

# The Lipid Handbook

SECOND EDITION

Frank D. Gunstone,  
John L. Harwood and  
Fred B. Padley



CHAPMAN & HALL  
CHEMICAL DATABASE

# The Lipid Handbook

GUNSTONE, HARWOOD and PADLEY

SECOND EDITION

QP  
751  
L547  
1994



CHAPMAN  
& HALL

89052232683



b89052232683a

# THE LIPID HANDBOOK

SECOND EDITION

FRANK D. GUNSTONE

*University of St Andrews, Scotland*

JOHN L. HARWOOD

*University of Wales, Cardiff, Wales*

FRED B. PADLEY

*Unilever Research, Sharnbrook, England*

with sections contributed  
by an international team  
of lipid researchers



CHAPMAN & HALL

Scientific Data Division

London · Glasgow · Weinheim · New York · Tokyo · Melbourne · Madras

1994

**Published by Chapman & Hall, 2-6 Boundary Row, London SE1 8HN**

---

Chapman & Hall, 2-6 Boundary Row, London SE1 8HN, UK

Blackie Academic & Professional, Wester Cleddens Road, Bishopbriggs,  
Glasgow G64 2NZ, UK

Chapman & Hall GmbH, Pappelallee 3, 69469 Weinheim, Germany

Chapman & Hall USA, One Penn Plaza, 41st Floor, New York NY 10119, USA

Chapman & Hall Japan, ITP-Japan, Kyowa Building, 3F, 2-2-1 Hirakawacho,  
Chiyoda-ku, Tokyo 102, Japan

Chapman & Hall Australia, Thomas Nelson Australia, 102 Dodds Street, South Melbourne,  
Victoria 3205, Australia

Chapman & Hall India, R. Seshadri, 32 Second Main Road, CIT East, Madras 600 035, India

---

First edition 1986

Second edition 1994

© 1986, 1994 Chapman & Hall

Typeset in Great Britain by EJS Chemical Composition, Midsomer Norton, Bath, Avon

Printed in Great Britain at the University Press, Cambridge

ISBN 0 412 43320 6

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the UK Copyright Designs and Patents Act, 1988, this publication may not be reproduced, stored, or transmitted, in any form or by any means, without the prior permission in writing of the publishers, or in the case of reprographic reproduction only in accordance with the terms of the licences issued by the Copyright Licensing Agency in the UK, or in accordance with the terms of licences issued by the appropriate Reproduction Rights Organization outside the UK. Enquiries concerning reproduction outside the terms stated here should be sent to the publishers at the London address printed on this page.

The publisher makes no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability for any errors or omissions that may be made.

A catalogue record for this book is available from the British Library

Library of Congress Catalog Card Number: 94-70866

# CONTENTS

|                                                                                           |                |
|-------------------------------------------------------------------------------------------|----------------|
| <b>List of contributors</b>                                                               | <b>page ix</b> |
| <b>Preface</b>                                                                            | <b>xi</b>      |
| <b>Preface to the First Edition</b>                                                       | <b>xiii</b>    |
| <b>1 Fatty acid structure</b>                                                             | <b>1</b>       |
| F.D. Gunstone                                                                             |                |
| 1.1 Saturated acids                                                                       | 1              |
| 1.2 Monoene acids                                                                         | 3              |
| 1.3 Methylene-interrupted and other non-conjugated polyene acids                          | 4              |
| 1.4 Conjugated polyene acids                                                              | 7              |
| 1.5 Allenic and acetylenic acids                                                          | 9              |
| 1.6 Branched-chain acids                                                                  | 11             |
| 1.7 Cyclic acids                                                                          | 13             |
| 1.8 Hydroxy acids                                                                         | 15             |
| 1.9 Epoxy and furanoid acids                                                              | 17             |
| 1.10 <i>Trans</i> acids                                                                   | 19             |
| <b>2 Lipid structure</b>                                                                  | <b>21</b>      |
| J.L. Harwood                                                                              |                |
| 2.1 Acylglycerols (glycerides)                                                            | 21             |
| 2.2 Glycerol ethers                                                                       | 22             |
| 2.3 Phospholipids                                                                         | 24             |
| 2.4 Glycosphingolipids                                                                    | 28             |
| 2.5 Glycosylglycerides                                                                    | 32             |
| 2.6 Sulphur-containing lipids                                                             | 34             |
| 2.7 Diol lipids                                                                           | 35             |
| 2.8 Other esters                                                                          | 36             |
| 2.9 Glycosides                                                                            | 38             |
| 2.10 Waxes                                                                                | 40             |
| 2.11 Cutin and suberin                                                                    | 42             |
| 2.12 Bacterial-wall lipids                                                                | 45             |
| <b>3 Occurrence and characteristics of oils and fats</b>                                  | <b>47</b>      |
| F.B. Padley, F.D. Gunstone and J.L. Harwood                                               |                |
| 3.1 Introduction (FBP)                                                                    | 47             |
| 3.2 Classification of oils and fats according to their major or unusual fatty acids (FDG) | 49             |
| 3.3 Major vegetable fats (FBP)                                                            | 53             |
| 3.4 Animal fats: milk and depot fats (FBP)                                                | 147            |
| 3.5 Marine oils: fish and whale oils (FBP)                                                | 167            |
| 3.6 Waxes (JLH)                                                                           | 184            |
| 3.7 Egg lipids (JLH)                                                                      | 193            |
| 3.8 Milk lipids (JLH)                                                                     | 195            |
| 3.9 Liver lipids (JLH)                                                                    | 198            |

|                                                                                   |            |
|-----------------------------------------------------------------------------------|------------|
| 3.10 Cereal lipids (JLH)                                                          | 200        |
| 3.11 Leaf lipids (JLH)                                                            | 202        |
| 3.12 Algal lipids (JLH)                                                           | 205        |
| 3.13 Fungal lipids (JLH)                                                          | 209        |
| 3.14 Bacterial lipids (JLH)                                                       | 216        |
| 3.15 Lipids of viruses (JLH)                                                      | 223        |
| <b>4 Separation and isolation procedures</b>                                      | <b>225</b> |
| F.D. Gunstone, M. Kates and J.L. Harwood                                          |            |
| 4.1 Crystallization (FDG)                                                         | 225        |
| 4.2 Urea fractionation (FDG)                                                      | 227        |
| 4.3 Distillation (FDG)                                                            | 228        |
| 4.4 Liquid chromatography (MK, JLH)                                               | 229        |
| 4.5 Gas-liquid chromatography (MK, JLH)                                           | 243        |
| 4.6 Enzymic procedures (FDG)                                                      | 245        |
| 4.7 Others separation methods (JLH)                                               | 246        |
| 4.8 Isolation of natural acids (FDG)                                              | 247        |
| <b>5 Processing of fats and oils</b>                                              | <b>249</b> |
| F.V.K. Young, C. Poot, E. Biernoth, N. Krog,<br>N.G.J. Davidson and F.D. Gunstone |            |
| 5.1 Introduction (FVKY)                                                           | 249        |
| 5.2 Storage and handling (FVKY)                                                   | 251        |
| 5.3 Preparation and extraction (FVKY)                                             | 253        |
| 5.4 Production of edible oils (FVKY)                                              | 258        |
| 5.5 Modification processes (FVKY)                                                 | 277        |
| 5.6 Process and production control (FVKY)                                         | 286        |
| 5.7 Margarine and butter production (CP, EB)                                      | 288        |
| 5.8 Surfactants and emulsifiers (NK)                                              | 296        |
| 5.9 Soap manufacture (NGJD)                                                       | 305        |
| 5.10 Paints and varnishes (FDG)                                                   | 313        |
| <b>6 Analytical methods</b>                                                       | <b>319</b> |
| P.W. Hendrikse, J.L. Harwood and M. Kates                                         |            |
| 6.1 Introduction (PWH)                                                            | 319        |
| 6.2 Standard analytical methods (PWH)                                             | 320        |
| 6.3 Other analytical procedures (JLH, MK)                                         | 343        |
| <b>7 Synthesis</b>                                                                | <b>359</b> |
| F.D. Gunstone and J.L. Harwood                                                    |            |
| 7.1 Fatty acid synthesis via acetylenes (FDG)                                     | 359        |
| 7.2 Fatty acid synthesis by the Wittig reaction (FDG)                             | 362        |
| 7.3 Isotopically labelled acids (FDG)                                             | 364        |
| 7.4 Acylglycerols (FDG)                                                           | 366        |
| 7.5 Glycerophospholipids (JLH)                                                    | 375        |
| 7.6 Sphingolipids (JLH)                                                           | 386        |
| 7.7 Glycosylglycerides (JLH)                                                      | 390        |
| 7.8 Fatty acid esters (FDG)                                                       | 394        |
| 7.9 Alcohols (FDG)                                                                | 396        |
| 7.10 Dibasic acids (FDG)                                                          | 397        |
| 7.11 Nitrogen derivatives of long-chain acids (FDG)                               | 398        |

|           |                                                                     |            |
|-----------|---------------------------------------------------------------------|------------|
| <b>8</b>  | <b>Physical properties: structural and physical characteristics</b> | <b>401</b> |
|           | K. Larsson and P.J. Quinn                                           |            |
| 8.1       | Solid-state behaviour of lipids (KL)                                | 401        |
| 8.2       | Lipid-water interaction and liquid-crystalline phases (KL)          | 407        |
| 8.3       | The liquid state of lipids (KL)                                     | 417        |
| 8.4       | Lipid monolayers at the air-water interface (KL)                    | 419        |
| 8.5       | Fatty acids and esters of monohydric alcohols (KL)                  | 423        |
| 8.6       | Soaps (KL)                                                          | 440        |
| 8.7       | Monoglycerides (monoacylglycerols) (KL)                             | 443        |
| 8.8       | Diglycerides (diacylglycerols) (KL)                                 | 447        |
| 8.9       | Triglycerides (triacylglycerols) (KL)                               | 449        |
| 8.10      | Phospholipids (KL)                                                  | 458        |
| 8.11      | Cholesterol and cholesteryl esters (KL)                             | 461        |
| 8.12      | Interaction between lipids and proteins (KL)                        | 463        |
| 8.13      | Structure of biological membranes (PJQ)                             | 465        |
| <b>9</b>  | <b>Physical properties: optical and spectral characteristics</b>    | <b>487</b> |
|           | D. Chapman, F.M. Goni and F.D. Gunstone                             |            |
| 9.1       | Infrared spectra (DC, FMG)                                          | 487        |
| 9.2       | Raman spectra (DC, FMG)                                             | 505        |
| 9.3       | Nuclear magnetic resonance spectra (DC, FMG, FDG)                   | 511        |
| 9.4       | Electron spin resonance spectra (DC, FMG)                           | 534        |
| 9.5       | X-ray diffraction (DC, FMG)                                         | 537        |
| 9.6       | Mass spectrometry (DC, FMG)                                         | 544        |
| 9.7       | Electronic spectra (DC, FMG)                                        | 557        |
| <b>10</b> | <b>Chemical properties</b>                                          | <b>561</b> |
|           | F.D. Gunstone                                                       |            |
| 10.1      | Catalytic hydrogenation, chemical reduction and biohydrogenation    | 561        |
| 10.2      | Autoxidation and photo-oxygenation                                  | 566        |
| 10.3      | Enzymic oxidation                                                   | 572        |
| 10.4      | Epoxidation, hydroxylation and oxidative fission                    | 575        |
| 10.5      | Halogenation                                                        | 581        |
| 10.6      | Oxymercuration                                                      | 583        |
| 10.7      | Metathesis                                                          | 584        |
| 10.8      | Stereomutation                                                      | 585        |
| 10.9      | Double-bond migration and cyclization                               | 586        |
| 10.10     | Dimerization                                                        | 588        |
| 10.11     | Other double-bond reactions                                         | 590        |
| 10.12     | Hydrolysis, esterification, interesterification, etc.               | 594        |
| 10.13     | Acid chlorides and anhydrides                                       | 598        |
| 10.14     | Peroxy acids and related compounds                                  | 599        |
| 10.15     | Nitrogen-containing compounds                                       | 601        |
| 10.16     | Other reactions of the carboxyl group                               | 603        |
| <b>11</b> | <b>Lipid metabolism</b>                                             | <b>605</b> |
|           | J.L. Harwood                                                        |            |
| 11.1      | Fatty acids                                                         | 605        |
| 11.2      | Glycerophospholipids                                                | 634        |
| 11.3      | Glyceride metabolism                                                | 646        |
| 11.4      | Glycosylglycerides                                                  | 652        |

## Contents

---

|           |                                                         |            |
|-----------|---------------------------------------------------------|------------|
| 11.5      | Sphingolipids                                           | 656        |
| 11.6      | Sterol esters                                           | 661        |
| 11.7      | Control mechanisms                                      | 663        |
| <b>12</b> | <b>Medical and agricultural aspects of lipids</b>       | <b>665</b> |
|           | J.L. Harwood, A. Cryer, M.I. Gurr and P. Dodds          |            |
| 12.1      | Human dietary requirements (JLH, MIG)                   | 665        |
| 12.2      | Obesity (AC)                                            | 669        |
| 12.3      | Lipids and cardiovascular disease (AC)                  | 671        |
| 12.4      | Skin lipids and medical implications (JLH)              | 679        |
| 12.5      | Sphingolipidoses (JLH)                                  | 684        |
| 12.6      | Other disorders of lipid metabolism (JLH)               | 688        |
| 12.7      | Pulmonary surfactant (lung surfactant) (JLH)            | 689        |
| 12.8      | Agricultural aspects (JLH, MIG, PD)                     | 694        |
|           | <b>Index</b>                                            | <b>709</b> |
|           | <b>Dictionary Section</b>                               | <b>1</b>   |
|           | <b>Compound Name Index</b>                              | <b>433</b> |
|           | <b>Formula Index</b>                                    | <b>471</b> |
|           | <b>Chemical Abstracts Service Registry Number Index</b> | <b>511</b> |

# OCCURRENCE AND CHARACTERISTICS OF OILS AND FATS\*

F.B. PADLEY, F.D. GUNSTONE and J.L. HARWOOD

## 3.1 Introduction

The characterization of oils and fats has been the subject of academic study for over 200 years. The commercial developments in the nineteenth and twentieth centuries placed a greater emphasis on the need for more precise methods of analysis. In the latter half of this century, an additional stimulus has been the growth of biochemistry and the desire to understand the mechanisms leading to the wide variety of natural products and their function.

The source of information concerned with characteristics of oils and fats is therefore very wide. Moreover, if one examines great reference works such as Hilditch and Williams (1964), it is immediately apparent that the available information is voluminous. The contents of this chapter are therefore necessarily restricted, and we do not pretend to offer an alternative to more detailed texts.

The main elements of this chapter are concerned first with describing the types of naturally occurring fatty acids and their origins. The next part describes the commercially important oils and fats. Certain minor oils and fats have been included that may be of current interest either on nutritional grounds or because they are seen to have some commercial potential. The final sections deal with the occurrence of other important lipids.

In compiling the data on commercial oils and fats, the following observations have been made:

The commercial importance of an oil cannot be directly correlated with the volume of published literature. Certain oils have been relatively neglected and modern analytical data are limited, e.g. castor oil, linseed oil, cottonseed oil.

Certain oils have been widely researched because of strong academic and/or commercial interest, e.g. cocoa butter.

Fatty acid compositional data are easily accessible for the majority of common oils and fats. The Codex ranges have been included in this review to indicate the wide range of compositions that can be associated with a single named oil. The use of these compositional ranges as a means of characterizing a fat, for example in a Court of Law, is, however, questionable. In normal commercial trading, the fatty acid range is generally much narrower within a given trading period.

Systematic triglyceride compositional data can now be obtained with the development of high-performance liquid and high-temperature gas-liquid chromatographic techniques.

Significant changes in the pattern of commercial trade are continuing. For example, although soybean still remains the major oil seed crop, there has been a virtually exponential growth of palm oil in Malaysia and the Far East. Exports of palm oil from Africa have, however, fallen to low levels. Rapeseed is increasingly grown in Europe. In the United Kingdom, for example, more rapeseed oil is now consumed than soybean oil.

The continuing interest in minor oil seed crops has led to the commercialization of evening primrose oil and Chinese vegetable tallow. There is also some commercial interest in crops such as *Cuphea*, *Crambe* and certain species of *Vernonia*.

Probably, the developments of greatest interest lie in the application of genetic engineering and tissue culture to already well commercialized crops in order to optimize yield and characteristics.

Information on world production of oils and fats is summarized in Tables 3.171–3.173, but it is of interest to note some significant predictions for the future. The editor of *Oil World* (*Oil World*, 1983 and 1991) reviewed the production of oils and fats for the 25 years 1958–82 and made informed predictions for the next 25 years (1983–2007). His major conclusions are summarized in Table 3.1. The most significant conclusion is the greatly increased production of

\* The authors gratefully acknowledge the assistance of J.P. Brun and R.I. Howker, Unilever Research Laboratory, Colworth House, Sharnbrook, Bedford, MK44 1LQ.

## Occurrence and characteristics

**Table 3.1** World production of oils and fats (Mt) in the quinquennia 1978–82 and 1986–90 and predicted for 2003–07 (annual averages). Market share is given in parentheses (From *Oil World*, 1983, and *Oil World Annual*, 1991)

|            | 1978–82   | 1986–90              | 2003–07   |
|------------|-----------|----------------------|-----------|
| Soya       | 12.4 (22) | 15.3 (20)            | 23.0 (22) |
| Palm       | 4.5 (8)   | 9.1 (12)             | 23.0 (22) |
| Cotton     | 10.7 (19) | 3.6 (5)              | 15.7 (15) |
| Groundnut  |           | 3.7 (5)              |           |
| Sunflower  |           | 7.3 (10)             |           |
| Lard       | 11.2 (20) | 11.9 (16)            | 15.7 (15) |
| Tallow     |           |                      |           |
| Greases    |           |                      |           |
| Rape       | 3.9 (7)   | 7.5 (10)             | 8.4 (8)   |
| Olive      | 7.3 (13)  | 1.9 (2)              | 8.4 (8)   |
| Butter     | 3.4 (6)   | 6.4 (8)              | 7.3 (7)   |
| Coconut    |           | 3.1 (4)              |           |
| Palmkernel |           | 1.2 (2)              |           |
| Others     | 2.8 (5)   | 4.6 <sup>a</sup> (6) | 3.0 (3)   |
| Total      | 56.2      | 75.6                 | 104.5     |

<sup>a</sup> Including sesame (0.7), corn (1.3), marine (1.5), linseed (0.7) and castor (0.4).

palm oil from a quinquennial average of 4.50 Mt (million tonnes) in 1978–82 to 23 Mt in 2003–07. This leads to an increase in the market share from 8 to 22%, bringing it equal to soybean oil. Soya is expected to maintain its market share at 22%, whilst rape, palmkernel and coconut show modest increases in market share. Total oil and fat production is predicted to rise by 86% from 56.2 to 104.5 Mt per annum. Others have argued that the rise of palm oil production will not be quite so large (Arndt, 1984). Figures for the quinquennium 1986–90 are also shown in Table 3.1, and have been taken from *Oil World Annual* (1991). See also Tables 3.171 and 3.172.

## References and further reading

- Arndt, S. (1984) *J. Am. Oil Chem. Soc.*, **61**, 1810.  
Hilditch, T.P. and Williams, P.N. (1964) *The Chemical Constitution of Natural Fats*, 4th Edn, Chapman & Hall, London.  
*Oil World* (1983) (ed. S. Mielke), *The Past 25 Years and the Prospect for the Next 25*, ISTA Mielke, Hamburg.  
*Oil World Annual* (1991) (ed. T. Mielke), ISTA Mielke, Hamburg.

