Formulation of Zero-*trans* Acid Shortenings and Margarines and Other Food Fats with Products of the Oil Palm

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ABSTRACT: The fruit of the oil palm yields two types of oil. The flesh yields 20–22% of palm oil (C16:0 44%, C18:1 39%, C18:2 10%). This represents about 90% of the total oil yield. The other 10%, obtained from the kernel, is a lauric acid oil similar to coconut oil. Palm oil is semisolid, and a large part of the annual Malaysian production of about 14 million tonnes is fractionated to give palm olein, which is widely used for industrial frying, and palm stearin, a valuable hard stock. Various grades of the latter are available. Formulae have been developed by straight blending and by interesterification of palm oil and palm kernel oil to produce shortenings and margarines using hydrogenated fats to give the consistency required. Products that include these formulations are cake shortenings, vanaspati (for the Indian subcontinent), soft and brick margarines, pastry margarines, and reduced fat spreads. Other food uses of palm products in vegetable-fat ice cream and cheese, salad oils, as a peanut butter stabilizer, and in confectioners fats are discussed briefly here.

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KEY WORDS: Confectionery fats, frying fats, margarines, palm oil, palm olein, palm stearin, shortenings, zero-*trans* acid products.

A number of national and international bodies have undertaken to make recommendations to reduce the dietary intake of *trans* FA as far as possible. This paper reviews product formulae that use palm oil as the *trans* FA-free source of solid fat required in many food products. Evidence of performance is given where it is available.

The products of the oil palm are twofold. The oil from the flesh is palm oil, whereas the seed yields palm kernel oil in a quantity of about 10% that of palm oil. Palm oil itself is semisolid in temperate environments, with a solid fat vs. temperature profile quite similar to butter. When allowed to crystallize, for example, at 22°C, 20–30% of the higher-melting components crystallize and can be readily separated to yield palm olein and palm stearin. The yield and properties of the stearin vary over a range that depends on process parameters and the efficiency of separation. Typical solids contents of these products are shown in Table 1. Butterfat is included for comparison.

The solid fat content (SFC) of palm oil clearly makes it a candidate as a major constituent of shortenings margarines, and spreads, whereas stearin is a useful hard stock. Furthermore, palm olein and palm oil are resistant to oxidation and are therefore widely used as a long-lived frying medium. All this is possible without hydrogenation.

Suitable formulations using palm oil products have been developed by straight blending with other oils. However, blends containing high levels of palm oil are somewhat slow to crystallize and can cause difficulty in continuous packing operations. This tendency is due to the glyceride structure and can be overcome by increasing the residence time in scraped surface heat exchangers (1). Alternatively, interesterification of suitable blends has been used and has some advantages. Interesterification has the reputation of incurring high losses due to saponification, with a negative impact on the process economics. The losses can be minimized by careful attention to the process conditions. The important factors were listed by R. Cook in a lecture entitled “Process and Safety Management” given at the Society of Chemical Industry, London, November 2000. The most important is to reduce the water content of the oil, which is best done by vigorously sparging the oil with nitrogen at an elevated temperature. The goal should be a water level of 0.01% FFA, and PV also should be as low as possible. Losses may be about 10 times the weight of sodium methoxide catalyst used, so this should also be kept low. Finally, the reaction should be terminated with citric acid, not water. Any losses are compensated by the cost differential between palm stearin and other oils. For example, oil prices in December 2004 were US$445 for palm oil CIF Rotterdam, US$458 for palm olein CIF Rotterdam, US$408 for palm stearin CIF Rotterdam, US$543 for soybean oil Dutch ex mill, and US$710 for rapeseed oil, Dutch ex mill.

Typical characteristics of most of the palm oil, stearin, and olein currently exported from Malaysia are shown in Table 2.

In a book on the History of Margarines, published in 1969 on the centenary of its invention, T. Feron (2) gave a number of margarine formulae and said, “The number of possible combinations (of oils) is unlimited, as we can see, so availability of supplies and nutritional and other requirements can be taken into account.” Only two of his many formulations were without hydrogenated components, and they contained high proportions of lard and beef fats.

This paper presents a few selected formulae for which some performance data are available.

