglycerides) (Strayer and others 2006);
- Fatty acid profile of the fat or oil (percentage of saturates and/or unsaturates will affect the physical and chemical behavior of the fat/oil) (Stauffer 1996);
- Hydrogenation (partially hydrogenated fats and oils experience an increase in saturation and the development of *trans* fatty acids which increases the melting point); and
- Crystal structure (α – lowest melting point, β' – intermediate melting point, and β – highest melting point, will be discussed in the next section) (Strayer and others 2006).

It is important to note that natural fats and oils are generally made up of a mixture of triglycerides. When combining various fats and oils, the melting point can be lowered. Also, their melting range will be larger than any individual component (Strayer and others 2006). In the mixtures of triglycerides, there will be some that are solid and some that are liquid at any given temperature. This is important to understand when formulating a spread product in order to maintain a spreadable product at refrigeration temperatures by making sure the product does not quickly melt into a liquid product when held and handled at room temperature. A useful analytical tool used for this is 'solid fat content' or SFC. This method allows one to see the percentage of solid fat in a product at temperatures ranging from refrigeration through room temperature and higher. Another analytical method to obtain this information is 'solid fat index.' This method is based on dilatometry readings and more biased than SFC which is based on low-resolution nuclear magnetic resonance (NMR) (Stauffer 1996).

Crystallization and Polymorphism

Fats and oils display polymorphism. Polymorphism, in the case of fats and oils, is defined as the ability of the triglyceride to be in different physical states, such as liquid, solid, and into different crystal structures (Figure 2.10). Different processing conditions can result in the formation of different crystal types (Strayer and others 2006). These crystal types will continue to change until a stable form is reached (Stauffer 1996). The different crystal types (alpha - α , beta-prime - β' and beta - β) have a marked effect on the textural and functional properties of fats and oils in food products (Strayer and others 2006).

Alpha crystals have the lowest melting point (54.7 °C for pure tristearins). These crystals are small (~5 μm) and appear random in shape (Figure 2.11) (Stauffer 1996). They are loosely packed, fragile, and are very unstable (Rajah 2002). Alpha-crystals typically form when the fat is cooled rapidly. For example, a fat poured onto a block of ice yields a substance similar to paraffin wax due to the formation of alpha crystals (Stauffer 1996).

After α -crystals, the next lowest melting point crystals are β' . Beta-prime crystals with pure tristearins have a melting point of 63.2 °C (Stauffer 1996). Beta-prime crystals are fairly stable (more so than alpha and less so than beta) (Rajah 2002) and are small, smooth, and fine (Strayer and others 2006). They are shaped like needles and most are less than 5 μm in length (Figure 2.11) (Stauffer 1996). Beta-prime crystals can pack together tightly and have the ability to trap large amounts of liquid fat (Rajah 2002). This is one of the reasons the β' crystal structure is the most desirable form for margarine and spreads products. Beta-prime crystal structure is an important factor in the product texture, function, and shelf life stability.

The highest melting crystals are called β crystals. For a pure tristearin, the β crystal has a melting point of 73.5 °C (Stauffer 1996). They are very stable but are large, coarse crystals (25-50 μm) (Figure 2.11) that can lead to sandy product texture (Rajah 2002). Beta crystallization can be prevented by modifications such as partial hydrogenation and interesterification, blending with other fats and oils with more β' tending fats, or by adding a crystal inhibitor (Rajah 2002).

Natural fats typically contain a variety of triglyceride molecules. This heterogeneous mixture causes the rate of crystal transformation to slow. It takes time for these various shaped triglycerides to pack together tightly into β crystals from β' . The reverse is also true. If the

triglycerides are predominantly homogeneous, it is easier for them to pack together into the large, stable, higher melting β crystal form (Rajah 2002).

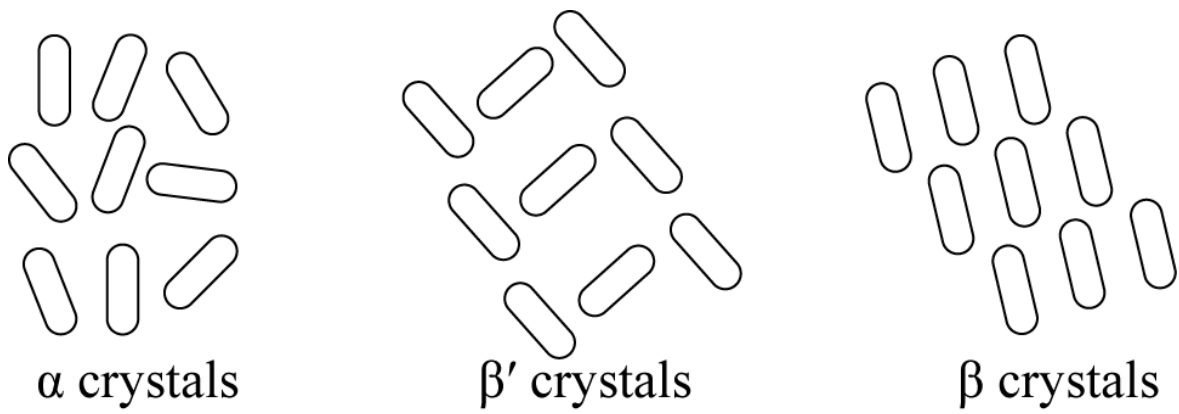


Figure 2.10–Orientation of triglyceride crystals.

This figure was taken from Fats and Oils (Stauffer 1996).

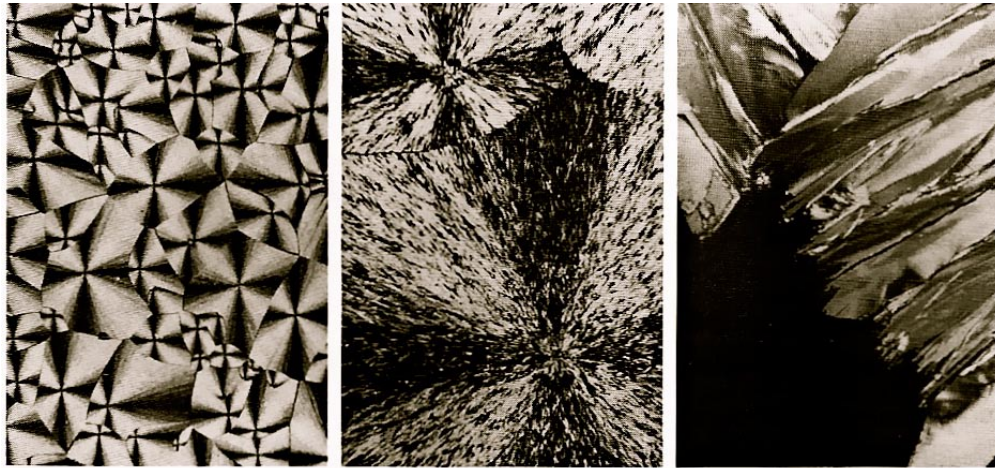


Fig. 1-5. Photomicrographs of fat crystals in polarized light. From left to right, α -crystals, β' -crystals, and β -crystals.

Figure 2.11–Polarized photomicrographs of triglyceride crystals.

This figure was taken from *Fats and Oils* (Stauffer 1996).

Oxidative Stability

Oxidation can be a major problem in fat-based products. Oxidation of fatty acids leads to rancidity resulting in undesirable flavors and odors in the food product. Control of oxidative rancidity is imperative to extend shelf life.

Saturated fatty acids are less prone to oxidative rancidity than unsaturated fatty acids. The greater the degree of unsaturation, the more reactive the molecule becomes (Strayer and others 2006). Table 2.2 provides the relative oxidative tendencies of a saturated, monounsaturated, and polyunsaturated fatty acid containing two and three double bonds. This is one of the reasons many vegetable oils containing a large percentage of unsaturated fatty acids need to be partially hydrogenated in order to increase shelf life. Palm oil, containing around 40% of the saturated fat palmitic acid, is fairly stable and thus does not need to be partially hydrogenated (Gunstone 2002). This makes it a useful alternative when reformulating products to eliminate *trans* fatty acids that are formed during partial hydrogenation.

Table 2.2–Relative oxidation comparison of fatty acids.

Fatty Acid	Relative Oxidation^a
Stearic (C18:0)	1
Oleic (C18:1)	10
Linoleic (C18:2)	100-120
Linolenic (C18:3)	160-250

^a This table shows that compared to stearic acid, oleic acid is ten times as easily oxidized.

Compared to oleic acid, linoleic is about ten times more easily oxidized and linolenic is about twenty times.

This data was adapted from the Development and Processing of Vegetable Oils for Human Nutrition (Przybylski and McDonald 1995).

CHAPTER 3 - Health Concerns and Consumer Trends

Cholesterol

Cholesterol is found predominantly in animal fats. It is also found in vegetable oils but only at very low levels. Cholesterol is delivered to the body through diet but is also synthesized by the liver (O'Brien 2009). Cholesterol is required in the body and plays a very important role in maintaining health. It is only when serum cholesterol levels increase to a point that normal metabolic functions can't process it properly that problems arise (Stauffer 1996).

Lipoproteins are water-soluble proteins combined with cholesterol that are carried through the body in the bloodstream. They are typically named based on their relative densities (low to high): chylomicron, very-low-density lipoprotein (VLDL), intermediate-density lipoprotein (IDL), low-density lipoprotein (LDL), and high-density lipoprotein (HDL). Each of these lipoproteins plays a key role in delivering cholesterol to various parts of the body. For example, LDL is the major carrier molecule that transports cholesterol to cells for use in membrane biosynthesis. When LDL is not needed by the cell, it is taken up by macrophages which bloat and attach to plaques or damage in blood vessels. This contributes to plaque growth, which can eventually lead to restricted blood flow and/or high blood pressure. Increased LDL cholesterol has been correlated with an increased risk of coronary heart disease. This is why LDL is sometimes referred to as the "bad" cholesterol. HDL is known as the "good" cholesterol because it is thought to return cholesterol to the liver for excretion or to tissues for use in hormone synthesis (O'Brien 2009).

Both HDL and LDL are influenced by many factors such as genetic predisposition, level of physical activity, diet, and age. In the diet, the LDL:HDL cholesterol ratio is influenced by saturated fatty acids, *trans* fatty acids, and unsaturated fatty acids. Saturated fats increase both LDL and HDL; *trans* fats increase LDL and reduce HDL. When replacing either of these two saturated fats with unsaturated fatty acids, a decrease in both LDL and HDL occurs. Medium- and short-chain fatty acids have been found to have a neutral effect on serum cholesterol (O'Brien 2009).

Cholesterol is a common term in today's society. Many spreads tout the claim of "low" or "reduced" cholesterol (O'Brien 2009). Butter and beef tallow are often associated with

products containing higher levels of cholesterol at 0.24-0.50% and 0.08-0.14% of lipids, respectively (Stauffer 1996). This is another probable reason for the decline of butter and tallow consumption in the U.S.

Saturated Fatty Acids

Saturated fatty acids have been attributed to an increase in the risk of coronary heart disease. The American Heart Association guidelines suggest that not more than 7% of total dietary fat be from saturated fats. Numerous studies have shown that the consumption of saturated fats increases LDL levels correlating strongly with increased risk of heart disease (White 2009).

Palmitic and stearic acids are commonly consumed in palm oil and butterfat, respectively. Both are saturated fatty acids. Stearic acid is unique among saturated fats in that numerous studies have shown that it has a neutral effect on serum cholesterol levels. In recent times, the hype around saturated fatty acids in the diet has died down somewhat as consumer interest has shifted to the dangers of consuming *trans* fats (White 2009).

***Trans* Fatty Acids**

Trans fatty acids have been a staple component of the American diet for several years. Typically partially hydrogenated soybean oil, being readily available and inexpensive, has been the choice of food processors in a wide variety of products. Hydrogenation is used to develop oil with desirable flavor, stability, and shelf life attributes. An undesirable effect of hydrogenation however, is the development of *trans* fatty acids (Adamy and Gray 2006).

Trans fats have fallen under intense scrutiny since their linkage to coronary heart disease. It has been shown that *trans* fatty acids not only increase LDL, but decrease HDL. According to a study in the New England Journal of Medicine, it is estimated that in the U.S., between 30,000 and 100,000 cardiac deaths each year can be attributed to *trans* fat consumption (Mozaffarian and others 2006). This research refers to artificial *trans* fatty acids. There are also naturally occurring *trans* fats (conjugated linoleic acids (CLA)) in meat and dairy products which have been shown to have an overall beneficial effect (Anthony 2008).

In 1994, the FDA was petitioned by the Center for Science in the Public Interest requesting that *trans* fat be added to nutritional labels. A proposed rule in the Federal Register was issued by the FDA on November 17, 1999 (in accordance with 21 CFR 101.9 and 101.36). The rule was finalized and published on July 11, 2003 (68 FR 41434). By providing consumers with *trans* fat labeling, the hope is that foods with lower levels of *trans* fat will be selected over foods rich in partially hydrogenated oils. The FDA estimated that this knowledge could prevent 600-1,200 heart attacks and save 200-500 lives each year (FDA 2006).

