Fish oils: past and present food uses

The U.S. Food and Drug Administration on Sept. 15, 1989, extended GRAS (generally recognized as safe) status to fully hydrogenated and partially hydrogenated menhaden oil. In this article, Anthony P. Bimbo of Zapata Haynie Corporation reviews past and present uses of hydrogenated menhaden oil and provides some data on physical and chemical characteristics. Zapata Haynie was among the firms urging FDA to confer GRAS status. The article was prepared at the request of Frank Orthoefer, JAOCS *Associate Editor for News in food technology.*

On Sept. 15, 1989, the U.S. Food and Drug Administration (FDA) affirmed GRAS (generally recognized as safe) status for partially hydrogenated menhaden oil (PHMO) and hydrogenated menhaden oils (FHMO) completing the second act of a four-part epic saga that began in mid-1977 (1). It was in June 1977 that the trade association for the U.S. menhaden industry, the National Fish Meal and Oil Association (NFMOA), at the urging of Zapata Haynie Corporation decided to seek GRAS affirmation for menhaden oil based on a "prior sanction," which simply means that if it can be demonstrated that the food had been consumed or had a government agency's approval for food use prior to 1958 then the product could be considered GRAS without further testing. Menhaden oil has been consumed in Europe as a food oil for well over 50 years. In fact, it has been commercially important for over 110 years. Table 1 shows a statistical history of fish oil production in the U.S. As the volume of these other oils fell, they were statistically merged into the "other" category. Today, U.S. fishery statistics show menhaden oil and "other" fish oils with menhaden accounting for 98% of the total.

The U.S. actually consumed hydrogenated fish oil (primarily sardine) produced on the west coasts of the U.S. and Canada during the period 1921-1951 but this ceased when the California sardine fishery failed in the late 1940s (2). During the peak consumption years, 75,000 tons of fish oil were consumed in margarine and shortening products. It could be theorized that menhaden oil was used to supplement the declining availability of sardine oil during the later years.

Armed with this information, a delegation met with FDA to discuss approval of menhaden oil. FDA rejected a prior sanction claim because U.S. regulations did not permit the acceptance of consumption data outside the U.S.; fish oil therefore would be treated as a new product requiring full toxicological testing and a petition before approval. The NFMOA formed a special task force consisting of members of industry and the National Marine Fisheries Service (NMFS) staff based in Washington, DC, and at several of their technical centers along with support from the International Association of Fish Meal Manufacturers (IAFMM). A plan was developed, studies were planned and funding was obtained from Saltonstall-Kennedy Funds along with industry matching funds.

The planning began in late 1977, protocols were finalized, and the studies were initiated in 1981 and results reported in 1982 (3). A parallel long-term study conducted by IAFMM in Europe began in 1979 and was completed in 1982 (4). The last U.S. study was completed in late 1984 and the final petition document was submitted to the U.S. Food and Drug Administration (5) almost nine years after the decision was made to seek GRAS affirmation. The petition covered two products, the hydrogenated family of products (PHMO) just approved by FDA and refined menhaden oil (RMO) which is still in the evaluation stage (6). One comment suggested that fully hydrogenated menhaden oil (FHMO)

TABLE 1

U.S. Production of Marine Oils, Historical Data (1,000 pounds)

Year	Menhaden	Sardine	Whale	Liver	Herring	Others
1875	20,111					
1880	15,262					
1885	17,597					
1890	22,044					
1895	13,258					
1901	28,593					
1905	22,530					
1910	28,340					
1915	20,458	2				
1921	46,954	1,282	1,267	375	847	5,120
1925	45,173	23,400	9,158	1,035	18,322	2,130
1930	23,934	43,522	10,898	1,988	27,727	3,771
1935	30,496	163,012	10,072	2,243	28,927	1,732
1940	43,310	94,703	19,215	5,932	16,808	2,800
1945	62,513	88,898	54	6,032	19,977	4,063
1950	76,575	46,415	514	2,484	24,821	6,301
1955	159,241	6,733	2,089	1,642	8,183	6,848
1960	183,403	1,201	3,279	245	15,004	5,697
1965	175,204	—	2,667	176	10,354	4,247
1970	177,470	—	680	—	5,437	10,150
1975	213,211	—	—	—	1,598	24,340
1980	291,434	—	—	—	1,738	15,246
1985	278,358	—	—	—	—	6,719
1986	332,017	—	—	—	—	4,689
1987	294,964	—	—	—	—	3,532
1988	217,493	—	—	—	—	7,240

Source: References 20-24.

should also be included in the GRAS affirmation review thus extending the petition.

