Trans-Free Fats With the Products of the Oil Palm – a Selective Review

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Abstract

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The results of nutritional research on fatty acids have led to the recommendation that the level of trans-fatty acids in foods (the products of partial hydrogenation of oils) should be reduced as far as possible. Palm oil and palm kernel oil are readily available and economical sources of solid fat. Formulae using oils to make fats for the main types of food products are reviewed.

Keywords: trans-free fats; palm oil; palm stearin; palm kernel oil

The subject of diet and health is one of universal interest, which has led to many scientific studies. In particular attention has focussed on the relation between fat intake and heart disease. The main effects of saturated and trans-fatty acids are on the cholesterol transport mechanism in the body. Cholesterol is complexed with lipoproteins of two main types for transport purposes. Low density lipoproteins (LDL-C) are used to move cholesterol to its sites of function whereas high density lipoproteins (HDL-C) remove excess cholesterol so that it can be metabolised and excreted. The LDL-cholesterol is implicated in the formation of deposits in the arteries which lead to coronary heart disease. The research has shown that some saturated fatty acids raise the level of LDL-C while leaving HDL-C largely unaffected, whereas trans-fatty acids (of which elaidic acid tr18:1 is the most important) both raise LDL-C and depress HDL-C.

Two specific studies of relevance may be mentioned. Ascherio *et al.* (1999) analysed the results of nine controlled dietary studies of the effect of trans fatty acids on blood lipids. For both saturated and trans fatty acids the LDL-C:HDL-C ratio increased linearly with higher intake, but the trans fatty acid line had about twice the slope, indicating a greater adverse effect.

The second paper (Sundram *et al.* 1997) describes a controlled dietary comparison of four fats: (1) hydrogenated soya bean oil (29% trans acids), (2) palm olein (zero trans), (3) a blend rich in oleic acid 18:1 (61%) with zero trans and (4) a blend rich in 12.0 + 14.0 (41%) with a total sof 60% saturated acids and zero trans. The trans-rich fat significantly raised both LDL and total cholesterol relative to palm olein and to the 18:1 rich fats, and also uniquely depressed HDL-cholesterol.

In an extensive review of a number of both case – controlled and epidemiological studies Aro (1998) concluded "A high intake of trans fatty acids affects the ratio between LDL- and HDL-cholesterol in a way that is unfavourable compared with all other fatty acids".

Current position

A general consensus has now developed among scientists that certain saturated fatty acids and trans fatty acids can have adverse health effects. As a result international and national bodies have made dietary recommendations in respect of trans fatty acids. The World Health Organisation recommends that consumption should be below 1% of energy intake, while in the United Kingdom the recommended limit is 2% of energy, whereas in the USA the Department of Agriculture and the US Academy of Sciences both advise a level "as low as possible". This advice has been followed up in the USA by labelling regulations which came into force on 01/01/2006, requiring the content of trans fatty acids of food products to be declared separately on the panel of nutritional facts. This change is expected to influence consumers purchasing of oils and fats. As a result the US food industry has reformulated many of its products. In Western Europe the trans fatty acid content of food products has already been reducing for some years.

The technical problem

The results of the nutritional research and the strong official recommendations present the technologists in the food industry with a problem.

Historically, the fat consumption of Northern Europe was largely based on the fats obtained from animal husbandry, that is butter, beef fat and lard. These fats have a content of saturated fats sufficient to make them solid at room temperature. Traditional foods of the region are based on this characteristic. Thus for example, butter is spreadable on bread, lard mixed into flour is the basis for short pastry, and butter can be aerated with sugar, flour and eggs as the basis of a large variety of cakes. Liquid vegetable oils were unable to fulfil these functions, until the advent of hydrogenation at the start of the 1900s enabled them to be partly saturated, thus becoming solid to varying degrees. An intermediate step in the hydrogenation of a fatty acid is the isomerisation of a cis- into a trans-double bond. Partly hydrogenated oils inevitably have varying levels of trans fatty acids.

Oleic acid (m. pt. 12°C) is transformed into elaidic acid (m. pt. 44°C) and then into stearic acid (m. pt. 70°C).

