Introduction to Fats and Oils Technology

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AOCS Mission Statement

To be a forum for the exchange of ideas, information and experience among those with a professional interest in the science and technology of fats, oils and related substances in ways that promote personal excellence and provide for a high standard of quality.

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Preface

During the organizing of a short course on fats and oils technology, many of the speakers expressed the idea that there is a need for a monograph as well as a short course to cover the processing technologies of the current practices in the edible fats and oils industry.

In the attempt to include all the essential components of the fats and oils technology, we chose to start from the sources of fats and oils, their properties, and the engineering principles and experiences. The main emphasis was to describe the various unit operations that are used to produce oil-based stocks and finished products. Topics on quality management, distribution, nutritional and environmental concerns also are discussed. Finally, the by-products of the industry and their utilizations are discussed to provide an overview of the many related businesses of this industry.

The American Oil Chemists' Society did hold the short course on "Introduction to Fats and Oils Technology" at the Pointe Tapatio in Phoenix, Arizona, during May 4–7, 1988. Anthony Chen and Peter Wan cochaired the course under the auspices of the AOCS Education and Planning Committee. The 19 papers in this monograph result from the lectures presented at the course.

There were 113 registrants from 17 countries at the Pointe Tapatio. One-third of them were from places outside the United States. The diverse audience consisting of plant managers, foremen, superintendents, chemists and merchants interacted well with the speakers in very productive sessions.

The Committee was strongly encouraged by the registrants to present on a regular basis both basic and practical courses on the technologies of the fats and oils industries. Short courses such as this one and the larger world conferences on similar subjects (*e.g.*, "World Conference on Emerging Technologies in the Fats and Oils Industries" in Cannes, France, in 1986, and the "World Conference on Edible Fats and Oils Processing" held in Maastricht, The Netherlands, in 1989) are vital parts of the AOCS education program, and the proceedings of these conferences is available.

We hope that the aim of this short course and monograph, to provide new professionals or managers with a reference and an overview about the fats and oils industry, has been achieved. We also hope that this material will serve as a starting point for the scientists and engineers to continue their efforts in the manufacture of new and improved products. In closing, we would like to take the opportunity to express our sincere appreciation for the editorial guidance that Dr. Dick Baldwin so generously provided.

Peter Wan

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Chapter One

The Raw Materials of the Fats and Oils Industry

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Commercial Sources of Fats and Oils

The edible vegetable and animal fats and oils important in world commerce are shown in Tables 1-1 and 1-2, respectively, along with their typical fatty acid compositions. Table 1-3 lists the compositions of several important fats and oils used in industrial products. The typical values given in Table 1-1 are subject to considerable variation, and many of the references cited give information about the range of variation that may be encountered. Vegetable fats and oils may vary as a result of environmental conditions and their genetic make-up (25). They often vary with the location in which they are produced because of climate, weather and the varieties favored in particular areas. Table 1-1 lists fatty acid compositions of some genetic variants of some common fats and oils. Animal fats may vary in composition from place to place on the carcass and with the animal's diet (25). Table 1-2 gives the range of variation in composition that has been reported.

By-Product Fats and Oils

The fats and oils listed in the first three tables are in production for a variety of reasons. Several fats and oils are by-products and the amount produced (Table 1-4) depends on the demand for some other product. Thus, cottonseed oil production is limited by the market for cotton. Corn oil production is tied to the corn milling industry because it is only profitable to extract oil after the corn germ is separated from the endosperm. Palm kernel oil is a by-product of palm oil production. Tallow and lard production depend on animal slaughter and the demand for meat products. Fish oil production depends on the size of the fish catch and the resources devoted to fishing. Butter's position has changed over the