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TABLE 1
Typical Solid Fat Content Percentage by NMR of Palm Oil Products

Temperature			Palm stearin		
(°C)	Palm oil	Palm olein	Hard	Soft	Butterfat
10	50.3	37.0	82.6	75.9	47.5
20	23.3	15.9	72.4	56.7	28
25	13.7			43.9	20
30	8.5		57.9	33.4	13
35	5.8		50.2	26.2	5
40	3.5		42.1	19.4	
50			24.7	6.6	
55			10.2		

BAKERY SHORTENING

The formulae in Table 3 were processed in a Schröder Kombinator (Lubeck, Germany) pilot plant and tested by baking Madeira-type cakes, in comparison with the best-performing commercial shortening. The cake formula chosen (see Ref. 3) was one using a relatively low proportion of fat. It is therefore a sensitive test of the important air-holding capacity of the fat in the batter. The results of the test are expressed as a percentage of specific volume of the control cakes baked at the same time. The texture and eating properties (of the experimental cake) were indistinguishable from the control cake. The interesterification process changes palm olein from a liquid (at summer temperatures) to a shortening of good performance (4). The effect of interesterification on TG composition and SFC is shown in Table 4.

These shortenings are equally suitable for the manufacture of biscuits (cookies); however, for some types, texturized palm oil is satisfactory.

Idris and coworkers (5) used palm oil and randomized palm oil, texturized in a Schröder Kombinator, to prepare short-bread cookies. The consistency of the interesterified fat was somewhat softer, and this was reflected in the cookie texture, as measured by breaking strength. Evaluation of texture by a trained taste panel confirmed this finding.

Blends of palm oil and a soft grade of stearin have been used in the production of white bread (6). There was little difference in performance between blends of different proportions. The texturized fats were predominantly in the β′ polymorphic form after 16 wk of storage. The blend containing 60% palm oil showed the least β form and gave marginally the softest bread after 2 and 4 d (Table 5). Average specific volume of the loaves was 4.27 cm^3/g compared with 3.50 cm^3/g for a loaf without added fat.

A series of experiments has been reported (7) in which palm oil products were blended with butterfat and used as texturized shortenings so as to obtain the benefit of the superior flavor of the butter component. In cakes, the best volume was obtained from a 40:60 palm stearin/butterfat blend. The *trans* acid content of the product, which is low, is attributable to the butterfat.

Figure 1 shows the specific volume of Madeira cakes made with the shortenings. The blends show superior performance compared with butterfat.

TABLE 2
Characteristics of the Main Palm Oil Products That Are Exported from Malaysia

	Slip melting point (°C)	Iodine value
Palm oil	36–37.5	51.5–53
Palm stearin[a]	52–55	28–34
Standard palm olein	20.5–22.0	56–57.5
Super olein	16	61

[a]Obtained using membrane filters. Softer and harder grades of stearin are also available.

The characteristics of bakery shortenings in use in China were measured, and fat blends using soft stearin (iodine value 44) and hard stearin (iodine value 14) were prepared to match these characteristics. The best match for the commercial products was an interesterified blend of soybean oil with hard stearin in equal proportions (8). Figure 2 shows the range of SFC found for the commercial products and for the matching interesterified blend.

FRYING FATS

Vegetable oils to be used in industrial frying usually must be hydrogenated to attain the required stability (9).

The satisfactory performance of palm olein or palm oil in the commercial production of potato crisps (in American terminology, "chips") has been reported (10–12), as has the use of palm

TABLE 3
Bakery Shortening Formulae[a]

	Blend	Interesterified blend	Interesterified
Composition			
Palm stearin (iodine value 44)	60	70	—
Low erucic rape oil	40	—	—
Soybean oil	—	30	—
Palm olein	—	—	100
Relative specific volume[b]	100	100[c]	99[c]
		100[d]	98[d]

[a]From Reference 3.
[b]Expressed as a percentage of the specific volume of the control cakes baked at the same time.
[c]Mixing operation at 20°C.
[d]Mixing operation at 27°C.

TABLE 4
The Effect of Interesterification of Palm Olein

TG composition (%)			Solid fat content (%)		
Carbon number	Interesterified olein	Olein	Interesterified olein	Olein	Average temperature[a] (°C)
46	1.5	—	10	49.9	38.3
48	8.9	2.3	15	37.4	19.9
50	30.1	42	20	28.9	5.7
52	39.6	45.7	25	19.3	2.1
54	18.8	9.9	30	12.8	—
56	0.1		35	10.6	—
			40	6.8	—

[a]Tempeature at which solid fat content was measured.