Elaidic acid or stearic acid promote a solid character to glycerides of which they are part. However, stearic acid with its high melting point soon gives a waxy character to the fat, if present at a higher level. In contrast elaidic acid has a melting point nearer to body temperature, and has therefore always been regarded as a useful component even at a fairly high level.

In the present situation technologists have to rethink their formulae. The following options are available to achieve the solid fat characteristics needed for making traditional food stuffs.

Natural sources of solids

Beef fat however animal fats with their cholesterol content are not favoured by consumers.

The products of the oil palm – palm oil and palm kernel oil. They are readily available on the world market. Current world production of palm oil is close to 30 million tons, with 80% being exported.

Table 1. Typical solid fat content percentage by NMR of palm oil products

Temperature (°C)	Palm oil	Palm olein	Palm stearin		Palm mid fraction*
			hard	soft	
10	50.3	37.0	82.6	75.9	89.9
20	23.3	5.9	72.4	56.7	82.6
25	13.7	2.0		43.9	50.2
30	8.5		57.9	33.4	0
35	5.8		50.2	26.2	0
40	3.5		42.1	19.4	
50			24.7	6.6	
55			10.2		

*data for palm mid fraction from Britannia Food Ingredients by permission

Table 2. Physical properties of refined palm kernel oils

Solid fat content % by NMR	Palm kernel oil	Palm kernel olein	Palm kernel stearin
5°C	72.8	65.6	93.2
10°C	67.6	56.9	91.6
15°C	55.7	40.4	90.1
20°C	40.1	20.9	82.8
25°C	17.1	1.4	68.2
30°C			34.6
Slip melting point (°C)	27.3	23.6	32.2

NMR– nuclear magnetic resonance; data from Palm Oil Research Institute of Malaysia, with permission

Seed oils from some tropical trees, for example illipe nut, sal fat, shea nut. They have a solid character, but are in very limited supply.

Complete hydrogenation of a liquid vegetable oil will result in a fat of high melting point with zero trans fatty acids. In practice it can be used in food fats after interesterification with a soft oil.

Plant breeders are seeking to modify the oil consumption of several liquid oils towards a higher content of stearic and palmitic acid. No such products are available in quantity at present.

This review describes the properties of palm oil and palm kernel oil products available followed by formulae for various oil and fat products for which performance date is available.

Palm oil products

Palm oil is readily fractionated into a high melting point and a low melting point fraction, the stearin and olein. A second fractionation can yield a mid fraction. The standard process involves crystallisation at a controlled temperature (say 22°C) followed by separation of the liquid fraction, most usually in a plate and frame filter press. Today the membrane filter press is widely used. An elastic membrane is fitted within each chamber of the press, a pressure of 5–15 bar is applied to give an efficient separation of the liquid phase. It is found that the olein is of rather uniform composition, whereas the properties of the stearin vary depending on the process conditions, particularly in the filtration. Table 1 shows the solid fat contents of palm oil products. On a second fractionation an olein of a lower solids content and a very hard stearin can be obtained if desired.

Figure 1 shows sold fat contents graphically for a similar set of samples (De Man & De Man 1994). Additionally a double fractionated palm olein of much lower solid fat content is shown.