## 3.2 Classification of oils and fats according to their major or unusual fatty acids\*

### 3.2.1 Short-chain acids

The lower saturated acids ( $C_4$ – $C_{10}$ ) occur in milk fats (section 3.4.1) and in a few seed fats. Cow milk fat contains butanoic acid (butyric,  $C_4$ , 10 mol%, 4 wt%) as well as smaller amounts of  $C_6$ ,  $C_8$ ,  $C_{10}$  and  $C_{12}$  acids. Sheep and goat milk fats contain the same range of acids, with decanoic as the most significant (up to 10 mol%). Octanoic, decanoic or dodecanoic acids are major components of seed oils from the elm (10:0, 60%), from *Zelkova serrata* (10:0, >70%) and from the *Cuphea* genus (section 3.3.12), which contains high levels of octanoic (~70%), decanoic (~85%) or dodecanoic (~60%) in different species.

Lauric (12:0) and myristic acid (14:0) occur extensively in seed fats of the Lauraceae and Myristiceae respectively, a fact that is reflected in the trivial names of these acids. Lauric acid, for example, is the dominant acid in cinnamon oil (80–90%), babassu fat (40–55%, section 3.3.2), coconut oil (41–56%, section 3.3.8) and palmkernel oil (41–55%, section 3.3.25). Myristic acid occurs in nutmeg butter (60–70%) and ucuhiba oil (~70%, section 3.3.40) and at lower levels in coconut (13–23%) and palmkernel oil (14–20%).

Because they are so easily available, coconut and palmkernel oil are the most convenient source of the  $C_8$ ,  $C_{10}$ ,  $C_{12}$  and  $C_{14}$  acids, which can be isolated in a pure state by fractional distillation.

### 3.2.2 Palmitic and stearic acids

Palmitic acid is the most widely occurring saturated acid, being present in practically every fat examined. It is present in fish oils (10–30%), in the milk and depot fats of land animals (up to 30%) and in vegetable fats. Useful sources of this acid include cottonseed oil (17–31%, section 3.3.10), palm oil (32–59%, section 3.3.24), Chinese vegetable tallow (60–70%, section 3.3.6) and animal fats from pig, sheep and cattle (20–37%, section 3.4.2).

Despite popular impression, stearic acid (18:0) is less common than palmitic. It is present in most vegetable fats, though a significant component in only a few, such as the vegetable butters: cocoa butter (30–36%, section 3.3.7), illipe or Borneo tallow (46%, section 3.3.17) and shea butter (44%, section 3.3.32). Present in most animal fats, it is a major

component in the tallow of ruminant animals (5–40%, section 3.4.2).

### 3.2.3 Long-chain acids

Saturated acids of molecular weight greater than that of stearic acid are major components in only a few uncommon seed oils. Arachidic (20:0), behenic (22:0) and lignoceric acid (24:0) are minor components of groundnut oil (total 5–8%, section 3.3.15) and this is probably the most convenient source of these acids. They are nevertheless present in larger amounts in the less well known seed oils of the Leguminosae and Sapindaceae. For example, rambutan tallow (*Nephelium lappaceum*, ca 35%) and kusum (*Schleichera trifuga*, 20–30%) are rich in arachidic acid. Behenic acid is a major component in *Lophira alata* (15–30%) and *L. procera* (20%) seed fats. Erucic acid from high-erucic rape provides on hydrogenation a ready source of behenic acid. Saturated acids with 24 to 30 carbon atoms are present as ester waxes in a number of commercially available waxes (section 3.6). See Hilditch and Williams (1964) for further information.

### 3.2.4 Oleic acid

Oleic acid, the most widely distributed of all the natural fatty acids, is present in practically all lipids and is a significant component in sources such as those listed below. Many of these are commercially available and are discussed in more detail in section 3.3. The least familiar is *Jessenia bataua*, which is a native Amazonian palm. Its oil is considered as a potential replacement for olive oil. The octadecenoic acids of plant origin are mainly oleic acid, though the 11c isomer is frequently present at low levels. Those of animal origin may contain other isomers.

Animal and vegetable fats rich in oleic acid include: filbert nuts (73–80%), *J. bataua* (70–76%), olive (section 3.3.23), almond (65–70%), pistachio (62–73%), pecan (53–67%), macadamia (50–59%), cashew (53–61%), zero-erucic rape (section 3.3.27), groundnut (section 3.3.15), shea nut (section 3.3.32), lard (section 3.4.2), palm (section 3.3.24), beef tallow (section 3.4.2), mutton fat (section 3.4.2), cocoa butter (section 3.3.7), illipe (section 3.3.17), high-oleic sunflower (section 3.3.35) and high-oleic safflower (section 3.3.29).

\* Further information on these acids is given in Chapter 1.

*Euphorbia lathyris* (caper spurge) is a Mediterranean annual containing about 50% of oil in its seed and 80–90% of oleic acid in its oil. The seed shatters and the plant contains a co-carcinogenic milky sap, but attempts are being made to get round these problems.

### 3.2.5 Linoleic acid

Many vegetable oils available on a commercial scale are rich in linoleic acid and are employed extensively for dietary purposes in a refined state or after some modification, such as partial hydrogenation, which removes some of the linoleic acid, or inter-esterification, which does not. Some of these oils also contain linolenic acid at a lower level and are discussed in greater detail in several subsections of section 3.3. Oils with a significant proportion of linolenic acid are used mainly for industrial purposes (section 3.2.6). Oils rich in linoleic acid include safflower (section 3.3.29), sunflower (section 3.3.35), black walnut (~58%), corn (section 3.3.9), English walnut (~57%), soybean (section 3.3.33), cottonseed (section 3.3.10), pine nut (~46%), sesame (section 3.3.31) and groundnut (section 3.3.15).

### 3.2.6 Linolenic acid ( $\alpha$ and $\gamma$ )

The most readily available source of  $\alpha$ -linolenic acid is linseed oil (section 3.3.19), which normally contains 45–60% of this acid. Other oils, richer in linolenic acid, but less readily available, include chia, camphor, black sesame and perilla (all in the range 60–70%). Candlenut (25–35%) and rubber (20–25%) contain useful quantities of linolenic acid in their seed oils along with appreciable proportions of linoleic acid (35–50 and 35–40% respectively). All of these can be used as drying oils, as can many of the linoleic-rich oils (section 5.5).

Linolenic acid is the major fatty acid of plant leaves, stems and roots and is also a significant component of other photosynthetic organisms. See Hilditch and Williams (1964) for more details.

$\gamma$ -Linolenic acid is present in evening primrose (section 3.3.13), borage and blackcurrant seed oils, and these oils are now readily available.

### 3.2.7 Petroselinic acid

Petroselinic acid (16c-18:1) is an isomer of oleic acid that occurs widely in seed oils of the order Umbelliferae (35–85%), usually along with oleic acid

and other saturated and unsaturated acids. The co-occurrence of petroselinic and oleic acids complicates the analysis of these seed oils, and the two isomers are usually distinguished after ozonolysis.  $^{13}\text{C}$  NMR spectroscopy can also be used for this purpose (section 9.3). Kleiman and Spencer (1982) analysed over 200 petroselinic acid-containing oils and designated 14 that were especially rich sources of this acid. These contained 32–50% of oil and the oil had 52–87% of petroselinic acid. There is interest in developing coriander as a new crop.

### 3.2.8 Erucic acid

Although erucic acid (13c-22:1) is present in seed oils of most Cruciferae, reaching a level of 80% in nasturtium seed oil, the most important erucic-containing oils are those from rape, mustard and *Crambe abyssinica* (sections 3.3.27, 3.3.21 and 3.3.11). The last of these is a potential new crop with 55–60% of erucic acid. Mustard seed (22–50%) is widely cultivated in Asia, but high-erucic rapeseed oil is the most important. High-erucic acid rape oils contain up to 50% of erucic acid along with 7–10% of the  $\text{C}_{20}$  homologue. Even higher levels of erucic acid are being achieved through plant breeding.

Most of the present interest is in zero-erucic rape oils (section 3.3.27). This is one of the few oils produced on a commercial scale in cooler climates and is being cultivated increasingly.

### 3.2.9 Epoxy acids

The structure of natural epoxy acids (section 1.9) and their synthesis by oxidation of appropriate unsaturated acids (section 10.4) are described elsewhere. Reference should also be made to the sections dealing with sal (section 3.3.30) and with *Vernonia* oil (section 3.3.41).

The best-known and most widely occurring of the natural epoxy acids is vernolic acid (12,13-epoxy-oleic), which is present in the seed lipids of several different plant families. Rich sources of the acid include the seed oils of *Vernonia anthelmintica* (72%), in which it was first discovered, *V. galamensis* (73–78%), Stokes aster (65–79%), *Cephalocroton cordofanus* (62%), *Euphorbia lagascae* (57–62%), *Erlangea tomentosa* (52%), *Crepis aurea* (52–54%) and *Crepis biennis* (68%). *Crepis* oils are of interest in that some contain vernolic acid, others contain crepenynic acid and yet others contain both these acids, even though there is no accepted biosynthetic relationship between the two. Most samples of

vernolic acid are the (+) isomer but seed oils of the Malvaceae contain the (–) isomer.

Coronaric acid (9,10-epoxyoctadec-12-enoic), a positional isomer of vernolic acid, is the second most common epoxy acid, and sometimes the two acids co-occur. It is present, for example, in the seed oils of *Chrysanthemum coronarium* (14%), *Helichrysum bracteatum* (14%, including some 9,10-epoxyoctadec-12-ynoic acid) and *Xeranthemum annuum* (8%, along with vernolic acid and 9,10-epoxystearic acid).

9,10-Epoxystearic acid occurs as its *cis* (both (+) and (–) forms) and *trans* isomers. The latter is present in orozu (sulphur olive oil), whilst sal fat contains the (+)-*cis*-epoxy acid.

### 3.2.10 Hydroxy acids

Hydroxy acids (section 1.8) do not occur very extensively, though they are present in sphingolipids, stilingia oil (section 3.3.34), waxes (section 3.6) and in fungal (section 3.13) and bacterial lipids (section 3.14). The best-known hydroxy acid is ricinoleic acid, which is the major component of the readily available castor oil (section 3.3.4). The structures of the natural hydroxy acids have been discussed in section 1.8, where there is also an account of the occurrence of the less common members.

The presence of the hydroxyl group sometimes leads to their natural occurrence in unusual forms, so that in addition to conventional triacylglycerols they may be present as glycerides with more than three acyl groups, as ester waxes, as polymers, or as lactones.

### 3.2.11 Acetylenic acids

Acetylenic acids occur in a number of rare seed oils and in some mosses. No oil containing acetylenic acids is available commercially.

Tariric acid (6a-18:1) occurs in the seed oils of several *Picramnia* species, reaching 95% in *P. sow* (Steger and van Loon, 1933). Crepenynic acid (9c,12a-18:2) has been recognized in several species of *Crepis* (0–65%) (Earle *et al.*, 1966), in *Saussurea candicans* (33%) (Smith, 1974) and in several *Azelaia* species (17–36%) (Gunstone *et al.*, 1972). Helenynolic acid (9-OH 10t,12e-18:2) is present in *Helichrysum bracteatum* (70%) (Powell *et al.*, 1965). The more complex acetylenic acids listed in Table 1.5 generally co-occur and several have been found in *Ximenia caffra* (Ligthelm and Schwartz, 1950), *Santalum album* (Gunstone and Russell, 1955),

*S. acuminatum* (Bu'lock and Smith, 1963), *Onguekoa gore* (Gunstone and Sealy, 1963; Morris, 1963), *Acanthosyris spinescens* (Powell *et al.*, 1966) and *Pyrularia pubera* (Hopkins and Chisholm, 1968).

### 3.2.12 Conjugated diene and triene acids

The most convenient source of conjugated diene acids is via the dehydration of castor oil (section 3.3.4) by heating (~250 °C) in the presence of an acidic catalyst. The product is complex and the dienes produced from ricinoleate are both conjugated (mainly Δ9,11) and non-conjugated (mainly Δ9,12) in the proportion 1:3 or 1:4. Several configurational isomers are produced, and double-bond migration complicates the product further. Alkaline isomerization of linoleic-rich oils also produces conjugated dienes (Δ9,11 and Δ10,12), but these processes have not proved to be of commercial value.

Conjugated octadecatrienoic acids are available in tung oil (α-eleostearic acid, 70–80%, section 3.3.39), in oiticia oil (licanic acid, ~80%, section 3.3.22) and in the seeds of some cucurbitaceae (punicic acid, ~20%). The occurrence of other isomers has been listed in Table 1.4.

Attempts are being made to develop calendula as a new crop (section 3.43).

### 3.2.13 Branched-chain acids

Branched-chain acids (for structures, see section 1.6) occur widely but mainly at low levels in animal fats, some marine oils and in the lipids of micro-organisms. They are very rare in plant lipids. They may be encountered in butter fats (section 3.4.1), tallows (section 3.4.2), bacterial lipids (section 3.14) and waxes (section 3.6). In this last group they may be a significant component of the total fatty acids. This is particularly true of skin lipids (including wool wax and vernix caseosa – the wax covering the newborn human) and of the uropygial waxes of birds. Branched-chain acids are major components of the lipids of Gram-positive bacteria (section 3.14). Wool wax is a convenient source of some acids of this class.

### 3.2.14 Cyclopropene acids

Cyclopropene acids such as sterculic and malvalic acids (section 1.7), frequently accompanied by their dihydro derivatives (cyclopropane acids), occur widely in plant families of the order Malvales (Sterculiaceae, Malvaceae, Bombaceae and other

families) but are not confined to these. In addition to the seeds, the cyclic acids are found in leaves, stems and roots and are present mainly as glycerides. The occurrence of these compounds has been reviewed by Christie (1970) and Badami and Patil (1982). Particularly rich sources of these acids include: malvalic acid in *Gnetum gnomen* (39%), *Pterospermum acerifolium* (32%), *Adansonia za* (28%) and *Eriolaena hookeriana* (26%); sterculic acid in *Sterculia foetida* (65%), *Bombacopsis glabra* (35%) and *Bombax oleaginum* (30%); and dihydrosterculic acid in *Litchi sinensis* (41%). 2-Hydroxysterculic acid has been recognized in *Pachira insignis* (~20%) and *Bombacopsis glabra* (~10%) and sterculynic acid in *Sterculia alata* (8%).

### 3.2.15 Allenic acids

Stillingia oil (section 3.3.34) contains a C<sub>8</sub> allenic acid. C<sub>18</sub> allenic acids have been identified in seed oils of the Labiatae, especially in the subfamily Stachyoideae (Hagemann *et al.*, 1967). Laballenic acid (5*e*,6*e*-18:2) was first identified in *Leonotis nepetaefolia* (~15%) (Bagby *et al.*, 1965) and lamallenic acid (5*e*,6*e*,16*t*-18:3) in *Lamium purpureum* (~14%) (Mikolajczak *et al.*, 1967).

### References and further reading

- Badami, R.C. and Patil, K.B. (1982) *Prog. Lipid Res.*, **19**, 119.
- Bagby, M.O., Smith, C.R. and Wolff, I.A. (1965) *J. Org. Chem.*, **30**, 4227.
- Bu'lock, J.D. and Smith, G.N. (1963) *Phytochemistry*, **2**, 289.
- Christie, W.W. (1970) *Top. Lipid Res.*, **1**, 1.
- Earle, F.R. (1970) *J. Am. Oil Chem. Soc.*, **47**, 510.
- Earle, F.R., Barclay, A.S. and Wolff, I.A. (1966) *Lipids*, **1**, 325.
- Gunstone, F.D. and Russell, W.C. (1955) *J. Chem. Soc.*, 3782.
- Gunstone, F.D. and Sealy, A.J. (1963) *J. Chem. Soc.*, 5772.
- Gunstone, F.D., Steward, S.R., Cornelius, J.A. and Hammonds, T.W. (1972) *J. Sci. Food Agric.*, **23**, 53.
- Hagemann, J.M., Earle, F.R., Wolff, I.A. and Barclay, A.S. (1967) *Lipids*, **2**, 371.
- Hilditch, T.P. and Williams, P.N. (1964) *The Chemical Constitution of Natural Fats*, 4th edn, Chapman & Hall, London.
- Hopkins, C.Y. (1972) *Top. Lipid Chem.*, **3**, 37.
- Hopkins, C.Y. and Chisholm, M.J. (1968) *J. Am. Oil Chem. Soc.*, **45**, 176.
- Kleiman, R. and Spencer, G.F. (1982) *J. Am. Oil Chem. Soc.*, **59**, 29.
- Kolattukudy, P.E. (ed.) (1976) *Chemistry and Biochemistry of Natural Waxes*, Elsevier, Amsterdam.
- Krewson, C.F. (1968) *J. Am. Oil Chem. Soc.*, **45**, 250.
- Lessman, K.J. and Anderson, W.P. (1981) *New Sources of Fats and Oils* (eds E.H. Pryde, L.H. Princen and K.D. Mukherjee), American Oil Chemists' Society, Champaign, p. 223.
- Ligthelm, S.P. and Schwartz, H.M. (1950) *J. Am. Chem. Soc.*, **72**, 1868.
- Mikolajczak, K.L., Rogers, M.F., Smith, C.R. and Wolff, I.A. (1967) *Biochem. J.*, **105**, 1245.
- Morris, L.J. (1963) *J. Chem. Soc.*, 5779.
- Morrison, W.R. (1970) *Top. Lipid Chem.*, **1**, 51.
- Powell, R.G., Smith, C.R. and Wolff, I.A. (1965) *J. Am. Oil Chem. Soc.*, **42**, 165.
- Powell, R.G., Smith, C.R., Glass, C.A. and Wolff, I.A. (1966) *J. Org. Chem.*, **31**, 528.
- Smith, C.R. (1974) *Lipids*, **9**, 640.
- Steger, A. and van Loon, J. (1993) *Rec. Trav. Chim.*, **52**, 593.
- Wolf, R.B., Graham, S.A. and Kleiman, R. (1983) *J. Am. Oil Chem. Soc.*, **60**, 103.

### 3.3 Major vegetable fats

#### 3.3.1 Aceituno oil

[*Simarouba glauca*; Quassia]

There is no reliable information available on world production. Other information is summarized in Tables 3.2 to 3.4.

The oil is obtained from the seeds of the 'Central American' or Salvador plant, which grows in Central and South America (Eckey, 1954). The tree is widely used to mark boundaries. The species was imported into India from Brazil in 1966 and large-scale plantations have been established (Satpathi, 1984; Rath, 1987). The fruit, similar to an olive, has a sweet edible pulp and contains seeds of which 30% is kernel and 70% shell.

**Table 3.2** Typical fatty acid composition (wt%) of aceituno oil

| 14:0            | 16:0 | 18:0 | 20:0 | 16:1 | 18:1 | 18:2 | 18:3 |
|-----------------|------|------|------|------|------|------|------|
| tr <sup>a</sup> | 11.5 | 27.5 | 1.5  | tr   | 57.5 | 2.0  | tr   |

<sup>a</sup> Throughout these tables tr indicates 'trace'.

**Table 3.3** Characteristics of aceituno oil: typical values (Lognay *et al.*, 1981)

|                                           |                       |
|-------------------------------------------|-----------------------|
| Relative density                          | Not available         |
| Refractive index, $n_D^{40}$ <sup>a</sup> | 1.4596                |
| Saponification value                      | 192, 198 <sup>b</sup> |
| Iodine value                              | 58, 51 <sup>b</sup>   |
| Unsaponifiable matter (%)                 | 0.4                   |
| Oil content of dry kernel (%)             | 55–65                 |

<sup>a</sup> Refractive index of sodium D line at 40°C.

<sup>b</sup> Two typical values.

