

# **VEGETABLE OILS IN FOOD TECHNOLOGY: Composition, Properties and Uses**

*FRANK D. GUNSTONE,  
Editor*

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# **Vegetable Oils in Food Technology**

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# **VEGETABLE OILS IN FOOD TECHNOLOGY**

## **Composition, Properties and Uses**

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## Preface

Our dietary intake comprises three macronutrients (protein, carbohydrate and lipid) and a large but unknown number of micronutrients (vitamins, minerals, antioxidants, etc.). Good health rests, in part, on an adequate and balanced supply of these components. This book is concerned with the major sources of lipids and the micronutrients that they contain.

Supplies and consumption of oils and fats are generally described in terms of seventeen commodity oils, four of which are of animal origin and the remainder of which are derived from plants. This selection of oils does not include cocoa butter with an annual production of around 1.7 million tonnes, which is used almost entirely for the purpose of making chocolate. Nor does it include oils consumed in the form of nuts. The production and trade data that are available and are detailed in the first chapter relate to crops either grown and harvested for the oils that they contain (e.g. rape and sunflower oils) or crops that contain oils as significant byproducts (e.g. cottonseed and corn oils).

Annual production and consumption of oils and fats is about 119 million tonnes and rising steadily at a rate of 2–6 million tonnes per year. This is required to meet the demand, which also grows at around this rate, partly as a consequence of increasing population but more because of increasing income, especially in developing countries. Around 14% of current oil and fat production is used as starting material for the oleochemical industry and around 6% is used as animal feed (and indirectly therefore as human food). The remaining 80% is used for human food—as spreads, frying oil, salad oils, cooking fat, etc. These facts provide the framework for this book.

After the first chapter on production and trade, there follow ten chapters covering thirteen oils. The four dominant oils are discussed first: soybean, palm, rape/canola, and sunflower. These chapters are followed by chapters on the two lauric oils (coconut and palmkernel), cottonseed oil, groundnut (peanut) oil, olive oil, corn oil and three minor but interesting oils (sesame, rice bran, and flaxseed). The authors—from Europe, Asia, and North America—were invited to cover the following topics: the native oils in their original form and in modified forms resulting from partial hydrogenation, fractionation or interesterification, and related oils produced by conventional seed breeding and/or genetic modification. For each of these, information is provided on component triacylglycerols, fatty acids, minor components (phospholipids, sterols, tocopherols, carotenoids, etc.) and their major food uses.

The book will serve as a rich source of data on these oils and the important minor components that they contain. It should therefore be of special value to food producers requiring up-to-date information on their raw materials, which will probably already have been processed, at least in part.

The editor thanks the authors for their efforts to convert his concept into a reality and for their patience and willing cooperation, and he acknowledges the generous help and advice that he has received from the publisher, Dr Graeme MacKintosh, and his colleagues.

Frank Gunstone

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## 3 Palm oil

Siew Wai Lin

### 3.1 Introduction

The oil palm (*Elaeis guineensis jacquin*) originated from South Africa. It was introduced to East Asia as an ornamental plant, planted at the Bogor Botanical Garden Java (Indonesia) in 1884. The descendants spread to different parts of the world as the *Deli duras* and were utilised for D × P seed production. This is the main palm material grown in Malaysia and Indonesia. The Malaysian Palm Oil Board (MPOB), formerly known as PORIM, has the largest collection of oil palm germplasm in the world. The present planting material is mainly *dura* × *pisera* (D × P) (*tenera*). Commercial plantings in Malaysia have been based on this D × P material as it gives the highest oil yield per bunch (22.5–25.5%). Another species of oil palm, *Elaeis oleifera*, originates from Central and South America. Its oil is more unsaturated, but the oil to bunch ratio is extremely low, making it uneconomical to plant on a commercial scale.

The oil palm is the most efficient oil-producing plant, with about 4.5 tonnes of oil per hectare per year (Robbelen 1990). The palm bears fruit in the third year of planting in the field, and continues for about 25 years. Two types of oil are obtained from the oil palm fruit: palm oil from the mesocarp and kernel oil from the kernel inside the nut (see Chapter 6). Fruit bunches are harvested regularly throughout the year, following harvesting standards set by the plantations. They are then transported to the palm oil mills where crude oil and palmkernels are produced by mechanical and physical extraction processes. Oil quality is maintained by careful harvesting of fruits at the optimum stage of ripeness, minimal handling of fruits during transportation, and proper processing conditions during oil extraction.

### 3.2 Composition and properties of palm oil and fractions

#### 3.2.1 Palm oil

Palm oil has a balanced fatty acid composition in which the level of saturated fatty acids is almost equal to that of the unsaturated fatty acids (Table 3.1). Palmitic acid (44–45%) and oleic acid (39–40%) are the major component acids along with linoleic acid (10–11%) and only a trace amount of linolenic acid. The low level of linoleic acid and virtual absence of linolenic acid make the

**Table 3.1** Fatty acid and triacylglycerol composition of palm oil

|                  | Malaysian (1981) <sup>a</sup> |                        | Malaysian (1990) <sup>b</sup> |                        | Brazilian (1993) <sup>c</sup> |                       |
|------------------|-------------------------------|------------------------|-------------------------------|------------------------|-------------------------------|-----------------------|
|                  | Mean                          | Range<br>(215 samples) | Mean                          | Range<br>(244 samples) | Mean                          | Range<br>(73 samples) |
| Fatty acids      |                               |                        |                               |                        |                               |                       |
| % by wt          |                               |                        |                               |                        |                               |                       |
| 12:0             | 0.2                           | 0.1–1.0                | 0.2                           | 0.1–0.4                | 0.2                           | Tr–2.6                |
| 14:0             | 1.1                           | 0.9–1.5                | 1.1                           | 1.0–1.4                | 0.8                           | Tr–1.3                |
| 16:0             | 44.0                          | 41.8–46.8              | 44.1                          | 40.9–47.5              | 39.0                          | 31.9–57.3             |
| 16:1             | 0.1                           | 0.1–0.3                | 0.2                           | 0–0.4                  | 0.03                          | Tr–0.4                |
| 18:0             | 4.5                           | 4.2–5.1                | 4.4                           | 3.8–4.8                | 5.0                           | 2.1–6.4               |
| 18:1             | 39.2                          | 37.3–40.8              | 39.0                          | 36.4–41.2              | 43.2                          | 33.8–47.5             |
| 18:2             | 10.1                          | 9.1–11.0               | 10.6                          | 9.2–11.6               | 11.5                          | 6.4–14.8              |
| 18:3             | 0.4                           | 0–0.6                  | 0.3                           | 0–0.6                  | 0.4                           | Tr–0.7                |
| 20:0             | 0.4                           | 0–0.7                  | 0.2                           | 0–0.4                  | 0.01                          | Tr–0.3                |
| Triacylglycerols |                               |                        |                               |                        |                               |                       |
| by carbon number |                               |                        |                               |                        |                               |                       |
| C <sub>46</sub>  | 0.8                           | 0.4–1.2                | 1.2                           | 0.7–2.0                |                               | NA                    |
| C <sub>48</sub>  | 7.4                           | 4.7–10.8               | 8.1                           | 4.7–9.7                |                               | NA                    |
| C <sub>50</sub>  | 42.6                          | 40.0–45.2              | 39.9                          | 38.9–41.6              |                               | NA                    |
| C <sub>52</sub>  | 40.5                          | 38.2–43.8              | 38.8                          | 37.1–41.1              |                               | NA                    |
| C <sub>54</sub>  | 8.8                           | 6.4–11.4               | 11.4                          | 10.3–12.1              |                               | NA                    |
| C <sub>56</sub>  | ND                            | ND                     | 0.6                           | 0.5–0.8                |                               | NA                    |
| Iodine value     | 53.3                          | 51.0–55.3              | 52.1                          | 50.1–54.9              | 58.0                          | 50.3–62.9             |
| SMP (°C)         | 36.0                          | 32.3–39.0              | 36.7                          | 33.0–39.0              | NA                            | NA                    |

Sources: <sup>a</sup>Tan *et al.* 1981; <sup>b</sup>Siew *et al.* 1990; <sup>c</sup>Tavares and Barberio 1995.  
ND = not detectable.  
NA = not available.

oil relatively stable to oxidative deterioration. Malaysian palm oil has a narrow compositional range, as indicated from several surveys carried out between 1977 and 1997. Early surveys of crude and refined palm oils were recorded by Chin and co-workers in 1982 on 215 samples, and by Tan and Oh (1981a). King and Sibley (1984) carried out a survey on oils collected from different geographical locations (Malaysia, Ivory Coast, Nigeria, Papua New Guinea, Solomon Island and Sumatra). In terms of fatty acid composition, iodine values (IV), and slip melting points, there are generally no major differences between the oils obtained from the different locations. The iodine values range from 50 to 55.

Brazilian palm oil appears to be more unsaturated, containing an average of 43.2% oleic and 11.5% linoleic acids with an iodine value of 58 (Table 3.1). The range is wider and iodine values vary from 50–63 (Tavares and Barberio 1995). These oils are likely to be of different oil palm variety. Elias and Pantzaris (1997) considered that the oils reported by Tavares and Barberio were rather

**Table 3.2** Fatty acid composition of palm oil from *E. guineensis*, *E. oleifera* and their hybrids

| Fatty acids (wt %) | <i>E. guineensis</i> | <i>E. oleifera</i> (Eo) |                    | Eg × Eo |                    |
|--------------------|----------------------|-------------------------|--------------------|---------|--------------------|
|                    | (Eg)                 | Mean                    | Range <sup>a</sup> | Mean    | Range <sup>a</sup> |
| 12:0               | 0.3                  | —                       | —                  | —       | —                  |
| 14:0               | 1.2                  | 0.2                     | 0.1–0.3            | 0.5     | 0.1–0.5            |
| 16:0               | 44.3                 | 18.7                    | 14.4–23.0          | 32.2    | 22.4–44.7          |
| 16:1               | —                    | 1.6                     | NA                 | 0.2     | NA                 |
| 18:0               | 4.3                  | 0.9                     | 0.6–1.8            | 3.2     | 1.6–4.9            |
| 18:1               | 39.3                 | 56.1                    | 55.8–64.0          | 51.8    | 36.9–60.1          |
| 18:2               | 10.0                 | 21.1                    | 16.2–22.5          | 10.8    | 8.8–16.8           |
| Others             | 0.6                  | 1.0                     | NA                 | 0.9     | NA                 |
| Iodine value       | 55.0                 | 85.0                    | NA                 | 67.5    | NA                 |

NA = not available.  
Source: Rajanaidu *et al.* 2000; <sup>a</sup>Rajanaidu *et al.* 1985.

unusual, in that the ranges for palmitic acid (32–57%) and oleic acid (34–47%) were exceptionally wide. They concluded that the oil in the survey consisted of ‘mixtures of oil of *Elaies oleifera* with various proportions of stearin’. This is apparent from the high levels of palmitic acid noted at the maximum end of the range (57.3%), and from the fact that the authors had already rejected 26 out of 99 samples as being adulterated. It is of interest to mention here that oils from *Elaeis oleifera* (South American palm) have oleic acid content as high as 55–64% and linoleic acid from 16–23% (Rajanaidu *et al.* 1985). *Elaeis oleifera*, also known as *Elaeis melanococca*, can be easily hybridised with *Elaeis guineensis*, producing oil with characteristics which are between those of the parent oils (Table 3.2). The composition of oil from the Nigerian population of *E. guineensis* shows considerable larger variation when compared with the commercial oils planted. Palmitic acid ranges from 27 to 55%, oleic acid from 28 to 56%, and linoleic acid from 6.5 to 18%. These materials provide oil palm breeders with genetic material for developing new palms with the required specifications such as high-oleic acid, carotenes or tocopherols.

The TAG profile of palm oil has been characterised by carbon-number gas chromatography (Table 3.1). The TAG of palm oil consists of C<sub>46</sub> to C<sub>56</sub> molecules in a near normal distribution, the major TAGs being of C<sub>50</sub> and C<sub>52</sub>. These carbon numbers represent the number of carbon atoms in the three acyl chains and exclude the glycerol carbon atoms. A more detailed profile of the TAGs is seen in Table 3.3. Palm oil has high contents of disaturated (POP and PPO) and monosaturated (POO and OPO) TAGs. Analysis of the 2-position of the TAGs by pancreatic lipase hydrolysis reveals the fatty acids at this position to be mainly unsaturated (oleic) (Tan 1979).