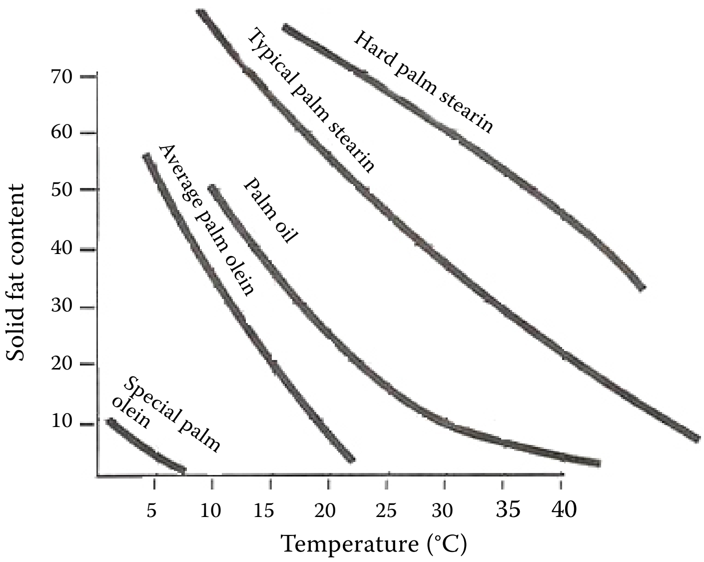

Figure 1. Solid fat content of palm oil product as determined by the IUPAC method

Table 3. Solid fat content (in %) of further processed palm kernel oil products

Temperature (°C)	Melting point (°C)		
	44.5 (fully hydrogenated palm kernel olein)	35.6 (same interesterified)	37.5 (palm kernel stearin fully hydrogenated)
10	90	82	–
15	82	74	–
20	72	60	90
25	64	45	84
30	38	25	38
35	22	6	17
37	18	3	4
40	13		3

The solid fat contents of palm kernel oil and its fractions are given in Table 2 (Siew & Berger 1981), while the data for further processed palm kernel oil fractions are given in Table 3 (Tang *et al.* 1999).

Because of their steep solid fat content/temperature profile, the various palm kernel oil products are useful in confectionary manufacture.

Formulation – margarine

The solid fat profile of palm oil is quite close to that of butter and it is therefore highly suitable for use in margarine. Quoting from a 1969 textbook on margarine "the number of possible combinations of oils is unlimited" (Feron 1969).

Furthermore, different markets and different manufacturers have varying concepts of the optimum product characteristics. Therefore a range of suitable formulae have been published.

Table 4 gives three formulae for packet margarines (spreadable at 20°C).

The use of palm kernel products with their high content of medium chain fatty acids gives the blend a rapid melt down and a mouth-feel similar to butter.

Blends containing a high proportion of palm oil crystallise somewhat slowly and this may result in some hardening and loss of spreadability on storage. This effect can be avoided by increasing the residence time in the scraped surface heat exchanger or by increasing its surface area by about 30% (Duns 1985). The slow crystallisation is inherent in the glycerides of palm oil, and does not occur in interesterified blends.

The experimental margarine blend (2) in Table 4 was tested with a cone penetrometer over six weeks storage at 20°C. It showed no change and remained of good consistency (as defined by Haighton 1965).

Formulae for soft tub margarines

De Man *et al.* (1991) found that the following blend was suitable for the Canadian market:

Table 4. Oil blends for packet margarine

Component		(1)	(2)	(3)
Liquid oil		40	30	60
Palm olein		–	40	
Palm stearin (a)		–	10	
Palm kernel oil		10		
Blend (b)		50		40
Palm oil		–	20	
Solid fat content %	5°C	58	40	37.7
	10°C	–	28	34.5
	15°C	–	18	26.5
	20°C	20	8.5	17.7
	25°C	–	5	11.6
	30°C	7	2.5	6.8
	35°C	2.5		2.1
Reference		Berger (1986)	Özay *et al.* (1998)	Berger (1986)

(a) stearin of Iodine value 37; (b) 30 parts palm kernel oil and 70 parts palm stearin (Iodine value 41) interesterified

Palm oil	7
Fully hydrogenated palm kernel oil	8
Sunflower oil	85

The margarine had a satisfactory texture and a stable β' structure, with only 0.6% trans fatty acids.

Analysis of a tub of margarine on the market in Malaysia (Idris *et al.* 1996) showed the following composition:

Palm oil	74%
Palm kernel oil	12%
Soyabean oil	14%

It had the following physical characteristics:

	Yield value (N/cm^2)	Solid fat content (%)
At 5°C	16.1	33.7
At 10°C	9.8	28.9

Teah and Ahmad (1991) reported a tub margarine formula suitable for the Japanese market:

Soft palm stearin	60 parts
Palm kernel olein	20 parts

This blend was interesterified, then blended with 20 parts sunflower oil and processed into margarine on a Schröder kombinator. The physical characteristics of the product are shown in Table 5.