TABLE 1-1

The Typical Fatty Acid Compositions of Some Edible Plant Fats and Oils

									Rapeseed		Safflower			Soybean			Sunflower	
Fatty acid	Cocoa Butter (1)	Coconut (2)	Corn (3)	Cottonseed (4)	Olive (5)	Palm (6)	Palm kernel (7,8)	Peanut (9)	(10)	Low 22:1 (11)	(10)	High 18:1 (10)	Sesame (12)	(13)	High 18:0 (14)	Low 18:3 (14)	(15)	High 18:1 (16)
6:0	—	0.4*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8:0	—	8.2	—	—	—	—	4.0	—	—	—	—	—	—	—	—	—	—	—
10:0	—	5.6	—	—	—	—	4.0	—	—	—	—	—	—	—	—	—	—	—
12:0	—	47.1	—	—	—	0.2	48.0	—	—	—	—	—	—	—	—	—	—	—
14:0	0.7	19.4	—	0.8	—	1.1	16.0	—	—	—	—	—	—	—	—	—	—	—
16:0	25.2	7.8	11.5	22.2	12.9	44.0	9.0	11.4	3.0	3.9	5.9	4.3	9.7	11.4	8.0	9.1	5.9	3.4
18:0	35.5	4.3	2.0	2.5	2.8	4.5	2.0	4.0	0.8	1.8	1.5	1.4	4.8	3.7	28.1	2.5	4.1	4.3
20:0	—	1.0	0.2	—	0.4	0.4	—	1.7	—	—	—	—	—	—	2.0	—	—	—
22:0	—	—	—	—	0.1	—	—	3.7	—	—	—	—	—	—	—	—	—	—
24:0	—	—	—	—	0.3	—	—	1.5	—	—	—	—	—	—	—	—	—	—
16:1	—	—	—	0.8	—	0.1	—	0.1	—	—	—	—	—	—	—	—	—	—
18:1	35.2	4.3	24.1	17.8	72.2	39.2	15.0	41.5	13.1	60.3	8.8	74.1	41.2	22.9	19.8	59.8	21.5	83.2
18:2	3.2	1.8	62.5	55.2	10.5	10.2	2.0	34.9	14.1	23.9	83.8	19.7	44.4	53.6	35.5	23.7	67.5	6.4
18:3	0.2	—	0.7	—	0.7	0.4	—	0.2	9.7	9.6	—	—	—	8.4	6.6	3.8	0.2	—
20:1	—	—	—	—	0.2	—	—	1.0	7.4	—	—	—	—	—	—	—	—	—
22:1	—	—	—	—	—	—	—	—	50.7	—	—	—	—	—	—	—	—	—

TABLE 1-2

Range of Fatty Acid Compositions of Some Animal Fats and Oils

Fatty acid	Herring (17)	Meneheden (17)	Lard (18)	Tallow (18)	Milkfat (19)
4.0	—	—	—	—	7-14
6:0	—	—	—	—	2-7
8:0	—	—	—	—	1-3.5
10:0	—	—	—	—	1.5-5
12:0	—	—	—	—	2.5-7
14:0	6.0-16.3	5.6-7.7	1-4	2-8	8-15
16:0	19.6-24.0	11.8-18.6	20-28	24-37	20-32
18:0	11.2-17.9	6.2-8.0	5-14	14-29	6-13
20:0	2.4-3.4	1.1-2.0	—	—	0.3
22:0	—	11.7-25.2	—	—	0.1
10:1	—	0.1-0.6	—	—	0.3
12:1	—	—	—	—	0.1
14:1	—	—	—	—	0.8
16:1	—	—	—	—	1.5
18:1	10.7-23.4	11.7-25.2	41-51	40-50	13-28
18:2	0.9-1.7	0.1-0.6	2-15	1-5	1-4
18:3	0.4-3.7	—	0-0.1	—	0.4-2
18:4	0.8-3.6	1.1-2.8	—	—	0.1
20:1	1.1-2.7	7.3-19.1	—	—	—
20:2	—	—	—	—	0.1
20:3	—	—	—	—	0.1
20:4	0.6-2.3	0.3-0.8	0.3-1.0	—	0.1
20:5	10:2-14.1	11.4-15.2	—	—	—
22:1	0.2-1.0	6.9-15.2	—	—	—
22:4	—	—	—	—	0.1
22:5	1.1-2.5	0.3-1.0	—	—	0.1
22:6	3.8-10.6	4.8-7.8	—	—	—
24:1	—	0.6-1.3	—	—	—

years from the primary product of some dairying regions to more of a by-product status. The amount of milkfat diverted into butter can vary with the demand for other dairy products and the nature of government support programs. Tall oil, a source of free fatty acids for industrial use, is a by-product of paper manufacture.