After a series of follow-up requests from FDA for clarification of certain parts of the petition, the FDA announced that it would split the menhaden oil petition and evaluate the hydrogenated product independently of the refined oil product. To help with the internal review of the refined oil portion, FDA contracted with a research firm in the Washington, DC, area to evaluate the literature on omega-3 fatty acids between the period 1986 and 1988. This study, known as the Mitre Report, was issued in February 1989 and found no serious problems with the safety of refined menhaden oil (7). FDA's response to this report is awaited as is its decision on affirmation of RMO as GRAS.

Because margarine is covered by a standard of identity which appears to omit the use of marine oils, a petition to amend the standard is in preparation. A simpler means of amending the margarine standard would be to adopt the Codex Alimentarius Commission's margarine standard (8) with the marine oil limited to menhaden oil.

Past food uses of fish oils

Fish oils have been used as food for a long time. The fishermen of Iceland, Greenland, Norway and Scotland have used it for thousands of years. Cod liver oil was known to have some therapeutic value as early as 1657 when it was found that something in the oil helped alleviate the causes of night blindness. It was also reported during the Middle Ages that cod oil could be used to treat rickets. Between 1752–1784 Dr. Samuel Kay, a physician at Manchester Infirmary in England, conducted extensive clinical tests on the treatment of bone diseases and rheumatism. In a paper given before the British Medical Society around 1770, he reported that cod liver oil was effective in treating arthritis. In 1890 many children suffered from rickets and by the beginning of the 20th century doctors recognized that cod liver oil was a curative for this disease. By 1920 it was discovered that cod liver oil contained vital ingredients not routinely found in sufficient quantity in other foods (vitamins A and D) and so it became a preventive rather than curative agent. Unfortunately, the flavor of the oil was extremely objectionable and its use dropped dramatically until World War II when it was freely distributed to infants up to 5 years of age and to pregnant and nursing women (9). By that time new processing techniques had been developed and bland pleasant tasting oils suitable for food use were being produced.

Margarine was invented in 1869 to fill a growing consumer need for table fat due to expanding populations during the Industrial Revolution. The production of butter was lagging far behind the requirements of the population especially in Western Europe and something was needed to fill the expanding void. As first produced, margarine was made from rendered beef fat which had been chilled, crystallized and pressed to separate an oil which was the raw material for the margarine. The oil was then mixed with milk and salt, churned, pressed into a semisolid mass and pounded into barrels for sale as bulk margarine. In spite of the availability of beef tallow in the U.S., the continued growth of the world population in the early 1900s made the supply of margarine insufficient to meet demand. About this time, 1903, the chemistry of preparing hardened fats from liquid oils was perfected and various oils, including fish oils, were being produced in greater quantities. The development of the hydrogenation process enabled the margarine manufacturers to utilize a wide range of liquid oils to produce a product that was acceptable to the consumer.

The development of products from hardened fats grew rapidly in Europe during the period 1910–1920 but lagged in the U.S. because of legislative restrictions. A shortage of fats and oils in the U.S. during World War I led to further research and development work on oils and fats in general and marine oils in particular, primarily with the California sardine, and by 1925, 50 tons of sardine oil had been processed into margarine. By 1928, the annual usage of sardine oil had risen to about 8,000 tons and in 1936 it peaked at 20,000 tons. Fish oil was also being used in shortening during this period. The shortening use peaked during 1930–1940 at 50,000 tons per year. The total U.S. consumption of fish oil for all edible purposes during this period was approximately 75,000 tons per year. In 1951, because of the declining availability of fish oil due to the disappearance of the California sardine, the large processing plants in California ceased operations. Shortly after this, FDA set standards of identity for margarine. Since, by then, no fish oil was being used in margarine production in this country, fish oil was not included in the list of acceptable ingredients for its manufac-

TABLE 2

Specifications for Hydrogenated Menhaden Oils

	Partially (PHMO)	Fully (FHMO)
Color	Opaque white	Opaque white
Odor	Odorless	Odorless
Saponification number	180–200	180–200
Iodine number	85 Max.	10 Max.
Unsaponifiables %	1.50	1.50
Free fatty acids %	0.10	0.10
Perox. value (Meq/Kg)	5.0 Max.	5.0 Max.
Nickel (PPM)	0.50 Max.	0.50 Max.
Mercury (PPM)	0.50 Max.	0.50 Max.
Arsenic (PPM)	0.10 Max.	0.10 Max.
Lead (PPM)	0.10 Max.	0.10 Max.

Source: Reference 23.

ture (10). Soon after that the GRAS list was published and marine oils were excluded for the same reason.