The polymorphic behaviour of a fat is determined to a large extent by the fatty acids within the TAGs. Fats which are composed of fatty acids predominantly of

**Table 3.3** Triacylglycerol (TAG) composition of palm oil products

| TAG<br>(Wt %)             | Palm oil <sup>a</sup> |           | Palm olein (IV < 60) <sup>b</sup> |           | Palm olein (IV 60–64) <sup>b</sup> |           | Palm olein (IV 65–67) <sup>b</sup> |           | Stearin<br>IV 38.0 | Stearin<br>IV 45.8 | Stearin<br>IV 11 |
|---------------------------|-----------------------|-----------|-----------------------------------|-----------|------------------------------------|-----------|------------------------------------|-----------|--------------------|--------------------|------------------|
|                           | Mean                  | Range     | Mean                              | Range     | Mean                               | Range     | Mean                               | Range     |                    |                    |                  |
| OLL                       | 0.5                   | 0.2–0.9   | 0.05                              | 0.5–0.6   | 0.7                                | 0.6–0.8   | 0.8                                | 0.7–0.8   | 0.3                | 0.5                | 0.1              |
| PLL                       | 2.5                   | 1.3–3.4   | 2.8                               | 2.3–3.2   | 3.4                                | 3.2–3.7   | 3.7                                | 3.3–4.1   | 1.8                | 2.3                | 0.4              |
| MLP                       | 0.6                   | 0.2–1.0   | 0.6                               | 0.5–0.7   | 0.7                                | 0.6–0.8   | 0.6                                | 0.6–0.7   | 0.4                | 0.5                | –                |
| OLO                       | 1.7                   | 1.3–2.3   | 2.3                               | 1.7–2.6   | 2.6                                | 2.2–3.0   | 3.0                                | 2.3–3.3   | 1.3                | 1.7                | 0.2              |
| PLO                       | 9.9                   | 9.0–11.2  | 11.8                              | 10.9–13.0 | 13.6                               | 12.9–14.9 | 15.4                               | 15.0–17.3 | 7.1                | 8.4                | 1.7              |
| PLP                       | 9.5                   | 6.5–11.0  | 9.9                               | 9.6–10.2  | 9.8                                | 9.0–10.2  | 8.4                                | 7.9–9.7   | 8.3                | 9.4                | 3.5              |
| OOO                       | 4.3                   | 3.3–6.6   | 4.5                               | 4.2–5.2   | 5.1                                | 4.6–6.1   | 6.1                                | 5.0–6.8   | 2.3                | 2.7                | 3.8              |
| POO                       | 22.8                  | 20.5–26.2 | 26.8                              | 25.1–29.0 | 30.2                               | 28.4–32.5 | 34.5                               | 33.4–35.7 | 16.7               | 18.4               | 5.0              |
| POP                       | 29.0                  | 27.1–31.0 | 26.6                              | 23.4–29.4 | 19.1                               | 16.1–20.7 | 12.8                               | 9.0–17.0  | 29.8               | 30.9               | 13.6             |
| PPP                       | 5.4                   | 0.7–7.2   | ND                                | ND        | ND                                 | ND        | ND                                 | ND        | 18.6               | 12.5               | 59.6             |
| SOO                       | 2.5                   | 1.0–3.6   | 3.3                               | 3.0–3.9   | 4.2                                | 3.4–6.9   | 4.5                                | 3.9–6.3   | –                  | –                  | –                |
| POS                       | 5.1                   | 4.6–5.9   | 4.7                               | 3.9–5.2   | 3.6                                | 2.9–4.8   | 2.5                                | 1.9–3.5   | 4.8                | 5.4                | 2.4              |
| PPS                       | 1.0                   | 0.1–1.8   | 0.07                              | 0.1–0.3   | 0.2                                | 0.1–0.3   | 0.2                                | 0.1–0.3   | 3.6                | 2.7                | 8.0              |
| SOS                       | 0.5                   | 0.1–1.4   | 0.16                              | 0.2–0.6   | 0.4                                | 0.2–0.5   | 0.2                                | 0.1–0.4   | 0.6                | 0.6                | –                |
| Diacylglycerols<br>(wt %) | 4.9                   | 3.0–7.6   | 5.3                               | 4.7–6.1   | 6.4                                | 5.6–6.9   | 7.1                                | 6.2–8.6   | 4.5                | 4.0                | 1.1              |

ND = not detectable.

<sup>a</sup>Tan *et al.* 1997.

<sup>b</sup>Siew and Chong 1998.

<sup>c</sup>Siew, unpublished.

Symbols such as PLO refer to all the triacylglycerols with these three acyl chains.

a single chain length are most likely to be stable in the  $\beta$  form (DeMan, 1992). Palm oil, containing  $C_{16}$  and  $C_{18}$  acids in most of its glycerol esters, is highly stable in the  $\beta'$  form.

Palm oil is unique among vegetable oils in having a significant amount of saturated acids (10–15%) at the 2-position of its TAGs. The appreciable amounts of disaturated (POP and PPO) and monosaturated (POO, OPO and PLO) are apparent as high-melting and low-melting fractions in the differential scanning calorimetry (DSC) thermograms (Figure 3.1). The oil can be easily separated into two products, palm olein and palm stearin. Figure 3.2 shows the products obtained from multiple fractionations of palm oil. A wide range of fractions

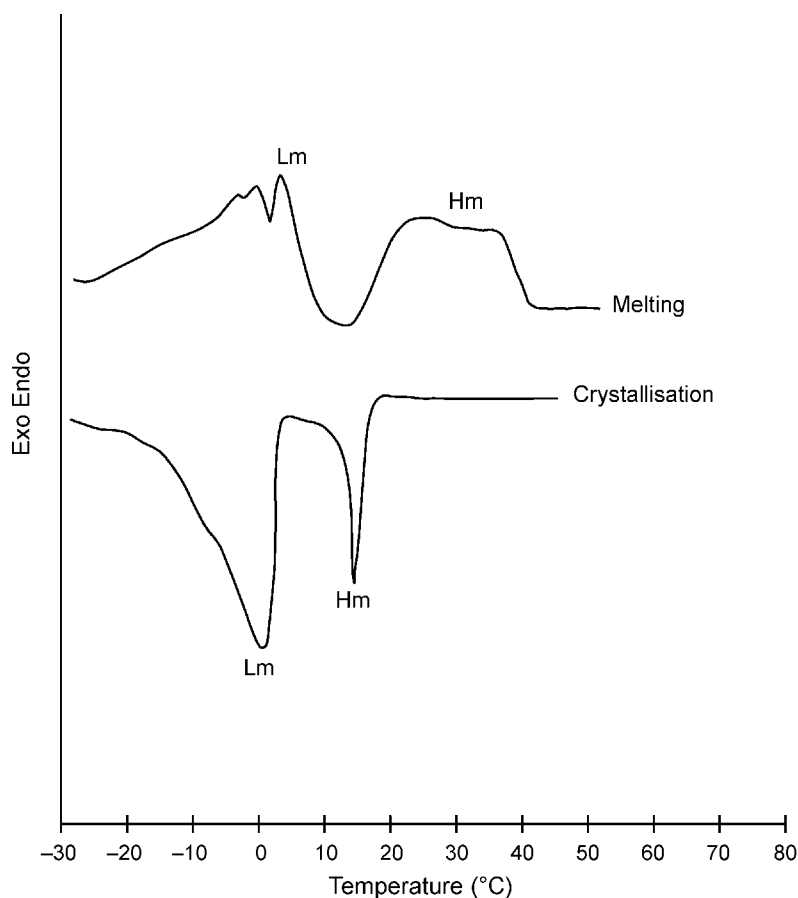


**Figure 3.1** DSC melting and crystallisation thermograms of palm oil. For melting thermogram, sample was cooled to  $-30^{\circ}\text{C}$  at rate of  $40^{\circ}\text{C}/\text{min}$ , held for 10 mins and heated to  $80^{\circ}\text{C}$  at  $5^{\circ}\text{C}/\text{min}$ ; for cooling thermogram, sample was melted to  $80^{\circ}\text{C}$  and cooled to  $-30^{\circ}\text{C}$  at  $5^{\circ}\text{C}/\text{min}$ . Lm: low melting fraction, Hm: high melting fraction.

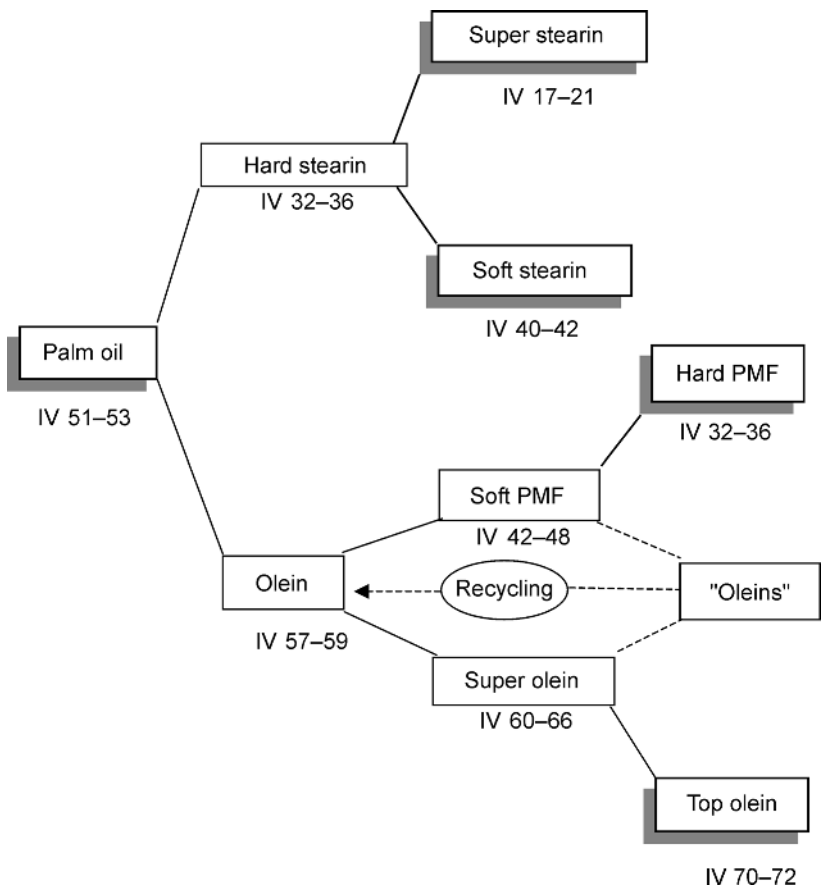


**Figure 3.2** Dry multiple fractionation of palm oil (adapted with permission from Deffense, 1995).

with different properties to suit requirements of the food industry is available through dry fractionation.

3.2.2 *Palm oleins*

Palm oil, a semi-solid at ambient temperature (25–30°C), may be fractionated into a liquid fraction (olein) and a more solid fraction (stearin). The olein contains higher levels of oleic (39–45%) and linoleic acids (10–13%) compared to the oil (Table 3.4). Palm olein remains clear at ambient temperature of 25°C. Further fractionation of the olein produces a more unsaturated fraction, often called super-olein or double fractionated olein. These have higher levels of oleic and linoleic acids, ranging from 43–49% and 10–15% respectively, resulting in

**Table 3.4** Fatty acid and triacylglycerol composition of palm olein

|                                             | Palm olein (IV < 60) <sup>a</sup> |           | Super olein (IV > 60) <sup>b</sup> |           | Top olein<br>(IV 70–72) <sup>c</sup> |
|---------------------------------------------|-----------------------------------|-----------|------------------------------------|-----------|--------------------------------------|
|                                             | Mean                              | Range     | Mean                               | Range     |                                      |
| Fatty acid composition<br>(wt %)            |                                   |           |                                    |           |                                      |
| 12:0                                        | 0.3                               | 0.2–0.4   | 0.3                                | 0.2–0.4   | –                                    |
| 14:0                                        | 1.1                               | 0.9–1.2   | 1.0                                | 0.9–1.1   | 1.0                                  |
| 16:0                                        | 40.9                              | 36.8–43.2 | 35.4                               | 30.1–37.1 | 28.8                                 |
| 18:0                                        | 4.2                               | 3.7–4.8   | 3.8                                | 3.2–4.3   | 2.5                                  |
| 18:1                                        | 41.5                              | 39.8–44.6 | 45.1                               | 43.2–49.2 | 52.0                                 |
| 18:2                                        | 11.6                              | 10.4–12.9 | 13.4                               | 10.7–15.0 | 14.6                                 |
| 18:3                                        | 0.4                               | 0.1–0.6   | 0.3                                | 0.2–0.6   | 0.4                                  |
| 20:0                                        | 0.4                               | 0.3–0.5   | 0.3                                | 0.0–0.4   | 0.2                                  |
| Iodine value                                | 56.8                              | 55.6–61.9 | 61.9                               | 60.1–67.5 | 70–72                                |
| Slip melting point (°C)                     | 21.5                              | 19.2–23.6 | 15.1                               | 12.9–16.6 | NA                                   |
| Triacylglycerols by<br>carbon number (wt %) |                                   |           |                                    |           |                                      |
| C <sub>44</sub>                             | 0.1                               | 0.0–0.5   | ND                                 | ND        | NA                                   |
| C <sub>46</sub>                             | 0.8                               | 0.4–1.4   | 0.2                                | 0.1–0.2   | NA                                   |
| C <sub>48</sub>                             | 3.3                               | 2.4–3.9   | 1.9                                | 1.7–2.6   | NA                                   |
| C <sub>50</sub>                             | 39.5                              | 37.9–40.9 | 30.8                               | 23.0–34.2 | NA                                   |
| C <sub>52</sub>                             | 42.7                              | 41.9–43.7 | 53.4                               | 50.2–59.6 | NA                                   |
| C <sub>54</sub>                             | 12.8                              | 11.8–13.5 | 13.6                               | 11.6–15.9 | NA                                   |
| C <sub>56</sub>                             | 0.7                               | 0.5–1.1   | 0.2                                | 0.1–0.4   | NA                                   |

ND = not detectable.

NA = not available.

<sup>a</sup>Siew *et al.* 1990.<sup>b</sup>Tang *et al.* 1995.<sup>c</sup>Deffense 1995.

iodine values of 60–67 (Tang *et al.* 1995) and with lower cloud points of about 2–5°C. In contrast, oleins with IV of less than 60 have cloud point of 6–10°C. As the iodine value increases, the cloud point decreases, though not linearly. A cloud point of below 0°C can only be obtained with an olein of iodine value above 70. The palmitic acid content should be below 35%, preferably below 31%, for palm olein to remain clear at 10°C. Fractions with iodine above 70 and a cloud point of –4°C (Deffense 1995) are described as top-oleins. This olein can satisfy the cold test in which the oil must remain clear after 5.5 h at 0°C.