TABLE 1-3

Typical Fatty Acid Composition of Some Plant Industrial Oils

Fatty acid	Castor (20)	Crambe (21)	Linseed (22)	Rapeseed (10)	Tall (23)	Tung (24)
14:0						
16:0	1.3	8	6.0	3.0	6.5	3.1
18:0	1.0		4.0	0.8	2.0	2.1
20:0						
22:0						
24:0						
16:1	—	—	—	—	1.0	
18:1	4.2	17	19.7	13.1	40.0	11.2
18:2	4.5	9	15.3	14.1	39.0	14.6
18:3	0.6	6	55.0	9.7	0.5	
18:1 OH	88.3					
18:3 conj						69.0
20:1		5		7.4		
22:1		55		50.7		

Edible Fats and Oils with Special Properties

Melting Behavior

Many fats and oils are produced and valued because of their particular properties such as melting behavior, flavor, flavor stability, nutritional advantage or particular industrial uses. Cocoa butter, for example, is valued because its fairly sharp melting point near human body temperature makes it ideal in the manufacture of various confections. This melting behavior depends not only on the fatty acid composition of cocoa butter but also on its glyceride structure. Its relatively high price causes numerous attempts to duplicate its properties with less expensive raw materials (1,25).

Cottonseed oil is valued in some hydrogenated fats because of its palmitic acid content which is around 20%. The major unsaturated fatty acids in most other vegetable oils all have chain lengths of 18 carbons. This can lead to the undesirable β-crystal form in hydrogenated products. Cottonseed with its relatively high palmitic acid content gives rise to the more desirable β'-crystal forms in hydrogenated products (27).

Of the animal fats, lard is valued because its unusual glyceride structure gives it an advantage in certain shortening uses (28). Butter also is valued for its melting behavior although many consider it too hard when

TABLE 1-4

World Disappearance of Various Fats and Oils in Millions of Metric Tons and Major Producing Areas (26)

Oil	84/85	85/86	86/87	87/88	Major producing areas
Coconut	2.28	3.03	3.03	2.84	Philippines, Indonesia, India, Sri Lanka
Corn	1.05	1.06	1.13	1.14	USA, Japan, S. Africa, Brazil
Cottonseed	3.75	3.74	3.25	3.40	China, USSR, USA, Pakistan
Olive	1.77	1.82	1.85	1.90	Spain, Italy, Greece, Tunisia
Palm	6.44	7.31	7.73	8.38	Malaysia, Indonesia, Nigeria, Ivory Coast
Palm kernel	1.08	1.20	1.31	1.35	Malaysia, Indonesia, Nigeria, Ivory Coast
Peanut	3.49	3.44	3.44	3.10	China, India, Senegal, Burma
Sesame	0.57	0.64	0.62	0.58	China, India, Sudan, Japan
Soybean	13.73	13.97	14.91	15.64	USA, Brazil, China, Argentina
Sunflower	6.42	6.88	7.16	7.50	USSR, EEC, Argentina, E. Europe
Butter[a]	6.28	6.33	6.47	6.44	EEC, USSR, India, E. Europe
Fish	1.56	1.54	1.54	1.52	Japan, Chile, Peru, USA
Lard	5.42	5.48	5.62	5.80	China, EEC, E. Europe, USSR
Tallow	6.44	6.61	6.37	6.41	USA, EEC, USSR, Australia
Castor	0.37	0.39	0.38	0.37	India, Brazil, China, USSR
Linseed	0.68	0.68	0.70	0.76	EEC, Argentina, India, USA
Rapeseed	5.57	6.29	7.27	7.62	EEC, China, India, Japan
Tung	0.04	0.04	0.04	—	China, Paragua, Argentina, Hong Kong

[a]Fat basis. Butter is ~ 80% fat.

used as a spread, but its melting properties are the basis for a number of baked products. Probably the unique flavor more than the melting behavior of butter is responsible for its popularity. This flavor is complex but it is caused partly by the presence of short-chain fatty acids and also by small amounts of hydroxy- and keto-fatty acids which can give rise to lactones and methyl ketones (29).