In January 2006, the final rule requiring the labeling of *trans* fatty acids in food products went into effect (Freudenberg and Galea 2008). This regulation has some exceptions. Raw fish, meat and chicken, and food purchased at in-store bakeries and delis do not have to be labeled with *trans* fat content. Also exempt is food packaged for foodservice applications. In the U.S., foods containing less than 0.5 g of *trans* fat per serving may be labeled as zero (Shelke 2006). Natural *trans* fats (conjugated linoleic acid) do not require declaration (Anthony 2008).

Many food producers saw the January 2006 deadline for *trans* fat labeling as a mandate to eliminate or reduce *trans* fat from their products. The removal of partially hydrogenated oil is a challenging task. Currently, there is no substitute oil that directly compares to partially hydrogenated oils (Shelke 2006). Alternative oils include but are not limited to canola, sunflower, and palm. However, these oils can have an undesirable effect on flavor, texture, smell, and shelf life of a product (Adamy and Gray 2006).

Technical advances are being made in this industry as oil producers are investing time and money researching possible solutions to this problem. The development of low linolenic acid yielding soybeans, canola seeds that produce oil that does not require hydrogenation and the investigation of lesser used oils such as cottonseed oil, all represent innovative solutions in this industry (Anthony 2008).

In the U.S., *trans* fat bans in the foodservice industry are becoming ever more prevalent. Unlike the *trans* fat labeling regulations, which pressured food producers to eliminate *trans* fats from their labels, restaurants and foodservice operations had no incentive to make formula changes. In response, various states and cities have or are enacting regulations that require restaurants to reduce or eliminate *trans* fat in their food products. A ban of *trans* fats in foodservice establishments was enacted in New York City. As of July 2007, all restaurants now have to use *trans* fat free oils and spreads. Starting July 2008, all food items, including bakery,

had to contain <5 g *trans* fat per serving (Frieden and others 2008). As of December 2007, seven cities and counties, as well as Puerto Rico, have adopted bans (Frumkin 2007). Most recently on July 25, 2008, Governor Schwarzenegger of California passed a law banning *trans* fats from restaurants starting in 2010 and bakeries in 2011 (INFORM 2008). Now, after many regulations have been passed or proposed, many major chain restaurants are making changes to eliminate *trans* fat due to consumer and governmental pressures (Mozaffarian 2010).

It is clear that *trans* fat regulations will continue to impact the U.S. for many years to come. Through proper education and labeling, consumers will be able to make heart healthy decisions and have an impact on their own health in the future. Research and development by the food industry will provide innovative new oils and processes that will allow for the high quality food Americans desire, as well as, eliminating harmful *trans* fat.

The Omega Family of Fatty Acids

The omega group of fatty acids consists of omega-3, omega-6, and omega-9. Although omega-9 is a member of this family, it is not an essential fatty acid like omega-3 and -6. Omega-9 fatty acids (oleic acid for example) have been shown to have neutral or limited effects on anti-inflammatory responses in the body. As such, the remainder of this section will focus on omega-3 and omega-6 fatty acids (Challem 2009).

The term ‘omega fatty acids’ is becoming well known to consumers. ‘Omega’ simply refers to the position of the final carbon-carbon double bond in an unsaturated fatty acid. If it is the third bond from the methyl end it is termed ‘omega-3,’ if it is the sixth, it is termed ‘omega-6.’ Many omega fatty acids can be found in nature but the most familiar are the omega-3 fatty acids alpha-linolenic (ALA), docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), and the omega-6 linoleic acid. These are essential fatty acids that the body cannot synthesize on its own (Challem 2009).

The most common sources of DHA and EPA are cold-water fish. Fish eat plankton and microalgae which synthesize these compounds. ALA can be found in significant amounts in walnut, soybean, and canola oils. The omega-6 linoleic acid is found in most natural animal and vegetable fats but is predominantly found in palm, soybean, canola, and sunflower oils (Challem 2009).

The omega-3 fatty acids EPA and DHA are long chain fatty acids that can be used in the body without modification whereas ALA is a precursor to the formation of EPA and DHA. Linoleic acid, an omega-6, is the parent molecule of arachidonic acid, another omega-6 fatty acid. This essential fatty acid is involved in many signaling pathways involving both inflammation and the central nervous system (Challem 2009).

Many health benefits have been linked to the consumption of omega-3 fatty acids, specifically EPA and DHA. Consumption of these omega-3 fatty acids have been reported to have beneficial effects such as aiding in cardiovascular disease prevention, cancer prevention, rheumatoid arthritis prevention, immune function, and brain health. (Challem 2009).

Aside from an interest in the effects of increased consumption of omega-3 fatty acids, much research has been done on what effects the ratio of omega-6 to omega-3 has on the body. Today, this ratio in the average American's body is approximately 20:1. Such abundance of omega-6 has been reported to have detrimental effects on the population. Since omega-6 is a pro-inflammatory agent, it is possible that frequent inflammation can lead to disease (Challem 2009).

Omega-6 fatty acids are important in the diet but should be consumed in equal or lesser proportions as omega-3. The pro-inflammatory properties of omega-6 fatty acids are favored in the human body since they play a role in a robust immune system. Omega-3 and omega-6 fatty acids follow parallel, competitive biochemical pathways. Imbalance in the diet leads to a pro-inflammatory response (Challem 2009).

Consumers are becoming aware of this imbalance, and are beginning to increase the amount of omega-3 fatty acids in their diets. Many food products now feature fish oils (DHA and/or EPA) or ALA in their formula. This is a growing trend in the food industry. One challenge is the typical "fishy" flavor of fish oil that is undesirable in most food products (Challem 2009).

CHAPTER 4 - Common Natural Fats and Oils Used in Development of Margarine and Spreads

Commodity Information

Consumption versus Production

It's not surprising that countries that produce the most fats and oils are often not the largest consumers. Rich countries (such as the U.S. and those in Europe) and countries with very large populations (such as China and India) consume far more fats and oils than they produce. Countries such as Indonesia and Malaysia, which produce and export predominantly palm oil, consume much less than they produce. It is important to realize that the high numbers for the disappearance of fats and oils are total usage including food as well as other uses (Table 4.1). Malaysia, for example, uses much of its oil for industrial purposes. The U.S. and Europe have above average usage of fats and oils for oleochemical and biodiesel production which contribute to the high consumption levels shown in Table 4.1 (Gunstone 2010a).

Table 4.1–2008/2009 Fats and oils consumption, production, and disappearance.

Country	Population (July 2009)	Consumption (million tons)	Production (million tons)	Disappearance (lbs./person/yr)
China	1,323,000,000	26.86	17.60	40.48
EU-27 ^a	497,000,000	25.02	16.99	100.54
India	1,198,000,000	14.91	7.70	24.86
U.S.	315,000,000	12.25	10.73	77.66
Indonesia	230,000,000	6.63	25.02	57.64
Malaysia	27,000,000	5.72	21.91	422.84

^a The European Union's 27 member countries.

This data was adapted from the The AOCS Lipid Library – Oils and Fats in the Market Place (Gunstone 2010a).

Cost

The cost of vegetable fats and oils has increased dramatically since the turn of the millennia (Table 4.2). In the last few years, oils such as soybean, sunflower, peanut, palm, rapeseed, and coconut have seen the highest ever recorded prices (Table 4.2). This surge in

prices can be attributed to several factors stemming from supply and demand. Countries are growing larger and richer every year, yielding a rise in the demand for oil. Industrial uses for vegetable oil, such as biodiesel production, have also driven up demand. As their demands have risen, production increases have not been able to keep up. Production, storage, and transportation costs have all increased which in turn creates a rise in prices for the consumer. Some countries have experienced drought and other damaging weather conditions yielding a smaller quantity of oil than forecasted. Finally, speculators drive up the cost of fats and oils to turn a profit for themselves (Gunstone 2008).

Table 4.2–Vegetable oil prices – U.S. dollars per ton.

Yearly Averages^a (Oct – Sep)	Soybean	Cottonseed	Sunflower	Peanut	Palm	Canola	Coconut	Corn
98/99	483	663	489	965	536	531	824	615
99/00	379	522	402	860	341	396	594	433
00/01	343	388	386	846	259	410	356	329
01/02	400	436	565	789	363	497	428	465
02/03	536	917	806	1,139	464	648	495	684
03/04	728	758	813	1,451	530	738	694	689
04/05	559	671	1060	1,290	432	727	701	677
05/06	569	715	987	1,081	458	849	641	612
06/07	754	867	1,409	1,381	722	939	895	773
07/08	1,264	1,787	2,215	2,452	1,166	1,554	1,439	1,685
08/09	781	904	1,221	1,696	698	957	810	796
09/10	856	963	1,268	1,331	812	1,008	834	941

^a Oct-Feb

This data was adapted from Oilseeds: World Markets and Trade. Foreign Agricultural Service/United States Department of Agricultural (USDA 2010).

Animal Fats

Raw animal fats yield a very desirable texture in many baked goods. These saturated fats are solid at room temperature and are not prone to oxidative rancidity. In 1968, the American

Heart Association published guidelines encouraging the reduction of saturated fats, specifically animal fats, in the American diet. These guidelines are still in use today (Gunstone 2010b).

As noted in previous sections, animal fat consumption in the U.S. has been on the decline. For the purpose of this discussion, animal fat will be used in reference to the collective group of butter, beef tallow, and fish oils, all of which, have been or still are used as or in spreads. Surprisingly, world production of tallow and butter rank five and seven, respectively, after the major vegetable oils palm, soybean, rapeseed (canola), and sunflower (Gunstone 2010b).

These animal fats may be considered byproducts of other industries. Butter, for example, is a byproduct of the milk industry, tallow, a byproduct of the meat industry and fish oil, of the fish industry. As byproducts, with the exception of milk for which butter is a primary reason for its production, the production of these fats is linked to the demand of the industry with which it's associated. Tallow production is predicted to decrease as meat consumption declines. Butter and beef tallow have been associated with high levels of saturated fat and cholesterol which also drives consumers away from their consumption (Gunstone 2010b).

Fish oils containing desirable omega-3 fatty acids, are gradually finding their way into more food product formulations and are gaining momentum as a health supplement. Even with rising popularity, fish oil production remains fairly low at about one million metric tons per year (Gunstone 2010b).

Butterfat

Milkfat influences the textures and flavors of many products including butter. Milk, typically containing 3.7% milkfat, can be used immediately or is processed into cream before it is churned into butter. In the U.S., butter must conform to a fairly rigid standard of identity that includes composition (e.g. $\geq 80\%$ milkfat) and restrictions on added ingredients as noted in previous sections (O'Brien 2009).

Butterfat is a fairly complex natural fat (Table 4.3). It contains 15 major fatty acids but over 500 fatty acids have been found in this product. Butterfat contains many isomers and branched-chain fatty acids, and is composed of approximately 98% triglycerides (Table 4.4).

These factors influence the physical properties of the butter product such as melting profile and solidification (Gunstone and others 1994).

Butterfat is often a gold standard for other fats and oils due to its desirable β' crystal habit, its taste, and functionality. Its melting profile is very desirable in that it remains a solid at room temperature but melts away quickly in the mouth. It also has good oxidative stability due to its high concentration of saturated fats (O'Brien 2009).

Butterfat may be modified to improve nutritional qualities and also to make it more spreadable at refrigeration temperatures. Nutritional modifications include decreasing saturated fatty acids, increasing conjugated linoleic acids (CLA), and increasing omega-3 fatty acids. Each of these modifications enhances the health benefits of the finished product. Butterfat is naturally high in saturated fatty acids. Saturated fats have been shown to increase cholesterol in humans and thus it is desirable to decrease saturated fat content. CLA can help protect against diabetes and cancer while omega-3 fatty acids are important in cognitive development and heart health (Hillbrick and Augustin 2002). CLA and omega-3 would also peak consumer interest as a healthy alternative.

Many strategies can be implemented in the farm setting as will be discussed in Chapter 5. A few notable exceptions occur post-farm. CLA content can be boosted by the interesterification of milkfat. This process uses lipase to enrich milkfat fractions with additional CLA. Omega-3 fatty acids can be increased by the addition of tiny, microencapsulated, fish oil beads or regular fish oil to finished products (Hillbrick and Augustin 2002). The more expensive microencapsulated fish oil is usually more desirable due to the pungent sensory attributes of regular fish oil.

Modifying butterfat to address nutrition and butter spreadability can have a positive impact on food products. When considering future manipulations to yield a specific targeted end product, understanding how different factors affect butterfat composition is critical. As benefits are considered, negative effects must also be taken into account. For instance, a decrease in saturated fatty acids requires an increase in polyunsaturated fatty acids. This composition change can decrease shelf life as the butterfat becomes more susceptible to oxidative rancidity (Hillbrick and Augustin 2002).

Table 4.3–Fatty acid profile of butterfat.