The major use of hydrogenated fish oil was an ingredient in shortening which involved the preparation of sardine oil hydrogenated mono- and diglycerides. Mixtures of these glycerides were added to the shortening at a level of 2.5–3% in the preparation of superglycerinated shortening. This type of shortening was in great demand in the baking industry, especially for use in cakes, since it permitted a higher sugar:flour ratio without harming the final texture of the product.

What is PHMO and FHMO?

According to 21 CFR Part 184.1472, partially hydrogenated and (fully) hydrogenated menhaden oils are prepared by the usual refining and hydrogenation techniques. If the oil is fully hydrogenated, the name to be used on the label of a product containing it shall include the term "hydrogenated," or if it is partially hydrogenated, the name shall include the term "partially hydrogenated," in accordance with 21 CFR Part 101.4(b)(14). Partially hydrogenated and hydrogenated menhaden oils are used as edible fats or oils, as defined in 21 CFR Part 170.3(n)(12), in food at levels not to exceed current good manufacturing practice. The actual CFR specifications for the two products appear in Table 2.

Because menhaden oil can vary in its fatty acid composition according to season and location of catch, only general comments can be made about the physical and chemical characteristics of these products. Sebedio and Ackman evaluated the changes that take place during the partial hydrogenation of menhaden oil under commercial conditions in Canada (11,12). In its petition requesting GRAS status for menhaden and partially hydrogenated menhaden oil, the NFMOA listed the composition of three batches of commercially produced PHMO produced in Europe. The combined summary data can be seen in Table 3. Young described the slip melting points, iodine value ranges and solid fat indices for a number of partially hydrogenated fish oils commercially produced in Europe (Table 4) (13). He mentioned that the solid fat index is the principal parameter in the specification of a fat product and is expressed at several useful temperatures: (a) 10°C is useful for table margarines spreadable from the refrigerator; (b) 20°C and 30°C for ambient temperatures; and (c) 35°C and 40°C for mouth feel, i.e., waxiness on the palate and performance of pastry fats.

In a presentation at the AOCS 80th Annual Meeting held during May 1989 in Cincinnati, D.A. Allen described his experiences with partially hydrogenated fish oils. The oils were taken from commercial production batches in the United Kingdom and are representative of what one would expect from fish oils in general (Table 5). The data in Table 5 are comparable to those in Table 4. As the oil petition included data from three commercial batches of partially hydrogenated menhaden oil (Table 6), the menhaden oil batches are quite similar to the generic fish oil batches with respect to their physical characteristics.

TABLE 3

Fatty Acid Composition of Partially Hydrogenated Menhaden Oils from Two Different Sources

	Iodine values				
	159[a,b]	84.5[b]	79.1[c]	83.7[c]	81[c]
C14:0	10.8	10.5	8.2	8.1	8
C16:0	23.2	24.1	19.8	20.7	20.8
C18:0	4.2	5.2	5.3	5.6	6.2
C16:1	11.4	15	13	12.1	12.5
C18:1	10.6	12.5	16	13.6	16.2
C20:1	1.3	4.9	6.9	4.8	6.2
C22:1	0.2	1.7	2.6	1.6	0.9
C18:2	1.8	2.4	2.7	3.6	2
C20:P	15.3	10.5	11	13.1	10.8
C22:P	8.8	7.9	9.6	10.8	9.7

[a]Starting oil; P = Dienes and higher. [b]Reference 11. [c]NFMOA 1986.

TABLE 4

Partially Hydrogenated Marine Oil, European Data

Melting point °C	26/28	30/32	32/34	34/36	36/38	40/42	43/45	46/48
	Solid fat index by NMR							
10	26	53	55	60	68	80	92	95
15	17	39	42	50	58	74	84	92
20	10	27	31	40	47	65	78	87
25	7	15	19	29	34	55	72	80
30	3	4	8	16	20	42	68	71
35	0	0	1	3	7	26	55	58
40	0	0	0	0	1	8	35	40
45	0	0	0	0	0	0		15
Iodine value	97	81	79	76	71	55	43	37

Source: Reference 13.

Present food uses of fish oils

Approximately 1.5 million metric tons (MMT) of marine oils are produced annually worldwide from a variety of species. The predominant part of the world's marine oil production is used in Europe, South America and Japan for the production of salad oils, frying fats, table margarines, low calorie spreads, baking fats and emulsifiers. The United States has been a major exporter of fish oil simply because fish oil was not approved for edible use here. On the other hand, the U.S. has developed a large industrial or technical market for fish oil (14).