TABLE 5
Compression Test on Bread[a]

Shortening	Temp (°C)	Day 0	Day 2	Day 4
PO				
	10	4.9 ± 0.49	9.3 ± 1.98	9.8 ± 0.64
	23	5.6 ± 0.35	12.5 ± 0.49	15.5 ± 0.92
	30	3.4 ± 0.07	9.8 ± 0.07	11.1 ± 2.33
PO/POS 80:20				
	10	5.4 ± 1.70	9.3 ± 3.11	13.2 ± 0.92
	23	4.5 ± 0.07	11.1 ± 0.49	15.2 ± 3.40
	30	3.8 ± 0.71	10.9 ± 3.04	10.3 ± 2.26
PO/POS 60:40				
	10	5.4 ± 1.84	9.9 ± 2.83	8.6 ± 0.07
	23	5.8 ± 1.56	14.0 ± 4.31	13.8 ± 1.84
	30	4.2 ± 0.71	11.3 ± 0.64	14.9 ± 4.31
PO/POS 40:60				
	10	6.2 ± 2.69	13.7 ± 5.59	13.8 ± 5.30
	23	6.9 ± 3.46	16.7 ± 0.78	20.2 ± 2.76
	30	4.8 ± 1.48	12.1 ± 3.68	10.6 ± 1.56

[a]Measurements (in Newtons) were made using a model T5K texture testing machine (J J Lloyd, Southampton, United Kingdom). PO, palm oil; POS, palm oil stearin.

oil for the preparation of French fries before freezing (13). In a large European Union-sponsored project designed to test the properties of a high-olein variety of sunflower oil, palm olein was used as the reference standard for frying potato crisps and French fries. Palm olein gave satisfactory results (14–17) throughout.

Palm oil or palm olein is extensively used in the production of instant noodles. This convenience food is popular throughout Asia but also finds a market in Europe and the United States. In manufacture, a dough is formed into noodles on a roller, and these are steamed and then fried in a continuous fryer. The product has about 3% moisture and 20% oil content, so its shelf life depends on the use of a stable oil. Because of its superior performance, palm oil has largely replaced the animal fats used when noodles were first manufactured. From production data, it is estimated that 500,000 tonnes/yr of palm oil is used in China, whereas world use is close to 1 million tonnes.

The experience of the author (KGB) with palm oil has been in using it over a number of years for frying doughnuts in a Doughnut Corporation of America continuous fryer. This production system specifies a hydrogenated shortening, but palm oil proved satisfactory, including the important aspect of enabling adhesion of the sugar glaze, which depends on a partly solid frying medium.

An interesterified blend of palm stearin (m.p. 54.4°C) and palm kernel oil in equal proportions was found to match the characteristics of local and imported commercial frying shortenings in Malaysia. Interesterification was carried out enzymatically at 80°C with *Rhizomucor miehei* lipase for 6 h. In this process there is less risk of oxidative damage than in chemical interesterification (18).

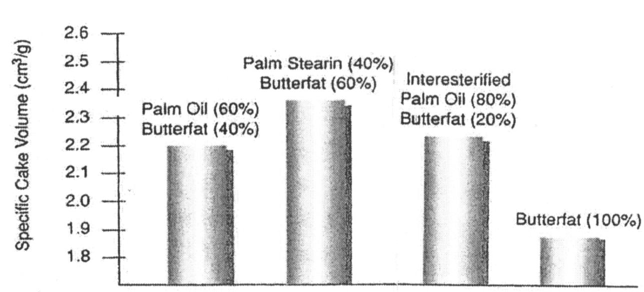

FIG. 1. Specific volume of Madeira cakes made with palm–butterfat shortenings. Reproduced by permission of the Malaysian Palm Oil Board from Reference 7.