Fatty Acid	Typical (%)	Range (%)
C4:0 Butyric	3.6	2.8-4.0
C6:0 Caproic	2.2	1.4-3.0
C8:0 Caprylic	1.2	0.5-1.7
C10:0 Capric	2.5	1.7-3.2
C10:1 Caproleic	–	0.1-0.3
C12:0 Lauric	2.9	2.2-4.5
C14:0 Myristic	10.8	5.4-14.6
C14:1 Myristoleic	0.8	0.6-1.6
C15:0 Pentadecanoic	2.1	–
C16:0 Palmitic	26.9	26.0-41.0
C16:1 Palmitoleic	2.0	2.8-5.7
C17:0 Margaric	0.7	–
C18:0 Stearic	12.1	6.1-12.5
C18:1 Oleic	28.5	18.7-33.4
C18:2 Linoleic	3.2	0.9-3.7
C18:3 Linolenic	0.4	<2.5

This data was adapted from the Fats and Oils, 3rd Edition (O'Brien 2009).

Table 4.4–Triglyceride profile of butterfat.

Fatty Acid	sn-1 (%)	sn-2 (%)	sn-3 (%)
C4:0 Butyric	NA	NA	26.4
C6:0 Caproic	NA	0.1	14.8
C8:0 Caprylic	0.2	2.9	4.4
C10:0 Capric	1.4	7.8	6.7
C12:0 Lauric	3.4	8.1	4.0
C14:0 Myristic	12.7	23.9	4.9
C14:1 Myristoleic	1.4	2.4	1.2
C15:0 Pentadecanoic	1.5	1.8	0.3
C16:0 Palmitic	41.2	36.7	6.1
C16:1 Palmitoleic	2.7	3.3	1.0
C17:0 Margaric	1.0	0.5	0.2
C18:0 Stearic	15.2	3.0	6.7
C18:1 Oleic	16.2	7.2	15.0
C18:2 Linoleic	1.2	0.6	1.6
C18:3 Linolenic	0.7	0.3	1.7

This data was adapted from the Lipid Handbook, 2nd Edition (Gunstone and others 1994).

Beef Tallow

Tallow is defined as the hard fat of ruminant animals. The U.S. gets most of its tallow from beef cattle (*Bos taurus*). Beef tallow is a direct byproduct of the beef cattle meat packing industry. Thus, beef tallow production is linked with demand for beef. In recent years, the demand for meat has declined due to health concerns (O'Brien 2009). Beef, as well as tallow, contain high levels of saturated fat and cholesterol. Cholesterol in beef tallow can range from 0.08-0.14% (Gunstone and others 1994).

Beef tallow has desirable physical characteristics due to its chemical composition. The high level of saturated fats in tallow makes it solid at room temperature (Table 4.5). The chemical composition of beef tallow can be influenced by factors such as breed of animal, diet and climate. Beef tallow does not have very good oxidative stability due to its lack of natural antioxidants as well as its low levels of linoleic and linolenic acids (Table 4.5). Beef tallow's β' crystal habit, solid fat content, and plasticity make beef tallow an ideal fat source in many food products. The triglycerides in beef tallow are highly asymmetric (Table 4.6). This, combined with the high concentration of palmitic acid, lends to its β' crystal-forming tendency. Often vegetable oils are partially hydrogenated in order to achieve the natural functionality of beef tallow (O'Brien 2009).

Table 4.5–Fatty acid profile of beef tallow.

Fatty Acid	Typical (%)	Range (%)
C12:0 Lauric	0.2	<0.2
C14:0 Myristic	4.0	1.4-7.8
C14:1 Myristoleic	0.5	0.5-1.5
C15:0 Pentadecanoic	1.0	0.5-1.0
C16:0 Palmitic	24.3	17.0-37.0
C16:1 Palmitoleic	2.5	0.7-8.8
C17:0 Margaric	2.1	0.5-2.0
C17:1 Heptadecenoic	1.3	<1.0
C18:0 Stearic	21.4	6.0-40.0
C18:1 Oleic	33.6	26.0-50.0
C18:2 Linoleic	1.6	0.5-5.0
C18:3 Linolenic	0.6	<2.5
C20:0 Arachidic	0.2	<0.5

This data was adapted from the Fats and Oils, 3rd Edition (O'Brien 2009).

Table 4.6–Triglyceride profile of beef tallow.

Fatty Acid	<i>sn</i>-1 (%)	<i>sn</i>-2 (%)	<i>sn</i>-3 (%)
C14:0 Myristic	0.2	4.3	2.9
C15:0 Pentadecenoic	0.4	0.7	0.5
C16:0 Palmitic	45.7	21.0	25.5
C16:1 Palmitoleic	0.4	2.4	1.3
C17:0 Margaric	1.5	0.7	1.7
C18:0 Stearic	33.1	12.5	31.2
C18:1 Oleic	16.6	52.0	33.7
C18:2 Linoleic	0.4	3.7	0.4

This data was adapted from the Lipid Handbook, 2nd Edition (Gunstone and others 1994).

Fish Oils

Fish oils come from a variety of species. Most are cold-water fish including herring, pilchard, menhaden, and anchovy. About one-third of fish harvested in the world are used to make fish oil and meal (Gunstone and others 1994). Fish oil was not recognized as an edible oil in the U.S. until 1989 when the FDA added it to the ‘generally recognized as safe’ (GRAS) list. In 1994, it was added as an acceptable food additive to the margarine standard of identity (O’Brien 2009).

Typically, fish oils are made up of approximately 8-10 major fatty acids (Gunstone and others 1994). These fatty acids vary in concentration based on the species of fish, season, habitat, diet, and age of the fish (O’Brien, 2009). Thus, there is not just one general fatty acid profile that can represent this group of oils. Menhaden oil (Table 4.7) is an example of a fish oil fatty acid profile. Fish oils have high concentrations of long-chain omega-3 fatty acids such as DHA and EPA. The health benefits of these fatty acids have been previously discussed. These important omega-3 fatty acids originate in the fish diet (phytoplankton and seaweed). Fish oils are predominantly unsaturated but the saturated fatty acids palmitic and myristic also represent a significant percentage of total fatty acids (Gunstone and others 1994). In menhaden oil, palmitic and myristic represent approximately 17% and 9%, respectively (O’Brien 2009). The common fatty acids linoleic and linolenic, found in many vegetable oils, do not contribute a significant

percentage of total fatty acids in fish oil. Partial hydrogenation has been used to increase oxidative stability of these oils. The high levels of polyunsaturated fatty acids increase oxidative instability to the point where they cannot be used 'as is' in many food products. Currently, many fish oils have been refined to such a quality that they may be added to food products without the need for hydrogenation (Kolanowski and others 1999).

Table 4.7–Fatty acid profile of menhaden oil.

Fatty Acid	Typical (%)	Range (%)
C14:0 Myristic	9.3	7.2-12.1
C14:1 Myristoleic	0.7	<i>na</i>
C15:0 Pentadecanoic	1.0	0.4-2.3
C16:0 Palmitic	17.1	15.3-25.6
C16:1 Palmitoleic	12.5	9.3-15.8
C16:2 Hexadecadienoic	1.7	0.3-2.8
C16:3 Hexadecatrienoic	1.7	0.9-3.5
C16:4 Hexadecatetraenoic	1.8	0.5-2.8
C17:0 Margaric	0.9	0.2-3.0
C18:0 Stearic	2.8	2.5-4.1
C18:1 Oleic	11.4	8.3-13.8
C18:2 Linoleic	1.5	0.7-2.8
C18:3 Linolenic	1.6	0.8-2.3
C18:4 Stearidonic	3.4	1.7-4.0
C20:0 Arachidic	0.2	0.1-0.6
C20:1 Gadoleic	1.6	<i>na</i>
C20:4 Arachidonic	2.0	1.5-2.7
C20:5 EPA	15.5	11.1-16.3
C22:1 Erucic	1.4	0.1-1.4
C22:5 Clupanodonic	2.4	1.3-3.8
C22:6 DHA	9.1	4.6-13.8

This data was adapted from Fats and Oils (Stauffer 1996).

Fish oils have been used as added ingredients in food products in liquid and encapsulated forms. They are desirable for their high levels of omega-3 fatty acids and the associated health benefits. In the U.S., the omega-6:omega-3 ratio is not ideal due to the skewed consumption of omega-6 fatty acids in the diet. Therefore, it is important to consumers to increase omega-3

consumption. Adding fish oil to a number of food products has proven to be challenging. The distinct fishy flavor has a negative impact on sensory attributes of food. This problem may be overcome by encapsulating the fish oil, keeping it at a low percentage of the formula, and/or adding it only to food products that are already strongly flavored. It was found that adding fish oil to low pH, water-continuous foods yields an accelerated degradation of the added fish oil by hydrolysis and oxidation. In this case, oxygen would have to be eliminated from the product and high levels of antioxidants would be required (Kolanowski and others 1999).

Vegetable Fats and Oils

Soybean Oil

History

Soybeans have been an important crop for thousands of years. It is thought to have been cultivated in China more than 2,000 years B.C. Since then its importance as a food crop has led to its commercial cultivation in North and South America, Europe, and throughout Asia (Gunstone and others 1994).

Soybean oil is pressed from *Glycina maxima*, the common soybean (O'Brien 2009). Soybean oil has become one of the dominant oils used in food products due to its nutritional properties, functionality, cost, and availability. In the U.S., soybean oil can be found in a wide variety of food products. In 1998, it was estimated that soybean oil could be found in 95% of all margarines (Gunstone 2002).

Soybeans are grown in many countries throughout the world but, as of the 2008/2009 growing season; over 80% were grown in North and South America (Table 4.8). For many years, the U.S. dominated in soybean production. A shift occurred in 2002/2003 when total production in South American countries (specifically Argentina and Brazil) overtook the U.S. (Gunstone 2009a).

Soybean farming in the U.S. began around 1804. It was cultivated only out of mild interest, however, and was not large-scale commercially produced for over a century. During World War II, fat and oil shortages led to the increase in soybean oil production from 0.3 billion pounds in 1938 to 1.3 billion pounds in 1945. At this time, the price of commonly used

cottonseed oil was four to nine cents more per pound than soybean oil. This led many food companies to reformulate products with soybean oil to generate greater profits on their goods. By 1950, soybean oil had overtaken cottonseed oil in usage in food products and, in 1953, it overtook lard. In the early 1960's, new varieties of soybeans were being developed. A soybean salad oil with reduced linolenic acid content (3-4%) was easily accepted by food manufacturers, who immediately began including it in dressings, mayonnaises, shortenings, and margarines. In 2005, soybean oil provided over 61% of all the oil used in these products (O'Brien 2009).

Table 4.8–2008/2009 Soybean oil consumption and production (million metric tons).

		Consumption	Production
Region	World	39.55	39.54
	China	10.46	8.06
	U.S.	8.10	9.48
	Brazil	6.72	4.69
	Argentina	1.33	6.93

This data was adapted from the AOCs Lipid Library (Gunstone 2009a).

Chemistry

Soybean oil contains predominantly unsaturated fatty acids (linoleic acid at 53% and linolenic acid at 8%) (Table 4.9). These two fatty acids are of nutritional importance due to their status as ‘essential fatty acids.’ Functionally however, these fatty acids have low melting points and oxidize easily (Gunstone 2009a). This is problematic in food applications as it contributes to undesirable textural differences and shorter shelf lives. Partial hydrogenation has been the solution to these deficiencies for many years.

Soybean oil contains few saturated fatty acids. Thus, the triglycerides contain almost no saturated fatty acids in the *sn*-2 position but instead many unsaturated linoleic acids are in this position (O'Brien 2009). These triglycerides, predominantly di- and tri- unsaturates, have very low melting points which causes soybean oil to be liquid at room temperature (Table 4.10). Since a semisolid fat is desired for most food applications, soybean oil must be partially hydrogenated to raise saturate content, thereby raising solid fat content (Gunstone and others 2009). Also, soybean oil that has not been hydrogenated tends to crystallize in the β form while

partially hydrogenated soybean oil tends to crystallize in the more desirable β' form (Table 4.10) (Gunstone 2002).

Table 4.9–Fatty acid profile of soybean oil.

Fatty Acid	Typical (%)	Range (%)
C14:0 Myristic	0.1	<0.2
C16:0 Palmitic	10.6	8.0-13.3
C16:1 Palmitoleic	0.1	<0.2
C18:0 Stearic	4.0	2.4-5.4
C18:1 Oleic	23.3	17.7-26.1
C18:2 Linoleic	53.7	49.8-57.1
C18:3 Linolenic	7.6	5.5-9.5
C20:0 Arachidic	0.3	0.1-0.6
C22:0 Behenic	0.3	0.3-0.7

This data was adapted from Fats and Oils, 2nd Edition (O'Brien 2009).

Table 4.10–Melting point of fatty acids and triglycerides of soybean oil and its partially hydrogenated product.

Fatty Acid		Triglycerides		
Name	Melt Pt. (°C)	Composition ^a	β Form (°C)	β' Form (°C)
Palmitic	62.9	PPP	65.5	56.0
Stearic	69.6	SSS	73.0	65.0
-	-	SPP	62.5	59.5
-	-	PSP	68.0	65.0
-	-	SPS	68.0	64.0
Oleic	16.3	OOO	5.5	-12.0
-	-	POP	35.2	30.4
-	-	SOS	41.6	37.6
-	-	POO	19.0	-
-	-	SOO	23.5	-
Elaidic	43.7	EEE	42.0	37.0
Linoleic	-6.5	LLL	-13.1	-
Linolenic	-12.8	LnLnLn	-24.2	-

^a P-palmitic, S-stearic, O-oleic, E-elaidic, L-linoleic and Ln-linolenic.