Because the GRAS petition spe-

TABLE 5

Partially Hydrogenated Marine Oil, United Kingdom Data

Melting point °C	30/32	32/34	36/38	40/42	47/49
	Solid fat index by NMR				
10	51	54	65	77	88
20	27	32	48	63	84
30	6	10	21	35	72
35	1	2	8	18	56
40	0	0	0.5	4	38
Iodine value	80	78	68	41	34

Source: D.A. Allen.

cifically covers menhaden oil, this paper will concentrate on the properties of this oil, drawing from the European and South American experience. The composition of menhaden oil represents the basic fish oil composition from temperate and polar latitudes, according to a presentation on basic fatty acid composition of Atlantic fish given by R.G. Ackman and co-authors during the AOCS Canadian Section Conference held during October 1986 in Guelph, Canada. If one analyzes menhaden oil by capillary column GC, one discovers that it contains numerous fatty acids extending from C12 to C24 and ranging from saturates to polyunsaturates with six double bonds. As a matter of interest data on the fatty acid composition of typical Atlantic and Gulf menhaden oils as determined by capillary column chromatography are included in Table 7. Most fish oils have similar physical characteristics with differences showing up in the parameters that differentiate one oil from another. Table 8 gives some of these typical physical characteristics for menhaden oil.

During the hydrogenation process many complex and competing reactions take place, influenced by the process conditions, the extent and type of catalyst and the condition of the raw material. These reactions include saturation of double bonds, geometric isomerization and positional isomerization. Since all of these reactions can take place simultaneously and since menhaden oil has a very wide range of fatty acids, it is possible to produce a family of partially hydrogenated menhaden oil products with very unique functional properties, something that has been known in Europe for many years and which must now be extrapolated in the United States' fats and oils experience.

TABLE 6

Partially Hydrogenated Menhaden Oil, United Kingdom Data

Melting point °C	33.5	33.9	32.0
	Solid fat index by NMR		
10	54.9	51.1	50.6
15	42.4	38.9	37.3
20	31.1	27.1	25.6
25	19.0	16.9	13.2
30	7.9	8	5.4
35	0.8	2.8	0
40	0	0.3	0
Iodine value	79.1	81	83.7

Source: NFMOA.

Some naturally occurring fats are solid at room temperature and provide products that have special uses. Menhaden oil separates into two fractions: an olein and a stearin. The stearin is rather unique because it possesses the physical characteristics of other naturally occurring hard butters but the chemical characteristics of fish oil—a content of 20% omega-3 fatty acids. Table 9 compares menhaden stearin with other naturally occurring hard butters. The wide possibilities for this product both hydrogenated and unhydrogenated have not been fully explored in Europe and therefore offer a unique area of development for the United States.

Partially hydrogenated menhaden oil

The major food uses for menhaden and other fish oils in Europe are, in the hydrogenated form, aiding in the production of margarine, table spreads, cooking fats, salad oils, emulsifiers, and industrial margarine and shortening used to make bread, pastries, cakes, cookies, biscuits and imitation creams (15).

Contrary to popular belief, partial hydrogenation doesn't increase the level of saturated fatty acids in menhaden oil. Modern selective processing techniques maintain a high proportion of mono- and polyunsaturates without increasing the saturates (Table 3).

The crystal structure of a solid fat, designated by the Greek letters alpha, beta and beta-prime, is critical in some area of fat utilization. Physically, fats in the alpha form are waxy; in the beta-prime form, fine grained; and in the beta form, coarsely crystalline. Beta-type fats are made up of fairly uniform triglyceride molecules while the beta-prime fats contain a variety of triglyceride molecules which seems to prevent them from growing too large (16). The beta-prime form is desirable because it produces a smooth texture in the end product and enhances the creaming performance (air entrainment) in industrial usage. As a result of the wide range of fatty acids and triglycerides formed during hydrogenation, the beta-prime stabilizing effect of menhaden oil is very good. In fact, based on the European experience, when hydrogenated fish oil is used in oil blends for industrial margarines and shortening, it enhances the performance of most products in which it is used. These enhancements include: (a) the incorporation of air during the "creaming" procedure of cake batter production, thus giving a baked product of better volume and crumb structure than is obtained from blends not containing hydrogenated fish oil, and (b) the production of "puff" or "flaky" pastry which requires a fat or margarine that is plastic and workable but resistant to "work softening" (17).