**Table 3.4** Typical triglyceride composition of aceituno oil (Lognay *et al.*, 1981)

| S <sub>3</sub> <sup>a</sup> | SOS | SSO | SOO | SL | SLO | OOO | Others |
|-----------------------------|-----|-----|-----|----|-----|-----|--------|
| 1                           | 29  | 3   | 42  | 1  | 2   | 15  | 7      |

<sup>a</sup> S, saturated; O, oleic; L, linoleic.

**Table 3.5** World production of babassu oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1983/84 |
|---------|---------|---------|---------|
| 105     | 170     | —       | 130     |

The semi-solid fat, isolated by expelling and extraction, is used directly as a component of vegetable shortenings. It can be converted to a vegetable butter by either partial hydrogenation or fractionation. The meal is toxic to livestock (Bhatnagar *et al.*, 1983).

#### 3.3.2 Babassu oil

[*Orbignya martiana*, *O. oleifera*;  
Palmaceae]

Information is summarized in Tables 3.5 to 3.8. The plant is one of a group of Central and South American palms of which babassu and tucum oils are of greatest economic importance. The problems facing larger-scale production of babassu and its effect on small farmers has been discussed (May *et al.*, 1985; Reufels, 1989). Babassu fruits are relatively large (20 cm long, 10 cm diameter) and have a particularly hard, thick shell. Special machines have been designed to crack the nut to obtain the four to eight kernels it contains.

**Table 3.6** Fatty acid composition (wt%) of babassu oil

| 8:0 | 10:0 | 12:0 | 14:0 | 16:0 | 18:0 | 18:1 | 18:2 |
|-----|------|------|------|------|------|------|------|
| 6   | 4    | 45   | 17   | 9    | 3    | 13   | 3    |

**Table 3.7** Characteristics of babassu oil: values from draft Codex (Codex, 1979 and 1993)

|                                                       |                  |
|-------------------------------------------------------|------------------|
| Relative density, $d_{20}^{25}$ <sup>a</sup>          | 0.914–0.917      |
| Refractive index, $n_D^{40}$                          | 1.448–1.451      |
| Saponification value                                  | 245–256          |
| Iodine value                                          | 10–18            |
| Unsaponifiable matter (g/kg)                          | Not more than 12 |
| Reichert value                                        | 4.5–6.5          |
| Polenske value                                        | 8–10             |
| GLC <sup>b</sup> ranges of fatty acid composition (%) |                  |
| 8:0                                                   | 2.6–7.3          |
| 10:0                                                  | 1.2–7.6          |
| 12:0                                                  | 40–55            |
| 14:0                                                  | 11–27            |
| 16:0                                                  | 5.2–11           |
| 18:0                                                  | 1.8–7.4          |
| 18:1                                                  | 9.0–20           |
| 18:2                                                  | 1.4–6.6          |

<sup>a</sup> Density at 25°C compared with water at 20°C.

<sup>b</sup> Gas-liquid chromatography.

**Table 3.8** Fatty acid composition of South American palmkernel oils

|                       | 8:0 | 10:0 | 12:0 | 14:0 | 16:0 | 18:0 | 18:1 | 18:2 |
|-----------------------|-----|------|------|------|------|------|------|------|
| Babassu               | 6   | 4    | 45   | 17   | 9    | 3    | 13   | 3    |
| Cohune                | 8   | 7    | 46   | 16   | 9    | 3    | 10   | 1    |
| Murumuru              | 1   | 1    | 42   | 37   | 5    | 2    | 11   | 1    |
| Ouricuri <sup>a</sup> | 10  | 8    | 46   | 9    | 8    | 2    | 13   | 2    |
| Tucum                 | 1   | 4    | 49   | 22   | 6    | 2    | 13   | 3    |

<sup>a</sup> Also 6:0, 2%, and 20:0, tr.

The oil provides an alternative to coconut and palmkernel oils and is used both as an edible oil and in soap-making (Arkcoll, 1988).

The compositions of some other South American palmkernel oils, cohune (*Attalea cohune*), murumuru (*Astrocaryum murumuru*), ouricuri (*Syagrus coronata*) and tucum (*Astrocaryum vulgare*), are compared with babassu in Table 3.8 (see also Table 3.91).

The lactones in babassu have been characterized (Van der Ven and de Jong, 1970; Hulsker *et al.*, 1989).

### 3.3.3 Buffalo gourd oil

[*Cucurbita foetidissima*; Cucurbitaceae]

World production is not commercialized. Other information is summarized in Tables 3.9 and 3.10. Buffalo gourd has been studied as a potential commercial source of vegetable oil for many years. The gourds grow on vine-like plants, which come to maturity in their second year of planting. The plant is of interest because it grows on land too dry to support

**Table 3.9** Fatty acid composition (wt%) of buffalo gourd oil

| 16:0 | 18:0 | 18:1 | 18:2            |
|------|------|------|-----------------|
| 9    | 2    | 25   | 64 <sup>a</sup> |

<sup>a</sup> Of which 2.3% is conjugated.

**Table 3.10** Characteristics of buffalo gourd oil: reported values

|                              |               |
|------------------------------|---------------|
| Relative density             | Not available |
| Refractive index, 25 °C      | 1.471         |
| Saponification value         | 201           |
| Iodine value                 | 144           |
| Unsaponifiable matter (g/kg) | 0.94          |
| Oil content of seed (%)      | 28.5          |

other crops. It is indigenous to both arid and temperate regions, and grows in many parts of the USA, northern Mexico, Lebanon and India.

The crop has not been commercialized but increasing interest is being shown in the USA. Experimental plantings in Texas yielded between 300 and 900 kg of seed per acre.

The oil is high in linoleic acid and contains 2–3% conjugated 18:2 (Bemis *et al.*, 1978; Vasconcellos *et al.*, 1981; Vasconcellos and Berry, 1982). It has been fed to rats and to chickens without ill effects (Vasconcellos *et al.*, 1981; Khoury *et al.*, 1982). Laboratory-refined oil gave a peroxide value of 100 after 4.9 h under active oxygen method (AOM) stability test conditions (Vasconcellos *et al.*, 1981).

The botany, applications and food quality have been reviewed (Scheerens and Berry, 1986; Wright, 1988; Thompson, 1990).

### 3.3.4 Candlenut oil (lumbang oil)

[*Aleurites moluccana*, *A. trisperma*; Geraniales]

World production is not significant. Composition is given in Table 3.11. The seeds come from a tropical tree widely distributed in Australia, Sri Lanka, Hawaii, Java and Malaysia. The oil gets its name from the custom of stringing the nuts on bamboo and using them for lighting. The oil is not appreciably commercialized, but there has been a significant interest in the oil over a number of years because of its high unsaturation.

The kernels contain 57–69% oil similar to linseed oil but of slightly lower iodine value. The triacylglycerol composition is given in Table 3.159 (see also Afaque *et al.*, 1987).

**Table 3.11** Fatty acid composition (wt%) of candlenut oil

| 16:0 | 18:0 | 18:1 | 18:2 | 18:3 |
|------|------|------|------|------|
| 5.5  | 6.7  | 10.5 | 48.8 | 28.5 |

### 3.3.5 Castor oil

[*Ricinus communis*; Euphorbiaceae]

Summary information is given in Tables 3.12 to 3.15. This is the only commercially important oil that con-

**Table 3.12** Castor oil production, exports and disappearance (1000 tonnes)

|                      | 1982  | 1986  | 1990  |
|----------------------|-------|-------|-------|
| <b>Production</b>    |       |       |       |
| India                | 112.0 | 109.4 | 178.3 |
| Brazil               | 84.9  | 131.7 | 83.9  |
| China                | 44.3  | 51.0  | 77.5  |
| West Germany         | 10.8  | 16.3  | 16.5  |
| Thailand             | 14.3  | 13.9  | 17.7  |
| Italy                | 4.5   | 4.5   | 3.6   |
| Ecuador              | 3.5   | 2.6   | 2.2   |
| <b>Exports</b>       |       |       |       |
| India                | 59.1  | 48.0  | 122.0 |
| Brazil               | 54.7  | 98.7  | 45.0  |
| China                | 10.1  | 14.3  | 15.3  |
| West Germany         | 3.4   | 4.8   | 5.7   |
| Thailand             | 14.7  | 8.4   | 4.2   |
| Ecuador              | 3.8   | 2.0   | 1.6   |
| USA                  | 0.4   | 1.5   |       |
| Netherlands          | 1.3   | 1.1   | 0.9   |
| France               | 0.3   | 0.5   | 0.5   |
| UK                   | 0.3   | 0.2   | 0.2   |
| Italy                | 0.1   | 1.2   | 0.1   |
| Belgium              | 0.1   | 0.1   | 0.1   |
| Sweden               | 0.1   |       |       |
| <b>Disappearance</b> |       |       |       |
| Soviet Union         | 62.7  | 60.1  | 62.1  |
| China                | 34.3  | 38.8  | 55.7  |
| India                | 47.9  | 57.8  | 54.1  |
| France               | 37.9  | 46.8  | 53.7  |
| Brazil               | 31.5  | 27.2  | 31.9  |
| USA                  | 30.5  | 33.5  | 29.9  |
| West Germany         | 21.5  | 20.5  | 24.0  |
| Japan                | 17.2  | 19.0  | 19.2  |
| Thailand             | 5.5   | 16.5  |       |
| Italy                | 5.4   | 7.2   |       |
| UK                   | 8.3   | 6.8   |       |
| Poland               | 2.2   | 5.0   | 4.7   |
| Romania              | 2.6   | 3.4   | 4.1   |

Source: *Oil World Annual*

**Table 3.13** Fatty acid composition (wt%) of castor oil

| 16:0 | 18:0 <sup>a</sup> | 18:1 | 18:2 | 18:3 | 18:1(OH) <sup>b</sup> |
|------|-------------------|------|------|------|-----------------------|
| 1    | 1                 | 3    | 4    | tr   | 90                    |

<sup>a</sup> Dihydroxystearic acid.

<sup>b</sup> Ricinoleic acid.

tains a hydroxy fatty acid, 12-hydroxyoctadecenoic acid (ricinoleic), as its major component (sections 1.8 and 3.2.10). Its history has been traced back to the Egyptians, who used it in embalming.

The castor plant is normally cultivated as an annual, but it can be grown as a perennial herb to a height of 8 m. The development of shatter-resistant varieties will aid the mechanical harvesting of the seed (8–15 mm long depending on variety). Brazil, India, the former USSR and USA are the main producers.

The relationship between cultivation site and time of sowing on fatty acid composition has been studied (Conte *et al.*, 1984). Site influenced the content of ricinoleic acid.

The oil is isolated by pressing and solvent extraction. The first pressing yields No. 1 oil (USA), a virtually colourless oil (free fatty acid 2%) suitable for medicinal use. The residual meal contains three toxins: ricinine, a mildly toxic alkaloid; ricin, an extremely poisonous protein; and a heat-stable allergen, which forms approximately 12% of the cake. The seed also contains a very active lipase.

The properties of castor oil are dictated by the triacylglycerols of the hydroxy acid (ricinoleic), which is strongly dextrorotatory. The oil is more viscous than normal oils. It has limited solubility in petroleum solvents but is soluble in alcohol and other polar solvents. The oil is, however, sufficiently soluble in hot hexane for this to be used in seed extraction.

The determination of the fatty acid composition of castor oil by gas-liquid chromatography (GLC) normally relies on first converting the hydroxy acid to a less polar derivative, e.g. acetate or trimethylsilyl ether. Great care must therefore be exercised in carrying out the derivatization and analysis to obtain meaningful results (Sreenivasan, 1969; Wood *et al.*, 1965). In addition to the major acids, an optically active 9,10-dihydroxystearic acid is present (*ca* 1%) (King, 1942).

An analysis of 36 castor bean varieties gave a range of 83 to 90% ricinoleic acid (Ramos *et al.*, 1984). A similar range for ricinoleic acid content (87–90%) was found in 17 varieties of castor seed grown in India (Lakshminarayana *et al.*, 1984).

The triacylglycerols of castor oil consist mainly of triricinolein and other triacylglycerols containing two ricinoleic acyl groups (Table 3.15).

The composition of the triterpene alcohols, 4-methylsterols and sterols are given in Tables 3.163–3.165.

The tocopherol content of a castor oil as determined by thin-layer chromatography (TLC) was  $\alpha$ -tocopherol 28 mg/kg,  $\beta$ -tocopherol 29 mg/kg,  $\gamma$ -toco-

**Table 3.14** Characteristics of castor oil

|                                 | Typical No. 1 oil  | American Oil Chemists' Society (1946) |
|---------------------------------|--------------------|---------------------------------------|
| Relative density, $d_{25}^{25}$ | 0.957–0.961        | 0.945–0.965                           |
| Refractive index, 25 °C         | –                  | 1.473–1.477                           |
| Saponification value            | 179–185            | 176–187                               |
| Iodine value                    | 82–88              | 81–91                                 |
| Unsaponifiable matter (%)       | –                  | 1.0                                   |
| Hydroxyl value                  | 160–168            | –                                     |
| Acetyl value                    | –                  | 144–150                               |
| Acid value                      | 2–3                | –                                     |
| Colour (Gardner)                | 1–2                | –                                     |
| Viscosity, 25 °C (St)           | 6.5–8.5            | –                                     |
| Oil content of seed (%)         | 35–55 (typical 44) | –                                     |

**Table 3.15** Triacylglycerol composition of castor oil (Achaya and Craig, 1964)

| RRR <sup>a</sup> | RRO | RRSt | RRL | Others |
|------------------|-----|------|-----|--------|
| 68               | 7.5 | 5    | 8.5 | 11     |

<sup>a</sup> R, ricinoleic acid; O, oleic, St, stearic; L, linoleic.

pherol 111 mg/kg and  $\delta$ -tocopherol 310 mg/kg. A range of 400–500 mg/kg total tocopherol has been reported (Muller-Mulot, 1976).

Unmodified castor oil is not used in edible products apart from its limited medicinal use. It is mainly used as a component of paints and varnishes after dehydration (dehydrated castor oil, DCO), where it is noted for its non-yellowing characteristics. Castor oil is used as a lubricant and is also added directly to alkyd and urethane systems as a plasticizer. The condensation of castor oil at high temperature yields polyglycerol polyricinoleate, which has unusual surface-active properties. When used in chocolate it reduces the yield value to virtually zero (Bamford *et al.*, 1970). The chemistry and uses of castor oil have been reviewed (INFORM, 1991).

Castor oil is converted to numerous derivatives typified by the following reactions.

1. Pyrolysis of methyl esters at 450–500 °C to give methyl 10-undecenoate. The acid is an intermediate in the manufacture of perfumes and polymers. Derivatives are also used in the manufacture of nylon-11, an engineering plastic.
2. Pyrolytic decomposition in the presence of alkali at 250–275 °C yields sebacic acid, 2-octanol and hydrogen. Sebacic acid (decanedioic acid) is condensed with hexamethylenediamine in the manufacture of nylon-6,10.

3. Esterification of the hydroxyl group with sulphuric acid gives 'turkey red oil', which has excellent wetting and emulsification characteristics. Sulphated oils are used in the textile industry to assist fibre wetting and as a dyeing agent (Kremers, 1971).
4. Hydrogenation to give hydrogenated castor oil, which is used in solvent-thinned paints to introduce thixotropy. Hydroxystearic acid (Naughton, 1974) is reported to gel hydrocarbon oils (Tachibana and Kambara, 1968). Salts of castor oil acids, e.g. lithium, are used in solid greases.
5. Dehydration by heating (230–280 °C) under vacuum with a suitable catalyst (e.g. mineral acids or acid clays) converts the hydroxyoleic acid to a mixture of geometric and positional isomers of octadecadienoic acid, both conjugated and non-conjugated (Achaya, 1971; Body and Shorland, 1965; Von Mikusch, 1955).

## 3.3.6 Chinese vegetable tallow and stillingia oil [*Sapium sebiferum*, *Stillingia sebifera*; Euphorbiaceae]

There are no current data on production available from China. Other information is given in Tables 3.16–3.18. Between 1951 and 1956 an average of 800 tonnes per year of stillingia oil was imported into the UK at between £70 and £126/tonne.

The Chinese tallow tree, a deciduous tree, has been cultivated in China for centuries, partly because the leaves yield a black dye used for dyeing silk. The tree grows to a height of 7–10 m under wet subtropical conditions and is found in China, the USA and Pakistan. Recent studies suggest that with proper harvesting techniques it could provide an oil yield per

hectare similar to the oil palm (Morgan and Shultz, 1981; Glumac and Cowles, 1990).

Chinese vegetable tallow (Hopper and Nesbitt, 1937; Gupta and Meara, 1950; Jeffrey and Padley, 1991) is obtained from the outer seed coating (ca 50% of fat) by hexane extraction prior to crushing. Stillingia oil, a drying oil, is obtained from the seed kernel by solvent extraction after crushing. The tallow is of potential interest as an edible oil, for example in confectionery (Itagaki *et al.*, 1989; Qing, 1989). It is reported to be widely used in China both for edible use and soap-making. The edibility of the tallow will depend, amongst others, on the ability to produce a material free of stillingia oil (Jeffrey and Padley, 1991). The kernel oil has been used in paints and varnishes.

Chinese vegetable tallow consists primarily of trisaturated triacylglycerols (25%) and 2-oleo-disaturated triacylglycerols (70%), of which the major components are tripalmitin and 2-oleodipalmitin respectively (Wang *et al.*, 1988; Jeffrey and Padley, 1991).

Stillingia oil, the kernel oil, is unusual in that it contains significant amounts of deca-2,4-dienoic acid (8–10%) and the optically active allenic acid 8-hydroxy-octa-2,3-dienoic acid (8–10%) (Sprecher *et al.*, 1965; Christie, 1969). These short-chain acids are present as a C<sub>18</sub> estolide, which can be

separated by chromatography (Payne-Wahl and Kleiman, 1983; Jeffrey and Padley, 1991) (sections 1.4, 1.5, 1.8, 3.2.10 and 3.2.15).

### 3.3.7 Cocoa butter

[*Theobroma cacao*; *Sterculia*]

Data are summarized in Tables 3.19–3.27. The commercial exploitation of cacao or cocoa beans was probably first practised by the Aztecs. The Spanish introduced the bean from Mexico into Europe in the sixteenth century, where it was consumed as a drink. Chocolate was not developed until the nineteenth century (Minnifie, 1980).

The cocoa plant is an evergreen tree growing 5–10 m in height but normally 6 m. It originated in tropical rainforests and grows within 20° of the equator (Martinson *et al.*, Alvim, 1989). The flowers and fruit grow from eyes or cushions located directly on either the main trunk or heavier branches of the tree. Flowers and fruit are born continually but harvesting reaches a maximum at certain times of the year. The fruit is a large pod approximately 15–20 cm long and 7 cm in diameter. The pod contains between 25 and 50 seeds or beans embedded in a soft, sweet, edible pulp.