The differences in TAG composition between olein with iodine value not exceeding 60 and those above 60 are detailed in Table 3.3. The major differences are for levels of PLO (mean values of 11.8% and 13.6% respectively), POO (26.8% and 30.2%), and POP (26.6% and 19.1%). Stated in another way, SUU glycerol esters rise from 44.7 to 51.4% and SUS glycerol esters fall from 42.0 to 33.6% (S = saturated and U = unsaturated acyl chains). The ratio of POP/POO

**Table 3.5** Nucleation behaviour of three palm oleins

| IV of olein | POP/POO ratio | Nucleation test (11°C) |
|-------------|---------------|------------------------|
| 59.3 ± 3.0  | 0.89 ± 0.24   | <1 h                   |
| 61.4 ± 2.9  | 0.83 ± 0.22   | 1–6 h                  |
| 63.6 ± 2.8  | 0.56 ± 0.20   | >6 h                   |

Source: Siew 2000.

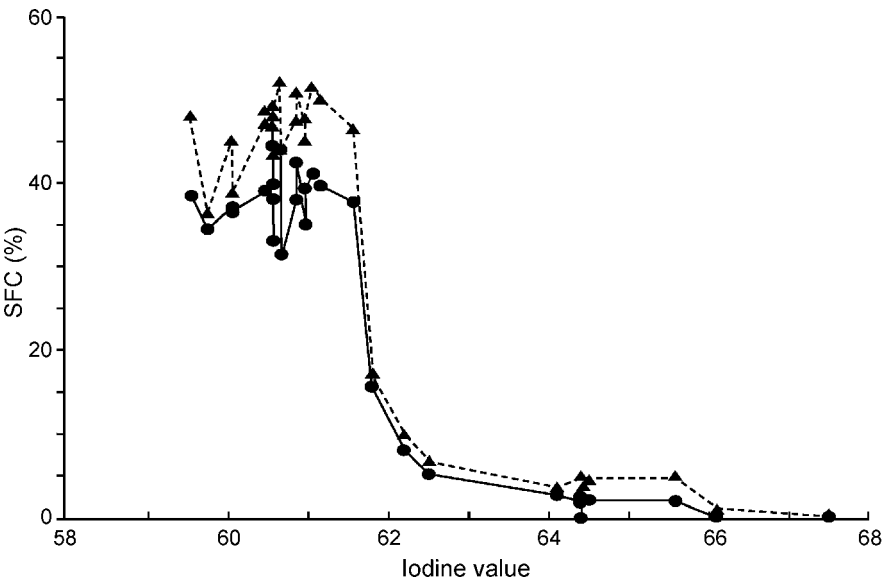


**Figure 3.3** Solid fat content of palm superolein in relation to iodine value. Key: —, SFC at 5°C; ----, SFC at 2.5°C (Tang *et al.* 1995, with permission from MPOB).

influences the crystallisation of palm oil as shown in Table 3.5. Figure 3.3 shows the quite remarkable change in SFC which happens in palm oleins at an iodine value around 62.

Saturated TAGs such as PPP, MPP and PPS are the seeds of crystallisation (Mohd Zaki *et al.* 1997). Other crystallisation inducers are diacylglycerols such as dipalmitoylglycerol. Siew and Ng (1996a) found high concentrations of 1,3-dipalmitoylglycerol in crystals obtained from palm olein by tempering the olein through a alternating temperature cycle of 28°C and 10°C. It is notable that diacylglycerols are preferentially distributed into the olein phase during fractionation. A higher concentration of diacylglycerols is found in more unsaturated oleins.

The content of unsaturated acids in superolein is about 59% compared to only 53% in the single fractionated olein. Figure 3.3 shows the solid fat content of the olein in relation to the iodine value (Tang *et al.* 1995). It is clear that in

order to remain clear at lower temperatures, the iodine value of olein has to be 62 and above.

### 3.2.3 *Palm stearin*

Palm stearin, the harder fraction of palm oil, contains the more saturated fatty acids and TAGs. The comprehensive survey of fractionated products of palm oil (Tan and Oh 1981b) indicated a wider compositional range for stearin, in contrast to olein (Table 3.6). The wide iodine value range (21–49) is reflected in the slip melting points (44–56°C). The palmitic acid content of the stearins varies from 47–74%, while oleic acid ranges from 15–37%. The authors found that the distribution was rather skewed and did not compute mean values. A later survey (Siew *et al.* 1990) showed a palmitic acid content in the range of 49–68% and oleic content of 24–34%. Samples in the 1981 survey were from dry, detergent and solvent processes, while samples from the later survey were generally dry fractionated types. Due to the higher cost of operations, detergent and solvent, fractionations are no longer popular processes.

**Table 3.6** Fatty acid and triacylglycerol composition of palm stearin

|                                        | Stearin <sup>a</sup> | Soft stearin <sup>a</sup> | Palm mid fraction <sup>b</sup> |
|----------------------------------------|----------------------|---------------------------|--------------------------------|
| Fatty acid composition<br>(wt %)       |                      |                           |                                |
| 12:0                                   | 0.1–0.6              | 0.1                       | 0–0.3                          |
| 14:0                                   | 1.1–1.9              | 1.1                       | 0.8–1.4                        |
| 16:0                                   | 47.2–73.8            | 49.3                      | 41.4–55.5                      |
| 16:1                                   | 0.05–0.2             | 0.1                       | –                              |
| 18:0                                   | 4.4–5.6              | 4.9                       | 4.7–6.7                        |
| 18:1                                   | 15.6–37.0            | 34.8                      | 32.0–41.2                      |
| 18:2                                   | 3.2–9.8              | 9.0                       | 3.6–11.5                       |
| 18:3                                   | 0.1–0.6              | 0.2                       | 0–0.2                          |
| 20:0                                   | 0.1–0.6              | 0.4                       | 0–0.6                          |
| Iodine value                           | 21.6–49.4            | 46.7                      | 34.5–54.8                      |
| SMP °C                                 | 44.5–56.2            | 47.7                      | 24.3–44.9                      |
| Triacylglycerols<br>(by carbon number) |                      |                           |                                |
| C <sub>46</sub>                        | 0.5–3.3              | 1.2                       | 0–1.6                          |
| C <sub>48</sub>                        | 12.2–55.8            | 15.3                      | 1.4–11.3                       |
| C <sub>50</sub>                        | 33.6–49.8            | 42.7                      | 45.5–73.9                      |
| C <sub>52</sub>                        | 5.1–37.3             | 33.4                      | 19.4–42.0                      |
| C <sub>54</sub>                        | tr–8.4               | 7.4                       | 1.7–8.5                        |
| C <sub>56</sub>                        | ND                   | ND                        | 0–0.9                          |

<sup>a</sup>Tan and Oh 1981b; <sup>b</sup>Tan *et al.* 1981.

ND = not detectable.

tr = trace.

A much harder stearin is also available with as much as 79% palmitic acid. This stearin has a tripalmitoylglycerol (PPP) content of 60% and is used as hard stock for soft margarines and in infant fat formulas. Advances in crystalliser designs, cooling programs and filtration technology have enabled a wider range of stearins to be produced. Another stearin, produced from a second fractionation of the olein, is called palm mid-fraction (Figure 3.2). This oil contains high C<sub>50</sub> (POP) TAG (Table 3.6) and is utilised in manufacture of a cocoa butter equivalent. Tan and co-workers (1981) characterised palm mid-fractions and proposed the following specifications: ratio of C<sub>50</sub>/C<sub>48</sub> + C<sub>54</sub> 4 minimum, C<sub>52</sub> TAGs content 43% maximum, iodine value 32–55, and slip melting point 23–40°C. The iodine value and slip melting point ranges, though representative of mid-fractions, were too wide to represent good quality palm mid-fractions. Palm mid-fraction is often refractionated by a solvent process to enrich the POP esters further. Dry fractionation processes are now available which can produce high quality palm mid-fractions (Tan 2001). The use of high-pressure membrane filtration has helped to improve the quality of palm mid-fractions. Products of iodine value around 33–35, previously only available through solvent fractionation, can now be produced from dry fractionation processes.

### 3.3 Physical characteristics of palm oil products

#### 3.3.1 *Palm oil*

Palm oil is a semi-solid at room temperature (28°C), the melting point range being from 32–40°C. The slip melting point method is commonly adopted for measuring this parameter. By the DSC method the fat melts completely at 39–40°C, when heated at 5°C/min, from an oil cooled rapidly to –40°C at 5°C/min. The slip melting point is affected by the content of free fatty acids and diacylglycerols. Thus crude oils have slightly higher slip melting point than refined oils.

The solid fat content of a fat determines its applications and usage. As an oil with saturated and unsaturated fatty acids in roughly equal proportions, solids exist from 50°C down to 10°C (Table 3.7). At a temperature of 10°C, the solid content amounts to about 50%, reducing to half of this at 20°C. The variation between samples arises from differences in fatty acid and TAG compositions, as well as in the levels of diacylglycerol in the oil. Siew and Ng (1999) observed that 10% of added diacylglycerol reduces the solids content by 20%.

The melting and crystallisation characteristics of the oil can be followed using the DSC technique (Figure 3.1). Both the melting and cooling thermograms show two main endotherms/exotherms representative of the high and low melting fractions of the oil. From these thermograms, it is clear that palm oil is an excellent oil for fractionation. Suitable cooling programs produce oleins

Table 3.7 Physical properties of palm oil and its fractions

| No. of samples                                  | Palm oil <sup>a</sup><br>244 |                            | Palm olein <sup>a</sup><br>238 |                            | Super olein <sup>b</sup><br>32 |                            | Palm stearin <sup>a</sup><br>205 |                            | Palm mid fraction <sup>c</sup><br>39 |           | Palm mid fraction <sup>d</sup> |      |
|-------------------------------------------------|------------------------------|----------------------------|--------------------------------|----------------------------|--------------------------------|----------------------------|----------------------------------|----------------------------|--------------------------------------|-----------|--------------------------------|------|
|                                                 | Mean                         | Range                      | Mean                           | Range                      | Mean                           | Range                      | Mean                             | Range                      | Mean                                 | Range     | soft                           | hard |
| Refractive index                                | 1.4548                       | 1.4544–1.4550<br>(at 50°C) | 1.4589                         | 1.4589–1.4592<br>(at 40°C) | 1.4634                         | 1.4631–1.4641<br>(at 30°C) | 1.4493                           | 1.4482–1.4501<br>(at 60°C) | NA                                   | NA        | NA                             | NA   |
| Apparent density (g/ml)                         | 0.8899                       | 0.8896–0.8910<br>(at 50°C) | 0.8972                         | 0.8969–0.8977<br>(at 40°C) | 0.9046                         | 0.9042–0.9054<br>(at 30°C) | 0.8822                           | 0.8813–0.8844<br>(at 60°C) | NA                                   | NA        | NA                             | NA   |
| Solid fat content by nuclear magnetic resonance |                              |                            |                                |                            |                                |                            |                                  |                            |                                      |           |                                |      |
| Temperature (°C)                                |                              |                            |                                |                            |                                |                            |                                  |                            |                                      |           |                                |      |
| 10                                              | 53.7                         | 46.1–60.8                  | 38.3                           | 23.9–45.5                  | 17.5                           | 0–26.3                     | 76.0                             | 49.5–84.1                  | 10                                   | 52.7–90.6 | 75.0                           | 95.0 |
| 15                                              | 39.1                         | 33.4–50.8                  | 19.9                           | 10.7–25.9                  | 0.9                            | 0–9.0                      | 68.9                             | 37.2–79.0                  | 15                                   | 40.0–85.0 | 64.0                           | 93.0 |
| 20                                              | 26.1                         | 21.6–31.3                  | 5.7                            | 0.0–9.0                    |                                |                            | 60.2                             | 25.2–71.2                  | 20                                   | 10.3–73.1 | 45.0                           | 90.0 |
| 25                                              | 16.3                         | 12.1–20.7                  | 2.1                            | 0.0–4.3                    |                                |                            | 50.6                             | 15.8–63.5                  | 25                                   | 0–24.9    | 11.0                           | 78.0 |
| 30                                              | 10.5                         | 6.1–14.3                   |                                |                            |                                |                            | 40.4                             | 11.2–55.0                  | 30                                   | 0–20.2    |                                | 47.0 |
| 35                                              | 7.9                          | 3.5–11.7                   |                                |                            |                                |                            | 34.3                             | 7.2–46.6                   | 35                                   | 0–15.3    |                                | 6.0  |
| 40                                              | 4.6                          | 0.0–8.3                    |                                |                            |                                |                            | 28.1                             | 6.1–38.0                   | 40                                   | 0–7.8     |                                |      |
| 45                                              |                              |                            |                                |                            |                                |                            | 22.4                             | 1.0–32.2                   |                                      |           |                                |      |
| 50                                              |                              |                            |                                |                            |                                |                            | 12.5                             | 0.0–21.3                   |                                      |           |                                |      |
| 55                                              |                              |                            |                                |                            |                                |                            | 0.6                              | 0.0–9.1                    |                                      |           |                                |      |

Source: <sup>a</sup>Stew *et al.* 1992; <sup>b</sup>Tang 1995; <sup>c</sup>Tan *et al.* 1981; <sup>d</sup>Deffense 1995.  
NA = not available.

and stearins of different compositions to suit market requirements. The fact that palm oil crystallises in the  $\beta'$  form helps in the fractionation and filtration process as large crystals are formed, enabling easy filtration.

Other physical characteristics such as refractive index and apparent density of the oil are as given in Table 3.7.