Flavor

Oils which are prized for their flavor properties include olive (5), peanut (30), coconut, palm kernel (8), and sesame. The flavors of these oils often are important in the dishes that are native to their producing regions. Olive, peanut, and sesame have unique flavors that reflect the plants from which they arise. They often are sold with minimal processing to preserve these flavors. Coconut and palm both contain short-chain fatty acids that are flavorful when present in the free form.

Stability

The flavor stability of fats and oils also is an important onsideration in their utilization. Unsaturated fatty acids are subject to oxidation which can give rise to flavor compounds. In general, the more double bonds a fatty acid has, the more prone it is to oxidation (31). Although these oxidized flavors are important in some foods, many fats and oils are particularly valued for their stability. Thus, coconut and palm kernel are valuable because they are quite stable to oxidation and yet are fluid at room temperature (8). They owe their stability to being composed mostly of saturated fatty acids and having relatively little fatty acids with multiple double bonds. They are able to maintain their fluidity in spite of this high degree of saturation because much of the saturated fatty acids have short chains. For these reasons they are often used in foods that need a long shelf-life.

Fats with large amounts of long-chain saturated fatty acids and relatively little unsaturated fatty acids such as tallow, lard, and palm oil (6) are also quite stable but their high melting point and texture may limit them in various uses. They often are particularly valued as heat-transfer media in frying operations (18). Unsaturated oils can be hydrogenated to increase their stability and make them comparable to the more saturated fats.

Olive oil also is valued for its stability which is caused by its relatively small amount of polyunsaturated fatty acids (5,32). Its fluidity is due to its high percentage of monounsaturated oleic acid. It is not subject to the off-flavors on hydrolysis that may cause trouble with coconut and palm kernel oil with their short-chain fatty acids. The value of olive oil has led to attempts to reproduce its stability in safflower and sunflower oils by varieties that are rich in oleic acid (Table 1-1).

Corn, sunflower, peanut, cottonseed, and safflower contain significant amounts of the dienoic linoleic acid and are regarded as being less stable than olive and other high-oleic acid oils. Most of these oils require extensive processing and protection from further oxidation while in trade channels. Sesame oil which falls in the same category from its fatty acid composition is considered extraordinarily stable because of a unique natural antioxidant, sesaminol, that it contains (12).

Oils such as soybean and low-erucic rapeseed oil which contain appreciable amounts of trienoic linolenic acid are regarded as significantly less stable than those that contain little linolenic acid (33,34). Sometimes these oils have been selectively hydrogenated in an attempt to reduce the amount of linolenic acid that they contain. Linseed oil, which contains large amounts of linolenic acid is usually not regarded as an edible oil because of its flavor instability. Fish oils which contain appreciable amounts of fatty acids with four, five and six double bonds are particularly unstable and subject to development of off-flavors (35).

Nutritive Value

Nutritional considerations have played an important role in determining the value and utilization of fats and oils in recent years. The erucic acid found in rapeseed oil was shown to have deleterious consequences when a major constituent of the diets of animals, and several countries require that rapeseed oil going into human consumption have a low content of erucic acid (36,37).

The consumption of large amounts of saturated fatty acids and cholesterol-containing animal fats has been regarded as predisposing many people to artery disease and numerous pronouncements by health authorities have counseled against the consumption of large amounts of these fats. The public also has been advised to decrease the proportion of total calories coming from fat to reduce risks from cancer as well as artery disease (38,39). This advice has depressed the utilization of tallow, lard, milk fat, palm oil, coconut oil, palm kernel oil and hydrogenated oils in many products. However, this advice also has depressed the price of these fats and oils and this has made them more likely to be used in prepared foods and items that the public is less likely to monitor for saturated fatty acids and cholesterol. In the U.S., the per capita consumption of animal fats actually has increased in spite of this nutritional advice (39).

Peanut oil has also been identified as especially likely to be atherogenic, but the reasons for this are not completely clear (40). So far this trait of peanut oil seems not to be well known, and the consumption of peanut oil has been little affected.