The normal practice is to allow the beans with the adhering pulp to ferment after placing in boxes or heaps. Fermentation liquefies the pulp, which can be drained away. The flavour of the beans is also partly developed at this stage. The beans are then dried to 6–8% moisture. The full flavour of the beans is developed by roasting, which introduces a range of flavour compounds including pyrazine and flavanoids

**Table 3.16** Fatty acid composition (wt%) of Chinese vegetable tallow

| 14:0 | 16:0 | 18:0 | 18:1 | 18:2 |
|------|------|------|------|------|
| 4    | 62   | 6    | 27   | 1    |

**Table 3.17** Fatty acid composition (wt%) of stillingia oil

| 16:0 | 18:0 | $\omega$ -OH 8:2 | conj. 10:2 | 18:1 | 18:2 | 18:3 |
|------|------|------------------|------------|------|------|------|
| 5    | 2    | 5                | 5          | 13   | 23   | 47   |

**Table 3.18** Characteristics of Chinese vegetable tallow (Hopper and Nesbitt, 1937) and stillingia oil (Bolley and McCormack, 1950)

|                           | Vegetable tallow    | Stillingia oil      |
|---------------------------|---------------------|---------------------|
| Relative density          | Not available       | Not available       |
| Refractive index, $n_D$   | 1.455–1.457 (40 °C) | 1.482–1.484 (25 °C) |
| Saponification value      | 200–218             | 202–212             |
| Iodine value              | 16–29               | 169–191             |
| Unsaponifiable matter (%) | 0.5–1.3             | 0.5–3               |
| Oil content of seed (%)   | 20–23               | 10–17               |

## Occurrence and characteristics

(Marian, 1967; Rohan, 1969; Van der Waal *et al.*, 1968; Flament *et al.*, 1968; Mohr *et al.*, 1987).

Cocoa butter, a pale yellow solid at 20°C, is obtained by hydraulic pressing of the kernels or 'nibs' of cleaned, roasted and decorticated beans. The expelled butter (free fatty acids *ca* 1%) has a distinctive flavour and is used directly in confections.

**Table 3.19** World production (1000 tonnes) of cocoa beans

| 1970 | 1975 | 1980 | 1982 |
|------|------|------|------|
| 1541 | 1542 | 1557 | 1531 |

**Table 3.20** Fatty acid composition (wt%) of cocoa butter

| 14:0 | 16:0 | 18:0 | 20:0 | 22:0 | 16:1 | 18:1 | 18:2 | 18:3 |
|------|------|------|------|------|------|------|------|------|
| 0.1  | 26.0 | 34.4 | 1.0  | 0.2  | 0.3  | 34.8 | 3.0  | 0.2  |

**Table 3.21** Characteristics of cocoa butter, from draft Codex (Codex, 1979)

|                                 |             |
|---------------------------------|-------------|
| Relative density, $d_{15}^{20}$ | 0.856–0.864 |
| Refractive index, 40°C          | 1.453–1.458 |
| Saponification value            | 190–200     |
| Iodine value                    | 33–40       |
| Unsaponifiable matter (%)       | 0.2–0.6     |
| Oil content of whole bean (%)   | 40–50       |

**Table 3.22** Variation in the fatty acid composition (mol%) of cocoa butter <sup>a</sup> (Fincke, 1976)

|      |           |           |           |
|------|-----------|-----------|-----------|
| 14:0 | 0.02–0.16 | 16:1      | 0.1–0.4   |
| 16:0 | 23.6–30.5 | 18:1      | 33.2–38.2 |
| 17:0 | 0.1–0.2   | 18:2      | 2.2–4.8   |
| 18:0 | 30.2–36.5 | 18:3/20:1 | 0.3       |
| 20:0 | 0.7–1.4   |           |           |
| 22:0 | 0.2       |           |           |

<sup>a</sup> Data on 57 samples of authentic cocoa butters.

Lower-grade cocoa butter of higher free fatty acid content is normally refined and deodorized. Certain butters are also deodorized to control the flavour level in the final product. Cocoa butter is relatively very stable to oxidation. The cocoa bean and cocoa butter are used mainly as ingredients of chocolate (Minnifie, 1980), which is a finely ground mixture of roasted cocoa nibs, sugar, additional cocoa butter and also milk solids in the case of milk chocolate. Cocoa powder, the by-product from cocoa butter expelling, is used in a variety of confections and as the major ingredient of chocolate drinks. Cocoa powder contains up to 3% of theobromine and also caffeine.

The variation in fatty acid composition of cocoa

butter is given in Table 3.22. Typical glyceride compositions of some different types of cocoa butter are given in Tables 3.23, 3.24 and 3.158. The distribution of the major glycerides varies, but typical figures are POP 16%, POST 46%, StOSt 33% and others 5%, expressed as a percentage of total 2-oleo-disaturated triacylglycerols, SOS (P, palmitic; O, oleic; St, stearic; S, saturated). This is only an approximation. Factors regulating the synthesis of triacylglycerols in the maturing cocoa bean have been reviewed by Harwood (1991).

When the composition of the cocoa butter glycerides is expressed in terms of carbon number, as determined by GLC, a straight-line relationship between the C<sub>50</sub> and C<sub>54</sub> triglycerides is observed, and this can be used to detect adulterated cocoa butters (Padley and Timms, 1980; Fincke, 1980; Young, 1984; Chaveron and Verdoia, 1985).

The major triglycerides are reported to be racemic (Sampugna and Jensen, 1969). Changes in compo-

**Table 3.23** Typical glyceride compositions of cocoa butters of different origin <sup>a</sup> (Kattenberg, 1981)

|             | S <sub>3</sub> <sup>b</sup> | SOS  | SSO | S <sub>2</sub> L | SO <sub>2</sub> | SOL etc. |
|-------------|-----------------------------|------|-----|------------------|-----------------|----------|
| Ivory Coast | 1.6                         | 77.2 | 0.5 | 7.5              | 8.4             | 4.8      |
| Ghana       | 1.4                         | 76.8 | 0.4 | 6.9              | 8.4             | 6.1      |
| Cameroon    | 1.3                         | 75.2 | 0.5 | 7.1              | 11.0            | 4.9      |
| Brazil      | 1.0                         | 63.7 | 0.5 | 8.9              | 17.9            | 8.0      |

<sup>a</sup> Composition subject to natural variation.

<sup>b</sup> S, saturated; O, oleic; L, linoleic.

**Table 3.24** Triacylglycerol composition of a cocoa butters from different countries of origin (Chaiseri and Dimick, 1989)

|                    | Number of samples | Triacylglycerol (%) |     |      |      |      |       |      |       |      |
|--------------------|-------------------|---------------------|-----|------|------|------|-------|------|-------|------|
|                    |                   | PLP                 | POO | PLSt | POP  | StOO | StLSt | POST | StOSt | StOA |
| Bolivia            | 1                 | 1.1                 | 3.3 | 3.5  | 22.6 | 4.0  | 2.1   | 40.4 | 22.8  | 0.5  |
| Brazil             | 6                 | 0.9                 | 3.9 | 3.7  | 17.9 | 6.7  | 3.2   | 37.1 | 26.0  | 0.04 |
| Colombia           | 2                 | 1.1                 | 3.3 | 3.6  | 20.4 | 4.4  | 2.3   | 39.4 | 25.0  | 0.6  |
| Ecuador            | 3                 | 1.2                 | 3.0 | 3.2  | 19.2 | 5.4  | 2.3   | 38.4 | 26.9  | 0.4  |
| Peru               | 1                 | 1.5                 | 4.3 | 3.9  | 18.3 | 7.4  | 3.7   | 35.8 | 24.6  | 0.4  |
| Venezuela          | 1                 | 0.9                 | 1.0 | 3.1  | 20.4 | 2.8  | 1.9   | 40.4 | 28.8  | 0.8  |
| Costa Rica         | 1                 | 1.0                 | 2.6 | 3.5  | 17.8 | 5.5  | 3.0   | 38.7 | 27.4  | 0.4  |
| Dominican Republic | 4                 | 1.1                 | 3.3 | 3.2  | 18.4 | 6.1  | 2.7   | 38.2 | 26.5  | 0.6  |
| Guatemala          | 1                 | 1.0                 | 2.3 | 3.4  | 19.3 | 4.9  | 2.2   | 39.0 | 27.5  | 0.4  |
| Mexico             | 1                 | 1.1                 | 2.4 | 3.5  | 19.1 | 4.1  | 3.0   | 38.8 | 27.8  | 0.6  |
| Panama             | 1                 | 1.0                 | 1.5 | 3.0  | 19.1 | 3.1  | 2.7   | 41.4 | 27.3  | 0.8  |
| Cameroon           | 2                 | 1.0                 | 3.0 | 3.4  | 17.9 | 5.8  | 2.5   | 38.3 | 27.7  | 0.5  |
| Gabon              | 1                 | 0.9                 | 3.7 | 3.5  | 17.5 | 7.3  | 3.0   | 37.1 | 26.5  | 0.4  |
| Ghana              | 3                 | 1.2                 | 2.2 | 3.4  | 17.8 | 4.9  | 2.2   | 39.0 | 27.5  | 0.4  |
| Ivory Coast        | 9                 | 1.0                 | 1.9 | 3.0  | 19.0 | 3.9  | 2.5   | 39.6 | 28.5  | 0.6  |
| Nigeria            | 2                 | 1.0                 | 2.3 | 3.6  | 17.9 | 5.2  | 3.0   | 38.8 | 27.8  | 0.5  |
| Indonesia          | 2                 | 1.1                 | 1.6 | 3.0  | 19.9 | 3.6  | 1.7   | 40.6 | 28.1  | 0.5  |
| Malaysia           | 20                | 0.7                 | 1.2 | 2.8  | 18.4 | 2.9  | 2.2   | 40.0 | 31.1  | 0.8  |
| Solomon Islands    | 1                 | 1.0                 | 0.9 | 3.0  | 19.3 | 2.8  | 2.0   | 40.7 | 29.5  | 0.7  |

\* P, palmitic (16:0); St, stearic (18:0); A, arachidic (20:0); O, oleic (18:1); L, linoleic (18:2).

**Table 3.25** Tocopherols in cocoa butter (mg/kg) (Muller-Mulot, 1976)

|                      | Cocoa butter A<br>Non-deodorized | Cocoa butter B<br>Deodorized |
|----------------------|----------------------------------|------------------------------|
| $\alpha$ -Tocopherol | 10.9                             | 18.5                         |
| $\beta$ -Tocopherol  | tr                               | 3.9                          |
| $\gamma$ -Tocopherol | 170                              | 196                          |
| $\delta$ -Tocopherol | 17                               | 14                           |
| $\alpha$ -Tocopherol | 1.8                              | —                            |

**Table 3.26** Polymorphic behaviour of cocoa butter

| Willie and Lutton (1966) | Larsson (1966) | M.p. (°C) |
|--------------------------|----------------|-----------|
| Form I                   | $\beta_2'$     | 16–18     |
| Form II                  | $\alpha$       | 21–22     |
| Form III                 | Mixed          | 25.5      |
| Form IV                  | $\beta_1'$     | 27–29     |
| Form V                   | $\beta_2$      | 34–35     |
| Form VI                  | $\beta_1$      | 36        |

**Table 3.27** Solid fat content of typical West African cocoa butter

| Temperature (°C) | 20 | 25 | 30 | 32.5 | 35 |
|------------------|----|----|----|------|----|
| Solid fat (%)    | 76 | 69 | 32 | 8    | 0  |

sition during maturation have been studied, and an increase in temperature produces a more saturated cocoa butter (Lehrian *et al.*, 1980). The biosynthesis of lipids in the cocoa bean has been studied by Harwood (1991).

Numerous minor components including phospholipids (0.05–0.13%), tocopherols (200 mg/kg), flavours and hydrocarbons have been determined. The diglyceride content of cocoa butter (1.5–2.5%) has been compared with the diglyceride level and composition of other confectionery fats (Fincke, 1982); see also Table 3.160.

The compositions of the sterols, 4-methylsterols and triterpene alcohols are given in Tables 3.163–3.165.

The tocopherols present in non-deodorized and deodorized cocoa butters are given in Table 3.25. These, together with phenolic and other unidentified antioxidants, ensure that cocoa butter is very stable to autoxidation.

The melting and crystallization behaviour of cocoa butter is complicated because of the polymorphic behaviour of the major glycerides (Table 3.26). The crystal structure of symmetrical mono-unsaturated glycerides has been described (de Jong *et al.*, 1991; Hagemann and Rothfus, 1992). A more detailed study of the crystal structures of the  $B_2$  and  $B_1$  forms (forms V and VI) of POP, POST and StOSt has been described by Sato and co-workers (Yano *et al.*, 1994).

Typical solid fat contents of cocoa butters, determined by pulsed nuclear magnetic resonance (NMR), are given in Table 3.27.

In the chocolate-manufacturing process, the molten chocolate mass is passed through tempering units to nucleate and partially crystallize the fats so that when the bulk of fat solidifies it crystallizes in the stable form (Chapman *et al.*, 1971; Jewel and Bradford, 1981; Jeffery, 1991). A micro-scale study of continuous tempering has demonstrated the inter-relationship between temperature, throughput and degree of temper (Cebula *et al.*, 1991). Incorrect processing and high-temperature storage can result in the cocoa butter recrystallizing and appearing as bloom on the chocolate surface (Duck, 1967; Kleinert, 1961, 1970; Wille and Lutton, 1966). The addition of the mono-unsaturated dibehenoyl triglyceride (BOB) delays the onset of bloom in chocolate stored at elevated temperatures (Hachiya *et al.*, 1989; Koyano *et al.*, 1990).

The system is further complicated by the addition of milk fat, which softens and extends the crystallization rate of cocoa butter. The phase behaviour of cocoa butter/milk fat has been determined (Chapman *et al.*, 1971; Timms, 1980, 1984; Sato, 1987; Schlichter *et al.*, 1988).

NMR imaging has been applied to chocolate confectionery and was able to distinguish different states of the fat. Water migration could also be detected by the method (Duce *et al.*, 1990).

Cocoa butter fractions have been developed to allow a more flexible use of this valuable component of chocolate (Weyland, 1992).

The relatively high price of cocoa butter has resulted in the development of a number of lower-priced confectionery fats (Best *et al.*, 1956; Gordon *et al.*, 1979; Thomas and Paulicka, 1976; Soeters, 1970). Cocoa butter equivalents (CBEs) are produced by blending palm oil mid-fraction, a source of 2-oleodipalmitin, with illipe butter and/or shea stearin, sources of 2-oleopalmitostearin and 2-oleodistearin (Best *et al.*, 1956).

A new technology, enzymic inter-esterification, is being applied to manufacture 2-oleo-1,3-disaturated triglycerides (Macrae and Coleman, 1976; Eigtved, 1992).

### 3.3.8 Coconut oil

[*Cocos nucifera*; Palmae]

Summary data are shown in Tables 3.28 to 3.32. The coconut palm (Child, 1964; Piggott, 1964; Langstraad, 1976) grows along the shores of most tropical and subtropical lands. The major growing areas lie

between 20° north and south of the equator. Its history is obscure; the west coast of Central America and an Indian Ocean location have both been proposed as the origin. The tree grows to a height of 24 m, but these are increasingly being replaced by dwarf varieties, *ca* 12 m in height, which begin to yield four years after planting. The main producer is the Philippines.

The prospects for improving coconut palm propagation by tissue culture techniques have been reviewed (Jones, 1989; Sethuraj *et al.*, 1989).

The nuts are harvested either by allowing them to fall naturally, or by picking manually or mechanically. The fruit is ovoid, three-angled, 15–30 cm in diameter. It has a thick, fibrous outer husk (exocarp), which covers the hard, bony shell or endocarp. Adhering inside the shell is the testa with a thick endosperm layer. The shell is split open and the dried endosperm layer yields the copra of commerce. The coconut cavity contains a watery fluid known as coconut water.

Copra is the source of coconut oil and is available in two forms, cup copra and ball copra, depending on the method of drying: in the first case by sun, oven, kiln or smoke drying the isolated endosperm; in the second by drying in the shell and subsequently removing the dried endosperm. Smoke drying has the added advantage that it reduces microbial contamination but can introduce polycyclic aromatic hydrocarbons. Polycyclic aromatic hydrocarbons (PAHs) can be found in a range of crude oils including fish, soybean, sunflower, rape, palm, palmkernel and cottonseed oils. Apart from coconut oil and cottonseed oil from flame-delinted seed, the other oils were relatively free of PAHs. PAHs in coconut are largely eliminated during refining (Sagredos *et al.*, 1988). The yield of copra varies widely (300–3000 kg/ha) depending on the method of cultivation. Copra contains 65–68% oil and 4–7% moisture.

The microbiology of coconut in relation to plant growth, productivity and coconut products has been reviewed (Thomas *et al.*, 1987).

The oil is normally recovered by a two-stage process of expelling followed by solvent extraction. The free fatty acid content of the crude oil is generally higher than for other commercial edible oils and often exceeds 5%. The higher grades have a free fatty acid content of *ca* 3%. Good-quality crude oils are rela-

Table 3.28 World production of coconut oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1982/83 | 1989/90 |
|---------|---------|---------|---------|---------|
| 2375    | 3115    | 3150    | 2949    | 3187    |

**Table 3.29** Fatty acid composition (wt%) of coconut oil

| 6:0 | 8:0 | 10:0 | 12:0 | 14:0 | 16:0 | 18:0 | 20:0 | 18:1 | 18:2 |
|-----|-----|------|------|------|------|------|------|------|------|
| 0.5 | 7.8 | 6.7  | 47.6 | 18.1 | 8.8  | 2.6  | 0.1  | 6.2  | 1.6  |

**Table 3.30** Characteristics of coconut oil from draft Codex (Codex, 1979 and 1993)

|                                          |                  |
|------------------------------------------|------------------|
| Relative density, $d_{20}^{40}$          | 0.908–0.921      |
| Refractive index, $n_D^{40}$             | 1.448–1.450      |
| Saponification value                     | 248–265          |
| Iodine value                             | 6–11             |
| Unsaponifiable matter (g/kg)             | Not more than 15 |
| Reichert value                           | 6–8.5            |
| Polenske value                           | 13–18            |
| GLC ranges in fatty acid composition (%) |                  |
| 6:0                                      | 0–0.6            |
| 8:0                                      | 4.6–9.4          |
| 10:0                                     | 5.5–7.8          |
| 12:0                                     | 45.1–50.3        |
| 14:0                                     | 16.8–20.6        |
| 16:0                                     | 7.7–10.2         |
| 18:0                                     | 2.3–3.5          |
| 18:1                                     | 5.4–8.1          |
| 18:2                                     | 1.0–2.1          |
| 18:3                                     | 0–0.2            |
| 20:0                                     | 0–0.2            |
| 20:1                                     | 0–0.2            |

tively low in pigments and almost free of phosphatides.

The fatty acid composition, as with other oils, shows a natural variation (Tables 3.30 and 3.32). The oil is characterized by the presence of short-chain acids (6:0 to 12:0), and by its low level of unsaturated acids.

The oil is used for industrial purposes, notably in detergents either as soap or as derivatives of the fatty alcohols obtained by hydrogenation (Berger and Ong, 1985). The use of coconut esters as a liquid fuel has been proposed (Banzon, 1980). It is also widely used as an edible oil, where its sharp, cooling, melting characteristics are appreciated. It is used in ice cream, ice cream couvertures, margarine, confectionery and filled milk. Blends of coconut oil with other long-chain edible oils foam badly when used for frying (Kim *et al.*, 1988; Lee and Timms, 1988). Soapy off-flavour may develop in food owing to the hydrolytic action of lipases releasing the short-chain fatty acids (Fritsch *et al.*, 1971). Ketonic rancidity can also develop as a consequence of fungal conversion of short-chain acids to methyl ketones one carbon less than the parent acid (Kinderlerer and Hatton, 1991).

Coconut and palmkernel (section 3.3.25) oils bear a superficial resemblance and have similar applica-

tions. Coconut oil is generally more stable because it is more saturated than palmkernel oil. Both oils can be fractionated to give sharp-melting stearins useful in confectionery products (Rossell, 1985; Timms, 1985). The melting point of these oils is raised, coconut only slightly, by hydrogenation.

Typical melting characteristics of coconut and palmkernel oil are compared in Table 3.31. The oils normally form eutectic compositions with other fats, leading to a significant lowering of solid fat content. This effect on melting behaviour can be particularly disadvantageous when formulating chocolate substitutes because of the incompatibility of lauric stearins with cocoa butter (Gordon *et al.*, 1979).