(Continued)

TABLE 7

Atlantic and Gulf Menhaden Oil Composition

Fatty acid	Gulf	Atlantic
13:0	0.36	0.3
14:0 Branched	0.30	0.22
14:0	9.35	8.57
15:0 Branched	0.79	0.69
15:0	0.99	0.78
16:0 Branched	0.60	0.46
16:0	12.73	14.87
17:0 Branched	1.63	1.26
17:0	0.91	0.76
18:0 Branched	0.19	0.61
18:0	2.87	3.16
19:0	0.02	0.38
20:0	0.19	0.15
22:0	0.11	0.1
24:0	0.29	0.18
Saturates	31.33	32.49
16:1N-7	12.15	9.66
16:1N-5	0.52	0.47
18:1N-9	7.71	6.44
18:1N-7	2.81	2.79
18:1N-5	0.23	0.72
20:1N-11	0.08	0.11
20:1N-9	0.82	0.76
20:1N-7	0.13	0.15
22:1N-11+N-13	0.15	0.16
22:1N-9	0.10	0.1
22:1N-7	0.00	0
24:1N-9	0.56	0.3
Monoenes	25.26	21.66
16:2N-4	2.18	2.29
18:2N-5+N-11	0.55	0.77
18:2N-6	1.00	2.05
18:2N-4	0.36	1.04
20:2N-6	0.15	0.14
Dienes	4.24	6.29
16:3N-4	2.92	2.25
18:3N-6	0.24	0.93
18:3N-4	0.56	0.36
18:3N-3	0.70	0.89
20:3N-6	0.25	0.18
20:3N-3	0.05	0.14
Trienes	4.72	4.75
16:4N-3	0.22	0.56
16:4N-1	1.52	2.06
18:4N-3	1.91	2.79
18:4N-1	0.39	0.34
20:4N-6	0.83	0.56
20:4N-3	1.01	1.37
22:4N-6	0.14	0.25
22:4N-3	0.07	0.13
Tetraenes	6.09	8.06
20:5N-3	13.07	13.11
21:5N-3	0.76	0.69
22:5N-6	0.28	0.52
22:5N-3	2.28	2.07
Pentaenes	16.39	16.39
22:6N-3	6.84	10.25

Source: Zapata Haynie Corporation internal data.

Due to its mixture of fatty acids, PHMO has a particularly high crystal stability. Unlike animal fats and many vegetable oils, it will remain stable in the beta-prime form during storage. Thus there will be no crystal growth, and margarines and shortening made with PHMO will retain their smoothness and plasticity. For this same reason, cake margarines and shortening made primarily with PHMO will have better creaming properties than their vegetable counterparts.

Partially hydrogenated marine oils with low and medium melting points generally have steep melting curves, giving a nice cool feeling on the palate. In this respect they are similar to hydrogenated soybean oil; better than palm oil, lard and tallow; but not as good as coconut oil and palm kernel oil. The mouth feel of PHMO can be further improved by adding a small amount of coconut oil.

Partially hydrogenated marine oils with melting points between 40–50°C are used widely to give body or increased plasticity to products over a wide temperature range. Even at melting points between 46–48°C, the solid fat content curve falls sharply away at temperatures above 30°C so that by suitable blending, improved "body" can be obtained without materially affecting the melting characteristics.

For melting points below 38°C, the fats possess relatively steep solid fat curves and are thus very useful for retail margarines and as

TABLE 8

Physical and Chemical Properties of Menhaden Oil

Refractive index ND65		1.4590–1.4623
Saponification value		192–199
Iodine value, Wijs		150–200
Unsaponifiable matter, %		0.6–1.6
Specific heat (CAL/GM)		0.50–0.55
Heat of fusion (CAL/GM)		ca 54
Caloric value (CAL/GM)		ca 9500
Slip melting point °C		10–15
Flash point °C		
Triglycerides		ca 360
Fatty acids		ca 220
Boiling point °C		>250
Specific gravity	15°C	ca 0.92
	30°C	ca 0.91
	45°C	ca 0.90
Viscosity (CP)	20°C	60–90
	50°C	20–30
	90°C	ca 10

Source: Reference 25.

TABLE 9

Solid Fat Index and Melting Points of Naturally Occurring Fats

		Solid fat index by dilatation				
	Melting point °F	50	70	80	92	100
Butter	97	32	12	9	3	0
Cocoa butter	85	62	48	8	0	0
Coconut oil	79	55	27	0	0	0
Lard	110	25	20	12	4	2
Palm oil	103	34	12	9	6	4
Palm kernel oil	84	49	33	13	0	0
Tallow	118	39	30	28	23	18
Menhaden stearine[a]	102	26	17	15	8	1

Source: Reference 16.
[a]Zapata Haynie Corporation internal data.

the middle-melting components of industrial cake and creaming products. Hardened fish oils with higher melting points have flat curves at lower temperatures and melt more rapidly above 30°C. This property is of use for increasing the plastic range of shortening and for producing the desired toughness and plasticity in puff pastry fats (13).

Partially hydrogenated marine oils with melting points between 26–32°C can be used in a manner similar to lightly or brush hydrogenated soybean oil and can replace it when it is considered too expensive (13).