When animals consume linoleic and linolenic acids they convert them into longer chain fatty acids with additional double bonds. Animals can introduce additional double bonds near the carboxyl end of the fatty acid chain, but they cannot alter the configuration near the methyl end of the chain. Thus, linoleic and linolenic give rise to two separate families of fatty acids in animals. Some of these polyunsaturated fatty acids are converted to the prostaglandin hormones, and the hormones arising from the two families of fatty acids have different physiological effects. This understanding and dietary analyses have somewhat revived the economic fortunes of oils containing linolenic acid and eicosapentenoic acid (41). The latter, which is chiefly available to humans through fish, suffers from such flavor instability that incorporating it into food with appealing flavor is a formidable technological problem. It is less clear to what extent linolenic acid-containing oils such as soy and low-erucic rape will serve to meet these needs or what levels of consumption of these oils will be most advantageous.

The consumption of fats and oils tends to rise with national income up to a point, but among the relatively rich nations there is a great variation in the amounts of fats and oils consumed (39). In the U.S., per capita consumption of fats and oils which has been rising for many years now appears to be leveling off (Figure 1-1). This may be a result of the nutritional advice to which Americans have been subjected. There also has been a proliferation of foods with minimally hydrogenated fats and reduced fat contents. There has been increased interest in the production of foods with reduced-calorie and indigestible fat substitutes (43,44).

Industrial Uses of Fats and Oils

Some fats and oils are valued for their properties in non-food products. Linseed oil is used as a drying oil in paints and protective coatings (45). Its high content of linolenic acid makes it dry quickly and form a tough, flexible film. Safflower also makes an excellent drying oil. Castor oil contains large amounts of the unusual ricinoleic acid which contains a hydroxy group. The well-known use of castor oil as a laxative is a very minor use, most of it goes into drying oils. Castor oil can be dehydrated to form a conjugated diene which has desirable drying properties for special uses. Ricinoleic acid also is a raw material in the production of heptanal and undecylenic acid. Tung oil has a unique fatty acid, the conjugated triene, eleostearic acid which has special uses in drying oils. Castor and tung oils are relatively expensive because of high production costs. The castor bean contains allergens and toxic components that make its production especially difficult. Tung oil is produced from trees with a rather restricted growth range.

High-erucic rapeseed oil has special uses in lubricants (45). Erucic acid can be oxidized at its double bond to produce the dicarboxylic