The triglyceride compositions of coconut and palmkernel oils are compared in Table 3.92 (Bezard, 1971; Bezard *et al.*, 1971). The 2 position analyses for coconut and palmkernel oils are compared in Table 3.162. The sterols, 4-methylsterols and triterpene alcohols are given in Tables 3.163–3.166 (Fedeli *et al.*, 1966; Gracian and Martel, 1969; Itoh *et al.*, 1973a, b).

The oil contains C<sub>6</sub>–C<sub>14</sub>  $\delta$ -lactones (~150 ppm total), the major ones being  $\delta$ -C<sub>8</sub> (46 ppm),  $\delta$ -C<sub>10</sub> (50 ppm) and  $\delta$ -C<sub>12</sub> (20 ppm) (Allen, 1965; Van der Ven and de Jong, 1970). The  $\alpha$ -,  $\beta$ - and  $\gamma$ -tocopherols do not occur at any significant level in coconut oil. The major tocopherols are  $\delta$ -tocopherol (2–3 ppm) and  $\alpha$ -tocotrienol (20 ppm) (Muller-Mulot, 1976) (see also Tables 3.167–3.170).

**Table 3.31** Melting characteristics of coconut and palmkernel oils<sup>a</sup>

|                | N <sub>10</sub> | N <sub>15</sub> | N <sub>20</sub> | N <sub>25</sub> | N <sub>30</sub> |
|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Coconut oil    | 81              | 64              | 35              | 0.5             | 0               |
| Palmkernel oil | 71              | 59              | 41              | 17              | 0               |

<sup>a</sup> N<sub>20</sub> signifies solid fat content measured by NMR at 20°C.

### 3.3.9 Corn oil (maize oil)

[*Zea mays* L.; Graminae, grass family]

A summary of relevant information is given in Tables 3.33–3.37. Corn is grown as an annual crop mainly for fodder. A relatively small proportion is grown for human consumption and industrial processing. The total kernel or grain contains approximately 5% oil

**Table 3.32** Distribution of fatty acid compositions with sample origin for coconut oil (Rossell *et al.*, 1985)

| Origin (no. of samples)    | Fatty acid composition (wt%) |         |         |           |           |         |         |         |         |         |        |
|----------------------------|------------------------------|---------|---------|-----------|-----------|---------|---------|---------|---------|---------|--------|
|                            | 6:0                          | 8:0     | 10:0    | 12:0      | 14:0      | 16:0    | 18:0    | 18:1    | 18:2    | 20:0    | 20:1   |
| Philippines (11)           | 0.4-0.6                      | 7.1-8.3 | 6.2-6.8 | 46.2-48.7 | 18.0-19.2 | 8.3-9.5 | 2.3-3.2 | 5.6-7.1 | 1.3-2.1 | 0.1-0.2 | tr-0.1 |
| Papua New Guinea (4)       | 0.4-0.6                      | 6.9-7.5 | 6.4-6.8 | 47.1-50.3 | 17.8-18.1 | 8.3-9.3 | 2.3-3.0 | 5.8-6.3 | 1.4-1.6 | 0.1     | tr     |
| Vanuatu (5)                | 0.5-0.6                      | 7.3-9.4 | 6.6-7.8 | 47.1-48.4 | 16.8-17.9 | 7.7-9.1 | 2.3-2.9 | 5.4-6.5 | 1.4-2.0 | tr-0.2  | tr-0.2 |
| North Sulawesi (1)         | 0.5                          | 7.3     | 6.3     | 45.9      | 18.1      | 9.7     | 2.7     | 7.4     | 1.9     | 0.1     | tr     |
| Sri Lanka (2) <sup>a</sup> | 0.4-0.5                      | 7.3-7.4 | 5.9-6.2 | 49.3-52.6 | 18.6-19.6 | 7.0-7.9 | 2.9     | 4.5-5.3 | 0.6-0.9 | 0.1     | tr     |
| Overall range (21)         | 0.4-0.6                      | 6.9-9.4 | 6.2-7.8 | 45.9-50.3 | 16.8-19.2 | 7.7-9.7 | 2.3-3.2 | 5.4-7.4 | 1.3-2.1 | tr-0.2  | tr-0.2 |
| Mean (21 samples)          | 0.5                          | 7.8     | 6.7     | 47.5      | 18.1      | 8.8     | 2.6     | 6.2     | 1.6     | 0.1     | tr     |

tr = trace (unquantified amount of less than 0.05%). Traces of 18:3 were found in all origins ranging up to 0.2% in one Vanuatu sample.

<sup>a</sup> These results relate to desiccated coconut and were not used in calculation of ranges and means. All other oil samples were extracted from samples of commercial copra.

of which 80% is concentrated in the germ. Corn oil is obtained from the germ after it has been separated from the grain by either wet or dry milling. The majority of corn oil is obtained by wet milling, a process used in the production of corn starch, sugar and syrup (Leibovitz and Ruckenstein, 1983).

The characteristics of the oil and its contribution to the American diet are reviewed (Dupont *et al.*, 1990).

The crude oil, dark reddish amber in colour, is isolated from the germ by a combination of expelling and solvent extraction. The crude oil normally contains less than 3% free fatty acid and 1–3% phospholipids. These are removed during conventional refining. Traces of wax (0.05%) can be removed by winterization.

The refined oil is highly regarded as an edible oil because of its good oxidative and flavour stability despite its high degree of unsaturation. Corn oil behaves in a similar way to sunflower oil when used in deep fat frying (Huang *et al.*, 1981). The oil is used as a salad and frying oil, and as a component of margarine, in some cases after partial hydrogenation.

There is considerable genetic variability, in terms of both yield and fatty acid composition. Percentage oil is positively correlated with oleic acid and both are negatively correlated with linoleic acid (Kabul, 1985).

The triglycerides of corn oil follow the normal distribution anticipated for a vegetable oil (Table 3.159). The stereospecific distribution of the fatty acids (de la Roche *et al.*, 1971) is influenced by the overall fatty acid composition. The triglyceride carbon-number distribution is given in Table 3.160. Reverse-phase HPLC was used to characterize the triglycerides in corn oil and 20 glycerides identified (Grossberger and Rothschild, 1989).

Corn oil contains approximately 1% of sterols, which is unusually high for a vegetable oil. The composition of the triterpene alcohols, methylsterols and sterols are given in Tables 3.163–3.166.

**Table 3.33** World production of corn oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 |
|---------|---------|---------|---------|---------|
| 325     | 440     | 665     | 680     | 725     |

**Table 3.35** Characteristics of corn oil, from draft Codex (Codex, 1979 and 1993)

|                                          |                  |
|------------------------------------------|------------------|
| Relative density, $d_{20}^{20}$          | 0.917–0.925      |
| Refractive index, $n_D^{40}$             | 1.465–1.468      |
| Saponification value                     | 187–195          |
| Iodine value                             | 103–128          |
| Unsaponifiable matter (g/kg)             | Not more than 28 |
| GLC ranges in fatty acid composition (%) |                  |
| <12:0                                    | 0–0.3            |
| 14:0                                     | 0–0.3            |
| 16:0                                     | 8.6–16.5         |
| 16:1                                     | 0–0.4            |
| 18:0                                     | 1.0–3.3          |
| 18:1                                     | 20.0–42.2        |
| 18:2                                     | 39.4–62.5        |
| 18:3                                     | 0.5–1.5          |
| 20:0                                     | 0.3–0.6          |
| 20:1                                     | 0.2–0.4          |
| 20:2                                     | 0–0.1            |
| 22:0                                     | 0–0.5            |
| 22:1                                     | 0–0.1            |
| 24:0                                     | 0–0.4            |

**Table 3.36** Quality characteristics of corn oil (Codex, 1979)

|                 |                                                                                           |
|-----------------|-------------------------------------------------------------------------------------------|
| Colour          | Characteristic of the designated product                                                  |
| Odour and taste | Characteristic of the designated product and free from foreign and rancid odour and taste |
| Acid value      |                                                                                           |
| Virgin oil      | Not more than 4 mg KOH/g oil                                                              |
| Non-virgin oil  | Not more than 0.6 mg KOH/g oil                                                            |
| Peroxide value  | Not more than 10 milliequivalents peroxide oxygen/kg oil                                  |

**Table 3.37** Tocopherols in corn oil (mg/kg) (Muller-Mulot, 1976)

| $\alpha$ -T | $\beta$ -T | $\gamma$ -T <sup>a</sup> | $\delta$ -T | $\alpha$ -T <sub>3</sub> | $\beta$ -T <sub>3</sub> | $\gamma$ -T <sub>3</sub> |
|-------------|------------|--------------------------|-------------|--------------------------|-------------------------|--------------------------|
| 134         | 18         | 412                      | 39          | –                        | –                       | –                        |

The non-polar fractions from corn, soybean and sunflower seed oils have been compared (Trost, 1989). In corn oil this is mainly steryl and triterpenyl esters.

**Table 3.34** Fatty acid composition (wt%) of corn oil

| 12:0 | 14:0 | 16:0 | 18:0 | 20:0 | 18:1 | 18:2 | 18:3 | 20:1 |
|------|------|------|------|------|------|------|------|------|
| 0.1  | 0.2  | 13.0 | 2.5  | 0.5  | 30.5 | 52.0 | 1.0  | 0.2  |

## Occurrence and characteristics

The main tocopherol in corn oil is  $\gamma$ -tocopherol. Typical values are  $\alpha$ -tocopherol 150 mg/kg,  $\beta$ -tocopherol 10 mg/kg,  $\gamma$ -tocopherol 400–900 mg/kg and  $\delta$ -tocopherol 40 mg/kg. More recent analyses of refined corn oil are given in Table 3.37 (Muller-Mulot, 1976). In a separate study (Carpenter, 1979) no  $\beta$ -tocopherol was found. The oil also contains significant levels of ubiquinone (Dupont *et al.*, 1990).

Ferulic acid has been detected as an ester with dihydro- $\beta$ -sitosterol (Tamurat *et al.*, 1958).

Adulteration has been detected using carbon isotope ratio measurement (Rossell, 1991).

### 3.3.10 Cottonseed oil

[*Gossypium hirsutum* (American),  
*G. barbadense* (Egyptian),  
*G. herbaceum* (Asiatic); Malvaceae]

Data for cottonseed oil are given in Tables 3.38–3.42. Cotton has been grown since antiquity. There are numerous varieties and species, ranging in size from herbs 25 cm high to some the size of a small tree. There are two main groups: the American or New World and the Asiatic or Old World cottons. These are genetically distinct and do not form natural fertile hybrids. Most cultivated varieties are grown as annual crops (Bailey, 1948; Cornelius and Raymond, 1967; Hyer, 1966).

Cottonseed oil is a by-product arising from the cultivation of cotton. The cotton is attached to the seed and up to 40 seeds occur in a single cotton boll. The cotton is removed from the seed by ginning the shorter fibres or linter still attached (10–15% of whole seed). Bald seed types have *ca* 2% of linter. The seed yields approximately 16% oil, 45% meal, 9% linters (depending on type) and 26% hull (Kromer, 1977).

Oil is extracted either by pressing or increasingly by solvent extraction. The crude oil has a strong characteristic flavour and odour and has a dark reddish brown colour. The free fatty acid content of the oil

**Table 3.38** World production of cottonseed oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 | 1989/90 |
|---------|---------|---------|---------|---------|---------|
| 2450    | 2433    | 3035    | 3320    | 3090    | 3588    |

**Table 3.40** Characteristics of cottonseed oil, from draft Codex (Codex, 1979 and 1993)

|                                          |                       |
|------------------------------------------|-----------------------|
| Relative density, $d_{20}^{20}$          | 0.918–0.926           |
| Refractive index, $n_D^{40}$             | 1.458–1.466           |
| Saponification value                     | 189–198               |
| Iodine value                             | 99–119                |
| Unsaponifiable matter (%)                | Not more than 1.5     |
| Halphen test                             | Positive <sup>a</sup> |
| GLC ranges in fatty acid composition (%) |                       |
| <12:0                                    | 0–0.2                 |
| 14:0                                     | 0.6–1.0               |
| 16:0                                     | 21.4–26.4             |
| 16:1                                     | 0–1.2                 |
| 18:0                                     | 2.1–3.3               |
| 18:1                                     | 14.7–21.7             |
| 18:2                                     | 46.7–58.2             |
| 18:3                                     | 0–0.4                 |
| 20:0                                     | 0.2–0.5               |
| 20:1                                     | 0–0.1                 |
| 22:0                                     | 0–0.6                 |
| 22:1                                     | 0–0.3                 |
| 22:2                                     | 0–0.1                 |
| 24:0                                     | 0–0.1                 |

<sup>a</sup> Heated and hydrogenated oils may not give a positive test.

depends on the conditions of harvesting and moisture content of the seed: good-quality oil has free fatty acid of 0.5–1%. Normally it is increasingly difficult to bleach the oil satisfactorily, as the free fatty acid of the crude oil increases. However, there is no direct relation between the quality of the crude oil and the stability and flavour of the fully refined oil.

The oil is mainly used for edible purposes, in the manufacture of margarine and shortenings, as a frying oil and as a salad oil.

One feature distinguishing cottonseed oil from other commercial oils is its content of C<sub>20</sub>, C<sub>22</sub> and C<sub>24</sub> saturated fatty acids. The presence of cyclopropenoid acids (0.1–1.3%) (Bailey *et al.*, 1966; Pandey and Suri, 1982) is of even greater importance. These acids are responsible for giving a positive Halphen test (Halphen, 1897), which has been used to characterize cottonseed oil for almost 100 years. The major cyclopropenoid acids are sterculic (C<sub>19</sub>) (1) and malvalic (C<sub>18</sub>) (2) (Shenstone and Vickery, 1959, 1961) (sections 1.7 and 3.2.14).

Adverse biological effects have been observed following the incorporation of sterculic acid in animal

**Table 3.39** Fatty acid composition (wt%) of *Gossypium hirsutum*

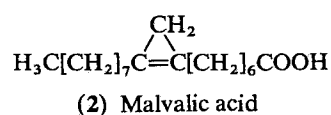
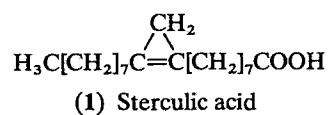
| 14:0 | 16:0 | 18:0 | 20:0 | 16:1 | 18:1 | 18:2 | 18:3 |
|------|------|------|------|------|------|------|------|
| 0.8  | 24   | 2.6  | 0.3  | 0.8  | 19   | 52.5 | tr   |

**Table 3.41** Phospholipids of glandless cottonseed oil (Cherry, 1983)

| Phospholipid                   | Composition<br>(% of total phosphorus) |
|--------------------------------|----------------------------------------|
| Uncharacterized, polar         | 4.1                                    |
| Phosphatidylinositol           | 13.4                                   |
| Phosphatidylserine             | 2.4                                    |
| Phosphatidylcholine            | 23.2                                   |
| Phosphatidylethanolamine       | 13.5                                   |
| Phosphatidylglycerol           | 7.6                                    |
| Phosphatidic acid              | 8.8                                    |
| Lysophosphatidylcholine        | 2.6                                    |
| Lysophosphatidylserine         | —                                      |
| Lysophosphatidylethanolamine   | —                                      |
| Unknown (sum of six TLC spots) | 25.3                                   |

**Table 3.42** Tocopherols in cottonseed oil (mg/kg) (Muller-Mulot, 1976)

| $\alpha$ -T | $\beta$ -T | $\gamma$ -T | $\delta$ -T |
|-------------|------------|-------------|-------------|
| 402         | 1.5        | 572         | 7.5         |



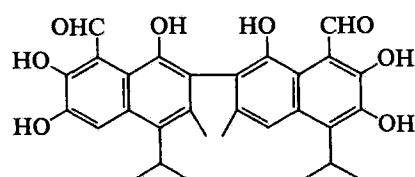
diets (Phelps *et al.*, 1965; Kircher, 1964). Pink coloration of eggs is caused when sterclic acid (25 mg/day) is fed to laying hens. The cyclopropenoid group is destroyed either by hydrogenation (Zarins *et al.*, 1982) or by heating the oil in the presence of free fatty acid (Vickery, 1980; Fisher and Schuller, 1981; Hopkins *et al.*, 1973).

Methods of determining cyclopropene acids continue to be developed (Fisher and Schuller, 1981; Vickery, 1980). Methyl malvalate and methyl sterculate have been separated by spinning band distillation (Pawlowski *et al.*, 1981).

The presence of cyclopropene acids in 40 seed oils including a number of the Malvales is reported (Vickery, 1980).

The triglyceride composition of cottonseed oil follows the 2-random, 1,3-random theory within the limits of current experimental accuracy (Tables 3.159 and 3.160).

The disaturated triglycerides partially crystallize as the oil temperature is lowered to 5–10 °C. Cottonseed



(3) Gossypol (aldehyde tautomer)

oil is for this reason dry-fractionated or winterized to produce oleins, which remain liquid at lower temperatures and can be used as salad oils.

Crude cottonseed oil contains numerous minor components (approximately 2%). These include gossypol (3) (a yellow pigment), phospholipids, sterols, carbohydrates, pigments and hydrocarbons, mainly squalene (0.004–0.012%).

Gossypol is a 2,2'-di-(1-naphthol) derivative. It is converted to the purple pigment gossypurpurin in seeds stored for prolonged periods. Gossypol occurs in the pigment glands of the seed and is toxic to certain animals (Abou-Donia, 1976). It has received recent attention as a possible natural contraceptive (Kobayashi and Yuyama, 1988). The pigment remains mainly in the meal after oil extraction, but any material extracted into the oil is removed during alkali refining and subsequent heat treatment. Non-gossypol pigments remaining in the oil confer on it a yellow–amber colour. A glandless variety of cottonseed containing no gossypol has been developed and is increasingly replacing older varieties (Kromer, 1977; Cherry, 1983). Analytical methods for determining gossypol (based on HPLC) have been developed (Abou-Donia *et al.*, 1981).

The composition of some of the other minor components of significance in the oil, sterols, 4-methylsterols and triterpene alcohols, are given in Tables 3.163–3.166. The phospholipids in glandless cottonseed oil are given in Table 3.41.

The tocopherols in crude cottonseed oil (Table 3.42), as with other oils, are partially removed during refining. This, together with the removal of gossypol and related phenolic compounds with antioxidant activity, is possibly the reason for cottonseed oil's relatively poor oxidative stability compared to groundnut oil, but this is probably only part of the explanation. Refined cottonseed oils still contain 74–94 mg/kg of tocopherols.

### 3.3.11 Crambe oil

[*Crambe abyssinica*, *C. hispanica*;  
Cruciferae]

Crambe oil is produced in limited quantities in Eastern Europe and is at the early stages of commer-

**Table 3.43** Fatty acid composition (wt%) of crambe oil (Downey, 1971)

|                      | 14:0 | 16:0 | 18:0 | 20:0 | 22:0 | 16:1 | 16:3 | 18:1 | 18:2 | 18:3 | 20:1 | 22:1 | 24:1 |
|----------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| <i>C. abyssinica</i> | 0.1  | 1.7  | 1.0  | 1.3  | 2.7  | 0.3  | 1.0  | 16.7 | 7.8  | 6.9  | 2.9  | 55.7 | 2.9  |
| <i>C. hispanica</i>  | 0.1  | 3.7  | 0.5  | tr   | 1.6  | 0.4  | 0.5  | 20.1 | 10.7 | 5.5  | 4.6  | 52.4 | —    |

**Table 3.44** Characteristics of crambe oil (Lessman and Anderson, 1981)

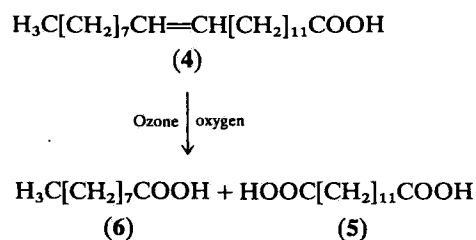
|                                   |       |
|-----------------------------------|-------|
| Relative density, $d_{25}^{25}$   | 0.908 |
| Refractive index, $n_D^{20}$      | 1.472 |
| Saponification value              | —     |
| Iodine value                      | 93    |
| Unsaponifiable matter (%)         | 0.5   |
| Oil content of seed, dehulled (%) | 33–54 |

cial development in the USA. A two-year field study placed crambe in the moderately sensitive salt-tolerance category (Francois and Kleiman, 1990). Seed has been processed successfully in commercial oil seed facilities in the USA (Carlson *et al.*, 1985). Summary data are shown in Tables 3.43 and 3.44.