Partially hydrogenated marine oils with melting points between 30–36°C are the most commonly used fish oils in Europe. They are valued as the middle melting components of margarine and shortening blends because of their steep solid fat content. The plastic range of blends incorporating these oils can be increased by the use of higher melting point fats combined with soft oils. Blends containing 50–70% hardened fish oils of this melting point range are widely used for both table and industrial margarines and shortenings (13).

In most food products where fat is added, PHMO is at least equal in quality to the more expensive vegetable fats. In most applications it is better than lard and tallow.

Shortenings

Shortenings are 100% fat products sold in both the retail and industrial market and are used in almost all bakery products. Shortenings contribute to the finished product in a number of ways: (a) they impart tenderness; (b) they enhance aeration; (c) they add flavor; (d) they promote a desirable grain and flavor; (e) they assist in the development of flakiness in pie crusts, danish and puff pastry; (f) they modify wheat gluten in yeast-raised doughs; and (g) they act as emulsifiers to retain liquid (18).

Shortenings come in two forms, emulsified and nonemulsified. Nonemulsified shortenings have a wide plastic range and are formulated by adding 10–15% of a fully hydrogenated beta-prime hard fat to a partially hydrogenated vegetable oil, and interesterified lard or a blend of each. Many baked products require shortenings in different components, for example, the filler, topping and cake could each require different types of shortening. Some highly specialized baked goods use margarines instead of shortening; however, they are really shortening formulations in margarine form (16).

A wide plastic range is important in general bakery work because ambient temperatures vary through the year in different plants and in various parts of the world. Wide plastic range shortenings are tolerant to broad variations in working temperature. They are also resistant to breakdown during creaming which causes textural defects that can result in uneven cakes and icings (16).

A number of shortenings are manufactured for use in bread and sweet dough products. These contain added emulsifiers which produce a softening of the baked product, and assist it in retaining its softness over a period of time. This softness is often referred to as "tenderness" and the retention of softness as "anti-staling." Maximum tenderness is achieved from the highest melting mono- and diglycerides to produce more workable and plastic shortenings (18).

Hard fats

Because of their relatively high solid fat content at 30°C and above, partially hydrogenated marine oils with melting points (MP) above 40°C are frequently referred to as hard fats. They give the product its skeleton of solid triglycerides between 25° and 35°C which is responsible for the wide plastic range needed for good bakery performance. The 40/42°C MP oil is frequently used in combination with the 32/36°C MP product or, for convenience, a product with a 36/38°C MP is used to replace the blend (13).

Pastry fats

Compound fats for puff pastries can be made from blends similar to those used for margarines. Industrial puff or flaky pastry margarines use three fat blend melting point ranges. PHMO (35/39°C MP) is used in Danish pastries and has excellent melting characteristics in the mouth. PHMO (40/44°C MP) is used under standard commercial conditions with acceptable melting characteristics, while PHMO (46/52°C MP) is used primarily for baked products that are eaten hot (13).

(Continued)

TABLE 10

Typical Margarine and Shortening Blends Used in the United Kingdom (% of Fat Blend)

	Partially hydrogenated marine oils				Palm	Soft		
Melting point °C	32/34	34/36	40/42	46/48	oil	oil	Tallow	Lard
Refrigerator margarine	65	0	0	0	15	20	0	0
Standard cake margarine	45	0	0	5	0	25	25	0
Standard pastry margarine	0	0	0	60	0	10	0	30
Standard cooking margarine	0	40	35	0	0	25	0	0
Puff pastry margarine	0	50	0	15	35	0	0	0
Domestic shortening	55	0	0	5	0	0	0	40
General-purpose shortening	50	0	0	5	40	5	0	0
Bread fat	0	0	0	30	0	0	70	0
Cake shortening	0	25	0	20	15	40	0	0

Source: Adapted from Reference 13.

Cake shortenings
Standard cakes are baked with all-purpose emulsified shortening. Dry mix cakes utilize highly individualized shortenings. Each mix manufacturer has shortenings designed for the firm's own mixes. Each mix type requires a different shortening: yellow cake mixes, devil's food cake mixes and white cake mixes each will require a different formulation. As with all cake shortenings, those for mix use must have a beta-prime crystal structure. A good general-purpose shortening that will improve cake and pastry baking performance and produce moist crumb structure in cakes consists of a fat blend containing 15% PHMO (46/48°C MP), 50% PHMO (34/36°C MP), and 35% palm oil (13).

Biscuit dough
Shortenings for biscuit doughs have melting points between 36°C and 40°C depending upon the type of dough mixing equipment used. Satisfactory blends for such products are composed of hydrogenated fish oil, palm oil and/or beef tallow (18).