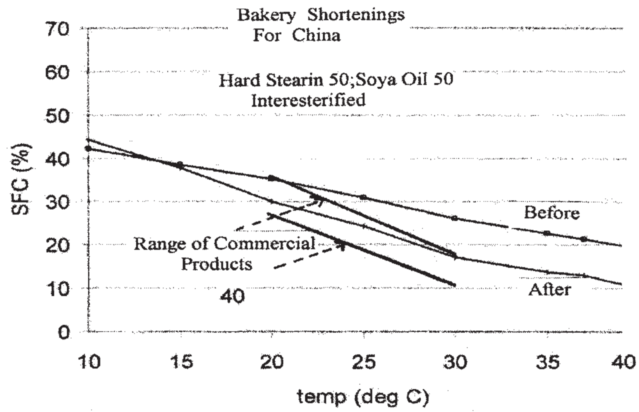

FIG. 2. Solid fat contents (SFC) found in commercial products from China and for interesterified blends. "Before" and "after" refer to before and after interesterification (Teah, Y.K., unpublished data)

VANASPATI

Vanaspati is a form of shortening originally developed in India as an alternative to butterfat ghee (rendered butterfat). It was based on partly hydrogenated vegetable oils (of high *trans* acid content) with a melting point of 37°C, and it was expected by the consumer to have a grainy consistency resembling butterfat ghee. Vanaspati is widely used in the Middle East and the Indian subcontinent and, in a number of countries, higher melting points are acceptable. The grainy consistency is obtained by filling the containers with the liquid blend and allowing slow crystallization in a cool room.

Blends of palm stearin with liquid oils have been proposed for use as vanaspati, the proportion of stearin being dependent on the grade selected. Interesterified blends develop a more grainy structure. Typical current formulae are given in Table 6.

TABLE 6
Blends and Interesterified Blends for Vanaspati Using Palm Oil Products

Blend components	Percentage	Reference
Blend		
Palm stearin, hard grade;	40	19
Rapeseed oil	60	
Palm stearin, soft grade;	60	20
Liquid oil	40	
Palm stearin (iodine value 42.5; m.p. 50°C)	50	21
Rice bran oil	50	
Palm oil;	55	22
Palm kernel oil;	20	
Butterfat[a]	25	
Interesterified blend		
Palm stearin (iodine value 45; m.p. 49.6°C)	70	23
Soybean oil	60	—[b]

[a]A commercial product sold as "Ghee Blend" in Malaysia. It will have a low *trans* FA content.
[b]This product, "Dalda," has been on the market in Pakistan since 1999. It is sold as being "virtually *trans* free" at 5,000 tonnes/month.

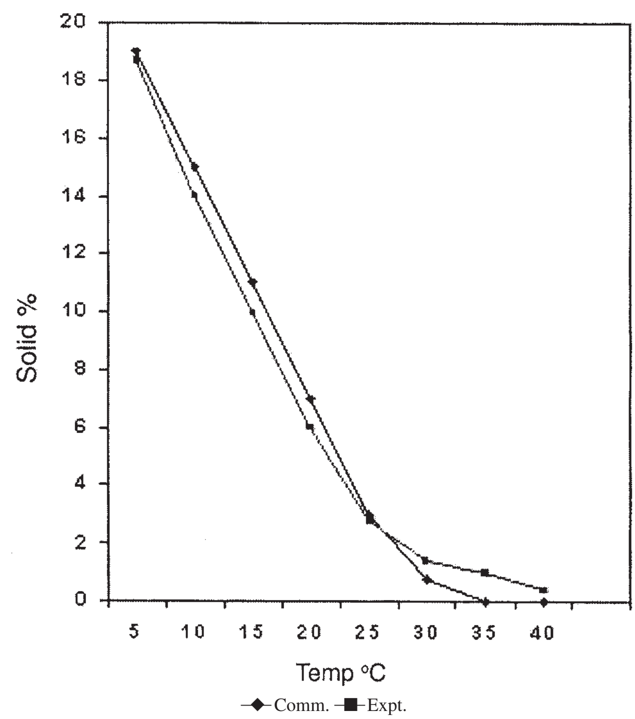

FIG. 3. Solid fat content profiles of commercial and experimental margarine blends. Reprinted by permission of the Malysian Palm Oil Board (Ref. 26).

MARGARINES AND SPREADS

Characteristics of soft (tub) margarines on the market in Canada were reported by de Man *et al.* (24). A formula containing 7% palm oil, 8% fully hydrogenated palm kernel oil, and 85% sunflower oil had satisfactory texture (measured by cone penetrometer) and a stable β′ crystal structure. The *trans* FA content was 0.6%.