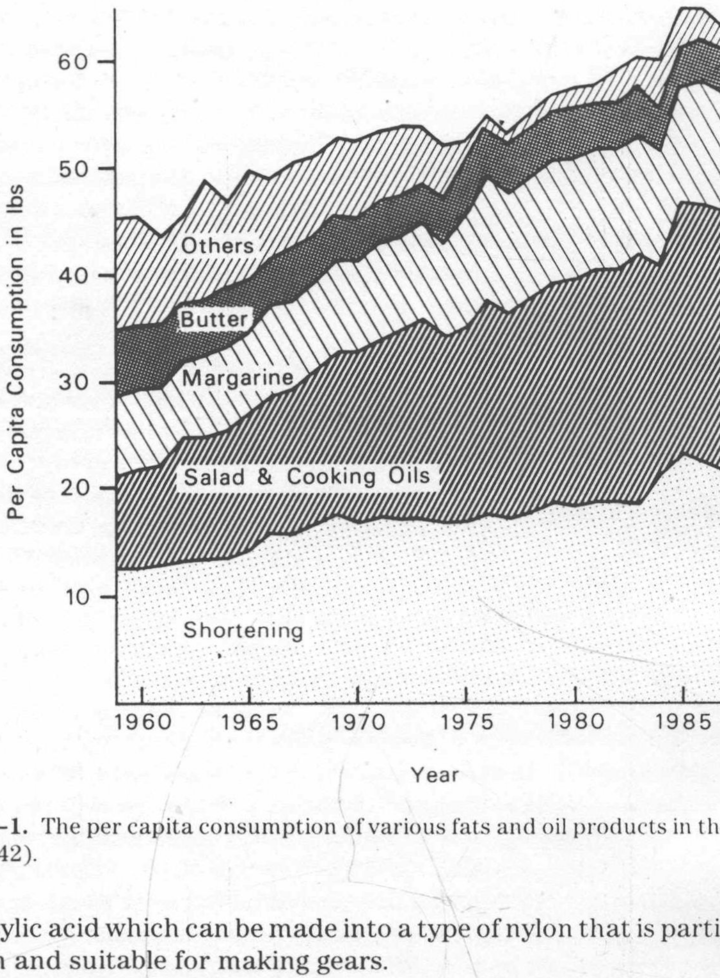

Fig. 1-1. The per capita consumption of various fats and oil products in the U.S. by year (42).

brassylic acid which can be made into a type of nylon that is particularly tough and suitable for making gears.

Oils such as coconut and palm kernel with their short-chain fatty acids have special uses in the detergent and surfactant fields especially because of the foaming properties of these fatty acids (45).

Aside from these special fats and oils that go into industrial uses, there is a more general demand for fats and oils in the feed, protective coating and detergent industries (45). A considerable amount of fats and oils are converted to free fatty acids to meet a multitude of industrial needs. The amount of fats and oils used in feed and industrial products has ranged from 25-30% of total use in recent years (42). These needs tend to be met by the least expensive source that will produce the properties needed. The least expensive sources for free fatty acids are tall oil, a by-product of the paper industry, and from the refining of other fats and oils.

Generalized Demand for Fats and Oils

Palm, soybean, sunflower, and rapeseed oils, which are the products of the tropic (palm), temperate (soybean and sunflower), and high latitudes (rapeseed) tend to be the crops that meet generalized demands for oils, taking up whatever market is left from the specialty and by-product fats and oils. The increasing per capita consumption of fats and oils (39) has caused a massive increase in the production of these oils in recent years (Figure 1-2). Each of these oils have particular advantages. Palm oil is produced with great efficiency in yield per acre compared with other oilseed crops (46). Soybeans, besides oil, produce an equally valuable by-product in the form of a high-protein meal. The animal feed industry of the world has provided an almost limitless sink for the meal. Other vegetable oils produce meals of some value in animal feeds but

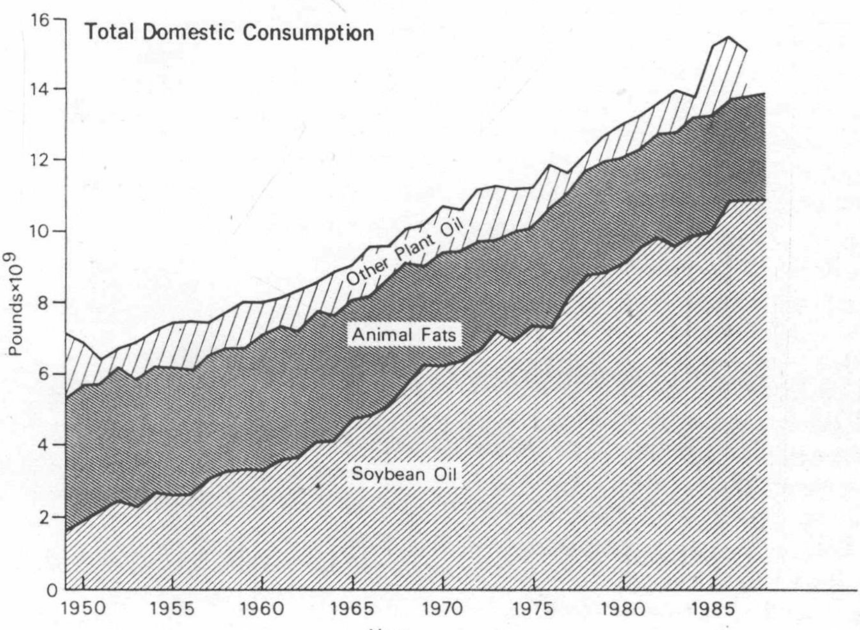

Fig. 1-2. Consumption by year of various types of fats and oils in the U.S. (42).