Bread fats and emulsions
Bread fats and bread emulsions use partially hydrogenated marine oils with a melting point range of 32–36°C. These are used alone or blended with PHMO (46/47°C MP), palm, lard and beef tallow depending upon the texture and melting point desired (13). Partially hydrogenated marine oils with melting points between 36 and 42°C also are suitable for use in bread fats and are adjusted where necessary to obtain the desired melting point or solid fat content.

Bread doughs
For high speed dough mixing, a fat with a higher melting point is required to withstand the temperature rise during mixing. For this purpose, partially hydrogenated marine oils with 46–48°C MP are used at levels of 20–50%, in combination with one or more PHMO (32/36°C MP), lard and beef tallow and, in some instances, liquid vegetable oils. PHMO (36/38°C MP) has been used at the 1% level as an antistaling agent in South Africa. Table 10 summarizes some typical blends of PHMO with other oils in U.K. food systems (13).

Emulsified shortenings
Emulsified shortenings are similar to the nonemulsified types except for the addition of mono- and diglycerides and other emulsifiers at the 2.5–3% level. They are used to increase aeration, hold moisture, enhance tenderness, modify texture and retain softness. Creaming ability is the most important function of this shortening. Cake volume and structure are best when the monoglyceride component is prepared from fully hydrogenated fats. Icings are the smoothest and fluffiest when the monoglycerides are prepared from unhydrogenated oils. A compromise is reached by using monoglycerides from partially hydrogenated oils with an iodine value (IV) range of 72–76. Beta-prime crystals are vital to the satisfactory creaming performance of emulsified shortenings. A shortening that is borderline between beta-prime and beta may deteriorate in storage and lose its creaming power (16).

Since about 1933 a special type of shortening with superior emulsification properties has been on the market. These shortenings, because of added mono- and diglycerides, contain a higher level of combined glycerine than ordinary fats. These compounds are extremely effective in promoting dispersion of the shortening in bakers' doughs, particularly those with a high proportion of sugar. The superior strength conferred upon the dough by the fine dispersion of the fat enables the baker to use a higher ratio of sugar to flour and other ingredients than with ordinary shortening. These have been termed "superglycerinated." They are extremely popular for use in cakes, sweet dough and similar products (18). This was one of the major uses for PHMO in the United States during the period 1930–1950.

Biscuit fillings
Biscuit cream filling fats are required to have quick melting characteristics so that they melt or soften readily in the mouth. The fat blends preferably are made from palm or lauric oils, soft or hydrogenated. A lower priced substitute is made from a blend of partially hydrogenated marine oil with a 34–36°C MP and palm oil (13).

Icings
Icing shortenings are designed to cream with sugar and water, and to incorporate large volumes of air. Beta-prime hard fat plasticizers are essential for icing shortening for-

TABLE 11

Comparison of the Solid Fat Indices of Various Oils at the Same Melting Point

			Solid fat content by NMR				
	Melting point °C	I.V.	10	20	30	35	40
PH Soya	36/38	70	80	56	23	8	1
PH Canola	36/38	72	80	53	21	8	2
PH Menhaden	36/38	71	65	48	21	8	0.5
PH Palm olein	36/38	51	75	50	21	8	0
PH Soya	49/51	40	95	90	80	65	45
PH Canola	49/51	40	95	90	70	55	40
PH Menhaden	47/49	34	88	84	72	56	38
PH Palm	49/51	50	95	90	80	65	45
Beef olein	33	—	33	19	6	—	0
PH Menhaden	28/30	85	39	19	5	—	0
PH Coconut	36.7	—	62	38	10	2.5	0
PH Menhaden	34/36	76	60	40	16	3	0
Palm stearine	52	—	80	65	40	31	23
PH Menhaden	40/42	55	80	65	42	26	8

PH = partially hydrogenated.
Source: D.A. Allen and Zapata Haynie Corporation internal data.

mulations (16). The fat must be sufficiently firm to remain plastic at the highest temperature to which the icing is subjected, as the body of the product depends on the plastic properties of the fat (18).

Cake and creaming margarines
Industrial cake and creaming margarines are required to give good air incorporation into the cake batter or cream so that the product has good volume and a light texture. A longer plastic range is required for those products compared to the wrapped retail margarines to allow for the higher temperature normally experienced in bakeries. However, when used to produce imitation creams, the margarine must be included in such a way that the final cream melts clearly in the mouth. Depending upon ambient conditions, 5% partially hydrogenated marine oil with 46–48°C melting point or 15% partially hydrogenated marine oil with 40–42°C melting point can be used (13).