The properties of interesterified blends with various palm oil products are shown in Table 6. These blends are suitable for dilution with liquid oil before processing into margarine (Berger 1986).

While the term 'margarine' usually implies a fat content of 80%, many products of reduced content are offered with the description of spreads. Noor Lida and Rahim (1998) analysed products from the market containing 40–60% fat to define the range of physical properties being offered and developed formulae with similar behaviour.

For block spreads in packets the conditions were satisfied by blends in the range between palm oil 80%, palm kernel olein 10% and sunflower oil 10% and palm oil 75% with sunflower oil 25%. Alternatively, interesterified palm olein or an interesterified blend of 80% palm olein with 10% palm kernel olein and 10% sunflower oil were satisfactory. The compositions intermediate between these two extremes also satisfied the criteria.

For spreads in tubs, blends of between 50% palm oil with 50% sunflower oil, and 25% palm oil with 75% sunflower oil were suitable. Using interesterification, a blend of 75% palm olein with 25% sunflower oil and one of 50% palm oil with 50% sunflower oil were suitable.

Bakery shortening

Several palm oil based formulae were tested in practical baking tests (Idris *et al.* 1989). A madeira cake recipe was selected which had a relatively low fat content (10.5%). The test therefore put emphasis on the capability of the fat to develop the required aerated structure. Baking tests on brands of shortening available in the supermarket led to the selection of the best performing product in terms of cake volume and crumb structure as the control for comparison. Table 7 below shows the experimental formulae, with the baking test results expressed as a percentage of the control result. In each experiment the experimental and control cakes were prepared and baked side by side. This method eliminated factors of variability in the process.

It is of interest to note the change in the physical properties of palm olein on interesterification. The reaction results in the formation of a significant amount of tripalmitin and a very different solid fat content profile, as shown in Table 8.

The shortenings shown in Table 7 are also suitable for the preparation of short pastry and for biscuits, though for some products a small increase in the proportion of liquid oil may be needed.

Frying fats

The manufacture of starch based snack foods such as potato crisps, and of convenience foods

Table 5. Physical characteristics of tub margarine

Temperature (°C)	Solid fat content (%)	Yield value (g/cm^2)
10	16.0	450
15	14.0	–
20	11.0	200
30	5.9	–

Table 6. Randomised blends for margarines

	Composition					
	POS:PKOF (60:40)	PO:PKO (80:20)	POF:PKO (90:10)	POS:SBO (40:60)	POS:RSO (L.E.) (40:60)	POS:CSO (20:80)
M. Pt (°C)	35.5	35.5	33.2	32.3	36.0	34.0
SFC (%)						
10°C	52.7	57.5	41.6	17.5	19.4	18.7
15°C	43.7	49.5	30.2	10.7	12.7	10.3
20°C	30.0	37.1	20.8	5.9	9.6	6.5
25°C	19.3	25.8	13.8	3.9	5.7	3.7
30°C	11.4	17.4	7.8	2.5	3.7	2.8
35°C	3.8	9.3	4.3	0.8	3.6	2.2
37°C	0.4	4.3	2.3	0.9	2.3	1.1
40°C	–	2.6	0.8	–	1.6	0.4

POS = Palm stearin (Iodine value 50); PKOF = Palm kernel olein; SBO = Soyabean oil; RSO (L. E.) = Low erucic rapeseed oil; CSO = Cottonseed oil

involves frying in large continuous fryers containing 1–2 tonnes of fat. Resistance to oxidation during extended use is necessary and has led in part to the use of partly hydrogenated vegetable oils. Palm oil or palm olein, with their good resistance to oxidation are today used world wide for industrial frying (Berger 2005) with an estimated use of between 5 and 10 million tonnes/year. Their satisfactory performance in potato crisps (Du Plessis & Meredith 1999; Martin-Porvillo *et al.* 1996; Hammond 2002) and in prefried French fries has been reported (Sebedio *et al.* 1991).