This data was adapted from Vegetable Oils in Food Technology (Gunstone 2002).

Soybean oil, which contains large amounts of linoleic and linolenic acids, is very prone to oxidation. Linolenic acid is especially unstable (Gunstone and others 1994). Oxidation can lead to undesirable flavors such as paint-like, beany, grassy, or fish-like flavors in products. In order to create a product with a longer shelf life, modifications must be made to the oil. In the 1960s, soybean salad oil with reduced linolenic acid content (3-4%) was brought to market. This product was lightly hydrogenated and then winterized to remove hard fractions. This process reduces the oxidative instability of the oil and gives it other desirable functional qualities for use in many products including spreads. A byproduct of partial hydrogenation is *trans* fat. The realization of the health implications of *trans* fats in the diet has caused further research into the development of a functional soybean oil that does not require hydrogenation (O'Brien 2009).

Much research has been done over the past 35 years in genetic manipulation and breeding of soybeans to create a type of soybean oil with more desirable fatty acid compositions. These techniques are able to target specific fatty acids in soybean oil for increase or decrease depending on specific applications. The four major modifications include: decreasing the oxidatively unstable linoleic acids; increasing heart healthy oleic acids; decrease the saturated palmitic fatty acids, and/or increasing saturated fatty acids to increase solid fat content and oxidative stability. Plant breeding techniques are not an easy answer due to problems consisting of poor harvest yields, trait stability issues, and identity preservation which all cause the price of these specialty oils to increase dramatically (O'Brien 2009).

Nutrition

Soybean oil is unsaturated oil containing approximately 53% linoleic acid and 8% linolenic acid. Linoleic and linolenic acids, apart from being unsaturated, are also essential fatty acids. Linoleic is an omega-6 fatty acid and linolenic is an omega-3 fatty acid. The high percentage of soybean oil in the U.S. diet coupled with the large percentage of the omega-6 linoleic acid in soybean oil has led to a larger omega-6:omega-3 ratio than is desirable (see Health Concerns and Consumer Trends section on the Omega Family of Fatty Acids). Soybean and canola are the only plant oils yielding a meaningful amount of alpha-linolenic acid (ALA) (Gunstone 2002).

Soybean oil is usually partially hydrogenated to increase its functionality and thus its utilization. The *trans* fat content in the oil is of particular nutritional concern. *Trans* fatty acids

have been shown to have detrimental effects on serum cholesterol levels and thus their consumption is discouraged (see Health Concerns and Consumer Trends section on *Trans* Fats) (Gunstone 2002).

Canola Oil

History and Use of Canola Oil

Rapeseed was domesticated thousands of years ago for use in oil lamps and as cooking oil (Gunstone 2004). It has long been an important resource in India and China but despite its introduction to Europe in the 13th century, it was not grown in Western countries for edible purposes until the 1940's (Gunstone 2002). Concern over rapeseed oil's high erucic acid content (22-60%), with respect to potential heart problems, led to the development of low erucic acid varieties of rapeseed oil to be used for edible purposes (Shahidi 1990).

Rapeseeds are small (0.1-0.2 mm diameter) and round with an oil content of about 40-60%. Rape belongs to the Cruciferae family which also includes the mustard and turnip plants (Gunstone and others 1994). *Brassica rapa*, or turnip rape, is typically grown in western Canada. *Brassica napus*, or swede rape, is found in Europe, Canada and China, and *Brassica juncea*, which is adapted to survive well in dry conditions, is grown predominantly in India and China. Rape is a fairly hardy plant and can survive where other plants, such as soybean and sunflower, may not (Gunstone 2004). Rape is a term that is not pleasing to consumers due to its negative association with the sexual definition of the word. The rape plant gets its name from the Latin word 'rapum' which translates to 'turnip', to which the plant closely resembles (Shahidi 1990).

High-erucic rapeseed oil, or HEAR, contains between 40 and 60% erucic acid. Until the 1970's, this oil was used for a number of purposes including human consumption. Due to potential heart damage from erucic acid, the FAO/WHO recommended that only oils low in erucic acid should be used for edible purposes. Low-erucic rapeseed oil, or LEAR, was developed in Canada in 1968. This new oilseed, created through plant breeding experiments, contained less than 3.5% erucic acid. Another term for this oil was Canbra (Gunstone and others 1994).

Further research into traditional plant breeding of rape led to the creation of the “double-low” or “double-zero” cultivar of rape known as canola in 1974. The cultivar contains less than 2% erucic acid and reduced sulfur-containing components called glucosinolates (Gunstone 2004). The term ‘canola’ comes from the phrase “Canadian oil, low acid” referring to its Canadian discovery and its low erucic acid content. This name was adopted in 1979. In 1985, canola oil was granted GRAS status by the FDA (O’Brien 2009).

Chemistry

Canola oil has a higher concentration of oleic (15-60%) and linoleic (14-20%) acids than rapeseed oil (Table 4.11). These acids increased as erucic acid was decreased to below 2% in canola oil. Canola has the lowest percentage of saturated fatty acids of all major commodity vegetable oils and is second only to olive oil in its high concentration of oleic acid (Gunstone 2004). Canola is high in linolenic (7-11%), an omega-3 fatty acid, which gives it a desirable omega-6 (linoleic) to omega-3 (linolenic) ratio of two to one. Linolenic acid, however, also results in the oxidative instability of this oil. Due to its fatty acid concentration and triglyceride composition, the oxidative instability of canola oil is similar to that of soybean oil. The affinity of the unsaturated fatty acids linoleic and linolenic for the *sn*-2 position gives the oil some protection from oxidation. The major triglycerides in canola oil are OOO (22.4%), LOO (22.5%), LnOO (10.4%), LLO (8.6%), and LnLO (7.6%) (Gunstone 2002).

Hydrogenation can be used on canola oil to yield more desirable components for margarine and spreads formulations. The crystallization of hydrogenated canola oil is β -tending. This is undesirable in margarine and spreads products due to grainy texture. However, the *trans* fatty acids formed during the partial hydrogenation process increase the heterogeneity of the oil and thereby reduce the β -crystal habit (Gunstone 2002).

Nutrition

In the U.S., canola oil is regarded as “healthy” oil. It has high concentrations of the monounsaturated oleic acid which has been shown to reduce the risk of coronary heart disease, it has high levels of the essential omega-6 linoleic acid, has a desirable 2:1 ratio of omega-6 (linoleic) to omega-3 (alpha-linolenic) fatty acids, and has the lowest saturated fat content of any major vegetable oil. As a whole, canola has been shown to be as good at reducing total and LDL (the “bad” cholesterol) as other popular polyunsaturated oils when substituted for saturated fats

in the diet. It has also been associated with increased long-chain omega-3 EPA production (Gunstone 2004).

Table 4.11–Fatty acid profile of low-erucic rapeseed oil (LEAR), high-erucic rapeseed oil (HEAR), and canola oils.

	LEAR	HEAR	Canola	
	Range (%)	Range (%)	Typical (%)	Range (%)
C14:0 Myristic	NA	NA	0.1	<0.2
C16:0 Palmitic	3.3-6.0	1.5-6.0	4.1	2.5-6.0
C16:1 Palmitoleic	0.1-0.6	0.0-3.0	0.3	<0.6
C18:0 Stearic	1.1-2.5	0.5-3.1	1.8	0.9-2.1
C18:1 Oleic	52.0-66.9	8.0-60.0	60.9	50.0-66.0
C18:2 Linoleic	16.1-24.8	11.0-23.0	21.0	18.0-30.0
C18:3 Linolenic	6.4-14.1	5.0-13.0	8.8	6.0-14.0
C20:0 Arachidic	0.2-0.8	0.0-3.0	0.7	0.1-1.2
C20:1 Gadoleic	0.1-3.4	3.0-15.0	1.0	0.1-4.3
C22:0 Behenic	0.0-0.5	0.0-2.0	0.3	<0.5
C22:1 Erucic	0.0-2.0	5.0-60.0	0.7	<1.0

This data was adapted from Fats and Oils (O'Brien 2009).

Corn Oil

Corn had been grown in the Americas prior to the arrival of European explorers. This grain was a very important food product to the Native Americans. Corn (*Zea mays* L.) is a member of the grass family (O'Brien 2009). Most corn oil is extracted from the germ which contains roughly 80% oil. This is equal to approximately 5% oil concentration per kernel. Corn oil production is tied to other corn processing industries such as the starch, corn syrup, and ethanol industries (Gunstone and others 1994). The U.S. produces over 50% of the world's supply of corn oil. Corn oil is desirable for use in spreads products due to its mild flavor, high PUFA content but low linolenic acid, and its low saturated fat levels (Gunstone and others 1994). Around 2000, it was estimated that one quarter of all corn oil consumed in the U.S. was used in margarine and spreads products (Gunstone 2002).

Corn oil saw a surge in popularity during the period between 1950 and 1980. During this time, consumer's heightened awareness to the health benefits of consuming PUFAs drove demand for corn oil. Corn oil production climbed from 15 to 250 million pounds per year. In recent years consumption has declined due to consumer concern over *trans* fatty acids developed as a byproduct of partial hydrogenation. Corn oil is typically partially hydrogenated for use in margarine and spreads and can contain between 10%-20% *trans* fats of total fatty acids. Also, it has been marketed as premium oil at a premium price which could also have contributed to its decline (Gunstone 2002).

Corn oil has good oxidative stability. This may be surprising due to its high concentration of unsaturated fatty acids (Table 4.12). Researchers have shown that 98% of the *sn-2* positions on triglycerides contain unsaturated fatty acids (Table 4.13). The *sn-1* and *sn-3* positions are available to saturated fatty acids and any unsaturates not esterified in the *sn-2* position. The *sn-1* and *sn-3* positions are more reactive than the *sn-2* position. Therefore, the saturated fats in the *sn-1* and *sn-3* positions are less likely to be oxidized and the *sn-2* unsaturated fatty acids are fairly protected from oxidation (O'Brien 2009).

Corn oil contains high levels of linoleic acid (~60%) and very low levels of linolenic acid (~1.5%) (Table 4.12). This is desirable since linolenic acid is easily oxidized leading to rancidity. Corn hybrids are being developed to increase oil yield and also increase the monounsaturated oleic acid content. Genetically modified corn cultivars can reverse the oleic and linoleic acid contents in the oil. This increases the oxidative stability to the point that the oil can be used in frying and spray-drying applications (O'Brien 2009).

Table 4.12–Fatty acid profile of corn oil.

	Typical (%)	Range (%)
C14:0 Myristic	0.1	<0.1
C16:0 Palmitic	10.9	8.0-19.0
C16:1 Palmitoleic	0.2	<0.5
C18:0 Stearic	2.0	0.5-4.0
C18:1 Oleic	25.4	19.0-50.0
C18:2 Linoleic	59.6	34.0-62.0
C18:3 Linolenic	1.2	0.1-2.0
C20:0 Arachidic	0.4	<1.0
C22:0 Behenic	0.1	<0.5

This data was adapted from Fats and Oils, 3rd Edition (O'Brien 2009).

Table 4.13–Triglyceride profile of corn oil.

Triglyceride^a	(%)	Triglyceride	(%)
LLO	19.98	LnLO	2.20
LLL	17.79	OOS	0.56
LLP	13.71	POS	0.20
OOL	11.82	PLnL	0.43
PLO	10.85	PPP	0.00
PPL	2.48	OOLn	1.09
OOP	3.48	PLnO	0.00
LLS	2.64	PPS	0.36
LOS	1.77	SSL	0.00
OOO	4.35	LnLS	0.00
PPO	1.55	SSO	0.00
PLS	0.78	PPLn	0.00
LLLn	0.91	SSP	0.00
		SSS	0.00

^a L-linoleic, O-oleic, P-palmitic, S-stearic and Ln-linolenic.

This data was adapted from Vegetable Oils in Food Technology (Gunstone 2002).

Cottonseed Oil

Cotton has been grown for thousands of years. India has been growing cotton for over 4,000 years. Cottonseed oil, however, is a fairly recent development as its extraction did not take

place until the 1800's. The primary species of cotton used in oil production are *Gossypium hirsutum* L. (American) and *Gossypium barbadense* (Egyptian). Cottonseed is a byproduct of the cotton industry (O'Brien 2009). Each cotton ball can contain as many as 40 seeds (Gunstone and others 1994). Thus, cottonseed oil production is linked with demand for cotton (O'Brien 2009).

Cottonseed oil dominated the oil market in the U.S. and some other countries in the world until the end of World War I (WWI). This dominance was due to its preference by some food manufacturers; it had a relatively low cost and was easy to supply since it was tied to the cotton industry. Cottonseed oil began its decline after WWI due to crop shortages during a period of increasing demand for vegetable oils. After WWII, soybean oil emerged as the dominant source of edible oil. Cottonseed oil, however, still remains a prominent source of oil for some liquid oils, margarines, and shortenings due to its mild flavor, stability, and polymorphic structure (O'Brien 2009).