### 3.3.2 Palm olein

Palm olein, being the liquid fraction of palm oil, is clear at a room temperature of 28°C. Its clarity depends on iodine value, TAG composition, and diacylglycerol content. Table 3.8 shows the cold stability of palm olein in relation to its iodine value (Nor Aini *et al.* 1993). The clarity of the olein can be significantly affected by the diacylglycerol content as shown in Table 3.9. Diacylglycerols derived from palm oil affect the cold stability of palm olein. While dipalmitoylglycerol (PP) causes rapid crystallisation of the olein, other diacylglycerols such as palmitoyl oleoylglycerol (PO) and dioleoylglycerol (OO) do not significantly affect cold stability. The physical characteristics of palm olein are closely related to its chemical composition.

Solid fat contents are low, 37% at 10°C for normal olein and only 17% for super oleins (Table 3.7). At 25°C, most oleins are completely liquid. Super oleins fall into two categories. Those with iodine value below 61.5 have higher solids of 40–52% at 2.5°C and 31–42% at 5°C and those with iodine values exceeding 61.5 have much lower solids of 0.5–17% at 2.5°C and 0–16% at 5°C. (Tang *et al.* 1995), Improved cold stability can thus be expected with such oils.

Cooling and melting thermograms of palm olein are illustrated in Figures 3.4 and 3.5. In contrast to the thermograms of palm oil, those for palm olein reveal only a single broad crystallisation peak. This exotherm is generally sharper in

**Table 3.8** Cold stability of palm olein at 5–20°C

| Iodine value     | Single fractionated palm olein |                |                | Double fractionated palm olein |       |                |        |
|------------------|--------------------------------|----------------|----------------|--------------------------------|-------|----------------|--------|
|                  | 56                             | 58             | 62             | 60                             | 62    | 65             | 67     |
| Cloud point (°C) | 8.3                            | 6.3            | 3.5            | 4.5                            | 4.0   | 2.0            | 1.5    |
| Temperature (°C) |                                |                |                |                                |       |                |        |
| 5                | < 3 h                          | < 3 h          | < 3 h          | < 3 h                          | < 3 h | < 5 h<br>< 1 d | < 5 h  |
| 10               | < 3 h                          | < 3 h          | > 5 h<br>< 1 d | < 3 h                          | 1 d   | < 2 d          | 1 d    |
| 15               | < 3 h                          | < 3 h          | > 1 d          | < 1 d                          | < 4 d | < 7 d          | < 5 d  |
| 20               | > 5 h<br>< 1 d                 | > 5 h<br>< 1 d | > 20 d         | < 1 d                          | < 4 d | > 60 d         | > 60 d |

\*Time the oil remains clear (h denotes hour, d denotes day).

Source: Nor Aini and Hanirah 1996, 1997.

**Table 3.9** Effect of added diacylglycerols (DAG) on the crystallisation of palm olein at 5°C

| Percentage<br>of DAG       | Crystallisation time (min) |        |                 |        |        |        |        |
|----------------------------|----------------------------|--------|-----------------|--------|--------|--------|--------|
|                            | PDG                        | 1,2-PP | 1,3-PP          | 1,2-PO | 1,3-PO | 1,2-OO | 1,3-OO |
| Olein IV 58.1 <sup>a</sup> |                            |        |                 |        |        |        |        |
| 0.0                        | 3.9                        | 3.9    | 3.9             | 3.9    | 3.9    | 3.9    | 3.9    |
| 0.5                        | 1.9                        | 1.7    | 1.2             | 2.5    | 2.5    | 2.7    | 2.3    |
| 1.0                        | 1.9                        | 0.8    | 0.8             | 2.6    | 2.3    | 2.7    | 2.3    |
| 1.5                        | 1.9                        | 0.7    | rt <sup>c</sup> | 2.8    | 2.3    | 3.0    | 2.4    |
| 2.0                        | 1.9                        | 0.7    | rt              | 3.0    | 2.3    | 3.0    | 2.8    |
| 2.5                        | 1.9                        | 0.6    | rt              | 3.0    | 2.0    | 3.0    | 3.3    |
| 5.0                        | 1.4                        |        |                 |        |        |        |        |
| 7.5                        | 1.4                        |        |                 |        |        |        |        |
| 10.0                       | 1.4                        |        |                 |        |        |        |        |
| Olein IV 62.8 <sup>b</sup> |                            |        |                 |        |        |        |        |
| 0.0                        | 35.0                       | 35.0   | 35.0            | 35.0   | 35.0   | 35.0   | 35.0   |
| 0.5                        | 36.0                       | 8.5    | 1.9             | 37.5   | 38.0   | 29.5   | 29.5   |
| 1.0                        | 33.5                       | 2.1    | rt              | 37.5   | 38.0   | 29.5   | 29.5   |
| 1.5                        | 17.5                       | 1.4    | rt              | 37.5   | 38.5   | 29.5   | 29.5   |
| 2.0                        | 12.5                       | 1.4    | rt              | 40.5   | 42.0   | 29.5   | 29.5   |
| 2.5                        | 9.0                        | 1.4    | rt              | 45.0   | 45.0   | 29.5   | 29.5   |
| 5.0                        | 2.0                        |        |                 |        |        |        |        |
| 7.5                        | 1.3                        |        |                 |        |        |        |        |
| 10.0                       | 1.3                        |        |                 |        |        |        |        |

<sup>a</sup>LSD (P < 0.05) 0.7; <sup>b</sup>LSD (P < 0.05)1.31; <sup>c</sup>rt, crystallise at room temperature (28°C); <sup>d</sup>PDG refers to diacylglycerols extracted from palm oil.  
*Source:* Siew and Ng 1996b.

oleins with higher iodine values. The exotherm is shifted slightly from 2.8 to 0.2°C in moving to a more unsaturated olein, from iodine value of 56 to 65. The shift in peak temperature is minimal. In the melting thermograms for oleins of iodine value 56, 60 and 65, respectively, the change in peak temperature varies from 6.9, to 5.7, to 4.4°C, while the melting temperature changes from 24, to 15, to 13°C.

3.3.3 *Palm stearin*

Palm stearin, the more saturated fraction of palm oil, is more variable in composition and thus in physical characteristics. The wide range in solid fat content (Table 3.7) is consistent with the wide range in iodine value for the oil. The variation in composition allows food manufacturers a wide choice of materials for their formulations. In fact, many product formulations require some material to provide the solids required at a certain temperature range. Palm stearin can provide the required solids in blends with unsaturated vegetable oils.

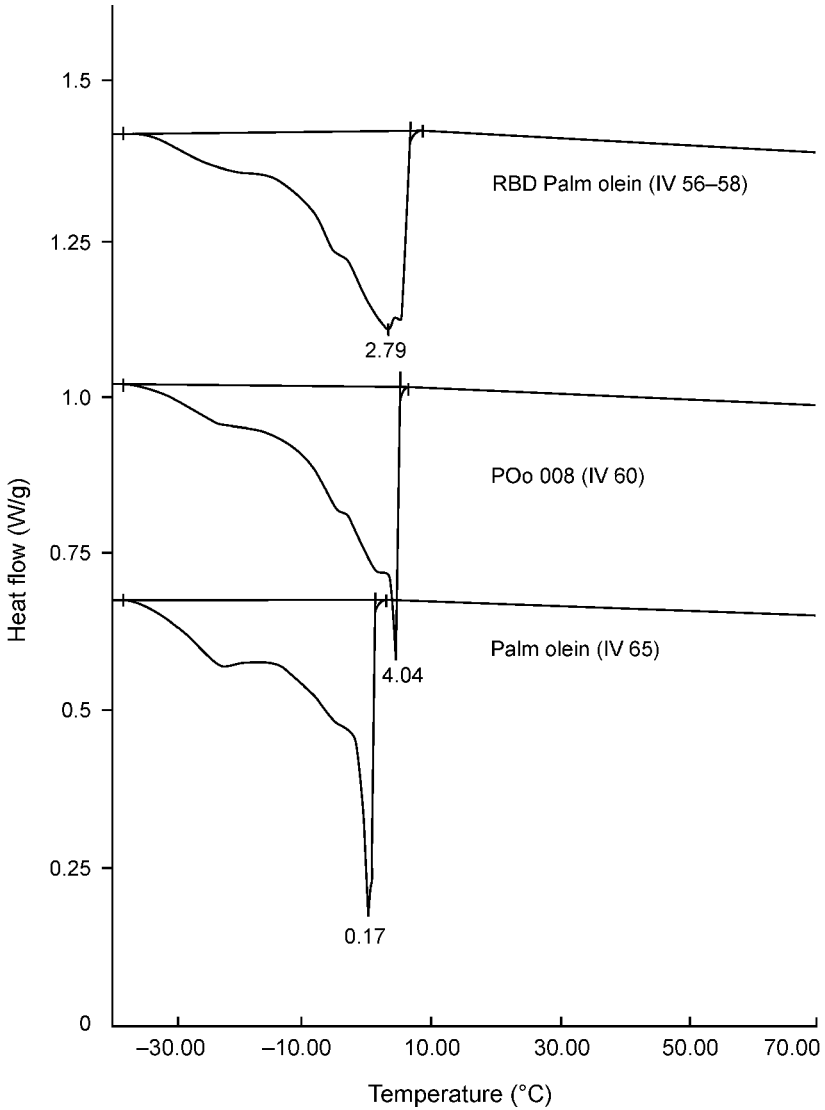


**Figure 3.4** Cooling thermograms of palm oleins. Sample was melted to 80°C and cooled to -30°C at 5°C/min.

The crystallisation and melting behaviour of palm stearin depends on the composition. Figures 3.6 and 3.7 show the behaviour of different palm stearins. PMF shows crystallisation exotherms which overlap into several peaks, while its melting thermogram shows one main endotherm with a shoulder, finally melting

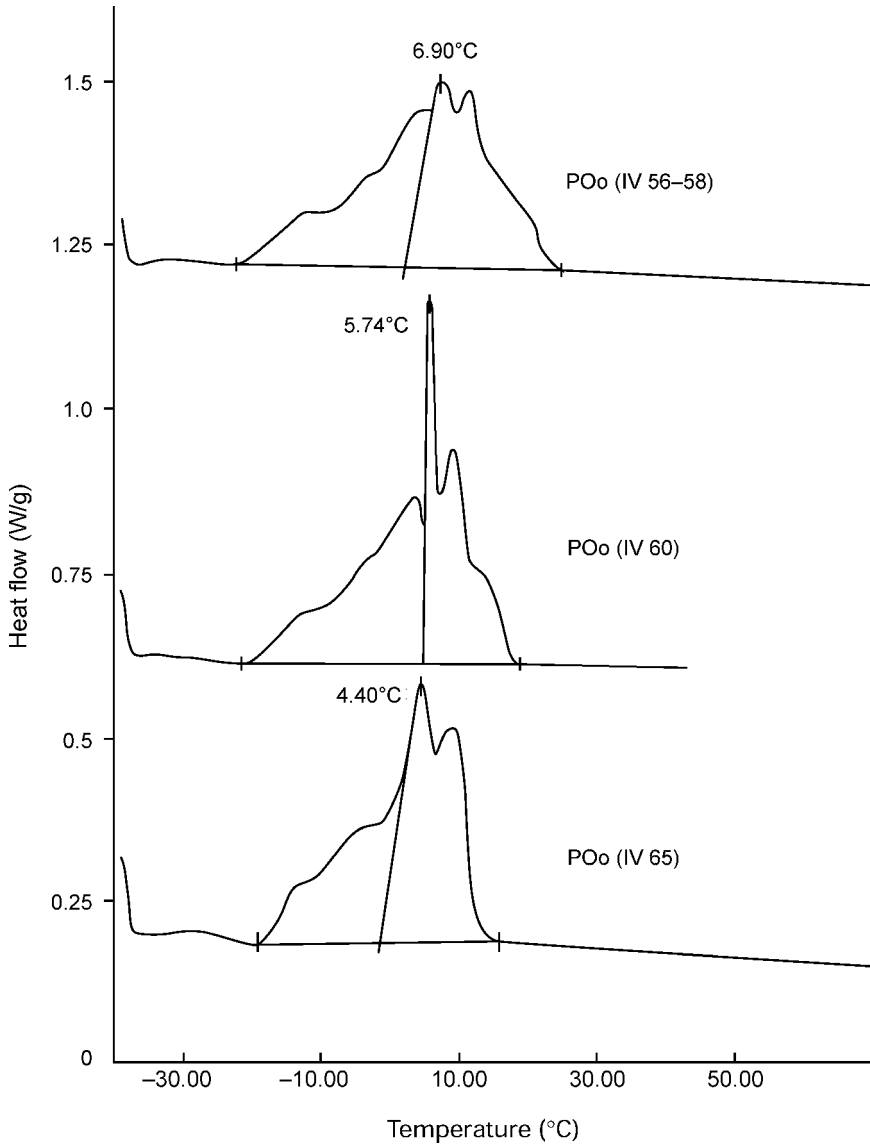


**Figure 3.5** Melting thermograms of palm oleins. Sample was cooled to  $-30^{\circ}\text{C}$  at rate of  $40^{\circ}\text{C}/\text{min}$ , held for 10 mins and heated to  $80^{\circ}\text{C}$  at  $5^{\circ}\text{C}/\text{min}$ .

at  $31^{\circ}\text{C}$ . The two other stearins (of iodine value 35 and 44) have different melting and crystallisation profiles, although both still have considerable proportions of the more unsaturated TAGs. Some polymorphic transformations are also observed in both stearins. A high melting fraction is also observed which results