Crambe is an annual herb adapted as a spring crop in wheat-growing areas (Brun and Matchett, 1963; Cornelius and Simmons, 1969; Earle *et al.*, 1966; Lessman and Anderson, 1981; Mustakas *et al.*, 1965). It produces a great number of seeds borne singly at or near the terminus of branches. Yields of unhulled seed vary from 255 to 2000 g/ha depending on climatic conditions, etc.

The conversion of commercial rape (see section 3.3.27) to low-erucic-acid varieties has favoured the exploitation of crambe as a source of erucic acid, this despite the presence of undesirable thioglucosides (*epi*-progoitrin) and a bitter alkaloid (sinapin). Treatment with ammonia combined with heat treatment removes these materials and increases the nutritive value of the meal (Kirk *et al.*, 1966; Tookey *et al.*, 1980).

Erucic acid (4) is converted by ozonolysis (section 10.4) to a mixture of brassylic (tridecanedioic) (5) and pelargonic (nonanoic) (6) acids, which are separable by distillation. Crambe oil can also be used as a lubricant in steel casting.



### 3.3.12 *Cuphea* species oil [Lythraceae]

This oil is currently at the experimental stage. Interest in the genus arises because these annual species offer the possibility of producing medium-chain-length glycerides based on capric (10:0) or lauric (12:0) acid. Some species are rich in caprylic (8:0) or myristic (14:0) acid. The fatty acid patterns of *Cuphea* oils are very diverse, as is indicated in Table 3.45.

All *Cuphea* species exhibit wild-plant characteristics: dormancy; non-uniform germination; indeterminate flowering and seed maturation over a period of up to 8 weeks; extreme dehiscence and the presence of viscid glandular hairs on stem, leaves, flowers and fruits. Commercial exploitation of this crop is being studied, particularly in Germany and the USA (Wolf *et al.*, 1983a; Princen and Rothfus, 1984; Thompson, 1984; Hirsinger, 1985; Thompson and Kleiman, 1988). Various species are being studied and include *C. viscosissima* and *C. lanceolata* as sources of capric acid,  $\text{C}_{10}$  (Knapp *et al.*, 1991; Webb and Knapp, 1991; Bafor *et al.*, 1990). The development of *Cuphea* has been reviewed (Röbbelin, 1988; Graham, 1989).

### 3.3.13 Evening primrose oil [*Oenothera biennis*, *O. lamarckiana*; Onagraceae] and other sources of $\gamma$ -linolenic acid

World production is approximately 100–150 tonnes per annum (1984). Oil obtained from *Oenothera biennis* or *O. lamarckiana* is designated as evening primrose oil. Interest in this oil has developed in recent years because of its content of  $\gamma$ -linolenic acid ( $\Delta 6,9,12$ -18:3) (Hudson, 1984). It is claimed that the dietary intake of this highly unsaturated oil is beneficial in combating certain diseases, e.g. multiple sclerosis, and is useful as a health supplement (Lovell *et al.*, 1981; Horrobin, 1982, 1992; Horrobin and Manku, 1989; Kies, 1989; Gunstone, 1992). The seeds are grown in the USA, Europe, Israel and New Zealand. Oil content of seed is 22–28%. Alternative

Table 3.45 Fatty acid composition of *Cuphea* seed oils expressed as percentages of total fatty acid composition (Graham, 1989)

| Species <sup>a</sup>              | 8:0 | 10:0            | 12:0 | 14:0 | 16:0 | 18:0 | 18:1 | 18:2              | 18:3 | 20:0 |
|-----------------------------------|-----|-----------------|------|------|------|------|------|-------------------|------|------|
| <b>Subg. <i>Cuphea</i></b>        |     |                 |      |      |      |      |      |                   |      |      |
| Sect. <i>Archocuphea</i> (3/1)    |     |                 |      |      |      |      |      |                   |      |      |
| <i>mimuloides</i>                 | —   | —               | 25.0 | 10.0 | 20.0 | 3.0  | 10.0 | 30.0 <sup>b</sup> | nr   | nr   |
| Sect. <i>Cuphea</i> (15/6)        |     |                 |      |      |      |      |      |                   |      |      |
| <i>utriculosa</i>                 | —   | 0.2             | 0.8  | 0.5  | 25.4 | 3.5  | 26.4 | 30.7              | nr   | nr   |
| <i>salicifolia</i> <sub>2</sub>   | —   | —               | —    | 0.4  | 20.7 | 3.0  | 30.8 | 43.3              | nr   | nr   |
| <i>decandra</i>                   | —   | 1.3             | 0.6  | 0.3  | 29.6 | 2.4  | 20.6 | 44.7              | nr   | nr   |
| <i>lindmaniana</i>                | 0.1 | 0.5             | 0.6  | 0.6  | 17.3 | 1.6  | 18.2 | 55.3              | —    | 4.1  |
| <i>racemosa</i>                   | —   | —               | 0.1  | 0.2  | 15.3 | 1.7  | 17.4 | 58.8              | nr   | nr   |
| <i>fruticosa</i>                  | —   | tr <sup>c</sup> | tr   | 0.1  | 16.8 | 0.4  | 12.8 | 67.2              | —    | 2.0  |
| <b>Subg. <i>Bracteolatae</i></b>  |     |                 |      |      |      |      |      |                   |      |      |
| Sect. <i>Heteranthus</i> (10/3)   |     |                 |      |      |      |      |      |                   |      |      |
| <i>setosa</i>                     | —   | 1.1             | 62.2 | 26.0 | 5.3  | —    | 1.3  | 1.4               | nr   | nr   |
| <i>tetrapetala</i>                | —   | 0.4             | 32.4 | 51.0 | 7.0  | 0.9  | 1.5  | 6.4               | 0.4  | 0.1  |
| <i>epilobiifolia</i>              | tr  | 0.3             | 31.8 | 55.3 | 5.2  | 0.8  | 1.2  | 4.9               | 0.1  | 0.1  |
| Sect. <i>Melicythium</i> (1/0)    |     |                 |      |      |      |      |      |                   |      |      |
| Sect. <i>Brachyandra</i> (22/5)   |     |                 |      |      |      |      |      |                   |      |      |
| <i>elliptica</i>                  | —   | 1.3             | 48.4 | 25.8 | 7.7  | 1.2  | 7.9  | 6.8               | nr   | nr   |
| <i>micrantha</i>                  | —   | 2.4             | 53.2 | 17.8 | 6.3  | 0.8  | 6.8  | 12.9              | nr   | nr   |
| <i>carthagenesis</i> <sub>5</sub> | 0.4 | 9.0             | 65.8 | 10.5 | 2.9  | 0.2  | 4.8  | 5.5               | nr   | nr   |
| <i>parsonsia</i>                  | —   | 7.9             | 73.9 | 4.4  | 0.9  | —    | 1.3  | 6.0               | nr   | nr   |
| <i>calophylla</i> <sub>4</sub>    | 0.1 | 11.1            | 76.9 | 4.1  | 1.9  | 0.1  | 2.1  | 3.1               | 0.3  | nr   |
| Sect. <i>Euandra</i> (74/11)      |     |                 |      |      |      |      |      |                   |      |      |
| <i>linariodes</i>                 | tr  | 0.2             | 3.2  | 3.1  | 17.7 | 2.1  | 11.6 | 62.1              | nr   | nr   |
| <i>linifolia</i>                  | tr  | tr              | 0.4  | 3.1  | 17.9 | 1.9  | 13.7 | 62.5              | 0.5  | —    |
| <i>strigulosa</i>                 |     |                 |      |      |      |      |      |                   |      |      |
| ssp. <i>nitens</i>                | 0.9 | 18.1            | 13.8 | 37.3 | 10.3 | 1.3  | 7.3  | 11.0              | —    | —    |
| ssp. <i>opaca</i>                 | tr  | tr              | 33.7 | 45.2 | 7.0  | 0.8  | 5.2  | 7.1               | 0.8  | 0.2  |
| <i>thymoides</i>                  | tr  | 3.6             | 55.7 | 8.2  | 7.3  | 0.9  | 7.0  | 14.5              | 0.2  | —    |
| <i>sclerophylla</i>               | tr  | tr              | 59.7 | 27.6 | 5.3  | 0.2  | 2.1  | 5.1               | tr   | —    |
| <i>diosmifolia</i>                | tr  | tr              | 64.0 | 31.3 | 1.8  | 0.4  | 1.5  | 1.0               | —    | —    |
| <i>glutinosa</i> <sub>3</sub>     | 0.5 | 17.6            | 64.8 | 3.9  | 2.3  | 0.4  | 3.0  | 7.1               | 0.2  | —    |
| <i>ingrata</i>                    | 0.2 | 12.5            | 68.8 | 8.0  | 1.9  | —    | 2.9  | 4.0               | nr   | —    |
| <i>pseudovac</i> <sub>2</sub>     | 0.3 | 6.7             | 75.9 | 6.6  | 3.2  | 0.9  | 3.6  | 3.4               | 1.4  | —    |
| <i>hyssopifolia</i>               | 0.2 | 7.3             | 78.5 | 4.8  | 1.5  | 0.2  | 2.4  | 3.8               | nr   | nr   |
| <i>polymorpha</i>                 | tr  | 7.4             | 80.1 | 3.6  | 2.0  | 0.1  | 2.5  | 4.3               | —    | —    |
| Sect. <i>Amazoniana</i> (17/0)    |     |                 |      |      |      |      |      |                   |      |      |
| Sect. <i>Trispermum</i> (17/1)    |     |                 |      |      |      |      |      |                   |      |      |
| <i>sessilifolia</i>               | 1.1 | —               | 10.2 | 36.6 | 19.1 | 9.9  | 23.1 | —                 | —    | —    |
| Sect. <i>Pseudocircaea</i> (5/1)  |     |                 |      |      |      |      |      |                   |      |      |
| <i>lutescens</i> <sub>2</sub>     | 0.5 | 0.9             | 70.9 | 22.8 | 2.2  | 0.1  | 1.5  | 1.1               | 0.2  | —    |
| Sect. <i>Heterodon</i> (28/26)    |     |                 |      |      |      |      |      |                   |      |      |
| <i>purpurascens</i>               | 2.2 | —               | 0.9  | 3.1  | 19.0 | 2.2  | 17.2 | 17.6              | 36.1 | —    |
| <i>ferrisiae</i> <sup>d</sup>     | 0.7 | —               | 0.8  | 35.2 | 12.0 | 2.7  | 20.0 | 22.5              | —    | —    |
| <i>ferrisiae</i>                  | 1.2 | 82.2            | 1.9  | 1.0  | 3.2  | tr   | 2.7  | 4.4               | 6.4  | —    |
| <i>lutea</i> <sub>2</sub>         | 0.4 | 29.4            | 37.7 | 11.1 | 4.1  | 0.7  | 9.2  | 7.0               | nr   | nr   |
| <i>wrightii</i> <sub>9</sub>      | —   | 29.4            | 53.9 | 5.1  | 2.3  | 0.4  | 3.1  | 4.6               | nr   | nr   |
| <i>glossostoma</i>                | —   | 17.4            | 59.5 | 9.2  | 3.1  | 0.5  | 4.6  | 5.5               | nr   | nr   |
| <i>viscosa</i>                    | 0.2 | 0.3             | 59.9 | 31.4 | 2.1  | 0.2  | 1.9  | 4.0               | —    | —    |
| <i>trochilus</i>                  | —   | 0.1             | 61.8 | 24.7 | 3.0  | 0.2  | 2.8  | 7.1               | 0.2  | 0.1  |
| <i>laminuligena</i> <sub>2</sub>  | —   | 17.1            | 62.6 | 9.5  | 2.8  | 0.2  | 2.0  | 3.5               | nr   | nr   |

# Occurrence and characteristics

Table 3.45 continued

| Species <sup>a</sup>              | 8:0  | 10:0 | 12:0 | 14:0 | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 |
|-----------------------------------|------|------|------|------|------|------|------|------|------|------|
| <i>tolucana</i> <sub>3</sub>      | —    | 23.0 | 63.3 | 4.5  | 1.8  | —    | 1.9  | 5.0  | nr   | nr   |
| <i>palustris</i>                  | 19.7 | 1.4  | 2.0  | 63.7 | 6.7  | —    | 3.0  | 2.9  | nr   | nr   |
| <i>lobophora</i>                  | —    | 10.9 | 66.2 | 13.1 | 2.4  | —    | 2.9  | 3.9  | nr   | nr   |
| <i>vesiculigera</i>               | tr   | 0.4  | 71.2 | 18.0 | 2.6  | 0.2  | 2.4  | 5.0  | —    | 0.1  |
| <i>calcarata</i>                  | —    | 64.3 | 6.3  | 6.9  | 6.5  | 0.9  | 7.7  | 6.9  | nr   | nr   |
| <i>viscosissima</i>               | 9.1  | 75.5 | 3.0  | 1.3  | 3.1  | 0.3  | 1.9  | 4.7  | 0.5  | 0.3  |
| <i>procumbens</i> <sub>3</sub>    | 0.4  | 80.1 | 2.7  | 1.5  | 4.5  | 0.3  | 4.4  | 4.4  | nr   | nr   |
| <i>angustifolia</i> <sub>2</sub>  | —    | 80.4 | 2.6  | 2.9  | 3.4  | 0.3  | 6.0  | 4.7  | nr   | nr   |
| <i>lophostoma</i>                 | 0.9  | 81.1 | 2.4  | 4.1  | 2.9  | 0.5  | 3.4  | 2.8  | nr   | nr   |
| <i>humifusa</i> <sub>2</sub>      | 1.2  | 82.0 | 2.9  | 1.6  | 3.1  | 0.4  | 5.4  | 5.1  | nr   | nr   |
| <i>lanceolata</i>                 | 0.6  | 83.2 | 2.1  | 2.0  | 3.4  | —    | 3.4  | 4.6  | nr   | nr   |
| <i>caesariata</i>                 | 1.1  | 85.9 | 1.6  | 0.6  | 2.2  | —    | 3.9  | 3.9  | nr   | nr   |
| <i>inflata</i>                    | 0.7  | 86.4 | 1.6  | 0.4  | 2.1  | 0.5  | 3.6  | 4.2  | nr   | nr   |
| <i>leptopoda</i> <sub>3</sub>     | 1.1  | 87.3 | 1.5  | —    | 2.3  | 0.3  | 2.9  | 3.9  | nr   | nr   |
| <i>paucipetala</i> <sub>2</sub>   | 1.2  | 87.4 | 2.0  | 0.8  | 1.9  | —    | 1.8  | 4.0  | nr   | nr   |
| <i>crassiflora</i> <sub>2</sub>   | 1.4  | 87.2 | 1.7  | 0.4  | 2.3  | 0.6  | 3.5  | 2.7  | nr   | nr   |
| <i>llavea</i> <sub>2</sub>        | 1.5  | 87.5 | 1.6  | 0.7  | 1.9  | 0.4  | 3.8  | 2.2  | nr   | nr   |
| <i>koehneana</i>                  | 0.1  | 91.6 | 1.5  | 0.6  | 1.3  | 0.3  | 1.1  | 3.1  | 0.2  | 0.1  |
| Sect. <i>Melvilla</i> (39/9)      |      |      |      |      |      |      |      |      |      |      |
| <i>flavovirens</i>                | tr   | 20.5 | 9.5  | 5.3  | 15.2 | 2.2  | 21.6 | 22.9 | 1.1  | 0.4  |
| <i>heterophylla</i> <sub>3</sub>  | 2.6  | 32.8 | 47.7 | 5.5  | 2.0  | 0.5  | 3.0  | 5.6  | nr   | nr   |
| <i>melvilla</i> <sub>2</sub>      | 0.2  | 1.6  | 49.0 | 13.9 | 7.5  | 0.8  | 10.0 | 15.3 | 0.6  | —    |
| <i>zorullensis</i>                | 0.1  | 32.0 | 53.1 | 4.1  | 1.5  | 0.6  | 2.7  | 5.0  | —    | 0.1  |
| <i>retroscabra</i>                | 3.1  | 24.7 | 54.9 | 4.2  | 2.0  | —    | 3.8  | 6.5  | nr   | nr   |
| <i>micropetala</i>                | 0.2  | 26.4 | 25.2 | 24.2 | 6.5  | 1.7  | 4.3  | 11.8 | nr   | nr   |
| <i>quaternata</i>                 | 0.1  | 62.9 | 8.2  | 15.6 | 4.1  | 0.5  | 2.2  | 5.1  | 1.4  | tr   |
| <i>caeciliae</i>                  | —    | 70.9 | 11.1 | 2.6  | 3.9  | 0.6  | 4.1  | 4.8  | nr   | nr   |
| <i>igneae</i>                     | 0.9  | 87.1 | 1.2  | 0.6  | 3.1  | 0.2  | 2.9  | 4.1  | nr   | nr   |
| Sect. <i>Leptocalyx</i> (7/4)     |      |      |      |      |      |      |      |      |      |      |
| <i>aequipetala</i>                | 24.6 | 1.3  | 1.8  | 56.0 | 6.6  | —    | 4.9  | 3.6  | nr   | nr   |
| <i>appendiculata</i> <sub>4</sub> | —    | 4.4  | 75.5 | 9.1  | 2.7  | 0.1  | 2.6  | 4.1  | —    | —    |
| <i>calaminthifolia</i>            | tr   | 43.7 | tr   | 4.1  | 13.0 | 1.5  | 12.5 | 25.2 | —    | —    |
| <i>bustamanta</i>                 | 25.8 | 62.5 | —    | —    | 2.1  | —    | 3.2  | 5.6  | nr   | nr   |
| Sect. <i>Diploptychia</i> (20/6)  |      |      |      |      |      |      |      |      |      |      |
| <i>spectabilis</i>                | 0.6  | 0.2  | 1.2  | 2.7  | 15.7 | 1.2  | 26.0 | 22.2 | 30.8 | —    |
| <i>nitidula</i>                   | 1.6  | 73.9 | 2.4  | 3.9  | 4.3  | —    | 5.5  | 7.6  | nr   | nr   |
| <i>pinetorum</i>                  | 48.1 | 40.3 | 0.4  | 0.4  | 2.6  | 0.4  | 3.0  | 4.1  | nr   | nr   |
| <i>hookeriana</i> <sub>3</sub>    | 50.2 | 25.4 | 3.6  | 1.0  | 7.1  | 0.7  | 4.3  | 4.6  | nr   | nr   |
| <i>painteri</i>                   | 65.0 | 24.0 | 0.2  | 0.4  | 2.8  | 0.4  | 3.3  | 3.9  | nr   | nr   |
| <i>cyanea</i>                     | 67.8 | 24.4 | —    | —    | 1.4  | —    | 2.4  | 3.1  | nr   | nr   |

<sup>a</sup> Each section is followed in parentheses by number of species in the section/number of species sampled. When more than one collection was sampled, the mean is presented and number of sampled collections indicated as a subscript. In a few instances, names or number of species in a section may differ from those in the original publications owing to subsequent taxonomic changes.