Cottonseed oil is a member of the group of oleic/linoleic vegetable oils. Combined, these two fatty acids make up close to 75% of total fatty acids (Table 4.14). Containing around 24% saturated palmitic acid provides cottonseed oil with a desirable β' crystal habit. In cottonseed oil, over 90% of fatty acids are oleic, linoleic, and palmitic. As this is the case, most of its triglycerides are combinations of these fatty acids (Table 4.15). Also, saturated fats have an affinity for the *sn*-1 and *sn*-3 positions while unsaturated fatty acids predominate in the *sn*-2 position. Typically cottonseed oil is hydrogenated prior to use in margarine and spreads formulations to promote β' crystal structure. Genetic modification of cottonseed oil has yielded a high-stearic acid variety for use in margarine and spreads (Gunstone 2002).

Table 4.14–Fatty acid profile of cottonseed oil.

Fatty Acid	Typical (%)	Range (%)
C14:0 Myristic	0.7	0.6-1.0
C16:0 Palmitic	21.6	21.4-26.4
C16:1 Palmitoleic	0.6	0-1.2
C18:0 Stearic	2.6	2.1-3.3
C18:1 Oleic	18.6	14.7-21.7
C18:2 Linoleic	54.4	46.7-58.2
C18:3 Linolenic	0.7	0-1.0
C20:0 Arachidic	0.3	0.2-0.5

This data was adapted from Fats and Oils, 3rd Edition (O'Brien 2009).

Table 4.15–Triglyceride profile of cottonseed oil.

Triglyceride^a	%
PLL	25.7
LLL	16.1
POL	14.0
OLL	12.9
PPL	8.7
OOL	4.4
POO	3.3
PPO	2.5
OOO	2.4
SLL	2.4
SPL	2.1
SOL	1.5

^a P-palmitic, L-linoleic, O-oleic and S-stearic.

This data was adapted from Vegetable Oils in Food Technology (Gunstone 2002).

Olive Oil

History and Use of Olive Oil

Olive oil has been an important component of the diet in the Mediterranean region for thousands of years (O'Brien 2009). The earliest cultivation appears to have been in Syria and Pakistan around 6,000 years ago (Boskou 2006). The earliest olive industry took root in that

region during the mid to late Bronze Age (O'Brien 2009). More recently, olives were introduced to California by missionaries from Spain in the late 1800's and soon after immigrants from the Mediterranean region brought this important plant to South America (Gunstone and others 1994).

The term 'olive' is a general term used to describe approximately 35 species of evergreen, fruit-bearing plants. The most familiar of these is *Olea europaea* which is the most common edible olive species (O'Brien 2009). This tree is grown in climates that typically have mild winters and dry, warm summers. The olive tree grows particularly well in countries such as Spain, Italy, Greece, Tunisia, Turkey, Syria, Morocco, Algeria, Portugal, and Jordan. These countries are the world's leading olive oil producers (Boskou 2006).

Olive oil is pressed from the pulp of the olive fruit. The fruit is an oval-shaped drupe that turns black when ripe and contains approximately 22% oil. Virgin olive oil refers to the pressed oil that is allowed to rest as the aqueous material settles out. This oil is the most desirable and is used in this natural state. In general, olive oil is greenish-yellow and smells and tastes slightly of olives (O'Brien 2009). There are many standards and regulations in regards to olive oil grading. Organizations such as the International Olive Oil Council (IOOC), the EU Commission and the Codex Alimentarius have regulations and criteria that must be followed. According to the IOOC, the three grades of virgin olive oil are extra, fine, and ordinary. These standards are set based on flavor, fatty acid content, and other analytical tests (Gunstone and others 1994).

Overall, olive oil contributes only a small volume (<3.5%) to total world vegetable oil production totals. This oil, however, has garnered consumer interest due to its touted health benefits. Although the U.S. only consumed 6% of total olive oil in 2000, this is a dramatic increase from just twenty years earlier. In 1984, U.S. consumption of olive oil was about 42,000 tons. By 2004, that number had almost increased by six times to 248,000 tons. It is speculated that demand for olive oil from consumers can be tied to a large promotional campaign by the IOOC and funded by the EU that enhanced the important nutritional image of olive oil (Table 4.16) (Boskou 2006).

Chemistry

Olive oil has a very high oleic acid composition (55-85%). Other significant fatty acids are palmitic and linoleic (Table 4.17) (Gunstone 2002). This oil is fairly resistant to rancidity due to its high monounsaturated oleic content and very low levels of the oxidation prone

linolenic acid. Also, unsaturated fatty acids have an affinity for the *sn*-1 and *sn*-3 positions thereby increasing oxidative stability (O'Brien 2009). Predominant triglycerides are OOO (40-59%), POO (12-20%), OOL (12.5-20%), POL (5.5-7%), and SOO (3-7%) (Gunstone 2002).

The fatty acid profile of olive oil can vary based on many environmental and physical factors. For example, olive oil produced in Greece, Italy, and Spain have lower concentrations of linoleic and palmitic acid and increased oleic acid. Olive oil produced in Tunisia, on the other hand, is just the opposite. It has lower oleic acid content but with elevated palmitic and linoleic content. This variation can be attributed to geographical and climate differences. It has been found that olive oil produced in cooler climates contains greater levels of unsaturated fatty acids (Boskou 2006).

Typically olive oil is used in its natural liquid form. It can also be hydrogenated to yield more functional oil. However, hydrogenation promotes β -crystallization which is less desirable in margarine and spreads applications (Boskou 2006).

Nutrition

Consumers have increased consumption of olive oil primarily due to its well-known health benefits. Monounsaturated fatty acids, such as the high quantity of oleic acid found in olive oil, have been attributed to LDL oxidation resistance and the reduction of the risk of coronary heart disease. It has also been shown that monounsaturated fatty acids increase HDL, the “good” cholesterol, more so than polyunsaturated fatty acids when replacing carbohydrates. It is interesting to note that consumption of oleic acid is only slightly higher in the Mediterranean diet than in the U.S. diet. Thus, there are most likely other properties of olive oil that are responsible for its positive effects than just its monounsaturated oleic acid content (Boskou 2006).

Table 4.16–Olive oil consumption (thousand metric tons).

	1985-1989 (Avg)	2001-2005 (Avg)
USA+Australia+Canada+Japan+Brazil	85.73	312.88
World	1,773.13	2,738.00

This data was adapted from Olive Oil: Chemistry and Technology (Boskou 2006).

Table 4.17–Fatty acid profile of olive oil.

	Typical (%)	Range (%)
C14:0 Myristic	<i>na</i>	<0.1
C16:0 Palmitic	9.0	7.5-20.0
C18:0 Stearic	2.7	0.5-5.0
C18:1 Oleic	80.3	55.0-83.0
C18:2 Linoleic	6.3	3.5-21.0
C18:3 Linolenic	0.7	<0.9
C20:0 Arachidic	0.4	<0.6

This data was adapted from Fats and Oils, 3rd Edition (O'Brien 2009).

Sunflower Oil

The sunflower, *Helianthus annuus*, was domesticated by the Native Americans long before Columbus discovered America. It was an important resource providing the Native Americans with meal for food, oil used in medicinal rituals, and was used to season wood. The sunflower was brought to Europe by Spanish explorers in the 16th century. From there it was introduced and embraced by Russia. Around 1830, Russia became the first to commercially extract sunflower oil for edible purposes (O'Brien 2009). Oil extraction from sunflower ranges from 44-51% (Gunstone 2002).

Crude sunflower oil is a light amber color that turns pale yellow after commercial processing. Its light, mild flavor and color has made it popular oil in Mexico, the Middle East, and Japan. The largest sunflower growing countries are Russia, Ukraine, Argentina, some EU-27 countries, China, and the U.S. Between 1996/97 and 2008/09, 8.5-10.9 million metric tons of sunflower oil were produced (Table 4.18). The sunflower has particular growth requirements limiting the regions where it can be grown. It cannot tolerate extremes in temperature and has specific soil requirements. Also, climate, temperature, and genetics have a large impact on sunflower oil's fatty acid profile. In general, sunflowers grown above the 39th parallel have increased linoleic acid content while those grown below will have increased oleic acid content (O'Brien 2009).

Although sunflower oil is the fourth largest produced vegetable oil in the U.S., it is only 8th when ranked based on consumption (O'Brien 2009). There was a brief increase in demand for sunflower oil in the U.S. in the mid-1980's. Polyunsaturated fatty acids (PUFAs) were

beginning to be desired for their potential role in decreasing the risk of heart disease. Margarines at this time began including sunflower oil as a source of PUFAs. Since then, demand has decreased due to declining vegetable oil prices and competition with soybean crops for acreage. Other countries consume sunflower oil at much greater rates than the U.S. In fact, some countries prefer sunflower oil to soybean, cottonseed, and palm oils. In the U.S., it is still considered premium oil. The U.S. exports 60-90% of its sunflower oil overseas. In Western Europe sunflower oil is an important component in most spreads products (Gunstone 2002).

Sunflower oil contains almost no linolenic acid but has a combined linoleic and oleic content of greater than 90% (Table 4.19). Linoleic acid makes up the bulk of this percentage with average oil yielding 60-75% linoleic acid (Gunstone 2002). Considering the large percentage of linoleic and oleic acid in this oil, it is not surprising that its major triglycerides are on average LLL (14%), LLO (39%), LLS (14%), LOO (19%), and LOS (11%) (Gunstone 2009). The high level of linoleic acid in sunflower oil is primarily responsible for its oxidative instability. This is the primary reason new cultivars with reduced linoleic acid were developed (O'Brien 2009).

Through chemical mutation and/or selective breeding, mid- and high-oleic sunflower varieties have been developed. Mid-oleic cultivars contain approximately 55-75% oleic acid and 15-35% linoleic acid while high-oleic cultivars contain greater than 80% oleic acid and approximately 5-9% linoleic acid (Table 4.20). High-oleic sunflower oil was introduced to the U.S. in the early 1980's. One variety called sunola (High sun) contains approximately 85% or more oleic acid. Currently, a popular variety in the U.S. is the mid-oleic NuSun sunflower oil. NuSun contains approximately 60% oleic acid, was developed by the United States Department of Agriculture (USDA), and launched in 1998. It was first cultivated in the U.S. in 1996 and as of 2004, about 65% of all sunflower oil producing plants were of this variety. It is also desirable as it is a non-transgenic cultivar unlike some high-oleic varieties (O'Brien 2009).

Table 4.18–World production and consumption of sunflower oil (million metric tons).

	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009
Production	9.17	10.60	10.61	9.67	11.57
Consumption	8.52	9.81	10.27	8.60	10.93

This data was adapted from the AOCS Lipid Library (Gunstone 2009c).

Table 4.19–Saturated and unsaturated fatty acid profile of traditional, high-oleic and mid-oleic sunflower oils.

Fatty acid	Traditional (%)	High-oleic (%)	Mid-oleic (%)
Total Saturates	11-13	9-10	<10
C18:1 Oleic Acid	20-30	80-90	55-75
C18:2 Linoleic Acid	60-70	5-9	15-35
C18:3 Linolenic Acid	<1	<1	<1

This data was adapted from Vegetable Oils in Food Technology (Gunstone 2002).

Table 4.20–Fatty acid profile of traditional, high-oleic, and mid-oleic sunflower oil.

	Traditional (%)		High-oleic (%)		Mid-oleic (%)	
	Typical	Range	Typical	Range	Typical	Range
C14:0 Myristic	0.1	<0.2	NA	<0.1	NA	<0.1
C16:0 Palmitic	7.0	5.6-7.6	3.7	3.0-4.8	4.3	4.0-5.0
C16:1 Palmitoleic	0.1	<0.3	0.1	<0.1	NA	NA
C18:0 Stearic	4.5	2.7-6.5	5.4	2.7-6.5	4.7	3.0-5.0
C18:1 Oleic	18.7	14.0-39.4	81.3	75.0-85.0	60.4	50.0-65.0
C18:2 Linoleic	67.5	48.3-74.0	9.0	8.0-10.0	30.6	25.0-35.0
C18:3 Linolenic	0.8	<0.2	NA	<0.3	NA	<0.1
C20:0 Arachidic	0.4	0.2-0.4	0.4	0.2-0.5	NA	NA

This data was adapted from Fats and Oils, 3rd Edition (O'Brien 2009).

Palm Oil

History and Use of Palm Oil

Palm oil is pressed from the mesocarp of the *Elaeis guineensis* (Gunstone 2002). Like olive oil, palm oil is also fruit oil. The *Elaeis guineensis* is a perennial tree crop that survives best within a ten-degree band of the equator (O'Brien 2009). This species originated in Western Africa and was transported to Malaysia as a decorative plant in the late 1800's (Gunstone 2002). It is unique from other palm varieties in that it produces an estimated 3.68 metric tons per hectare (MT/ha) of palm oil; making it the highest yielding commercial oil producing plant (Sundram and others 2003). In comparison to soybeans, it only requires one tenth of the land planted to palm to yield the equivalent amount of oil (O'Brien 2009).