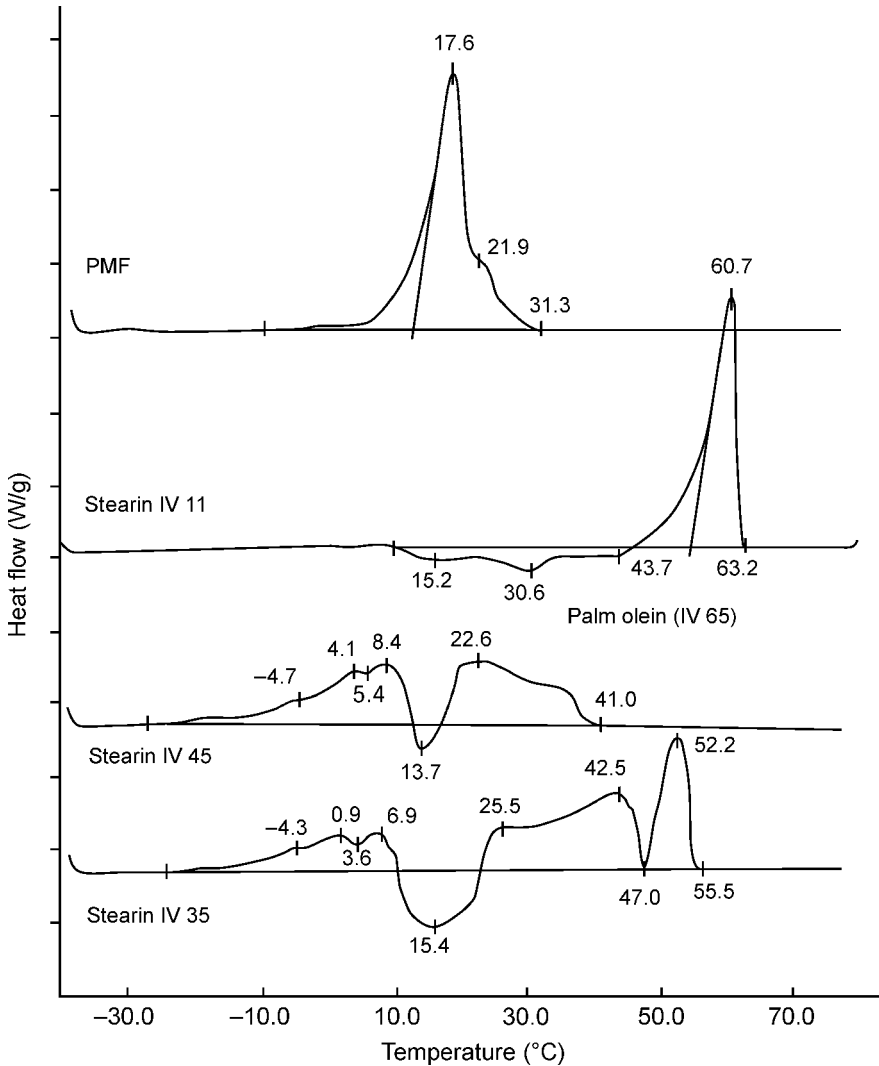


**Figure 3.6** Melting thermograms of palm stearins. Sample was cooled to  $-30^{\circ}\text{C}$  at rate of  $40^{\circ}\text{C}/\text{min}$ , held for 10 mins and heated to  $80^{\circ}\text{C}$  at  $5^{\circ}\text{C}/\text{min}$ .

in the oil melting at  $55^{\circ}\text{C}$ . In contrast, the hard stearin of iodine value 11 shows only one exotherm and endotherm, indicating that the lower melting fractions have been clearly removed during fractionation. It is obvious from the figures that the melting and crystallisation behaviour of palm stearins varies greatly. Understanding the properties and behaviour of different stearins enables full exploitation of usage and application in food products.

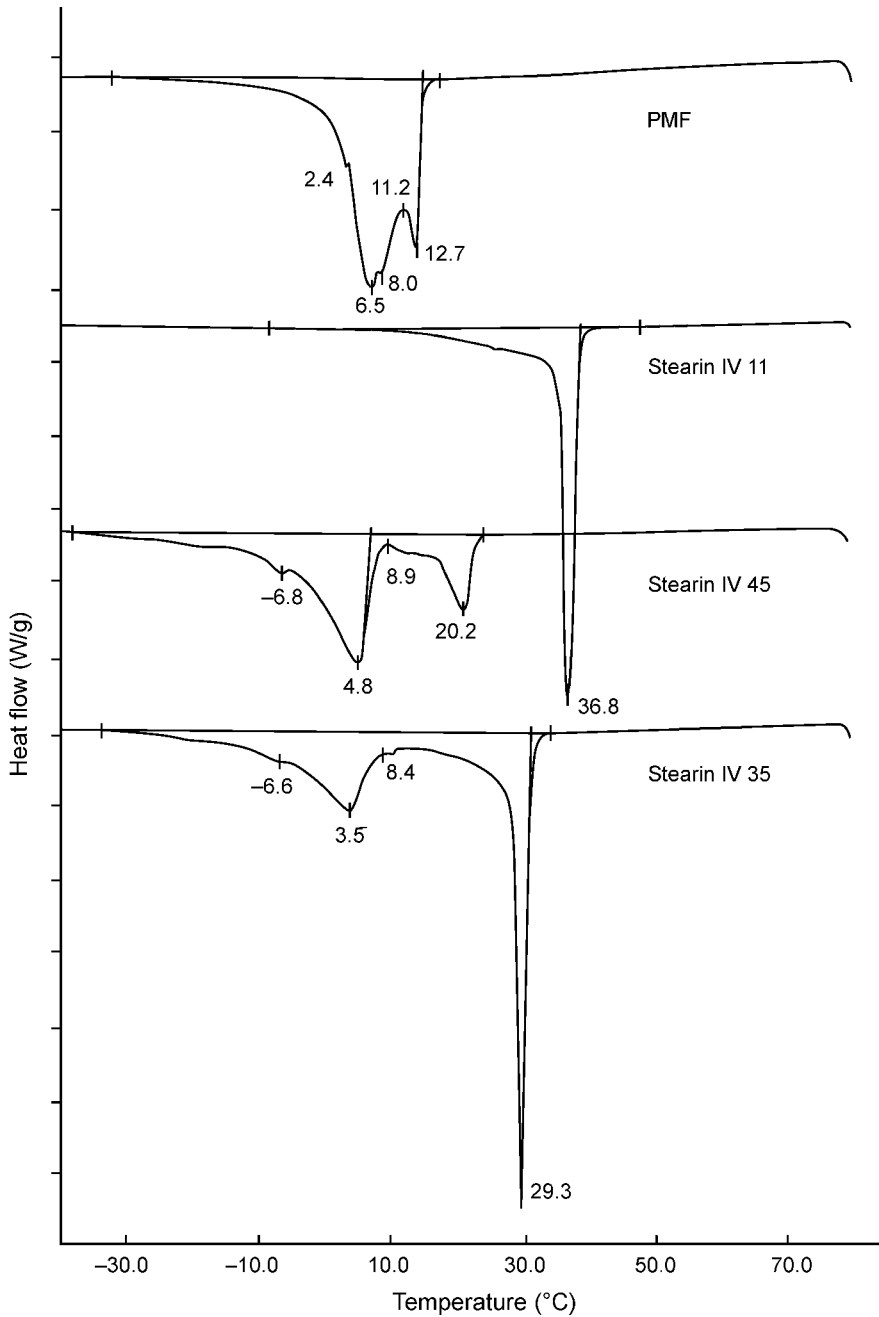


**Figure 3.7** Crystallisation thermograms of palm stearins. Sample was melted to 80°C and cooled to -30°C at 5°C/min.

### 3.4 Minor components of palm oil products

Crude palm oil is rich in minor components such as carotenoids, tocopherols, tocotrienols, sterols, phospholipids, triterpene alcohols, squalene, aliphatic alcohols and aliphatic hydrocarbons (Goh *et al.* 1985). The major components of interest are the carotenes, tocopherols, tocotrienols, sterols and squalene (Table 3.10). Carotenes and tocopherols are antioxidants and stabilise the oil against oxidation. During refining, the bleaching and steam deodorisation processes partially remove some of these valuable components. The amounts retained in the refined oils depend on the conditions of refining.

#### 3.4.1 Carotenes

The dark red-orange colour of oil palm fruit is due to the high concentration of carotenoids and anthocyanins. Crude palm oil, extracted commercially by sterilisation and press, contains 400–1000 ppm of carotenoids, the variation being due to process conditions, species of oil palm and level of oxidation. Carotenoids in palm oil are  $\alpha$ -carotene,  $\beta$ -carotene, phytoene, phytofluene, *cis*  $\beta$ -carotene, *cis*  $\alpha$ -carotene,  $\delta$ -carotene,  $\gamma$ -carotene,  $\zeta$ -carotene, neurosporene,  $\beta$ -zeacarotene,  $\alpha$ -zeacarotene and lycopene (Table 3.11) (Yap *et al.* 1991, Jalani *et al.* 1997). The carotenoid profiles of the crude olein and stearin were similar to that of the crude oil. All three contained the core group of compounds: neurosporene,  $\alpha$ -,  $\beta$ -,  $\gamma$ -carotenes and lycopene. The major components are  $\alpha$ -carotene and  $\beta$ -carotene. The crude oil obtained from the tenera variety of *Elaeis guineensis*, has a carotene content of 500–700 ppm (Table 3.11), while that of *Elaeis oleifera* is about 4600 ppm. The carotene content of hybrid palms,

**Table 3.10** Minor components of crude and refined palm oil

| Minor components                                                 | Crude palm oil<br>(ppm) | Refined oil<br>(ppm) |
|------------------------------------------------------------------|-------------------------|----------------------|
| Carotenoids (Jacobsberg 1974)                                    | 500–700                 | ND                   |
| Tocopherols and tocotrienols<br>(Abdul Gapor <i>et al.</i> 1981) | 600–1000                | 350–630              |
| Sterols (Rossell <i>et al.</i> 1983)<br>(Siew 1990)              | 326–527<br>210–620      | NA<br>70–316         |
| Ubiquinone (Hazura <i>et al.</i> 1996)                           | 10–80                   | 10–70                |
| Squalene (Goh and Gee, 1984)<br>(Abdul Gapor 2000)               | 200–500<br>421–979      | NA<br>184–791        |
| Phospholipids (Goh <i>et al.</i> 1982)                           | 5–130                   | NA                   |
| Triterpene alcohols (Itoh <i>et al.</i> 1973a)                   | 40–80                   | NA                   |
| Methyl sterols (Itoh <i>et al.</i> 1973b)                        | 40–80                   | NA                   |
| Aliphatic alcohols (Jacobsberg 1974)                             | 100–200                 | NA                   |

ND = not detectable.

NA = not available.

**Table 3.11** Composition of carotenoids in palm oil, given as % of total carotenoids

| Type                   | <i>E. guineensis</i><br>(Eg) | <i>E. oleifera</i><br>(Eo) | Eg × Eo hybrid |
|------------------------|------------------------------|----------------------------|----------------|
| Phytoene               | 1.27                         | 1.12                       | 1.83           |
| <i>Cis</i> β-Carotene  | 0.68                         | 0.48                       | 0.38           |
| Phytofluene            | 0.06                         | trace                      | trace          |
| β-Carotene             | 56.02                        | 54.08                      | 60.53          |
| α-Carotene             | 35.06                        | 40.38                      | 32.78          |
| <i>Cis</i> -α-Carotene | 2.49                         | 2.30                       | 1.37           |
| ζ-Carotene             | 0.69                         | 0.36                       | 1.13           |
| γ-Carotene             | 0.33                         | 0.08                       | 0.23           |
| δ-Carotene             | 0.83                         | 0.09                       | 0.24           |
| Neurosporene           | 0.29                         | 0.04                       | 0.23           |
| β-Zeacarotene          | 0.74                         | 0.57                       | 1.03           |
| α-Zeacarotene          | 0.23                         | 0.43                       | 0.35           |
| Lycopene               | 1.30                         | 0.07                       | 0.05           |
| (Total ppm)            | 500–700                      | 4300–4600                  | 1250–1800      |

Source: Jalani *et al.* 1997, Yap *et al.* 1991.

**Table 3.12** Carotene content in palm oil fractions

| Type of oil                                     | ppm       |
|-------------------------------------------------|-----------|
| Crude palm oil ( <i>E. guineensis</i> , tenera) | 500–700   |
| Crude palm olein                                | 600–760   |
| Crude palm stearin                              | 380–540   |
| Residual oil from fibre                         | 4000–6000 |
| Second-pressed oil                              | 1800–2400 |

produced from the cross of the two species, lies between those values. Second pressed oils (Table 3.12), obtained by double pressing process of palm fruits, have a much higher concentration of carotenoids (1800–2400 ppm) (Choo 1995). Physically refined oils show no trace of the carotenoids. These are either absorbed onto the bleaching earths or destroyed during thermal treatment. Carotenes preferentially segregate into the more unsaturated olein fraction, leaving little in the stearin fraction. This has important consequences for the oxidative stability of these two fractions.

Crude palm oil is consumed in some countries as a source of vitamin A. To retain these carotenes in the oil, processes are currently available to produce a red palm oil. These are either molecular distillation (Ooi *et al.* 1992) or chemical neutralisation followed by modified refining.