The chemical and physical properties of Malaysian tub margarines were surveyed by Idris *et al.* (25). From the analyses, the composition of a *trans*-free product was calculated as 74% palm oil, 12% palm kernel oil, and 14% soybean oil. Yield values (by cone penetrometer) were 16.1 N/cm^2 at 5°C and 9.8 N/cm^2 at 10°C, with SFC of 33.7 and 28.9%, respectively

A *trans*-free soft margarine was prepared using a fat phase containing 78% sunflower oil and 22% palm oil (26). The SFC profile of the blend was close to that of a commercial product (see Fig. 3). After texturizing in a Schröder Kombinator and storage, the consistency of the margarine was measured in comparison with the commercial product (Fig. 4).

Another basis for the formulation of margarines and spreads is the preparation of an interesterified hard stock, which is blended with liquid oil to obtain the margarine blend. A number of such hard stocks are tabulated in Table 7, and details of performance for each of them are then presented.

(i) Product #1. The product was required to reproduce the properties of a commercial Japanese soft margarine. 55 parts of the interesterified blend were blended with 45 parts soybean

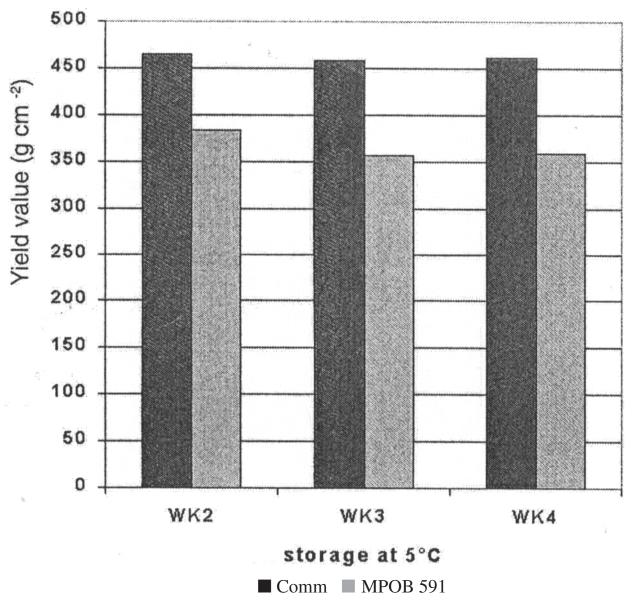

FIG. 4. Consistency of experimental and commercial margarines after storage. Reprinted by permission of the Malysian Palm Oil Board (Ref. 26).

oil to produce a soft tub margarine. The blend had the following characteristics: Slip m.p., 34°C; SFC at 10°C, 16.0%; 15°C, 14.0%; 20°C, 11.0%; 30°C, 5.9%. After processing in a Schröder pilot plant, the yield value at 10°C was 450 g/cm^2 and at 20°C was 200 g/cm^2.

(ii) Product #2. The objective was to reproduce the characteristics of a commercial block margarine from Russia that is based on hydrogenated sunflower oil with a *trans* FA content of 14.1%. Four parts of hard stock were blended with one part soybean oil. The SFC–temperature curves are shown in Figure 5, demonstrating a close match.

(iii) Product #3. Three parts hard stock were blended with 2 parts rapeseed oil for a soft tub margarine with the following solid characteristics:: m.p., 34.4°C; the SFC at 10°C was 22.3%; 15°C, 15.5%; 20°C, 9.3%; 25°C, 7.3%, and 30°C, 4.6%.

(iv) Product #4. The product is described as having good melting and crystallizing behavior and is suitable for blending with liquid oil for margarines and spreads.

TABLE 7
Blends for Interesterified Hard Stocks[a]

Component	1	2	3	4	5	6	7
Palm stearin (soft)	60				60	40	
Palm stearin (m.p. 50°C)			70				
Palm stearin (m.p. 54.4°C)							50
Palm oil				75			
Palm olein		75					
Palm kernel oil		25					50
Fully hydrogenated soybean oil				25			
Liquid oil[a]	20		30				
Palm kernel olein	20				40	60	
Reference	27	28	29	30	31	32	33

[a]Values are in percentages.
[b]Sunflower, rapeseed, and soybean oils.