<sup>b</sup> The dominant fatty acid is in *italic*.

<sup>c</sup> nr = not recorded; tr = trace <0.1%.

<sup>d</sup> Two collections of this species had inexplicably different patterns, both recorded here.

sources of  $\gamma$ -linolenic acid have been reviewed (Wolf *et al.*, 1983b) (Table 3.48).

Specific concentrations of  $\gamma$ -linolenic acid are achieved by urea fractionation (Traitler *et al.*, 1986). The seed oils from various *Oenothera* species have been characterized. The highest amount of  $\gamma$ -linolenic acid was found in *O. acerviphilla nova* (16%) and *O. paradoxa* (14%) (Lamer-Zarawska *et al.*, 1989).

Borage (Whipkey *et al.*, 1988) is also an attractive source of  $\gamma$ -linolenic acid (GLA) apart from the fact that high losses are incurred during harvesting due to seed shattering. Probably a more attractive alternative source is from blackcurrant (Traitler *et al.*, 1988). The seed is a by-product of blackcurrant juice production; the extracted oil contains up to 20% of GLA.

### 3.3.14 Grapeseed oil

[*Vitis vinifera* and others; Vitaceae]

Data on world production are not readily available. Other information is summarized in Tables 3.46 and 3.47. Grapeseed oil is a by-product of the wine

**Table 3.46** Characteristics of edible grapeseed oil, from draft Codex (Codex, 1979 and 1993)

|                                             |                  |
|---------------------------------------------|------------------|
| Relative density, $d_{20}^{20}$             | 0.923–0.926      |
| Refractive index, $n_D^{25}$                | 1.473–1.477      |
| Saponification value                        | 188–194          |
| Iodine value                                | 130–138          |
| Unsaponifiable matter (g/kg)                | Not more than 20 |
| Erythrodiol content<br>(% of total sterols) | Not less than 2  |
| GLC ranges in fatty acid<br>composition (%) |                  |
| 12:0                                        | <0.5             |
| 14:0                                        | <0.3             |
| 16:0                                        | 5.5–11           |
| 16:1                                        | <1.2             |
| 18:0                                        | 3.0–6.0          |
| 18:1                                        | 12–28            |
| 18:2                                        | 58–78            |
| 18:3                                        | <1.0             |
| 20:0                                        | <1.0             |
| 22:0                                        | <0.3             |
| 24:0                                        | <0.1             |

industry. The oil content of the seed varies: sweet white grape seeds approximately 20% oil, certain black grapes as low as 6% oil. The seeds are isolated from the wine pomace, freed of adhering pulp and dried. The seeds are then pressed and solvent-extracted. The best grades of oil are used for edible purposes (Curz Madueno, 1985; Rohne, 1984; Lanzini *et al.*, 1986); other grades are used for soap-making and in paint.

### 3.3.15 Groundnut oil (peanut oil, arachis monkey nut oil, huile d'arachide)

[*Arachis hypogaea*; Leguminosae]

Data on groundnut oil are summarized in Tables 3.49–3.53. The oil is of major commercial importance (Woodroof, 1966, 1983; Ayres, 1983). The plant grows as an annual in tropical and subtropical climates. Some varieties are erect, others prostrate. The fruit is a legume, which is borne under the ground after the flowers have been fertilized in the normal manner above ground level. Several perennial species grow in South America, where it is believed to have originated. The plant was carried to Africa by Portuguese traders, to the Philippines by Magellan in 1519 and hence to various parts of Asia. Groundnut is a major crop in Africa, India, China and the USA.

A critical review of the progress in cytogenetics and genetics of *Arachis* has been written (Wynne, 1989).

The mechanical properties and composition of the peanut are influenced by harvest date (Kim and Hung, 1991). The colour of the mesocarp can be used to group peanuts with similar shear-compression strength.

The groundnut or peanut is made up of the outer shell (or hull), the seed coat (or testa) and the kernel. The hull is separated either by hand or mechanically and the oil extracted by expelling and subsequent solvent extraction. The oil is pale yellow and has the flavour and odour of peanuts. A number of alternative oil extraction procedures have been proposed (Ayres, 1983). Crude oil can have a free fatty acid content as low as 0.3%, but most commercial oil is in the range 0.5–1.5%. Water activity ( $a_w$ ) of the crude oil influences the rate of peroxide formation. Peroxide formation decreased when  $a_w > 0.67$  (Gopalakrishna and Prabhakar, 1983).

**Table 3.47** Fatty acid composition (wt%) of grapeseed oil (Fedeli, 1983)

|         | 14:0  | 16:0 | 18:0 | 20:0  | 16:1  | 18:1  | 18:2  | 18:3  |
|---------|-------|------|------|-------|-------|-------|-------|-------|
| Typical | –     | 7    | 3    | 0.1   | tr    | 22    | 67    | 0.9   |
| Range   | 0–0.2 | 6–8  | 3–6  | 0–0.5 | 0–1.0 | 12–25 | 60–76 | 0–0.5 |

Table 3.48 Sources of  $\gamma$ -linolenic acid (Wolf *et al.*, 1983b)

| Species                                    | Total<br>$\gamma$ -linolenic acid<br>(% of seed) | Oil<br>(wt%)      | Fatty acids (area % by GC) |      |                 |      |      |      |                   |      |      |      |
|--------------------------------------------|--------------------------------------------------|-------------------|----------------------------|------|-----------------|------|------|------|-------------------|------|------|------|
|                                            |                                                  |                   | $\Delta 6,9,12-18:3$       | 16:0 | 16:1            | 18:0 | 18:1 | 18:2 | 18:3 <sup>a</sup> | 18:4 | 20:0 | 20:1 |
| Onagraceae                                 |                                                  |                   |                            |      |                 |      |      |      |                   |      |      |      |
| <i>Oenothera agrillicolla</i> Mackenz.     | 1.7                                              | 25.1 <sup>a</sup> | 6.7                        | 6.2  | 0.2             | 2.5  | 13.9 | 69.4 | 0.1               |      | 0.2  | 0.4  |
| <i>O. biennis</i> L.                       | 2.5                                              | 24.6              | 10.0                       | 7.0  | tr <sup>b</sup> | 2.0  | 9.0  | 72.0 |                   |      |      |      |
| <i>O. brevipes</i> Gray                    | 0                                                | 18.9 <sup>a</sup> |                            | 8.7  | 0.2             | 2.4  | 7.1  | 78.2 | 0.1               |      | 0.2  | 0.1  |
| <i>O. cardiophylla</i> Torr.               | 0                                                | 35.6              |                            | 11.2 | 0.1             | 2.2  | 6.4  | 77.7 | 0.2               |      | 0.3  | 0.1  |
| <i>O. clavaeformis</i> Torr.               | 0                                                | 34.6              |                            | 9.4  | 0.1             | 1.5  | 4.6  | 84.1 | 0.1               |      | 0.1  |      |
| <i>O. depressa</i> ° Greene                | 1.7                                              | 26.3              | 6.3                        | 7.3  | 0.1             | 2.0  | 8.2  | 69.8 | 0.2               |      | 0.3  | 0.2  |
| <i>O. drummondii</i> Hook                  | 0.1                                              | 29.1              | 0.5                        | 10.8 | 0.1             | 2.0  | 10.4 | 76.2 |                   |      |      |      |
| <i>O. elata</i> Hbk.                       | 1.6                                              | 24.4 <sup>a</sup> | 6.7                        | 5.9  | 0.1             | 2.5  | 10.4 | 73.3 | 0.4               |      | 0.2  | 0.2  |
| <i>O. grandiflora</i> Ait.                 | 0.3                                              | 3.7 <sup>a</sup>  | 9.3                        | 7.7  | 0.1             | 1.7  | 9.0  | 67.4 | 0.2               |      | 0.3  | 0.1  |
| <i>O. hookeri</i> Torr. & Gray             | 1.7                                              | 24.1 <sup>a</sup> | 7.0                        | 6.3  | 0.1             | 2.4  | 9.3  | 74.0 | 0.2               |      | 0.4  | 0.1  |
| <i>O. laciniata</i> Hill                   | 0.7                                              | 18.5 <sup>a</sup> | 3.9                        | 7.1  | 0.1             | 2.4  | 7.6  | 77.4 | 0.1               |      | 0.2  | 0.1  |
| <i>O. lamarkiana</i> Ser.                  | 2.3                                              | 28.3              | 8.2                        | 9.2  | 0.1             | 2.1  | 12.3 | 62.2 | 0.2               |      | 0.4  | 0.2  |
| <i>O. leptocarpa</i> Greene                | 0                                                | 28.5              |                            | 7.9  | tr              | 2.4  | 6.5  | 82.8 | 0.4               |      | tr   |      |
| <i>O. missouriensis</i> Sims               | 0                                                | 20.8              |                            | 6.5  | 0.3             | 3.0  | 16.3 | 71.5 | 0.2               |      | 0.6  | 0.1  |
| <i>O. odorata</i> Jacq.                    | 0.5                                              | 28.8              | 1.7                        | 10.8 | 0.1             | 3.7  | 10.9 | 70.5 | 0.1               |      | 0.3  | 0.2  |
| <i>O. parviflora</i> L.                    | 1.9                                              | 26.2 <sup>a</sup> | 7.1                        | 5.4  | 0.1             | 2.7  | 11.9 | 70.9 | 0.3               |      | 0.6  | 0.4  |
| <i>O. rhombipetala</i> Nutt.               | 1.9                                              | 30.7              | 6.1                        | 7.6  | 0.1             | 2.5  | 8.2  | 75.0 | 0.1               |      | 0.2  | 0.1  |
| <i>O. rosea</i> Ait.                       | 0                                                | 31.9              |                            | 10.2 | 0.1             | 2.8  | 7.7  | 77.9 | 0.4               |      | 0.3  | 0.2  |
| <i>O. serrulata</i> Nutt.                  | 0.3                                              | 22.0              | 1.2                        | 10.2 | 0.2             | 3.7  | 11.1 | 68.3 | 0.2               |      | 0.5  | 0.1  |
| <i>O. stricta</i> Steud.                   | 0.6                                              | 30.7              | 1.9                        | 9.8  | 0.1             | 2.8  | 8.7  | 75.8 | 0.3               |      | 0.3  | 0.2  |
| <i>O. strigosa</i> (Rydb.) Mackenz. & Bush | 2.0                                              | 29.0 <sup>a</sup> | 7.0                        | 5.8  | 0.1             | 2.6  | 10.6 | 72.6 | 0.2               |      | 0.4  | 0.2  |
| <i>O. tetragona</i> Roth                   | 1.8                                              | 30.8              | 5.9                        | 6.8  | 0.1             | 2.3  | 6.6  | 73.9 | 0.3               |      | 0.2  | tr   |

|                                                            | 1.8 | 30.8              | 5.9  | 6.8  | 0.1 | 2.3 | 6.6  | 73.9 | 0.3  | 0.2  | tr  |
|------------------------------------------------------------|-----|-------------------|------|------|-----|-----|------|------|------|------|-----|
| <b>Boraginaceae</b>                                        |     |                   |      |      |     |     |      |      |      |      |     |
| <i>Adelocaryum coelestinum</i> <sup>d</sup> (Lindl.) Brand | 2.7 | 21.5              | 12.4 | 11.0 | 0.2 | 3.1 | 31.2 | 14.1 | 4.7  | 3.7  | 4.6 |
| <i>Alkanna froedinii</i> Rech.                             | 4.6 | 47.0 <sup>a</sup> | 9.9  | 7.4  | 0.1 | 2.7 | 20.6 | 26.3 | 27.1 | 5.9  |     |
| <i>Alkanna orientalis</i> (L.) Boiss                       | 2.8 | 22.9              | 12.4 | 5.8  | 0.1 | 2.6 | 15.3 | 26.1 | 31.7 | 4.9  | 1.1 |
| <i>Amsinckia intermedia</i> F. & M.                        | 2.3 | 27.7              | 8.2  | 11.5 |     | 3.8 | 31.7 | 13.3 | 17.4 | 9.5  | 2.9 |
| <i>Amsinckia lunaris</i> Macbr.                            | 2.4 | 26.5              | 8.9  | 11.2 |     | 3.4 | 38.5 | 13.4 | 12.2 | 5.8  | 3.7 |
| <i>Anchusa strigosa</i> Labill.                            | 1.6 | 22.2              | 7.4  | 10.0 | tr  | 2.1 | 38.0 | 38.0 | tr   |      | 2.2 |
| <i>Brunnera orientalis</i> (Schenk.) I. M. Jtn.            | 4.2 | 27.2              | 15.4 | 9.6  | 0.1 | 2.8 | 28.9 | 27.1 | 8.8  | 2.5  | 2.6 |
| <i>Cryptantha grayi</i> (Macbr.) Jtn.                      | 1.8 | 29.2              | 6.2  | 7.9  | 0.2 | 3.4 | 15.9 | 21.4 | 33.8 | 9.6  | 0.2 |
| <i>Cynoglossum nervosum</i> <sup>e</sup> Benth. Exc.       | 1.9 | 24.2              | 7.8  | 10.1 | 0.4 | 1.9 | 32.7 | 21.7 | 7.0  | 3.1  | 4.7 |
| <b>B. Clarke</b>                                           |     |                   |      |      |     |     |      |      |      |      |     |
| <i>Echium glomeratum</i> Poir                              | 1.1 | 17.1              | 6.6  | 8.0  |     | 2.3 | 13.2 | 15.3 | 44.6 | 9.1  | 0.9 |
| <i>Hackelia floribunda</i> <sup>f</sup> (Lehm.) Johnston   | 1.6 | 25.2              | 6.4  | 8.5  | 0.3 | 2.8 | 33.1 | 15.5 | 13.8 | 6.9  | 5.9 |
| <i>Nonnea macrosperma</i> <sup>g</sup> Boiss & Heldr.      | 5.1 | 38.6              | 13.1 | 7.0  | 0.1 | 2.2 | 24.7 | 34.4 | 9.0  |      |     |
| <i>Pectocarya platycarpa</i> Munz. & Jonst.                | 2.3 | 15.0              | 15.2 | 9.5  | 0.1 | 2.9 | 19.0 | 17.9 | 19.9 | 12.0 | 1.5 |
| <i>Trichodesma zeylanicum</i> R. Br. (Burm. F.)            | 1.4 | 31.9              | 4.3  | 9.5  | 0.2 | 6.2 | 28.6 | 20.5 | 24.3 | 5.0  | 0.8 |
| <b>Scrophulariaceae</b>                                    |     |                   |      |      |     |     |      |      |      |      |     |
| <i>Scrophularia canina</i> L.                              | 1.4 | 31.1              | 4.5  | 8.4  | 0.1 | 2.8 | 28.1 | 55.9 | tr   | tr   | 0.2 |
| <i>S. grayana</i> Maxim.                                   | 1.6 | 43.4              | 3.8  | 6.4  | 0.1 | 1.8 | 16.3 | 71.0 | 0.5  | tr   | 0.1 |
| <i>S. koraiensis</i> Nakai                                 | 1.5 | 39.9              | 3.7  | 7.2  | 0.3 | 2.8 | 14.8 | 70.5 | 0.1  | 0.3  |     |
| <i>S. lanceolata</i> Pursh.                                | 2.1 | 26.3              | 8.0  | 5.8  | 0.1 | 2.1 | 16.6 | 66.0 | 0.5  | 0.4  | tr  |
| <i>S. marilandica</i> L.                                   | 3.6 | 37.9              | 9.6  | 7.2  | 0.6 | 2.5 | 14.9 | 62.6 | 0.6  | 0.9  | 0.2 |
| <i>S. michoniana</i> Coss & Kral.                          | 1.0 | 28.1              | 3.5  | 9.9  | tr  | 2.6 | 28.1 | 55.8 |      |      | 0.1 |
| <b>Saxifragaceae</b>                                       |     |                   |      |      |     |     |      |      |      |      |     |
| <i>Ribes alpinum</i> L.                                    | 1.7 | 18.7              | 8.9  | 5.6  | 0.2 | 1.4 | 18.1 | 39.0 | 22.0 | 4.4  | 0.1 |
| <i>R. inebrians</i> Lindl.                                 | 0.6 | 17.7 <sup>a</sup> | 3.4  | 5.4  | 0.1 | 2.0 | 17.6 | 40.4 | 26.4 | 2.4  | 0.8 |
| <i>R. monigenum</i> McClatchie                             | 0.8 | 22.0 <sup>a</sup> | 3.7  | 5.3  | 0.1 | 1.5 | 22.3 | 32.5 | 28.9 | 3.3  | 0.5 |
| <i>R. orientale</i> Desf.                                  | 0.2 | 11.7              | 1.9  | 6.8  | 0.2 | 1.4 | 18.1 | 49.1 | 19.6 | 0.9  | 0.2 |

<sup>a</sup> Oil percentage calculated on fresh weight basis.<sup>b</sup> tr = trace <0.1%.<sup>c</sup> Unknown fatty acids comprise 4.8% of the seed oil.<sup>d</sup> Also 2.2% 22:0 and 7.4% 22:1.<sup>e</sup> Also 0.7% 22:0 and 5.3% 22:1.<sup>f</sup> Also 4.3% 22:1 and 1.5% 24:1.<sup>g</sup> Unknown fatty acids comprise 8.8% of the seed oil.

## Occurrence and characteristics

The crude oil does not present any problems in refining and has excellent oxidative stability. The refined or crude oils (in the Orient) are used mainly for edible purposes, e.g. margarine, shortenings, frying oil and salad oil. The frying performance of groundnut and cottonseed oils was compared (du Plessis *et al.*, 1981). Similar properties were observed, with groundnut giving better-flavoured products. The oil has a cloud point in the range 0–5°C.

Work in the USA is aimed at increasing the oil content of peanuts both for edible purposes and as a diesel fuel (Hammons, 1981).

The compositions of oils from four major types of peanut are given in Table 3.54 together with ranges for the major sterols (Sheppard and Rudolf, 1991).

The presence of C<sub>20</sub>, C<sub>22</sub> and C<sub>24</sub> fatty acids distinguishes the oil from other major edible vegetable oils (Table 3.50). The oil contains only traces of linolenic acid (*ca* 0.05%). The overall fatty acid composition, low linolenic acid content and the presence of tocopherols and possibly other antioxidants provides a relatively stable liquid oil.

The stereospecific distribution of the fatty acids (Sanders, 1980; Treadwell and Young, 1982) shows that the greatest concentration of 16:0 and 18:0 is at the *sn*-1 position and that the 20, 22 and 24 acids occur mainly at *sn*-3. The entire amount of 20:0 was found at the *sn*-3 position. See also Table 3.161. The effect of season and location has been studied (Sanders, 1982). As the seed matures, the overall level of 18:1 increases (Pattee *et al.*, 1969; Sanders, 1980).

A survey of the fatty acid compositions of over 50 different *Arachis* species is reported (Stalker *et al.*, 1989).