In crude palm oil, the carotene content provides an indication of quality as is shown by the use of DOBI, an index for determining the 'bleachability' of palm oil (Swoboda 1982). As oils from a particular oil palm species will have

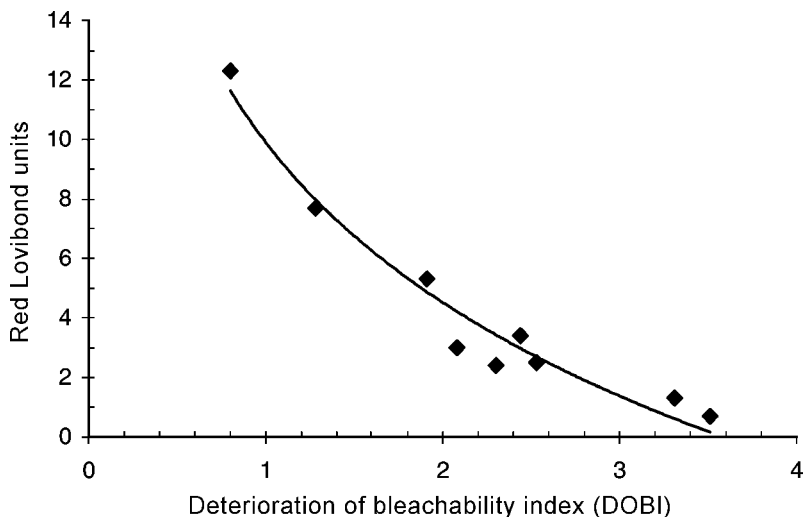


**Figure 3.8** Relationship between DOBI and colour of refined oil.

carotene values within a narrow range, any dramatic lowering of carotene is due to degradation of the oil. Good quality oils not only have high carotene values, but also low secondary oxidation characteristics as measured by absorption at 269 nm. The DOBI value, which is the ratio of the absorbance at 446 nm (measurement of carotene) to 269 nm, is well correlated to the colour remaining after refining (Figure 3.8). Oils with low DOBI values, due to low carotenes and high secondary oxidation values, are difficult to refine.

Palm carotenoids provide a source of pro-vitamin A and its orange-red colour is useful as a natural pigment for food preparations, margarines, biscuits and confectionery. Besides the role of providing a source of vitamin, carotenoids are considered to have anti-carcinogenic properties.

### 3.4.2 Tocopherols and tocotrienols

Crude palm oil, besides being rich in vitamin A, also has a high content of vitamin E, present as tocopherols and tocotrienols (Abdul Gapor 1990; Abdul Gapor *et al.* 1988) (Table 3.13 and Table 3.14), of which 70% are tocotrienols (Hashimoto *et al.* 1980). Crude palm olein has a higher content of tocopherols and tocotrienols. Refined oils retain about 70% of the tocopherols, the amount varying depending on conditions of refining. Most of the loss occurs at deodorisation, and consequently palm fatty acid distillate (PFAD) has up to five to ten times the level in crude oil and PFAD is a good starting material for recovery of vitamin E. There is considerable interest in the nutritional and physiological properties of vitamin E in palm oil, particularly the tocotrienols. Table 3.14 shows the

**Table 3.13** Vitamin E (total tocopherols and tocotrienols) content in palm oil products

| Type of oil                                     | Total (ppm) |
|-------------------------------------------------|-------------|
| Crude palm oil <sup>a</sup>                     | 708–1141    |
| Refined palm oil <sup>a</sup>                   | 378–890     |
| Crude palm olein <sup>a</sup>                   | 880–1129    |
| Refined palm olein <sup>a</sup>                 | 559–902     |
| Crude palm stearin <sup>a</sup>                 | 426–552     |
| Refined palm stearin <sup>a</sup>               | 348–381     |
| Palm oil fatty acid distillate <sup>b</sup>     | 744–8192    |
| Palm olein fatty acid distillate <sup>b</sup>   | 1018–7172   |
| Palm stearin fatty acid distillate <sup>b</sup> | 162–2408    |

<sup>a</sup>Abdul Gapor 1990.<sup>b</sup>Abdul Gapor *et al.* 1988.**Table 3.14** Composition of tocopherols and tocotrienols (% of total) in palm oils and fatty acid distillate

| Type of material                        | $\alpha$ -Tocopherol | $\alpha$ -Tocotrienol | $\gamma$ -Tocotrienol | $\delta$ -Tocotrienol | Total (ppm) |
|-----------------------------------------|----------------------|-----------------------|-----------------------|-----------------------|-------------|
| Crude palm oil <sup>a</sup>             |                      |                       |                       |                       |             |
| <i>E. guineensis</i> (Eg)               | 21                   | 23                    | 45                    | 11                    | 600–1000    |
| <i>E. oleifera</i> (Eo)                 | 15                   | 27                    | 54                    | 4                     | 700–1500    |
| Eg $\times$ Eo                          | 19                   | 28                    | 42                    | 11                    | 600–1600    |
| Palm fatty acid distillate <sup>b</sup> | 21                   | 16                    | 39                    | 24                    | 744–8192    |

<sup>a</sup>Jalani *et al.* 1997.<sup>b</sup>Abdul Gapor *et al.* 1988.

composition of tocopherols and tocotrienols in palm oils of different oil palm materials. Most of the vitamin E is in the form of  $\gamma$ -tocotrienols, in contrast to that of other oils where the vitamin E is mainly  $\alpha$ -tocopherol. According to Abdul Gapor (1990) the order of antioxidant activities of tocotrienols was  $\gamma$ - >  $\delta$ - >  $\alpha$ -. At 200 ppm, the  $\alpha$ -tocotrienol improves oxidative stability by a factor of 6.3.  $\gamma$ -Tocotrienol has twice the antioxidant effect of  $\alpha$ -tocotrienol.

Tocotrienols have become a focus of research in recent years because of findings showing high efficacy in protecting against heart related diseases and certain cancers. The tumour protective effect of tocotrienols from palm oil was demonstrated by Nesaretnam and co-workers (1995). This effect was studied *in vitro* on human breast cancer cell lines. A tocotrienol-rich fraction (TRF) inhibited the incorporation of (<sup>3</sup>H) thymidine into these cells by 50% at a concentration of 180  $\mu$ g/ml. In contrast,  $\alpha$ -tocopherols do not significantly reduce tumour growth at concentrations up to 500  $\mu$ g/ml. Other evidence that palm vitamin E has anticancer properties comes from work of Guthrie and co-workers (1997) on oestrogen receptor positive MCF-7 human breast cancer cells. Guthrie showed that a combination of tamoxifen with tocotrienols was more

**Table 3.15** Sterol content and composition of palm oil products

| Type of oil                                | Cholesterol<br>(ppm) | Campesterol<br>(ppm) | Stigmasterol<br>(ppm) | $\beta$ -Sitosterol<br>(ppm) | Others*<br>(ppm) | Total sterols<br>(ppm) |
|--------------------------------------------|----------------------|----------------------|-----------------------|------------------------------|------------------|------------------------|
| Crude palm oil <sup>a</sup>                | 2.7–13               | 46.4–150             | 26.3–65.7             | 120–369.5                    | 2–21             | 210–620                |
| Crude palm oil <sup>b</sup>                | 7–13                 | 90–151               | 44–66                 | 218–370                      | 2–18             | 326–527                |
| Refined palm oil <sup>a</sup>              | 1.2–5.5              | 15.3–65.4            | 8.5–36.9              | 45–198                       | 0–10.5           | 70–316                 |
| Crude palm olein <sup>a</sup>              | 6.2–7.5              | 56.7–103.8           | 29.9–51.0             | 149–253                      | 24.6–28.1        | 270–440                |
| Refined palm olein <sup>a</sup>            | 2.1–2.4              | 25.6–30.4            | 12.4–23.3             | 67.7–11.4                    | nil–1.2          | 109–170                |
| Palm stearin <sup>c</sup>                  | 2.7–4.9              | 20.6–24.2            | 11.4–11.8             | 56.7–58.4                    | 2.9–6.0          | 389–481                |
| Palm fatty acid<br>distillate <sup>d</sup> | 11                   | 23                   | 14                    | 52                           | –                | 1536–19,811            |

Source: <sup>a</sup> Siew 1990; <sup>b</sup> Rossell *et al.* 1983; <sup>c</sup> Downes 1982; <sup>d</sup> Abdul Gapor *et al.* 1988 (composition is expressed as percentage of total sterols).

\*Mixture of  $\Delta^5$ -avenasterol,  $\Delta^7$ -stigmastenol,  $\Delta^7$ -avenasterol.

effective than either tocotrienols and tamoxifen alone. Komiyama and Yamoka (1993) reported the effectiveness of palm tocotrienols against transplantable mice tumours.

In addition to anticancer effects, tocotrienol-rich fractions of palm oil have hypocholesterolaemic effects in humans and offer protection against heart diseases (Qureshi *et al.* 1991; Serbinova *et al.* 1993). Tocotrienols differ from tocopherols in the degree of saturation of the side chains; the prenyl side chain is considered to be responsible for the differential membrane distribution and metabolism of tocotrienols in comparison to tocopherols. Full investigations into the role and mechanisms of each tocotrienol and their interactions with other minor components, such as carotenoids, in inhibiting cancer development, as well as conferring protection against other age-related diseases, are now important areas of research.

### 3.4.3 Sterols, squalene and other hydrocarbons

Sterols form a major part of the unsaponifiable fraction of palm oil. The common vegetable oil sterols are also found in palm oil products. These are sitosterol, stigmasterol and campesterol, with cholesterol only a minor component. Crude palm oil contains 210–620 ppm of sterols (Table 3.15) (Siew 1990). Fractionation and refining change the content and composition of the sterols in the oil. Again, the palm fatty acid distillate is a good source of sterols, having 1500–20,000 ppm with an average of 6500 ppm (Abdul Gapor *et al.* 1988).

The C<sub>30</sub> hydrocarbon squalene is present at about 200–500 ppm in crude palm oil; sesquiterpene (C<sub>15</sub>) and diterpene (C<sub>20</sub>) hydrocarbons are present at lower levels. Abdul Gapor and Hazrina (2000) reported squalene as high as 979 ppm in some crude oils and 791 ppm in refined oils. These levels are generally higher than that of other vegetable oils, with the exception of olive oil. Palm fatty acid distillate has 5000 ppm to 8000 ppm of squalene. Crude palm oil also has 10–80 ppm of ubiquinone 10 (Hazura *et al.* 1996).

## 3.5 Food applications of palm oil products

Palm oil is one of the major oils in the world oils and fats trade and detailed figures are given in Chapter 1. Almost 90% of this oil is used as edible products in many applications, such as cooking/frying oils, margarines, shortenings, vanaspati, speciality fats and spray dried products. A large variety of possible product formulations can be made with either palm oil alone or in combination with palmkernel oil/fractions or with other vegetable oils. Its composition confers oxidative stability, having very little polyunsaturated acid. Being naturally semi-solid in nature, there is little necessity for hydrogenation.

### 3.5.1 Cooking/frying oil

Palm olein is much used as a cooking oil, domestically and in industrial outlets. Palm oil and its fractions are accepted as frying oils for food products such as snack chips, crackers, cookies, pastries, doughnuts, fries and instant noodles. Frying, being a thermal process, results in rapid deterioration of oil. The oxidative stability of palm oil, olein, and stearin (Table 3.16) is a major advantage of the oils. Palm olein has the longest induction period—44 h at 100°C. Blending less stable vegetable oils with palm olein improves their stability (Teah 1988; Razali and Badri 1993). Improvements are seen in the reduced levels of primary and secondary oxidation products, and formation of fatty acids, volatiles and polymers. In addition, the cloud points of most vegetable oils are raised slightly by blending with palm olein (Table 3.16). Free fatty acid content is one of the parameters used for evaluating the quality of frying oils. During frying, there is less formation of free acids when palm olein is used or blended with other vegetable oils (Teah 1988). Besides this, polymer content is lower, and thus less change in viscosity is observed. Most polyunsaturated oils have to be hydrogenated for use as frying oils to reduce high polymer formation and viscosity increase during frying. An alternative approach to this problem is to blend oils. Zalewski and co-workers (1999) showed that using palm olein (iodine value 62) and rapeseed oil (50:50), or a ternary mixture of palm olein

**Table 3.16** Induction period (IP) and cloud points of oils and blends

| Oils and blends                   | Induction period (h) | Cloud point (°C) |
|-----------------------------------|----------------------|------------------|
| Refined palm oil <sup>a</sup>     | 51.7                 | —                |
| Refined palm olein                | 44.0                 | 9.6              |
| Refined palm stearin <sup>a</sup> | 55.8                 | —                |
| Cottonseed                        | 11.1                 | −3.0             |
| Cottonseed/palm olein             | —                    | 5.0              |
| Groundnut                         | 15.0                 | 1.9              |
| Groundnut/palm olein              | 21.0                 | 2.0              |
| Maize                             | 9.0                  | −9.5             |
| Maize/palm olein                  | 12.0                 | −1.9             |
| Olive                             | 11.8                 | −10.0            |
| Olive/palm olein                  | —                    | −10.0            |
| Rapeseed                          | 11.5                 | −5.0             |
| Rapeseed/palm olein               | 16.0                 | 0.0              |
| Sesame                            | 8.0                  | —                |
| Sesame/palm olein                 | 7.0                  | 0.3              |
| Soybean                           | 16.0                 | −9.0             |
| Soybean/palm olein                | 19.0                 | −2.2             |
| Sunflowerseed                     | 6                    | −9.5             |
| Sunflowerseed/palm olein          | 7                    | −2.3             |

<sup>a</sup>Palm olein was added at 30% in each blend.

Source: Teah 1988.