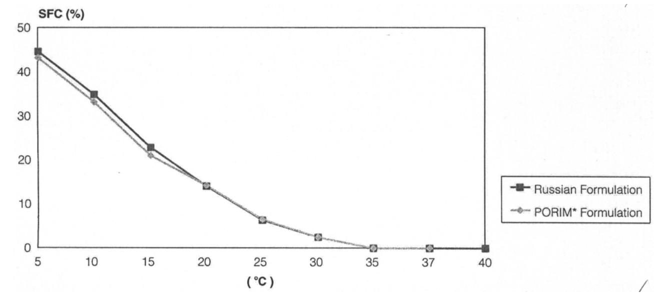

FIG. 5. Solid fats profile of low-*trans* table margarine for Russian market. Reprinted by permission of the Malaysian Palm Oil Board from Reference 28.

(v) Product #5. This product is to be diluted with liquid oil.

(vi) Product #6. This interesterified blend is suitable for a soft margarine (m.p. 31.7°C) stable in the β′ form. The SFC curves of the components are shown in Figure 6 and the blend before and after interesterification is in Figure 7.

(vii) Product #7. Interesterification was carried out using a *Pseudomonas* lipase. The product was stable in the β′ form with a SFC at 15°C of 52%; 20°C, 39%; 25°C, 27%; and 30°C, 15%.

A number of patents have described interesterified hard stocks having as one component palm stearin or fully hydrogenated palm oil and as the other component palm kernel stearin or fully hydrogenated palm kernel oil. Selected U.S. patent numbers are 6,117,475; 6,156,370; 6,808,737; and 5,667,837.

REDUCED FAT SPREADS

Noor Lida and Rahim (34) analyzed a number of commercial reduced fat (40–60%) spreads. They found *trans* FA contents of 6.5–11.7% in tub products and 13.9–20.4% in block products. They investigated both straight blends and interesterified blends of sunflower oil and palm kernel olein with either palm oil or palm kernel olein. They identified a range of blends and interesterified blends with m.p. and SFC at 5 and 10°C within the range found for the commercial products as shown in Tables 8 and 9.

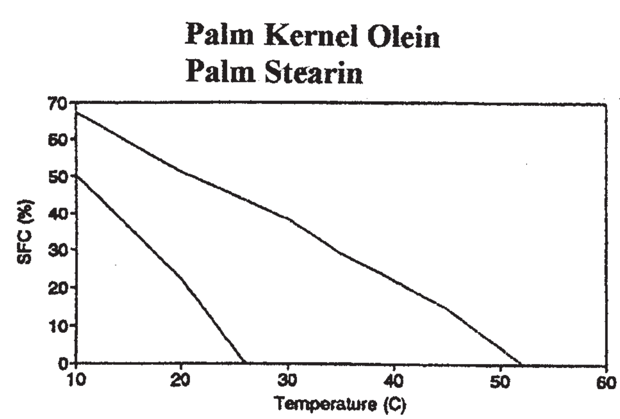

FIG. 6. Solid fat content (SFC) curves of components. Reprinted by permission of The Oily Press from Reference 32.

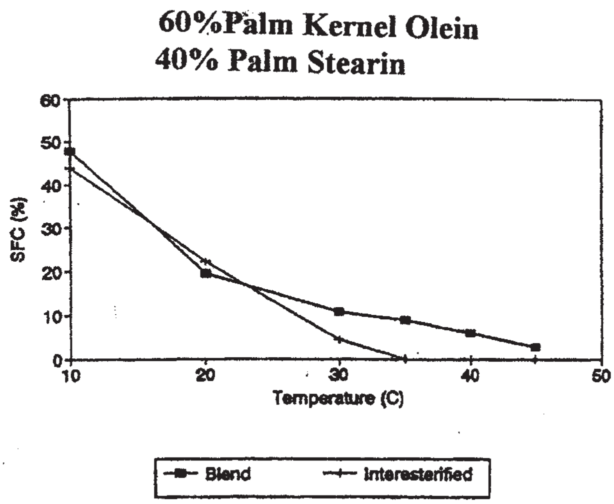

FIG. 7. Solid fat content (SFC) curves of blend before and after interesterification. Reprinted by permission of The Oily Press from Reference 32.

TABLE 8
Formulae for Reduced Fat Spreads Made from Straight Blends[a]

	For tubs	For blocks
PO	50 to 25	80 to 75
POo	0	0
SFO	50 to 75	10 to 25
PKOo	0	10 to 0

[a]PO, palm oil; POo, palm olein; SFO, sunflower oil; PKOo, palm kernel olein. Values are in percentages.

PALM OIL IN DAIRY PRODUCTS

The SFC of palm oil are compared with butterfat over a wide temperature range in Table 10.