This species of palm, *Elaeis guineensis* is predominantly used in commercial palm oil operations throughout the world. Southeast Asia is the largest palm oil producing region in the world (Sundram and others 2003). In the 2006/2007 season, Indonesia edged out Malaysia for the first time to claim its title as the world's leading palm oil producing country. Indonesia invested in expanding plantations and increasing productivity to rapidly grow its palm oil industry. Indonesia nearly doubled its production from the turn of the century to 2006/2007. Malaysia, whose palm oil industry dominated until 2006/2007, has little undeveloped land left and thus has no ability for further expansion of plantations (INFORM 2008). In 2008/2009, Indonesia produced 19.5 million metric tons of palm oil and Malaysia, 17.7 million metric tons (Gunstone 2009b).

Since the 1990's, the use of palm oil in food products has more than doubled. The U.S. lags behind most developed countries in palm oil consumption. This gap is narrowing each year and currently palm and soybean oils provide approximately 60% of the total of the top nine vegetable oils (Gunstone 2007). Palm oil accounts for 13% of global oil production and is predicted to overtake soybean oil in the near future as the most widely used vegetable oil (Sundram and others 2003).

Chemistry

Palm oil is unique in that it contains nearly equal parts of saturated and unsaturated fatty acids (Table 4.21). The saturated fatty acid, palmitic acid, is present in palm oil at a concentration of over 40%. This is greater than any other vegetable oil. Cottonseed oil, also used in spreads applications, has roughly half (20%) the palmitic acid content of palm oil (O'Brien 2009). Palm oil is semi-solid in temperate climates, has good oxidative stability, and has a similar solid fat content (SFC) profile to butter. Due to palm oil being semi-solid in nature and having a high saturate content; it is a desirable alternative to partially hydrogenated oils in food products.

Palm oil is commonly fractionated to yield oleins (liquid), stearins (higher melting) and mid-fractions (intermediate-melting) with a wide range of functionalities and uses. Palm stearin makes an excellent hardstock as its saturated fatty acid content is higher than palm oil (Timms 2007). Palm oil and its fractions can be added to margarines and spreads to enhance polymorphic stability. It is theorized that these blends benefit from the increase in chain-length diversity of the fatty acids (Yap and others 1989).

Table 4.21–Fatty acid profile of palm oil.

Fatty Acid	Typical (%)	Range (%)
C12:0 Lauric	0	0.1-1.0
C14:0 Myristic	1.1	0.9-1.5
C16:0 Palmitic	44.0	41.8-46.8
C16:1 Palmitoleic	0.1	0.1-0.3
C18:0 Stearic	4.5	4.5-5.1
C18:1 Oleic	39.2	37.3-40.8
C18:2 Linoleic	10.1	9.1-11.0
C18:3 Linolenic	0.4	0.4-0.6
C20:0 Arachidic	0.4	0.2-0.7

This data was adapted from Fats and Oils, 3rd Edition (O'Brien 2009).

The major fatty acids in palm oil are palmitic, oleic, linoleic, stearic, and myristic. Most of the fatty acids are present as triglycerides. Palm oil contains over 95% triglyceride mixtures. Saturated triglycerides (predominantly tripalmitin) make up 7-10% of triglycerides while 6-12% is completely unsaturated (Table 4.22) (Sundram and others 2003). Research has determined that the *sn*-2 position of the triglyceride has specificity for unsaturated fatty acids. Greater than 85% of the unsaturated fatty acids are located at the *sn*-2 position (Table 4.22). Oleic acid predominates at this position of the triglyceride, which may account for health benefits cited in many nutritional studies (Ong and Goh 2002).

Table 4.22–Triglyceride composition of Malaysian *tenera* palm oil.

No Double Bond (%) ^a		One Double Bond (%) ^a		Two Double Bonds (%) ^a		Three Double Bonds (%) ^a		≥ Four Double Bonds (%) ^a	
MPP	0.29	MOP	0.83	MLP	0.26	MLO	0.14	PLL	1.08
PMP	0.22	MPO	0.15	MOO	0.43	PLO	6.59	OLO	1.71
PPP	6.91	POP	20.02	PLP	6.36	POL	3.39	OOL	1.76
PPS	1.21	POS	3.50	PLS	1.11	SLO	0.60	OLL	0.56
PSP	0.12	PMO	0.22	PPL	1.17	SOL	0.30	LOL	0.14
		PPO	7.16	OSL	0.11	OOO	5.38		
		PSO	0.68	SPL	0.10	OPL	0.61		
		SOS	0.15	POO	20.54	MOL	N/A		
		SPO	0.63	SOO	1.81				
				OPO	1.86				
				OSO	0.18				
				PSL	N/A				

^a M-myristic, P-palmitic, S-stearic, O-oleic and L-linoleic.

This data was adapted from Palm Fruit Chemistry and Nutrition – Conference: Morocco (Sundram and others 2003).

Triglycerides in palm oil contribute to its functional capabilities in food products due to their effect on crystallization and melting behaviors. Palm oil naturally has a β' crystal habit (Gunstone 2002). X-ray diffraction studies have shown that there is an unusually long α to β' transition time in palm oil which in turn leads to slow crystallization behavior in food products. The slow crystallization is caused by the diglycerides combined with the high concentration of symmetrical saturated-unsaturated-saturated (SUS) triglycerides. When palm oil is at concentrations exceeding 15-25%, it can cause undesirable hardening and graininess in a spread product (O'Brien 2009). This problem can be addressed by increasing processing time, specifically the amount of time the product spends in the scraped surface heat exchanger. Palm oil can also be interesterified, fractionated, or fully hydrogenated to circumvent this issue; these terms will be discussed in later sections (Berger and Idris 2005).

Solid fat content analysis is useful in quantifying the melting properties of fats at different temperatures. The SFC of palm oil is similar to butter. This is due in large part to palm oil's high concentration of saturated fatty acids (Table 4.23), making it a desirable replacement for partially hydrogenated oils (Berger and Idris 2005).

Table 4.23–Solid fat content of palm oil.

Temperature (°C)	Typical (%)	Range (%)
10.0	34.5	30.0-39.0
21.1	14.0	11.5-17.0
26.7	11.0	8.0-14.0
33.3	7.4	4.0-11.0
37.8	5.6	2.5-9.0
40.0	4.7	2.0-7.0

This data was adapted from *Fats and Oils*, 3rd Edition (O'Brien 2009).

Nutrition

There are many conflicting studies on the effects of palm oil consumption. These studies tend to focus on the high saturated fatty acid content, specifically palmitic acid, of palm oil. Palm oil contains approximately 44% palmitic acids, 39% oleic acid, and 11% linoleic acid (Gunstone 2002).

Most studies have concluded that palm oil has a detrimental effect on health, due to its ability to increase total cholesterol as well as LDL-cholesterol in the blood. However, it appears that total cholesterol content in the diet and hypercholesterolemic predisposition of individuals may determine how palm oil affects cholesterol levels. For example, one study found that in hypercholesterolemic men that had a modest increase in palmitic acid (+4%), LDL-cholesterol increased even when dietary cholesterol remained low (Nestel and others 1994). Another study showed that there were no significant differences between diets rich in 18:0 and diets rich in 16:0. However, when cholesterol was increased as well, the 16:0 rich diet resulted in significantly higher total cholesterol and LDL-cholesterol (Khosla and Hayes, 1993).

Yet another study evaluated the rate of fat oxidation between diets rich in palmitic acid and diets rich in oleic acid. The changes in daily energy expenditure were significantly different between the two groups. It was concluded that increased dietary palmitic acid decreases fat oxidation and daily energy expenditure while increases in oleic acid had the opposite effect. Thus, increasing dietary palmitic acid may increase the risk of obesity and insulin resistance (Kien and others 2005). Those in the palm industry may counter this study by explaining palm oil contains a large percentage of oleic acid as well as palmitic acid.

There are also many studies that back the claim that palm oil has beneficial health effects. One study that replaced usual sources of saturated fat in the Dutch diet with palm oil found an increase in HDL-cholesterol and a decrease in the LDL:HDL cholesterol ratio (Sundram and others 1992). Another study found that replacing olive oil with palm oil olein resulted in similar plasma and lipoprotein cholesterol values. It was found that in healthy adults, palm olein could be used instead of olive and canola oils without having negative effects on cholesterol levels (Sundram and others 2003).

Many studies have confirmed the nutritional benefits of palm oil due to its high unsaturation at the *sn*-2 position of the triglyceride. Triglycerides are hydrolyzed by pancreatic lipase to 2-monoglycerides and free fatty acids from positions -1 and -3. Risk of cardiovascular disease is based on the ease or difficulty of the absorption of these molecules during metabolism. The 2-monoglycerides are readily absorbed. Long-chain free fatty acids are poorly soluble. In palm oil, the fatty acids in the *sn*-2 position of the triglyceride are 87% unsaturated. Thus, the fatty acids that are absorbed are mainly unsaturated while the saturated free fatty acids (-1 and -3 positions) will be less absorbed and therefore, contribute less to caloric intake and also contribute less to the absorption of dietary cholesterol in the bloodstream (Ong and Goh 2002).

The Lauric Oils: Palm Kernel and Coconut

The family of lauric oils is characterized, as the name suggests, by high levels of lauric acid. Of the 17 major commodity oils, two fall into this category. Coconut and palm kernel oil are similar in lauric acid concentration but coconut oil contains higher levels of caprylic and capric fatty acids but less oleic acid (Table 4.24) (Gunstone 2002).

Both of these oil crops are grown in tropical regions. The *Cocos nucifera* (coconut oil) and the *Elaeis guineensis* (palm kernel oil) are grown in humid climates within a few degrees of the equator. The major coconut oil producing countries are the Philippines, Indonesia, and India. The countries producing the most palm kernel oil are also those producing the most palm oil as both oils are extracted from the same plant. These are Malaysia and Indonesia. Palm kernel oil is now the predominant lauric oil due to the dramatic increase in palm oil production in this region. The primary importers of lauric oils are the EU-27 and the U.S. Lauric oils are not

consumed at high levels in the U.S. due to their high price and unique properties (Gunstone 2002).

Coconut oil is expelled from the copra, or dried kernel, of coconuts from the *Cocos nucifera* tree. Each copra contains 65-68% coconut oil which is typically extracted by screw pressing. Palm fruit is ovular and about 3 cm in length. Palm oil is pressed from the mesocarp of the fruit while the hard shell, or kernel, remains. The average palm kernel oil yield from kernels is 45%. Though palm oil and palm kernel oil come from the same source they have very different fatty acid compositions and functionalities (Gunstone 2002).

The predominant fatty acids in lauric oils are lauric acid (C12:0) and myristic acid (C14:0). As mentioned above, coconut and palm kernel oils contain roughly the same amount of lauric acid but vary on levels of caprylic, capric, and oleic acids (Table 4.24). Laurics contain a variety of medium and short-chain fatty acids that, when added to a spread, move the fatty acid profile closer to that of butter. Both coconut and palm kernel oil are hard and brittle at room temperature yet melt rapidly at body temperature (Table 4.25). This yields a clean, cool feeling in the mouth that is highly desirable in spreads products. This sharp melting profile is the result of similar triglyceride melting points. The inhibitory price point of this oil can be overlooked if it is required based on its unique functionality (Gunstone 2002).

Coconut and palm kernel oil are highly saturated with low levels of unsaturated (especially polyunsaturated) fatty acids (Table 4.24). This contributes to good oxidative stability and its β' crystal forming tendencies. Due to their fatty acid similarities, most functionalities are the same between coconut and palm kernel oils (Gunstone 2002).

Table 4.24–Fatty acid profile of lauric oils.

Fatty acid	Coconut Oil		Palm Kernel Oil	
	Typical (%)	Range (%)	Typical (%)	Range (%)
C6:0 Caproic	0.4	Tr-0.6	0.2	ND-0.8
C8:0 Caprylic	7.3	4.6-9.4	3.3	2.1-4.7
C10:0 Capric	6.6	5.5-7.8	3.5	2.6-4.5
C12:0 Lauric	47.8	45.1-50.3	47.8	43.6-53.2
C14:0 Myristic	18.1	16.8-20.6	16.3	15.3-17.2
C16:0 Palmitic	8.9	7.7-10.2	8.5	7.1-10.0
C18:0 Stearic	2.7	2.3-3.5	2.4	1.3-3.0
C18:1 Oleic	6.4	5.4-8.1	15.4	11.9-19.3
C18:2 Linoleic	1.6	1.0-2.1	2.4	1.4-3.3

This data was adapted from Vegetable Oils in Food Technology (Gunstone 2002).

Table 4.25–Solid fat content of palm kernel oil.

Temperature °C	Typical (%)	Range (%)
5	72.8	68.0-76.8
10	67.6	61.6-71.2
15	55.7	50.7-60.0
20	40.1	34.2-45.5
30	17.1	10.2-21.5

This data was adapted from Vegetable Oils in Food Technology (Gunstone 2002).