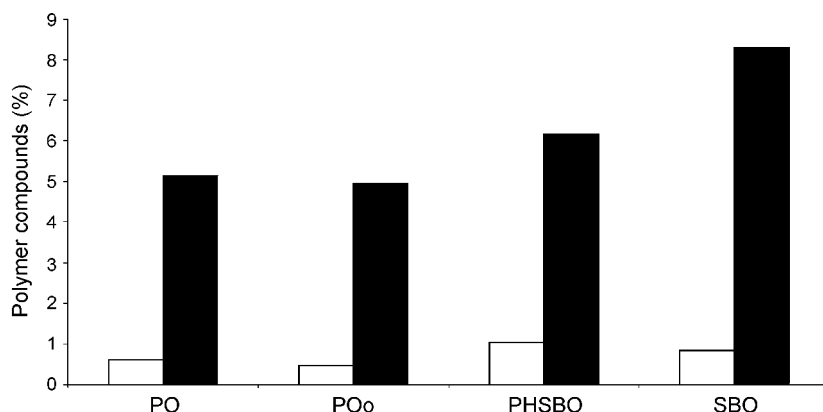


**Figure 3.9** Polymer content of some frying oils (Razali and Badri 1993). PO: palm oil; POo: palm olein; PHSBO: partially hydrogenated palm olein; SBO: soyabean oil. Key: □, day 0; ■, 5th day

(iodine value 56), palm stearin (iodine value 48), and rapeseed oil (40:40:20), produced fewer polar compounds than using pure rapeseed oil. Lower anisidine values also indicate that oil stability is better with a higher level of palm oil products. Palm olein blends with rapeseed oil allow for good sensory quality of chips up to six months of storage. A palm olein/sunflower blend has proven to be very successful, as there appears to be a synergistic effect on the stability (Van Twisk and Du Plessis 1997) and on formation of polymer compounds (Figure 3.9) (Razali and Badri 1993). Due to changing consumer demand for healthy foods, the usage of high-oleic oils in frying should grow significantly. Palm olein, especially double-fractionated palm olein, fits Appelqvist's (1997) criteria of 'a healthy frying oil' in having low saturated and polyunsaturated, high monounsaturated and no *trans* acids. A comparison of potato chips fried in olein with those fried in high-oleic sunflower oil showed comparable properties after 16 weeks of storage of the chips (Razali *et al.* 1999).

In temperate countries where palm olein crystallises or turns cloudy, blending with polyunsaturated oils is an easy and simple way to obtain a clear product for the retail supermarkets. The clarity of palm olein depends on its iodine value (Table 3.8) (Nor Aini and Hanirah 1996, 1997). The time that palm olein remains clear at 20°C varies from one day for oils of iodine value of 56 to more than 60 days for double fractionated oils of iodine value 65–67.

### 3.5.2 Margarines and shortenings

Margarine is a flavoured product containing 80% fat blended with water, and containing vitamins and other ingredients. Initially developed to replace dairy butter, it now appears in a variety of types including regular, whipped, soft-tub, liquid, diet, spreads, low-calorie, bakery and speciality. Today's margarines

incorporate nutritional as well as functional properties and cater for the requirements of different consumers. The properties of margarines depend on the characteristics of the oil forming the major ingredient of the product. The solid fat content of the oil at a range of temperatures is an indicator of the crystallisation properties of the finished product.

Palm oil and its fractions are suitable for margarine production. It is possible to incorporate them into margarine formulations as shown by Teah and co-workers (1994), Noor Lida and co-workers (1997) and Nor Aini and Mohd Suria (2000). Figure 3.10 shows the solid fat content of margarines formulated with mixtures of palm oil and/or palmkernel oil with other vegetable oils. Tub, packet, industrial/bakery and pastry margarines can all be formulated with some palm oil and/or its fractions in the formulation. Domestic margarines in Malaysia are formulated with palm oil/palm olein or palmkernel oil with liquid oil. For table margarines, as much as 50% of palm oil can be used in the fat blend, while for palm olein, up to 60% can be used. Palm stearin, with its high PPP content, is an excellent hard stock for margarines made from liquid oils (DeMan 2000). There are several advantages in using palm stearin as a component for interesterification with liquid oils to yield a good hard stock, such as availability of oil, cheap raw material, and the removal of the need for hydrogenation. The nutritional effects of *trans* acids produced during hydrogenation are a matter of controversy. By interesterification of ternary or binary blends, it is possible to obtain suitable formulations which are free of *trans* fatty acids. In fact many

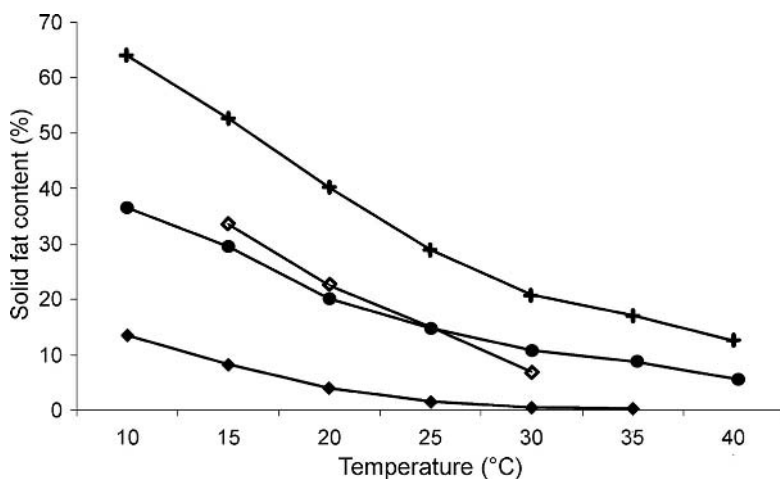


**Figure 3.10** Solid fat content of margarine using palm oil products (Noorlida and Mohd Suria 1995). PO: palm oil; POo: palm olein; POs: palm stearin; RSO: rapeseed oil; PKO: palmkernel oil; SBO: soyabean oil; IE: interesterification. Key: —●—, POo/POs/RSO (40/10/50); —◆—, IE POs/PKO (75/25); —●—, POo/POs/SBO (20/50/30); —+—, PO/POs (10/90).

**Table 3.17** SFC for several *trans*-free margarines from palm oil

| Blend                   | PS:PKOo | IE (PS:PKOo) | IE (POo:PKO) | IE (PS:PKOo:SFO) | PS:SBO |
|-------------------------|---------|--------------|--------------|------------------|--------|
| Composition             | 70:30   | 60:40        | 70:30        | 60:20:20         | 80:20  |
| Slip melting point (°C) | 45.5    | 34.3         | 33.3         | 38.5             | 43.3   |
| SFC (%) wideline        |         |              |              |                  |        |
| NMR                     |         |              |              |                  |        |
| 10°C                    | 56.3    | 31.8         | NA           | 33.7             | 69.1   |
| 15°C                    | 42.2    | 23.3         | 34.6         | 24.6             | 57.8   |
| 20°C                    | 29.8    | 15.6         | 22.7         | 18.9             | 46.3   |
| 25°C                    | 20.9    | 10.8         | NA           | NA               | 33.6   |
| 30°C                    | 16.3    | 6.3          | 7.8          | 7.1              | 23.9   |
| 35°C                    | 11.1    | 2.4          | –            | –                | 17.7   |
| 40°C                    | 10.7    | –            |              |                  | 8.3    |

Source: Teah *et al.* 1994.

suitable blends can be tailor-made to suit the requirements of the consumers of different countries, using the indigenous oils of those countries along with palm oil and/or its fractions. Interesterified palm stearin (60%) and palmkernel olein (40%) result in a product with suitable properties for margarines (Table 3.17) (Teah *et al.* 1994). With a wide range of palm stearins available, it is possible to make many combinations for stick and soft margarines (Petrauskaite *et al.* 1998). A new palm-based pourable margarine has been formulated by Miskandar and Mohd Suria (1998).

Palm oil is suited for industrial margarines, having 23% solids at 20°C. Palm stearins may also be included in the formulations as shown by Teah (1994) (Table 3.17). Puff pastry margarines, based on palm stearin and palm oil or with palmkernel olein or soyabean oil, have been reported (Teah *et al.* 1982). The basic requirements for puff pastry margarines are the most demanding with regard to crystallisation. The features of a rolled-in margarine are plasticity and firmness.

Palm, palm stearin and also the hydrogenated products tend to be  $\beta'$  stable (Yap *et al.* 1989a), providing the right crystal polymorph for a smooth texture in margarines. This interesting feature of the fat is utilised in production of margarines using liquid oils. Soft margarines based on hydrogenated palm olein and liquid oils, such as canola and sunflower, can incorporate high proportions of the liquid oil while still retaining the  $\beta'$  form required (Table 3.18) (DeMan *et al.* 1993). Palm oil in a mixture with hydrogenated canola oil can delay the formation of  $\beta$  crystals from  $\beta$  prone hydrogenated canola oil (D'Souza *et al.* 1991, Yap *et al.* 1989b). The stick margarines, which had  $\beta'$  form, had a palmitic acid content of approximately 20%. Addition of 10–12% of palm stearin or hydrogenated palm oil to liquid oils is sufficient to stabilise the product in the  $\beta'$  crystals. It appears that when the higher melting fraction of a fat is comprised of TAGs that are stable in the  $\beta'$ , the entire fat will then crystallise in the same form

**Table 3.18** The  $\beta'$  polymorphic stability of liquid oils containing hydrogenated palm olein

|                          |       | Drop point (°C) | SFC at 10°C | Polymorphic form<br>after four cycles |
|--------------------------|-------|-----------------|-------------|---------------------------------------|
| Hydrog. olein:SFO        |       |                 |             |                                       |
| IV 42.8                  | 30:70 | 36.5            | 20.0        | $\beta'$                              |
| IV 37.9                  | 30:70 | 41.4            | 23.7        | $\beta'$                              |
| IV 32.0                  | 30:70 | 44.0            | 25.5        | $\beta'$                              |
| Hydrog. olein:canola oil |       |                 |             |                                       |
| IV 42.8                  | 40:60 | 35.8            | 26.4        | $\beta'$                              |
| IV 37.9                  | 30:70 | 33.0            | 19.6        | $\beta'$                              |
| IV 32.0                  | 20:80 | 30.2            | 12.8        | $\beta'$                              |

Source: DeMan *et al.* (1993).

(DeMan *et al.* 1992). Thus it is useful to add small amounts of palm products, especially hard palm stearin, to margarines and shortening formulations.

### 3.5.3 Shortenings

Shortening was the term used to describe the function performed by naturally occurring solid fats, such as lard and butter, in baked foods. It is now generally applied to fat products which can affect the emulsification, lubricity, structure, aeration, flavour and heat-transfer of prepared foods. Palm oil, a semi-solid fat, is highly suited to this purpose and its tendency to form  $\beta'$  crystals is an advantage as such crystals provide better aeration in batters than  $\beta$  forms. Unlike margarines, shortenings are entirely oils and fats (100%) though some may have small amounts of emulsifiers added. Figure 3.11 shows the solid content of palm oil products which can be incorporated with other oils to be used as shortenings. Blends of soft stearin with palm oil give products with the solid content required of a shortening.

Shortenings made from palm oil products have been studied extensively (Nor Aini *et al.* 1989, 1995; Nor Aini 1988). Softer shortenings are made from palm oil (PO), hydrogenated palm oil (HPO), palm stearin (POs), anhydrous milk fat (AMF) and butterfat (BF) and low melting milkfat fractions (Table 3.19). These shortenings display crystalline structures in the  $\beta'$  polymorphic form. The yield values of these shortenings vary from 60–1120 g/cm<sup>2</sup> on day 15 to 70–1370 g/cm<sup>2</sup> on day 60. Shortenings based on hydrogenated palm oil are harder, but the plasticity and spreadability can be improved by addition of AMF. Interesterification helps to improve the creaming performances of the shortenings, as post-hardening problems which may be observed in palm based shortenings, are eliminated. Krawczyk and co-workers (1996), in reviewing the technology of low-fat spreads, reiterated the claim that products which are whipped, required 20–25% solid fat crystals, as these determine their creaming power and help to stabilise water droplets in the mixture. Again, large  $\beta$  crystals

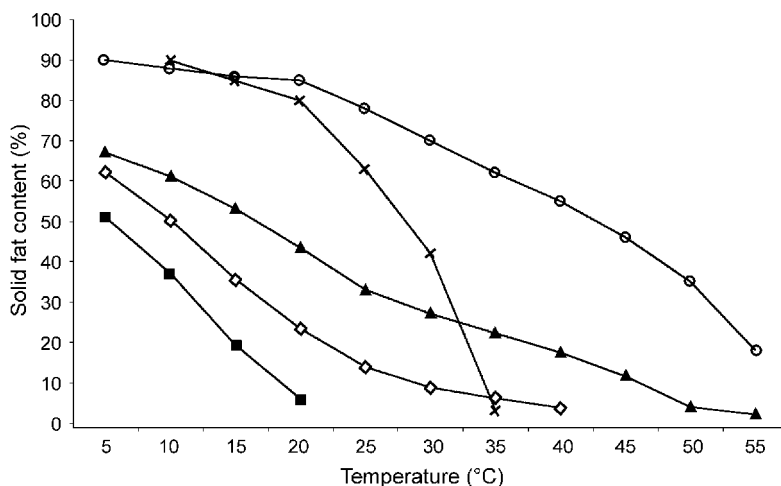


**Figure 3.11** Solid fat content of palm oil products. PO: palm oil; POo: palm olein; POs: palm stearin; PMF: palm mid-fraction. Key: —◇—, PO; —■—, POo; —▲—, POs; —×—, PMF; —○—, POs (hard).

are not desirable as they result in coarse and grainy structures. A suitable formulation for low fat spreads utilising palm in the mixture is shown in Table 3.20 (Krawczyk *et al.* 1996). A high palmitic content was also reported to be good for aeration of fat/sugar mixtures (Nor Aini *et al.* 1989). Blends of palm stearin (20–40%) with palm oil make good pastries for pies, tarts and curry puffs (Nor Aini 1992).