CHEESE

Cheese containing vegetable oils has a market in a number of countries. Nielsen and Pihl (35) used a blend of 50% palm oil, 40% coconut oil, and 10% rapeseed oil, emulsified with skimmed milk to make Havarti and Danish Blue types of cheese. Following extensive experiments with palm and palm kernel oil, Karimah *et al.* (36) found that a satisfactory mozzarella cheese could be made using a blend of 30 parts of palm oil with 70 parts palm kernel olein, homogenized with reconstituted skimmed milk powder, and using a thermophilic culture. The textural characteristics important for pizza preparation were similar to commercial products.

TABLE 9
Formulae for Reduced Fat Spreads Made from Interesterified Blends[a]

	For tubs	For blocks	
PO	50 to 0	0	80 to 75
POo	0 to 75	−80 to 100	0
SFO	50 to 25	10 to 0	10 to 25
PKOo	—	10 to 0	10 to 0

[a]For abbreviations see Table 8.

IMITATION WHIPPED CREAM

Whipped cream is a popular filling for baked confectionary, but products based on cream or butterfat do not have adequate stand-up properties in hot climates. An interesterified blend of fully hydrogenated palm kernel oil with a hard grade of palm stearin has been investigated (37). The results are summarized in Table 11. The interesterified blend was used in a proprietary bakers' cream formula. The cream, after aeration to a density of 0.34 (overrun 223%) showed no leakage of serum after 4 h at 35°C and little after 20 h. The mouthfeel was satisfactory with no sign of waxiness.

ICE CREAM

For a vegetable oil-based ice cream, either palm oil or a blend of palm oil with palm kernel oil (60:40 or 80:20) has been used in large-scale manufacture. The blends containing palm kernel oil have somewhat better eating properties and are more suited to processes using a low extrusion temperature at the freezer (38,39).

PALM OIL IN PEANUT BUTTER

To prevent oiling out in peanut butter, a hydrogenated vegetable oil is usually added to give sufficient structure to the fatty phase to hold the oil. A number of European manufacturers are using 2% of a hard grade palm stearin (40). Experiments at the University of Georgia have indicated that 2.5% palm oil imparts over 100 d of satisfactory shelf life (41,42).

CONFECTIONERY FATS

Blends of palm stearin with palm kernel oil or palm kernel olein are suitable for confectionery fats after interesterification. Table 12 lists some blend formulae using hard stearins, taken from old patents (43,44). The solids contents are expressed in terms of dilatations.

TABLE 10
Solid Fat Content of Two Fats as a Function of Temperature (%)

Temperature (°C)	−5	0	+5	+10	+20	+25	+35
Palm oil	82.4	78.6	69.5	54.6	23.2	13.7	6
Butterfat no. 1	75.7	72.5	66.0	52.2	NA[a]	NA	NA
Butterfat no. 2	71.6	68.2	61.7	46.9	26.0	18.0	6

[a]Values are in percentages. NA, not available.

TABLE 11
Characterization of Imitation Whipped Cream

Blend component	HPKO[a]	Palm stearin
Iodine value	1.0	19.0
Slip melting point (°C)	36.2	59.2
Proportion in blend (%)	66	34

[a]HPKO, hydrogenated palm kernel oil. Values are in percentages.

TABLE 12
Interesterified Blends for Confectionery Fats

	1	2	3
Palm stearin IV10[a]	25	30	—
Palm stearin IV8	—	—	25
Palm kernel olein	75	70	37.5
Palm kernel oil	—	—	37.5
m.p. (°C)	32	34.5	35.9
D20	970	1110	710
D25	275	405	345
D30	20	105	130
D40	15	15	10

[a]IV, iodine value. Solids contents are in terms of dilatations.

Recently an interesterified blend similar to those in Table 12 has been reported (45). A 50:50 blend of palm stearin (iodine value ~ 35) and palm kernel olein (iodine value ~ 22.5) gave SFC shown in Table13.

TABLE 13
Solid Fat Content (%) of Blends of Palm Stearin and Palm Kernel Olein

Temperature (°C)	Before interesterification	After interesterification
10	61.0	68.0
15	39.0	57.5
20	25.0	44.0
25	18.0	29.0
30	15.0	12.0
35	12.5	1.5
40	11.0	0.0
45	7.5	

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