Margarines and table spreads
PHMO does not recrystallize. Some fats, especially hydrogenated sunflower oil, hydrogenated canola (low-erucic acid rapeseed oil) and lard have a tendency to recrystallize during storage, making the margarines grainy with a sandy mouth feel. By using blends of these oils with PHMO, recrystallization can be prevented.

For table spreads, partially hydrogenated marine oil has better water retention ability than vegetable fats and is thus very suitable for spreads which contain 40–60% water.

Wrapped or stick table margarines have blends in which the solid fat content curve is adopted to the ambient temperature. This makes the blends extremely variable. Hardened fish oils in the 32–36°C melting point range are a principal and frequently the predominant components of such blends that are not of all-vegetable origin. It can make up 25–65% of the oil blend and can be used with palm oil, lard, beef tallow and liquid vegetable oils.

Partially hydrogenated marine oils with a 46–48°C melting point range are used either in small quantities of about 5% in wrapped or stick table margarines or in lower melting point industrial products to improve temperature resistance, or at much higher levels, about 50–60% for pastry margarines having melting points in the 40–44°C melting point range (13).

The solid fat content figures for hydrogenated fish oils are very similar to those of hydrogenated soybean and rapeseed oils for melting points from 30°C upward. Oils with the same melting points are interchangeable (19). A comparison of several oils with the corresponding menhaden oil can be seen in Table 11.

Cooking or salad oils
Fish oils with iodine values (IV) over 140 can be hydrogenated selectively to yield a product with IV 110–120. This product will have

TABLE 12

Comparison of the Fatty Acid Composition of Several Fully Hydrogenated Fats[a]

	Coconut	Palm	Soya	Cotton	LEAR[b]	Lard	HEAR[c]	Menhaden
C6	1							
C8	8							
C10	6							
C12	47							
C14	18	1		1		2		9
C16	9	45	11	23		29	3	35
C18	11	54	89	76	4	68	44	21
C20					96	1	13	18
C22							39	12

[a]Calculated to 100% saturation of the double bonds.
[b]LEAR = Low erucic acid rapeseed oil.
[c]HEAR = High erucic acid rapeseed oil.

TABLE 13

Summary of Suggested Uses for Partially Hydrogenated and Hydrogenated Menhaden Oils

Melting point °C	Uses
I.V. 110/120	Salad oil, single use shallow frying; stir frying
30/32	Economic replacement for brush hydrogenated soybean oil
32/34	Margarine, shortening (both table and industrial), bread fats and emulsions
34/36	Deep-fat frying blends, margarine, shortening (both table and industrial), biscuit cream filling fat, puff pastry compound fats
36/38	Bread fats and emulsions; anti-staling agent in bread dough
40/42	Baking fats, bread fats and emulsions, industrial cake and creaming margarine, retail shortening, puff pastry compound fats
46/48	Baking fats, stick table margarines, bread fats and emulsions, high-speed dough mixing, industrial cake and creaming margarines, retail shortening, puff pastry compound fats
35/39	Danish pastry
36/40	Shortenings for biscuit dough
40/44	Industrial puff or flaky pastry margarines
46/52	Baked products eaten when hot; polyglyceryl ester emulsifiers
54/56	Hard fat; economical source of long chain C20 and C22 fatty acids; emulsifiers

Source: Reference 10.

all fatty acid radicals with less than three double bonds. When this oil is winterized, a fluid fraction is obtained which can be blended with another refined oil such as soybean or corn oil and used as a salad oil. This type of product is used principally in South America. Although in use for many years there (at times with imported menhaden oil), this particular PHMO product was not included in the GRAS approval of menhaden oil. It probably would be included in the approval of refined menhaden oil (RMO) at a later time.

Frying fats

The hydrogenated fish oils of higher melting points, preferably 34–36°C, can be used for deep-fat frying either alone or as the major component of a blend with, for example, palm oil.

The salad oil products, IV 110–120, also can be used in single use shallow frying or for stir frying.

Emulsifiers

Emulsifiers are used in the oils and fats industry to stabilize margarine, shortenings and other baking fats, as well as to improve air incorporation in whipped creams, ice cream and cake batters. They can be prepared from partially or fully hydrogenated menhaden oil. Two types of products used in Europe are monoglycerides and polyglycerol esters of fatty acids.

Fully hydrogenated menhaden oil is a relatively rich, economically priced domestic source of edible C20 and C22 fatty acids which might offer some unique functionality as extenders or replacers of high erucic acid rapeseed oils (HEAR). A comparison of several fully hydrogenated products is shown in Table 12. Due to the wide range of fatty acids in menhaden oil, it offers the user functionality at an economical price. Table 13 gives a summary of some of the uses for various PHMO products in Europe.

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