### 3.5.4 Vanaspati

Vanaspati is an all-purpose fat widely used in the Middle Eastern countries and the Indo–Pakistan subcontinent. It is a substitute of ghee, which is made from butter fat.

Hydrogenated products are readily accepted as suitable oils for the vanaspati industry. The texture of the product varies with different consumers. In India and Pakistan, graininess is a required criterion. Pakistan consumers prefer grainy crystals among liquid oil, unlike the Indian counterparts who prefer their vanaspati to be grainy, yet dry and crumbly. The product melts at 37–39°C, which is a property of palm oil. Palm oil at ambient temperatures has a semi-solid texture like that of vanaspati, and the granular consistency can be obtained through interesterification. Kheiri and Oh (1983) provided details of hydrogenated palm oil products suited for the Indian and Pakistan markets (Table 3.21). Blends of hydrogenated palm olein and palm oil have the consistency of vanaspati. Mixtures of palm stearin and palm oil with melting points up to 40°C are suited for the Middle East countries (Table 3.22).

**Table 3.19** Characteristics of shortenings from palm oil products

| Shortening     | Slip melting<br>point (°C) | Polymorphic<br>form | Days of storage |                  |             |                  |
|----------------|----------------------------|---------------------|-----------------|------------------|-------------|------------------|
|                |                            |                     | 15              |                  | 60          |                  |
|                |                            |                     | Yield value     | Consistency      | Yield value | Consistency      |
| PO             | 38.3 ± 0.4                 | β'                  | 250             | good consistency | 300         | good consistency |
| PO:AMF 60:40   | 37.3 ± 0.1                 | β'                  | 60              | very soft        | 70          | very soft        |
| HPO            | 41.4 ± 0.1                 | β'                  | 1120            | very firm        | 1370        | very firm        |
| HPO:AMF 80:20  | 40.3 ± 0.3                 | β'                  | 880             | slightly firm    | 990         | slightly firm    |
| HPO:AMF 60:40  | 38.4 ± 0.1                 | β'                  | 640             | good consistency | 690         | good consistency |
| IEPO           | 35.7 ± 0.2                 | β >>> β'            | 190             | slightly soft    | 220         | slightly soft    |
| IEPO:AMF 80:20 | 33.8 ± 0.3                 | β >> β'             | 180             | slightly soft    | 190         | slightly soft    |
| POs:AMF 40:60  | 42.6 ± 0.7                 | β' > β              | 400             | good consistency | 550         | good consistency |
| POs:SIMF 60:40 | 43.7 ± 0.2                 | β'                  | 410             | good consistency | 1010        | very firm        |
| POs:SIMF 40:60 | 42.9 ± 0.6                 | β'                  | 370             | good consistency | 710         | slightly firm    |

Source: Nor Aini *et al.* 1995.

**Table 3.20** Low-fat spread formula based on palm and soybean oil

| Ingredients             | Composition (by % weight) |         |
|-------------------------|---------------------------|---------|
|                         | 40% fat                   | 25% fat |
| Water                   | 58.42                     | 64.41   |
| Other ingredients       | 1.58                      | 10.58   |
| Fat phase               | –                         | –       |
| Soybean oil             | 20.0                      | 11.51   |
| Hydrogenated soy oil    | 11.64                     | 7.15    |
| Refined palm oil        | 7.9                       | 5.65    |
| Distilled monoglyceride | 0.35                      | 0.35    |
| Polyglycerol ester      | –                         | 0.25    |
| Flavour                 | 0.05                      | 0.05    |
| Antioxidant             | 0.058                     | 0.038   |
| $\beta$ -Carotene       | 0.002                     | 0.002   |

Source: Krawczyk *et al.* 1996.

**Table 3.21** Binary blends of refined palm oil (PO) and hydrogenated palm olein (HPOo)

| Composition (%) |      | Solid fat content (%) |      |      |      |      |      | Melting point (°C) |
|-----------------|------|-----------------------|------|------|------|------|------|--------------------|
| PO              | HPOo | 20°C                  | 25°C | 30°C | 35°C | 37°C | 40°C |                    |
| 100             | 0    | 28.9                  | 19.8 | 11.1 | 9.0  | –    | 5.9  | 37.4               |
| 90              | 10   | 30.8                  | 20.8 | 13.0 | 7.3  | 5.2  | 3.6  | 38.7               |
| 80              | 20   | 36.1                  | 24.1 | 15.1 | 9.5  | 6.5  | 3.4  | 39.5               |
| 70              | 30   | 40.2                  | 27.3 | 18.0 | 11.3 | 7.8  | 4.7  | 39.8               |
| 60              | 40   | 45.0                  | 30.7 | 19.5 | 12.6 | 9.3  | 5.1  | 40.5               |
| 50              | 50   | 47.9                  | 34.3 | 22.6 | 14.7 | 10.4 | 5.7  | 41.3               |
| 40              | 60   | 51.0                  | 37.3 | 28.7 | 15.5 | 11.2 | 7.9  | 41.4               |
| 30              | 70   | 55.6                  | 40.4 | 27.2 | 17.9 | 13.1 | 8.2  | 41.9               |

Source: Kheiri and Oh (1983).

**Table 3.22** Binary blends of refined palm oil (PO) and palm stearin (POs)

| Composition (%) |     | Solid fat content (%) |      |      |      |      |      | Melting point (°C) |
|-----------------|-----|-----------------------|------|------|------|------|------|--------------------|
| PO              | POs | 20°C                  | 25°C | 30°C | 35°C | 37°C | 40°C |                    |
| 100             | 0   | 23.0                  | 16.0 | 9.8  | 6.9  | 3.1  | 3.1  | 6.3                |
| 90              | 10  | 26.2                  | 16.9 | 11.9 | 9.4  | 5.6  | 5.6  | 38.3               |
| 80              | 20  | 28.2                  | 18.5 | 12.2 | 10.1 | 6.2  | 6.2  | 39.0               |
| 70              | 30  | 28.7                  | 20.9 | 13.1 | 9.5  | 5.9  | 5.9  | 39.5               |
| 60              | 40  | 30.0                  | 21.7 | 15.3 | 10.5 | 6.8  | 6.8  | 40.2               |
| 50              | 50  | 32.4                  | 23.8 | 16.5 | 11.7 | 8.0  | 8.0  | 40.7               |
| 40              | 60  | 34.0                  | 24.7 | 17.4 | 13.4 | 9.5  | 9.5  | 41.5               |
| 30              | 70  | 36.4                  | 25.1 | 18.2 | 15.1 | 11.5 | 11.5 | 42.0               |

Source: Kheiri and Oh 1983.

*Trans*-free vanaspati can be formulated using palm stearin with other oils (Table 3.23) (Nor Aini *et al.* 1997). Interesterification allows more palm stearin to be incorporated into the formula. Other *trans*-free formulations are obtained with ternary blends of palm oil/palm stearin/palm olein or palm oil/palm stearin/palm kernel olein (Table 3.24). These products have characteristics similar to those of hydrogenated vanaspati. Formulations for vanaspati may be varied to suit the requirements of different consumers. Incorporation of more or fewer palm oil products in the formulation generally affects the melting point property, which is a limitation for certain countries.

### 3.5.5 Cocoa butter equivalents (CBE)

These are fats rich in symmetrical disaturated TAGs which behave like cocoa butter in all respects, and are able to mix in all proportions with cocoa butter. The desirable characteristics of cocoa butter are due to the SOS TAGs (S = saturated) which provide suitable melting point and solid fat content to give rapid melt in the mouth and cooling sensations. Palm mid-fraction (PMF), which has high contents of POP, is easily formulated with other SOS fats for chocolate products (Berger 1981). About 70%–80% PMF with 20%–30% shea or sal stearin, or 60%–65% PMF with 20%–30% shea or sal stearin and 15%–20% illipe are suitable for plain and for milk chocolate with 15% milkfat. Compatibility of cocoa butter (CB) and CBE is affected by addition of milkfat and its fractions into the product (Sabariah *et al.* 1998). Eutectic interactions between anhydrous milkfat (AMF), CBE and CB were noticeable due to different polymorphism encountered in these fats.

Cocoa butter-like fats can also be formulated with interesterified oils. Blends suitable for butter cream fillings in biscuits may be formulated from palm stearin/palm kernel olein (25:75) or palm stearin/palm kernel olein/palm kernel oil (25:37.5:37.5) (Noor Lida *et al.* 1997).

### 3.5.6 Other uses

Other uses of palm oil are in snack foods, biscuits, ice-creams, salad dressings, mayonnaise, and so on. Fat plays a key role in all the above food items and formulations using palm oil products essentially replace some of the oils used traditionally. Oil suitable for ice-creams should be partly solid at 5°C and at –5°C, substantially liquid at 37°C, and have good ‘melt’ feel characteristics. Palm oil, with a similar solid fat content profile to butterfat, is one such oil with suitable characteristics for ice-cream formulations. Palmkernel oil is also much used in ice cream products.

Salad oils, dressings, and mayonnaise are products used for mixing vegetables, meat and other ingredients together. Mayonnaise contains vegetable oils, acidifying agents and egg yolk. The stability of the oil in the emulsion

**Table 3.23** Physical characteristics of vanaspati based on direct and interesterified blends of palm stearin (Pos) with other oils

| Sample    | Direct blends      |                        |               | Intesterified blends |                     |             |
|-----------|--------------------|------------------------|---------------|----------------------|---------------------|-------------|
|           | Melting point (°C) | Appearance             | Consistency   | Melting point (°C)   | Appearance          | Consistency |
| POs:SBO   |                    |                        |               |                      |                     |             |
| 40:60     | 41.5               | Wet, granular          | Soft          | 35.9                 | Wet, oily, granular | Very soft   |
| 60:40     | 45.5               | Slightly dry, granular | Slightly firm | 41.5                 | Wet, oily, granular | Very soft   |
| 80:20     | 47.7               | Dry, granular          | Firm          | 45.6                 | Wet, oily, granular | Soft        |
| POs:RSO   |                    |                        |               |                      |                     |             |
| 40:60     | 43.6               | Wet, granular          | Soft          | 38.7                 | Wet, oily, smooth   | Very soft   |
| 60:40     | 45.9               | Slightly dry, granular | Slightly firm | 43.4                 | Wet, granular       | Soft        |
| 80:20     | 48.5               | Dry, granular          | Firm          | 45.6                 | Wet, oily, granular | Soft        |
| POs:SFO   |                    |                        |               |                      |                     |             |
| 40:60     | 43.8               | Wet, granular          | Soft          | 34.3                 | Wet, oily, granular | Very soft   |
| 60:40     | 45.3               | Dry, granular          | Slightly firm | 39.3                 | Wet, oily, granular | Very soft   |
| 80:20     | 48.6               | Dry, granular          | Firm          | 45.4                 | Oily, granular      | Soft        |
| Vanaspati | 39.0               | Dry, granular          | Slightly firm | 38.5                 | Granular            | Soft        |

Source: Nor Aini *et al.* 1997.

**Table 3.24** Characteristics of vanaspati containing palm oil (PO), palm stearin (POs), palm olein (POo) and palmkernel olein (PKOo)

| Sample formulation               | Slip melting point<br>(°C) | Softening point<br>(°C) | Dropping point<br>(°C) |
|----------------------------------|----------------------------|-------------------------|------------------------|
| PO:POs:POo<br>80:5:15            | 37.2                       | 37.7                    | 38.9                   |
| PO:POs:POo<br>80:10:10           | 39.2                       | 42.2                    | 41.2                   |
| PO:POs:POo<br>60:20:20           | 42.3                       | 41.9                    | 45.6                   |
| PO:POs:POo<br>40:30:30           | 46.8                       | 43.2                    | 47.0                   |
| PO:POs:PKOo<br>80:5:15           | 38.0                       | 39.0                    | 39.7                   |
| PO:POs:PKOo<br>80:10:10          | 41.2                       | 40.9                    | 41.9                   |
| PO:POs:PKOo<br>60:20:20          | 47.3                       | 45.6                    | 44.8                   |
| PO:POs:PKOo<br>40:30:30          | 48.3                       | 46.5                    | 44.9                   |
| Commercial sample<br>(vanaspati) | 38.5                       | 42.6                    | 42.7                   |

Source: Nor Aini *et al.* 1999.

is important. Salad dressing contains oil, egg yolk, acidifying agents and other ingredients. The salad oils used in these products are usually polyunsaturated oils. Blends of palm olein with polyunsaturated oils provide greater oxidative stability, and keep better. Red palm olein, containing high carotenoids, makes a good salad dressing but is reddish in colour.

**3.6 Conclusion**

The unique feature of palm oil is its balanced range of saturated and unsaturated fatty acids, which allow the oil to be easily fractionated into products containing more saturated or more unsaturated TAGs. The wide range in composition and properties of palm oil and its fractions allows many possible formulations to be made, incorporating the most suitable fractions in food products. Blending and interesterification are the main processes used to produce oils with properties suitable for margarine, shortening, vanaspati and frying oils, for example. The advantages of using palm oil products include the cheap raw material, ready

availability and the low cost of processing since hydrogenation is not necessary. The high oxidative stability of the oil is partly due to the fatty acid composition, but also to the carotenoids and tocotrienols present. Processing technologies enhance natural pigments, tocopherols and tocotrienols in the refined oils, enabling the creation of products with suitable specifications as required by customers. Future research should lead to oils with higher oleic acid content, and higher carotenoid and tocotrienol levels for the health conscious market. Nutritional research, focused on the beneficial effects of vitamin E and  $\beta$ -carotene, has helped to enhance the perception and use of palm oil as a healthy oil.

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