Linseed (Flax) Oil

Linseed and flax are technically different although both are cultivars of *Linum usitatissimum*. Flax produces smaller seeds and longer and thinner stems than linseed. Although different the terms ‘linseed’ and ‘flax’ are often used interchangeably (and will be throughout the rest of this section). This is probably because of the differences in the naming of this edible oil throughout the world. In India and the U.K., crops grown for oil are called linseed. In Canada, it is called flaxseed and in many European countries it is called either flax or seed flax (Gunstone 2002).

Flax has been cultivated for hundreds of years but was not originally used for edible purposes but for textile production (Gunstone 2002). Its preferred growing conditions are in

subtropical or temperate climates. Flax is primarily grown in Argentina, India, the U.S., Canada, and in the Russian region (Gunstone and others 1994). Edible flax yields an oil content of 35-44% and is pressed from small, oval seeds (Gunstone 2002).

More than 60 years ago, flaxseed oil production was greater than sunflower oil. However, its production has remained stagnant while other vegetable oils, including sunflower oil, have increased dramatically. At the turn of the millennium, Canada was the leading producer and exporter of flaxseed oil (Gunstone 2002).

Flaxseed oil is rich in omega-3 alpha-linolenic acid. Typical oil contains levels of over 50% of all fatty acids (Table 4.26). Linolenic acid concentration is affected by conditions such as seed type and growing environment. Its high content of alpha-linolenic acid results in oxidative instability. Food products produced with this oil develop rancid flavors in a short period. Storage conditions (cold, oxygen-free, dark) and the addition of antioxidants are used to preserve the oil from rancidity (Gunstone 2002).

Flaxseed has been genetically engineered to reduce the level of linolenic acid. Linola oil (brand name solin) has reduced linolenic content from over 50% to less than 2%, reduced saturated fatty acids and increased linoleic acid to over 70%. These traits give the oil oxidative stability with a fatty acid profile similar to sunflower oil, safflower oil, and corn oil. The FDA granted GRAS status to solin (Gunstone 2002).

Table 4.26–Fatty acid profile of flax oil.

Fatty Acid	Typical (%)	Range (%)
C14:0 Myristic	Trace	Trace
C16:0 Palmitic	6.0%	5.0-7.0%
C16:1 Palmitoleic	0.1%	Trace-0.2%
C18:0 Stearic	2.5%	2.0-6.0%
C18:1 Oleic	19.0%	14.0-19.0%
C18:2 Linoleic	24.1%	14.0-19.0%
C18:3 Linolenic	47.4%	35.0-60.0%
C20:0 Arachidic	0.5%	0.1-0.7%

This data was adapted from Vegetable Oils in Food Technology (Gunstone 2002).

Safflower Oil

Currently, safflower oil is not widely used in spreads applications. It is, however, growing in popularity and should be discussed. The safflower plant (*Corthamus tinctorius* L.) was used in ancient times primarily as a source of the dye corthamine. The plant resembles a thistle and contains seeds that look like small sunflower seeds (O'Brien 2009).

In the 1950's, greater oil yielding varieties were developed and safflower oil production began to expand. The interest in safflower oil development stemmed from the desire for more unsaturated vegetable oils that could potentially lower serum cholesterol. Safflower oil contains high levels of linoleic acid but very low levels of linolenic (Table 4.27). In fact, it has the highest linoleic acid (an essential fatty acid) content of all commercial vegetable oils (O'Brien 2009).

Hydrogenation is often used with safflower oil due to its high concentration of unsaturated fatty acids as well as its lack of natural antioxidants. Hydrogenated safflower oil has good oxidative stability and crystallizes in the β' form. However, its oxidative stability is less than soybean or corn oil hydrogenated to the same degree. High-oleic safflower has been developed which is more than three times as oxidatively stable as traditional safflower oil (O'Brien 2009).

Table 4.27–Fatty acid profile of safflower oil.

Fatty Acid	Typical (%)	Range (%)
C14:0 Myristic	0.1	NA
C16:0 Palmitic	6.8	4.0-7.0
C16:1 Palmitoleic	0.1	NA
C18:0 Stearic	2.3	1.0-2.5
C18:1 Oleic	12.0	12.0-16.0
C18:2 Linoleic	77.7	75.0-79.0
C18:3 Linolenic	0.4	<0.4
C20:0 Arachidic	0.3	NA
C20:1 Eicosanoic	0.1	NA
C22:1 Erucic	0.2	NA

This data was adapted from *Fats and Oils*, 3rd Edition (O'Brien 2009).

CHAPTER 5 - Modified Fats

Many fats and oils do not meet important functionality criteria in their native states and must be modified before use in specific food applications. Modifying fats and oils is essential to give food products the taste, texture, and other characteristic attributes that are expected in modern food applications. Each modification technique may have benefits in certain circumstances due to nutrition, cost, and functionality. New modification methods are being developed all the time. The topics below cover commonly used fat and oil modification methods in general terms. The methods can be adapted to meet specific needs or be optimized for use with specific products. Thus, a best fit can be chosen for each circumstance by understanding the modifications available.

Hydrogenation

“Partially hydrogenated” is a term that has gained national recognition in the last few years. Many commonly used edible oils are liquids in their native state, as they are composed of polyunsaturated fatty acids with very low melting points. This is undesirable for use in most food applications. Typically a solid or semisolid fat is required.

Partial hydrogenation is a cost-effective solution to convert liquid vegetable oils into their semisolid forms. The process involves the conversion of polyunsaturated fatty acids into saturated fatty acids by attaching hydrogen atoms at the points of unsaturation. Not only does this affect the oil’s functionality, but also enhances the oxidative stability (shelf life) of the food product (O’Brien 2009).

The process of hydrogenation involves the reaction of hydrogen gas with the oil at high temperatures and pressure in the presence of a catalyst. Typically nickel is used as a catalyst and must be removed from the oil after the process is completed. The process of hydrogenation can be stopped at any point. Most often, hydrogenated oils are only partially hydrogenated to convert some but not all unsaturated fatty acids. This yields an increased melting point. The melting point gradually continues to increase throughout the hydrogenation process. Thus, fully hydrogenated oils are solid, brittle, and have high melting points. These oils do not contain any

trans fatty acids but do not have the desired functionality of partially hydrogenated oils (O'Brien 2009).

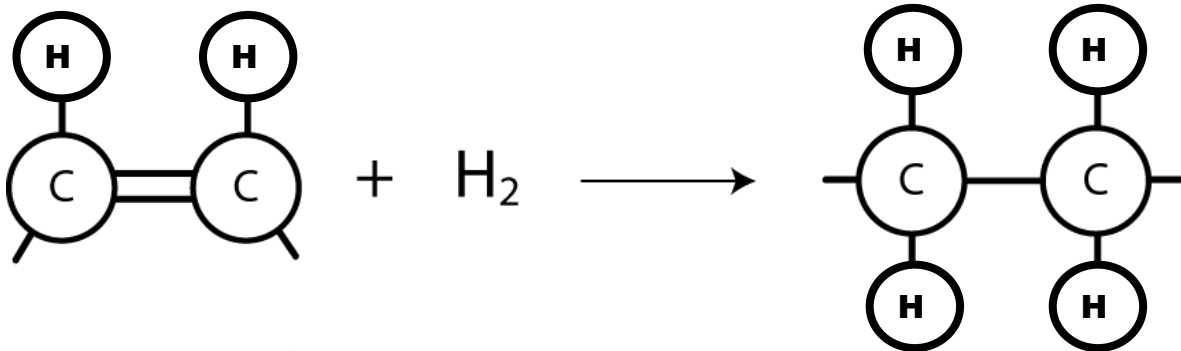


Figure 5.1–Hydrogenation process.

Partially hydrogenated oils have been criticized for the *trans* fat byproduct formed during the process. *Trans* fats are formed when the remaining unsaturated fatty acids go through isomerization from the *cis* formation, which predominates in natural oil, to the *trans* configuration. *Trans* fats are known to have the ability to increase low-density lipoproteins, to decrease high-density lipoproteins, to alter the integrity of cell membranes, and to reduce production of essential metabolites (Reyes-Hernández and others 2007).

Interesterification

Interesterification is a process that involves reorganizing fatty acids on the glycerol backbone of triglycerides in oil. Different combinations are formed that yield different, more desirable, physical properties. Types of interesterification include chemical (CIE) and enzymatic (EIE) (Strayer and others 2006).

Chemical and nonspecific enzymatic interesterification both result in randomized distribution of triglycerides. Chemical interesterification involves blending and drying of the desired oils and then adding a catalyst (such as sodium methoxide). After the interesterification process is finished, the catalyst is neutralized and the oil undergoes a clean-up stage of washing, bleaching, and deodorizing (Strayer and others 2006).

Enzymatic interesterification, using a specific lipase, preserves one of the three positions creating an end product more like natural fat (Dian and others 2006). EIE is a useful method for including hard fractions of palm oil and palm kernel oil into spread applications to yield a more stable, viscous end product (Criado and others 2007). EIE has both advantages and disadvantages. EIE is more selective, has milder reaction conditions, fewer process steps, lower start-up costs, and maintains tocopherol concentration. The primary disadvantage is the expensive biocatalyst required in EIE that is not required in CIE (Criado and others 2007). Interesterification in general is a good method to incorporate desired functionality changes in oil without producing *trans* fatty acids.

Alternative Hydrogenation

Trans fats can be significantly reduced while maintaining targeted positive attributes by altering the hydrogenation process itself. Changes to hydrogenation can include the use of new catalysts, binary gas mixtures, specialized conditions, and pressure-controlled systems (List and others 2007). A technique called electrochemical hydrogenation, documented in 1992 (Fu and others 2008), is an alternative to common gas hydrogenation. In this process, water or hydrogen gas is used as the source of hydrogen atoms. An electrochemical process is used to oxidize these atoms into H⁺ ions and electrons (List and others 2007). The electrons proceed to the cathode (made of a thinly pressed film of precious metal powder) and the protons flow through the cation-exchange membrane under the influence of an electric current. The H₂ reduction products interact with the double bonds of the oil's unsaturated fatty acids (List and others 2007). Low temperatures are needed for this process to reduce *trans* fat byproducts while maintaining desirable physical characteristics.

Fractionation

Oils and fats are made up of a variety of triglycerides that have many different melting points and solubilities. Fractionation is the process of cooling the oil slowly to yield solidified fat at various temperatures. The oil must be first heated and held at a higher temperature than its melting point in order to erase the 'crystal memory.' Slow cooling results in crystallization of higher melting triglycerides. When these solid fats are separated out by filtration they can be

used in food products based on desired functional characteristics. The three types of fractionation are dry, detergent, and solvent. Each results in similar end products (Strayer and others 2009).

For example, fractionation can be used to modify the spreadability of butter. In fractionation, milkfat is separated into many parts based on the melting points of its fatty acids. Separating out the softest (lowest melting point) fraction and adding it back to butter can have a positive impact on making butter more spreadable (O'Brien 2009).

A commonly fractionated vegetable oil is palm oil. Olein, or liquid fraction, of palm oil is desirable for applications such as cooking. Palm stearin, or hard fraction, may be blended with other oils for margarine and spreads applications. The olein has a melting point around 18-20 °C and stearin a melting point around 48-50 °C (Gunstone and Norris 1983).

Blending

The blending process is fairly simple. It involves adding different portions of desired basestocks into a tank with heat and agitation. Blending of oils offers a simple, cost-effective way to create functional oils that meet specific needs. The blending of a modified oil with oil in its natural state can result in the reduction of *trans* fatty acids, an acceptable level of functionality, and a lower cost than the use of only one of the alternatives to partial hydrogenation previously discussed (hydrogenation or interesterification) (O'Brien 2009).

Farm/Field Practices and Genetic Modification

For butter, many strategies can be implemented in the farm setting. A decrease in saturated fat can be achieved by environmental and physical parameters such as cow's age, breed, stage of lactation, feed regimen, and other factors. By selecting for genetics, one can achieve a desired amount of saturated fat for use in a specific food application. Omega-3 fatty acids can be included in milkfat by adding fish oil to bovine feed. Including soybeans and rapeseed in feed can decrease the solid fat content of milkfat, which can enhance the spreadability of butter (Hillbrick and Augustin 2002).

Many modification techniques have been developed for vegetable oils in order to mimic the desirable qualities of partial hydrogenation. One technique is the genetic modification and modified growth conditions of the oil's source. Consider the growth and processing of soybeans as an example. Genetics can be altered by conventional breeding or by using recombinant DNA

technology to manipulate the genome. In the latter case, the product has been genetically modified. Genetically altered versions of soybeans produce desirable oil that has an altered fatty acid profile. If palmitic acid is reduced, oleic acid is increased, and linoleic acid is reduced, the resulting soybean oil will take on additional desirable properties such as being more stable at high temperatures (Oliva and others 2006). This additional stability will reduce the need for hydrogenation.

Growing conditions also affect oil quality. According to Primomo and others (2002), temperature during soybean growth has a major impact on the development of unsaturated fatty acids. Oleic acid increases in warmer climates while linoleic and linolenic acids decrease with increasing temperature. They also found that specific, genetically modified soybean alleles need to be monitored due to potential loss during subsequent breeding. Overall, it appears that a soybean with a targeted fatty acid profile would probably be best suited in combination with another oil modification technique depending on application criteria (Primomo and others 2002).