In the author's experience palm oil proved satisfactory over a period of years in the frying of doughnuts. For this product, a fat that is solid at room temperature is needed to enable the sugar glaze to adhere to the surface.

Vanaspati

In the Indian subcontinent and in the Middle East butter does not have sufficient keeping properties due to the high ambient temperatures. Traditionally therefore an anhydrous butterfat is prepared. In the 1930's a replacement was developed in India, by partial hydrogenation of vegetable oil to have melting characteristics and the coarse crystal structure of butter. This required selective hydrogenation and a high trans fatty acid content (35% trans in India, up to 50% trans in Iran.) Trans free blends of palm stearin with liquid oil have been proposed (Ray & Bhattacharyya 1996; Nor Aini *et al.* 2001; Mayamol *et al.* 2004). 40–60% stearin is used, depending on the grade of stearin.

An interesterified blend of 70 parts palm stearin (Iodine value 45, melting point 49.6°C) and 30 parts

Table 7. Bakery shortening formulae

Component	Blend	Interesterified blend	Interesterified
Palm stearin (Iodine value 44)	60	70	–
Low erucic rape oil	40	–	–
Soybean oil	–	30	–
Palm olein	–	–	100
Relative specific volume	100	100[a], 100[b]	99[a], 98[b]

[a]mixing operation at 20°C; [b]mixing operation at 27°C

Table 8. Effect of interesterification on the solid fat content (%) of palm olein

Temperature (°C)	Before esterification	After interesterification
10	38.2	49.9
15	19.9	37.4
20	5.7	28.9
25	2.1	19.3
30	–	12.8
35	–	10.6
40	–	6.8

Table 9. Solid fat content (%) of palm stearin-palm kernel olein blend

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	Nil
45	7.5	–

Soya bean oil had good crystallising properties and a melting point of 41°C, suitable for India (Kheiri 1985).

Bakers whipping cream

Whipped dairy cream has inadequate stand-up properties in summer weather. An interesterified blend of 34 parts of fully hydrogenerated palm kernel oil (Iodine value 1.0) with 66 part of palm stearin (Iodine value 19.0), has superior stability. The blend was used in a proprietary baker's cream formula. The cream was aerated to a density of 0.34 and stored at temperatures between 25°C and 40°C. The cream remained completely stable for 4 h at up to 37°C and after 20 h at that temperature showed only minimal change (Nesaretnam *et al.* 1993). Firmness measured with a cone penetrometer, and mouth feel were judged to be satisfactory.

An interesterified blend of palm stearin with palm kernel olein is suitable for various confectionery applications (Timms 2003). Table 9 shows the solid fat content of a blend of equal parts of palm stearin (Iodine value 35) and palm kernel olein (Iodine value 22.5).

Conclusions

The adverse effects of trans fatty acids on blood lipids have led the World Health Organisation and national governments to recommend that the intake of trans acids should be reduced. The requirement in many food products for a consistent fat with a solids content at ambient temperature has in the past been largely satisfied by formulations containing partly hydrogenated vegetable oils. This has resulted in margarines and shortenings with trans fatty acid contents in the range of 10–30%. Reformulation to minimise trans content can be achieved by using the natural solid fat content of palm and palm kernel oils. Palm oil is readily fractionated to give an olein, liquid at 20°C, and a stearin, which can have a range of properties according to the fractionating conditions. Palm kernel oil is fractionated to give a stearin of low Iodine value with properties very useful in confectionary products, while the olein is useful in margarine blends. Numerous published formulae for margarines and reduced fat spreads use blends containing palm oil, and/or palm stearin, with palm kernel oil and a liquid oil. Often some components are interesterified before use in the final blend. Bakery fats using palm oil based blends give results in cakes and pastry equal to established commercial products. Aerated bakery creams using interesterified palm stearin with fully hydrogenated palm kernel oil had good eating quality. The formula could be adjusted for stability at higher ambient temperatures by a small increase in the proportion of stearin. Palm oil and palm kernel olein are used world-wide for industrial frying of snack foods, in fast food restaurants and domestically, having excellent high temperature stability.

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