Fat Replacers

With the problem of obesity growing in the U.S., consumer demand for lower calorie options has increased. Just pulling the fat out of products doesn't work due to its important role in flavor, texture, and functionality of food products. Fat replacement research is ongoing in order to come up with the best, most functional ingredient with reduced calories. Predominantly, starch and proteins are used as alternatives to fat (Table 5.1). This results in a caloric decrease in the food product; as fat contains nine calories per gram whereas protein and starch only contain four calories per gram (Strayer and others 2006).

Starch-based fat replacers can be used as gels. If a gel contains 25% starch and 75% water, then in 100 g it contains only 100 calories as compared to 900 calories for 100 g of fat. The same caloric ratio can be applied to gels made from carbohydrates. For example, gums (soluble dietary fiber) are carbohydrates and contain four calories per gram. A common sugar replacer, polydextrose, also has some use as a substitute for fat. Polydextrose contains only one calorie per gram (Strayer and others 2006).

Another type of fat replacer is a modified lipid. These fats have been modified so they are not absorbed in the gut to the same extent as natural fats and thus contribute less calories per gram. A familiar fat replacer by the name of Olestra is an example of this. Olestra contains

sucrose molecules that have been esterified with fatty acids. The pancreatic lipase in the gut is very specific and cannot hydrolyze this molecule in the gut. Since the fatty acids are not released from the molecule, the body cannot absorb them and use them as energy. This ingredient was approved by the FDA in 1996 (Strayer and others 2006).

In comparison to Olestra, there is an ingredient called Salatrim in which the fats are metabolized in a different way which leads to fewer calories per gram. In this case, the monoglyceride is made up of stearic acid, which is only partially absorbed, yielding about four calories per gram (Strayer and others 2006).

Diglyceride oil has been used as a “healthy” alternative to traditional oils. An example is Enova oil by Archer Daniels Midland, Decatur, Illinois. This oil was made from soybean and canola oils via interesterification. It was thought that diglyceride oils are absorbed and metabolized differently causing triglyceride levels in the blood to decrease after eating and also speed up metabolism. This can lead to less body fat being stored after consumption. However, Enova oil is no longer on the market in the U.S. due to presence of glycidol esters. Glycidol has been classified as “probably carcinogenic to humans” by the International Agency for Research on Cancer (IARC) (Watkins 2009).

Another type of fat replacer is emulsifiers. Typical polyglycerol ester emulsifiers contain about two-thirds the calories of fat. However, emulsifiers are expensive and can only replace about 2% of fat in the formula making it not very cost-effective (Strayer and others 2006).

New research on fat replacement technology will yield new and different ingredients in the future. Due to the fat-conscious nature of society and government today, companies have it in their best interest to develop new methods to reduce fat in their food products (Strayer and others 2006).

Table 5.1–Commercial fat replacers.

Supplier	Brand Name	Composition
Carbohydrate-based Substitutes		
FMC Biopolymer	Avicel	cellulose
DOW	Methocel	cellulose
International Fiber Corporation	Solka-Floc	cellulose
National Starch	N-Oil	dextrin
Fiber Gel Technologies	Z-Trim	fiber
CP Kelco	KELCOGEL	gums
	KELTROL	gums
	Slendid	gums
Avebe America, Inc.	Paselli EXCEL	maltodextrin
	Paselli SA2	maltodextrin
Tate & Lyle	STAR-DRI	maltodextrin
	STA-SLIM	starch
Danisco	Litesse	polydextrose
Avebe America, Inc.	Fairnext VA15, VA20	starch
	Etenia	starch
	Perfectamyl AC, AX-1, AX-2	starch
National Starch	N-Lite	starch
SunOpta	PolyCell's Barley Balance	beta-glucan
Conagra	Oatrim	hydrated oat flour
Fat-Based Fat Replacers		
Danisco	Benefat (Salatrim)	Short and long chain triglycerides
Lipid (Fat/Oil) Analog		
Proctor & Gamble	Olean	olestra

This data was taken directly from the suppliers' websites.

CHAPTER 6 - Processing

Margarine and spreads are considered water-in-oil emulsions consisting of a fat phase that usually includes oils, emulsifiers, oil-soluble flavors, and nutrient such as vitamins. The water phase consists of water, salt, proteins, starches and/or gums, and acid (Strayer and others 2006).

At the time of its invention in the 19th century, margarine processing was time consuming and labor intensive. The principals of mixing, emulsifying, chilling, working, and resting are still used in today's margarine and spreads processing but methods have evolved and become much more efficient (Rajah 2002). Today, the margarine and spreads manufacturing process can be summed up as preparing the fat-phase, aqueous-phase, addition of emulsifiers, blending, chilling, and tempering (when necessary). When blending it is important to add the aqueous-phase to the fat-phase in order to promote water-in-oil emulsion (O'Brien 2009).

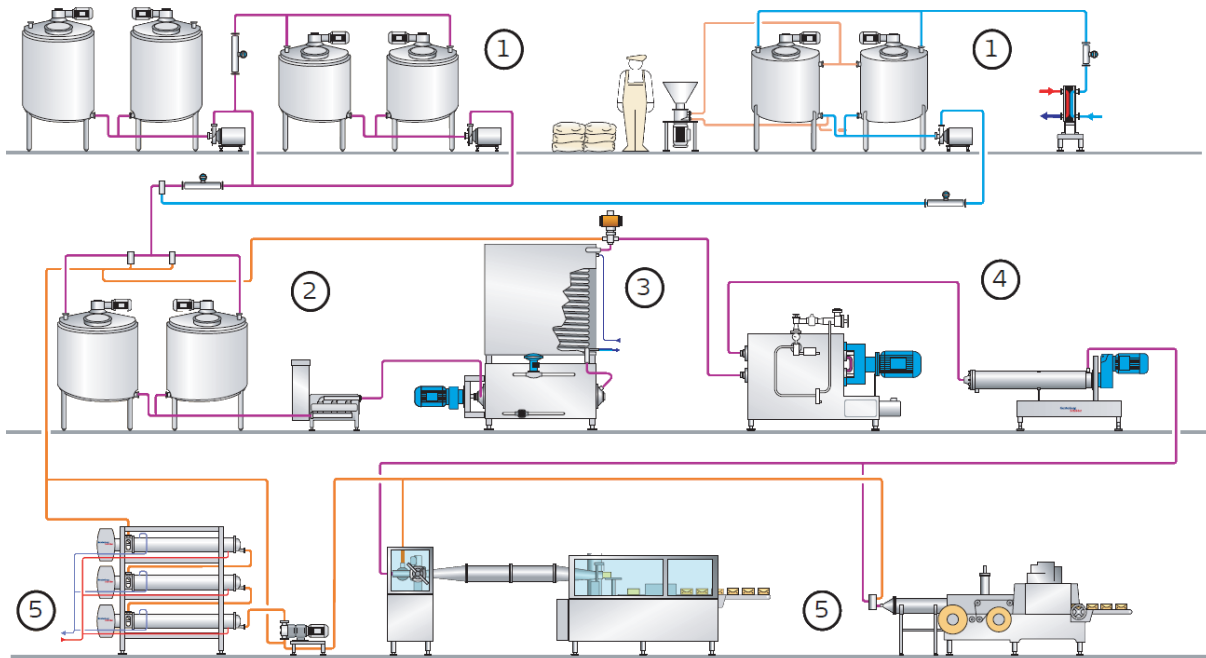
From the basic steps listed above there are several variations that can be utilized to optimize each product to meet specific consumer needs. These variations include formulation changes as well as changes to the processing and packaging. Typically, the margarine mix is heated to about 37.8 to 40.6 °C before being sent to the scraped surface heat exchanger for rapid chilling down to around 4.4 to 7.2 °C (O'Brien 2009).

Margarine and spreads manufacturing equipment includes tanks, pumps, pasteurizers, aerating units, inverters, scraped surface heat exchangers (for chilling), working units (for shearing), resting tubes (to promote crystallization), packaging, and equipment to process and handle rework. Some well-established names in margarine and spreads manufacturing units are Gerstenberg Schröder, Cherry Burrell, Chemtech, and Chris James Consultants (Rajah 2002).

When fats and oils are brought into the plant they must be stored with care in order to protect quality. The largest quality concern is oxidative rancidity. Fats and oils can be protected from oxidative rancidity by nitrogen blanketing of the oil silos, maintaining tight temperature and light control, being turned over every two to three weeks, and when applicable, adding antioxidants. The fats and oils must also be protected against contamination by moisture, impurities, odors, and flavors. Moisture and impurities may promote oxidative rancidity as well

as contaminate the product. Fats and oils readily absorb odors and flavors impacting product quality (O'Brien 2009).

Margarine and spreads can be processed as batches or continuously. In batch processing the fat-phase, aqueous-phase, and emulsifiers are blended with high speed agitation before being sent on to be chilled and worked. The mix tank represents one batch. In continuous processing automatic proportioning equipment is used and the emulsified mix is sent to a hold tank before it goes on to chilling and working. Thus, there is always mix in the hold tank to undergo the further processing (Gunstone and Norris 1983). The downside to the continuous process is that a rework handling system is necessary to deal with unexpected (or expected) stoppages on the production line (Rajah 2002).



1. Preparation of the water phase and the fat phase (zone 1)
2. Emulsion preparation (zone 2)
3. Pasteurization (zone 3)
4. Packaging and remelting (zone 5)

Figure 6.1–Margarine processing diagram.

This figure was taken from Margarine Production (Gerstenberg Schröder 2009).

Margarine and spreads are packaged in tubs or in a stick format. The packaging machinery varies depending on the product format. There are several tubs sizes that can be used to pack the finished product. The ease of use and convenience to consumers drives the packaging configuration (Rajah 2002).

After packaging the product can be tempered. This involves storing the finished product at elevated temperatures for a few days. This tempering process has been found to enhance plasticity, baking performance, and creaming properties. Typically retail margarines and spreads are not tempered (Gunstone and Norris 1983).

The push to remove *trans* fats from the American diet has brought about several changes to margarine and spreads production. This includes use of new oils such as palm, palm kernel, interesterified oil, and other oil blends. Processing considerations have also changed to suit the new oils, many of which require stringent processing conditions (O'Brien 2009). Margarine and spreads processing must be a continuously evolving science in order to meet changing consumer demands.

CHAPTER 7 - Conclusion

Fats and oils are an important topic in the margarine and spreads industry. The selection of these ingredients can be based on many factors including flavor, functionality, cost, and health aspects. In general, fat is an important component of a healthy diet. It provides nine calories per gram of energy, transports essential vitamins, and is necessary in cellular structure. Major shifts in consumption of fats and oils through history have been driven by consumer demand. An example is the decline in animal fat consumption due to consumers' concern over saturated fats. Also, consumers' concern over the obesity epidemic and coronary heart disease has driven demand for new, lower calorie, nutrient-rich spreads products. Governmental legislation has also been a catalyst for change in this category (e.g. *trans* fat labeling). The spreads category has increased dramatically as it does not have to adhere to strict governmental standards like butter and margarine. This allows spread products to shift rapidly to keep up with consumers' changing desires.

Fats and oils can be separated into many different subgroups. "Fats" generally refer to lipids that are solid at room temperature while "oils" refer to those that are liquid. Fatty acids can be either saturated or unsaturated. If they are unsaturated, they can be either mono-, di-, or poly-unsaturated. Also, unsaturated bonds can be in the *cis* or *trans* conformation. A triglyceride, which is three fatty acids esterified to a glycerol backbone, can have any combination of saturated and unsaturated fatty acids. Triglycerides are the primary components of animal and vegetable fats and oils. The ratio of saturated to unsaturated fatty acids in these fats and oils has a great impact on their functionality.

Functionality of fats and oils is an important consideration when formulating margarine or a spreads product. Features such as melting point, solid fat content, fatty acid profile, triglyceride content, and crystallization habits of fats and oils influence the functional aspects of the final food product. Fats can be modified to enhance specific desirable functional traits. Processing techniques such as hydrogenation, interesterification, and blending, as well as genetic modifications such as increasing specific fatty acids in crops, have been used to affect the functional characteristics of specific natural fats and oils.

Partial hydrogenation, which is used to increase the solid fat content and increase oxidative stability, produces *trans* fat byproducts. The consumption of *trans* fatty acids has been linked with an increased risk of coronary heart disease. As such, consumers' demand and governmental regulations have been seen as a mandate to the food industry to reduce or eliminate *trans* fats from food products. This is only one of the many health aspects that must be addressed when formulating margarine or a spreads product.

There are many processing techniques that can be utilized in margarine and spreads production. In general the processing steps involve preparing the fat-phase, aqueous-phase, and emulsifiers, blending, and then chilling. There are so many variables in this broad topic that the process can be optimized for each margarine or spreads product.

The spreads category is constantly changing and expanding. It is essential to have the necessary groundings in the chemistry, functionality, types, cost, and nutrition of various fats and oils used in these products in order to stay current with this profitable category. Although many ingredients and processes have been characterized in this broad segment, there is still much room for new innovations. Research into the various aspects of spreads formulations is ongoing and new discoveries are being published or patented all the time. Fat and oils remain an active area of food and consumer research.

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