The triglyceride composition is summarized in Tables 3.159 and 3.160. Unsaponifiable components occur at levels of 0.2–1% of the oil and include hydrocarbons, aliphatic alcohols, triterpene alcohols

(Table 3.165), sterols (Tables 3.163–3.166 and 3.52) and tocopherols (Table 3.53).  $\beta$ -Carotene and lutein are the major pigments, their level decreasing in the

**Table 3.51** Characteristics of groundnut oil, from draft Codex (Codex, 1979 and 1993)

|                                          |                          |
|------------------------------------------|--------------------------|
| Relative density, $d_{20}^{20}$          | 0.914–0.917              |
| Refractive index, $n_D^{40}$             | 1.460–1.465              |
| Saponification value                     | 187–196                  |
| Iodine value                             | 80–106                   |
| Unsaponifiable matter (%)                | 1.0 or less              |
| Oil content of seed (%) <sup>a</sup>     | Range 38–50 <sup>a</sup> |
| GLC ranges of fatty acid composition (%) |                          |
| 12:0                                     | 0–0.1                    |
| 14:0                                     | 0–0.1                    |
| 16:0                                     | 8.3–14.0                 |
| 16:1                                     | 0–0.2                    |
| 17:0                                     | nd                       |
| 17:1                                     | nd                       |
| 18:0                                     | 1.9–4.4                  |
| 18:1                                     | 36.4–67.1                |
| 18:2                                     | 14.0–43.0                |
| 18:3                                     | 0–0.1                    |
| 20:0                                     | 1.1–1.7                  |
| 20:1                                     | 0.7–1.7                  |
| 22:0                                     | 2.1–4.4                  |
| 22:1                                     | 0–0.3                    |
| 24:0                                     | 1.1–2.2                  |
| 24:1                                     | 0–0.3                    |

<sup>a</sup> Additional information, not in the draft Codex. nd, not detected.

**Table 3.52** Sterol composition of groundnut oil<sup>a</sup> (Rossell *et al.*, 1983)

| Sterol                   | Range (%) | Mean (%) |
|--------------------------|-----------|----------|
| Cholesterol              | 0.5–3.8   | 1.5      |
| Brassicasterol           | 0.0–0.4   | 0.0      |
| Campesterol              | 11.4–19.8 | 17.0     |
| Stigmasterol             | 4.8–13.3  | 8.7      |
| $\beta$ -Sitosterol      | 47.6–64.8 | 58.5     |
| $\Delta^5$ -Avenasterol  | 8.3–19.0  | 12.3     |
| $\Delta^7$ -Stigmasterol | 0.0–5.2   | 2.1      |
| $\Delta^7$ -Avenasterol  | 0.0–6.6   | 1.2      |
| Total sterol (mg/kg)     | 901–2850  |          |

**Table 3.49** World production of groundnut oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 | 1989/90 |
|---------|---------|---------|---------|---------|---------|
| 3230    | 3565    | 2605    | 3265    | 2955    | 3787    |

**Table 3.50** Fatty acid composition (wt%) of groundnut oil

| 16:0 | 18:0 | 20:0 | 22:0 | 24:0 | 18:1 | 18:2 | 18:3 | 20:1 | 22:1 |
|------|------|------|------|------|------|------|------|------|------|
| 12.5 | 2.5  | 1.2  | 2.5  | 1.3  | 37.0 | 41.0 | 0.3  | 0.7  | 1.0  |

**Table 3.53** The tocopherol content of groundnut oil (ppm)

| Reference                    | $\alpha$ -T         | $\beta$ -T       | $\gamma$ -T <sup>a</sup> | $\delta$ -T | $\Sigma T_3$ <sup>a</sup> |
|------------------------------|---------------------|------------------|--------------------------|-------------|---------------------------|
| Muller-Mulot (1976)          | 169                 | 5.4              | 144                      | 13          | —                         |
| Rossell <i>et al.</i> (1983) | 49–304 <sup>b</sup> | 1–41             | 99–389                   | —           | —                         |
| Rossell <i>et al.</i> (1983) | 178 <sup>c</sup>    | 9.8 <sup>c</sup> | 220 <sup>c</sup>         |             |                           |

<sup>a</sup> Tocotrienols are absent.<sup>b</sup> Based on 43 samples.<sup>c</sup> Mean of 43 samples.

oil as the seed matures. Changes in the major lipid classes during maturation have been studied (Pattee *et al.*, 1969; Sanders, 1980). Oleic acid increases as maturation progresses.

Aflatoxin can occur as a contaminant in crude oil, but this is removed during alkali refining and bleaching. Because this toxin is very prevalent in mouldy seeds, it is worth noting that seeds infected with 5500 ppb aflatoxin yielded a crude oil with 812 ppb aflatoxin. This was progressively removed by alkali refining (10–14 ppb in neutral oil) and bleaching (<1 ppb in oil) (Parker and Melnick, 1966). Electronic sorting can also be used to discard mouldy beans (Ayres, 1983).

The phospholipids of groundnut oil (0.3–0.4%) are composed of phosphatidylethanolamine (7.6%), phosphatidylcholine (22.6%), phosphatidylinositol (16.7%), phosphatidic acid (2.6%), phytoglycolipid (38.3%) and unidentified phospholipids (12.2%) (Singleton and Pattee, 1981; Wagner and Wolff, 1964).

### 3.3.16 Hemp seed oil (marijuana)

[*Cannabis sativa*; Cannabinaceae]

There are no recent data available on world production, but an estimated 55 000 tonnes were produced in 1970; it is produced in the Far East, the former USSR, Poland, the former Yugoslavia and Turkey. Summary information is shown in Tables 3.55 and 3.56.

Hemp is an annual herbaceous plant, which is cultivated for its seed, its fibre and for narcotics. Substantial quantities are grown in southern Europe, the former USSR, China, Japan and Chile. The oil is obtained mainly by expelling; lighter-coloured oil is obtained by cold pressing. The seed oil is used for similar purposes to linseed oil, which it resembles. The oil is widely used for edible purposes in Asia. The presence of 6% of 12,13-epoxyoleic acid has been reported (Latif and El Daly, 1973).

### 3.3.17 Illipe butter (Borneo tallow, tenkawang)

[*Shorea stenoptera*; Dipterocarpaceae]  
(see also Mowrah butter)

World production is confined to Indonesia, in small tonnages and very erratic: 7000 tonnes were reported in 1980/82. Other data are shown in Tables 3.57 and 3.58.

Illipe is indigenous to Borneo and is a large tree growing in the tropical rainforests. The trees bear large winged seeds, which are collected by natives (Raymond and Ward, 1956).

The availability of this uncultivated crop is unpredictable and only every 2–6 years is a crop collected that is of any commercial value. The harvested seed is subjected to a variety of treatments prior to export. These vary from kiln or sun drying to water soaking (to remove saponins) prior to drying. Good-quality oil is obtained from kiln- or sun-dried nuts that have not been water-soaked and provided that the drying is done reasonably quickly and in a controlled way. Soaking in water produces a seed with a higher oil content, but the oil has a high free fatty acid content and is of poor quality.

The seeds contain a pale yellow oil (45–50%), which can be obtained by expelling and subsequent solvent extraction. Commercial oils have a relatively high free fatty acid content (5–20%) depending on the age of the seed and the harvesting methods. The residual meal has a low nutritional value when used in animal feed. The analysis of 95 contractual samples showed oil contents of 45.6–59.7% with free fatty acid levels of 6.2–33.4% (Kershaw, 1987).

The refined oil of good quality melts sharply between 30 and 35 °C and is used almost solely as a partial replacer of cocoa butter in chocolate. The triglyceride composition is given in Table 3.158. Many of the minor components of illipe butter have been characterized, particularly the sterols and triterpene alcohols (Itoh *et al.*, 1974) (Tables 3.163–3.166).

Numerous fats available from uncultivated crops have also been considered as sources of cocoa butter-

**Table 3.54** Mean concentrations<sup>a</sup> of fatty acids and sterols by groundnut type and groups of types with similar fatty acid composition (Sheppard and Rudolf, 1991)

| Groundnut     | Fatty acid <sup>b</sup> (g/100 g of groundnut) |                |                 |                 |                |                |                | Sterols (mg/100 g) |                |                     |  |
|---------------|------------------------------------------------|----------------|-----------------|-----------------|----------------|----------------|----------------|--------------------|----------------|---------------------|--|
|               | 16:0                                           | 18:0           | 18:1            | 18:2            | 20:0           | 20:1           | 22:0           | Campesterol        | Stigmasterol   | $\beta$ -Sitosterol |  |
| Runner (R)    | 4.6 $\pm$ 0.49                                 | 1.5 $\pm$ 0.12 | 23.1 $\pm$ 2.1  | 12.4 $\pm$ 0.66 | 0.5 $\pm$ 0.58 | 1.0 $\pm$ 0.19 | 0.5 $\pm$ 0.75 | 26.3 $\pm$ 5.6     | 27.2 $\pm$ 5.5 | 135.5 $\pm$ 31.7    |  |
| Virginia (V)  | 5.2 $\pm$ 0.25                                 | 1.5 $\pm$ 0.12 | 23.5 $\pm$ 0.34 | 13.7 $\pm$ 1.1  | 0.7 $\pm$ 0.43 | 0.9 $\pm$ 0.55 | 0.3 $\pm$ 0.37 | 31.1 $\pm$ 6.1     | 32.8 $\pm$ 3.4 | 179.2 $\pm$ 14.5    |  |
| Valencia (VA) | 5.0 $\pm$ 0.16                                 | 1.5 $\pm$ 0.12 | 17.2 $\pm$ 0.50 | 17.6 $\pm$ 1.1  | 0.3 $\pm$ 0.49 | 1.2 $\pm$ 0.0  | 0.2 $\pm$ 0.08 | 55.2 $\pm$ 4.8     | 25.6 $\pm$ 5.8 | 290.6 $\pm$ 40.2    |  |
| Spanish (S)   | 5.6 $\pm$ 0.19                                 | 1.7 $\pm$ 0.12 | 18.0 $\pm$ 1.7  | 18.3 $\pm$ 0.96 | 0.5 $\pm$ 0.50 | 1.1 $\pm$ 0.10 | 0.3 $\pm$ 0.19 | 31.3 $\pm$ 6.7     | 32.4 $\pm$ 2.5 | 170.8 $\pm$ 35.8    |  |
| R + V         | 4.9 $\pm$ 0.46                                 | 1.5 $\pm$ 0.11 | 23.3 $\pm$ 1.4  | 13.0 $\pm$ 1.1  | 0.5 $\pm$ 0.45 | 0.9 $\pm$ 0.38 | 0.4 $\pm$ 0.56 | 28.2 $\pm$ 5.8     | 30.0 $\pm$ 5.2 | 157.6 $\pm$ 32.5    |  |
| VA + S        | 5.3 $\pm$ 0.34                                 | 1.6 $\pm$ 0.15 | 17.6 $\pm$ 1.2  | 17.9 $\pm$ 1.0  | 0.4 $\pm$ 0.47 | 1.1 $\pm$ 0.10 | 0.2 $\pm$ 0.13 | 41.5 $\pm$ 13.9    | 29.5 $\pm$ 6.3 | 222.1 $\pm$ 72.6    |  |
| All types     | 5.1 $\pm$ 0.44                                 | 1.6 $\pm$ 0.14 | 17.7 $\pm$ 6.4  | 15.5 $\pm$ 2.7  | 0.5 $\pm$ 0.47 | 1.0 $\pm$ 0.29 | 0.3 $\pm$ 0.45 | 34.4 $\pm$ 12.1    | 29.8 $\pm$ 5.0 | 187.7 $\pm$ 62.5    |  |

<sup>a</sup> Mean  $\pm$  standard deviation, based on 4, 4, 4, 8 and 16 values, respectively, for the seven groundnut types.<sup>b</sup> Trace levels were arbitrarily assigned a value of 0.1 when mean concentrations were calculated.**Table 3.55** Fatty acid composition of hemp seed oil (Archer-Daniels-Midland, 1961)

|      |      |      |      |      |
|------|------|------|------|------|
| 16:0 | 18:0 | 18:1 | 18:2 | 18:3 |
| 6    | 2    | 12   | 55   | 25   |

**Table 3.56** Characteristics of hemp seed oil (typical values)

|                                 |             |
|---------------------------------|-------------|
| Relative density, $d_{25}^{25}$ | 0.923–0.925 |
| Refractive index, $n_D^{45}$    | 1.470–1.473 |
| Saponification value            | 190–193     |
| Iodine value                    | 140–175     |
| Unsaponifiable matter (%)       | 1           |
| Oil content of seed (%)         | 30–35       |

**Table 3.57** Fatty acid composition (wt%) of illipe butter

|      |      |      |      |      |      |      |
|------|------|------|------|------|------|------|
| 14:0 | 16:0 | 18:0 | 20:0 | 16:1 | 18:1 | 18:2 |
| 0.2  | 17.5 | 46.0 | 0.1  | 0.2  | 35.0 | 1.0  |

**Table 3.58** Characteristics of illipe butter

|                                  | Typical            | Range       |
|----------------------------------|--------------------|-------------|
| Relative density, $d_{15}^{100}$ | –                  | 0.852–0.850 |
| Refractive index, $n_D^{65}$     | 1.4487             | –           |
| Saponification value             | 194                | 189–200     |
| Iodine value                     | 34                 | 29–38       |
| Unsaponifiable matter (%)        | 0.9                | 0.4–2.0     |
| Oil content of seed (%)          | 45–50 <sup>a</sup> | –           |

<sup>a</sup> Depends on pretreatment.

Table 3.59 Natural fats providing a source of StOst, POST and POP (Bracco, 1973; Lakshminarayana *et al.*, 1983)

| Family           | Botanical name<br>(species)      | Common name<br>of oil    | Analytical values |                         | Fatty acid composition |      |       |       |       |      | Triglyceride composition |           |         |         |
|------------------|----------------------------------|--------------------------|-------------------|-------------------------|------------------------|------|-------|-------|-------|------|--------------------------|-----------|---------|---------|
|                  |                                  |                          | Iodine value      | Saponification<br>value | M.p.<br>(°C)           | 14:0 | 16:0  | 18:0  | 18:1  | 18:2 | 20:0                     | Saturated | Monoene | Polyene |
| Dipterocarpaceae | <i>Shorea robusta</i>            | Sal oil                  | 34-36             | 181-189                 | 30-35                  | -    | 5     | 44    | 42    | 3    | 6                        | 2         | 64      | 34      |
|                  | <i>S. stenoptera</i>             | Illipe butter            | 31-33             | 190-196                 | 34-38                  | -    | 19-20 | 40-42 | 35-38 | 1    | -                        | 4         | 79      | 17      |
|                  | <i>Vateria indica</i>            | Malabar tallow           | 35-38             | 185-190                 | 34-36                  | 1    | 12    | 41    | 45    | 1    | -                        | 2         | 74      | 24      |
| Euphorbiaceae    | <i>Sapium sebiferum</i>          | Chinese vegetable tallow | 27-33             | 199-204                 | 38-44                  | 5    | 60    | 2     | 33    | -    | -                        | 26        | 56      | 18      |
| Gnetaceae        | <i>Gnetum scandens</i>           |                          | -                 | 199                     | -                      | -    | 14    | 56    | 27    | 3    | -                        | -         | -       | -       |
| Guttifera        | <i>Garcinia indica</i>           | Kokum butter             | 33-35             | 189-195                 | 38-42                  | 1    | 4     | 53    | 40    | 2    | -                        | 2         | 74      | 24      |
|                  | <i>G. morella</i>                | Gamboge                  | 38-46             | 189-195                 | 30-41                  | 1    | 7     | 42    | 43    | 6    | 1                        | 3         | 45      | 50      |
|                  | <i>Platonia insignis</i>         | Bacury                   | 39-44             | 191-201                 | 54-58                  | 1    | 55    | 7     | 33    | 4    | -                        | 24        | 56      | 25      |
| Sapotaceae       | <i>Dumoria heckeli</i>           | Maccore                  | 53                | 192                     | 24-26                  | -    | 3     | 38    | 58    | 1    | -                        | 1         | 10      | 89      |
|                  | <i>Madhuca butry</i>             | Phulwara butter          | 45                | 194                     | 40-42                  | -    | 60    | 4     | 36    | 4    | -                        | 8         | 69      | 23      |
|                  | <i>Plagium oleosum</i>           | Siak nuts                | 38                | 187                     | 35-39                  | -    | 6     | 54    | 40    | -    | -                        | 2         | 77      | 21      |
|                  | <i>Butyrospermum parkii</i>      | Karite-shea              | 51-60             | 180-198                 | 32-34                  | -    | 6     | 40    | 50    | 4    | -                        | -         | 52      | 48      |
| Sterculiaceae    | <i>Theobroma grandiflorum</i> S. | Cupu assu                | 37                | 195                     | 32-34                  | 1    | 8     | 34    | 41    | 2    | 9 <sup>a</sup>           | -         | -       | -       |
|                  | <i>Theobroma bicolor</i>         | Lupu                     | 38-45             | 188-189                 | 30-32                  | -    | -     | -     | -     | -    | -                        | -         | -       | -       |
|                  | <i>Mangifera indica</i>          | Mango kernel             |                   |                         |                        |      | 3-18  | 24-57 | 34-56 | 1-13 | tr-4                     |           |         |         |

<sup>a</sup> Also 22:0 2%.

## Occurrence and characteristics

like triglycerides. Some of these are summarized in Table 3.59.

### 3.3.18 Kapok seed oil

[*Ceiba pentandra* (*Eriodendron anfractuosum*), *Bombax malarbaricum* (Indian kapok); Bombacaceae]

World production: data are not readily available; 22 000 tonnes were reported in 1978. Other information is given in Tables 3.60 and 3.61.

A number of tropical trees in the *Bombax* family, of which *C. pentandra* is the most commercialized, bear seed pods that contain fibre that finds use as a stuffing material. The seeds, a by-product of kapok fibre production, contain an oil resembling cottonseed oil (Earle and Jones, 1962). The oil is obtained by crushing followed by solvent extraction. In the past it has been refined to produce an 'edible' oil. This should not be permitted because of possible toxic effects arising from the presence of cyclopropene acids (13%). The oil gives a positive Halphen test. It does not, however, contain any gossypol, and can be distinguished from cottonseed oil by the Besson test (Mehlenbacher, 1936). Characterization of the triterpene alcohols offers a more definitive test. The sterols, 4-methylsterols and triterpene alcohols of kapok oil are given in Tables 3.163–3.166. The oil is used for lubrication and in soap-making.

**Table 3.60** Characteristics of kapok seed oil (American Oil Chemists' Society, 1941)

|                                 |             |
|---------------------------------|-------------|
| Relative density, $d_{15}^{15}$ | 0.920–0.933 |
| Refractive index, $n_D^{25}$    | 1.466–1.472 |
| Saponification value            | 189–197     |
| Iodine value                    | 86–110      |
| Unsaponifiable matter (%)       | 0.5–1.8     |
| Oil content of seed (%)         | 22–25       |

### 3.3.19 Linseed oil

[*Linum usitatissimum*; Linaceae]

The relevant data are summarized in Tables 3.62 to 3.65. Linseed flax or common flax is an annual, 25–100 cm in height. There are two distinct strains of flax: linseed flax gives high yields of seed (oil content 35–44%) and linen flax is grown for its fibre. It is a sub-tropical or warm-temperature crop, and is harvested either manually or by combined harvester. It is grown principally in Argentina, India, the former USSR, the USA and Canada.

The small (5 mm long), oval, flat seeds are usually pressed then solvent-extracted, yielding crude linseed oil, which is dark amber in colour. The colour of the oil is improved by refining and bleaching. This also removes phosphatides. Waxes are removed from the refined oil by winterization.

The oil is a drying oil used principally as a component of paints, varnishes, linoleum and printing inks. It has been used as an edible oil, preferably after partial hydrogenation.

The triglycerides of linseed reflect its high linolenate composition. A wide variation in linolenate content has been noted (Table 3.65). This is related both to variety and to climatic conditions during maturation: the colder the climate, the higher is the iodine value. Early work (Dillman and Hopper, 1943) has also shown that moisture deficiency during growth tends to reduce the iodine value. There is a

**Table 3.62** World production of linseed oil (1000 tonnes)

| 1980/81 | 1981/82 | 1982/83 | 1989/90 |
|---------|---------|---------|---------|
| 660     | 665     | 860     | 645     |

**Table 3.63** Fatty acid composition (wt%) of linseed oil

| 16:0 | 18:0 | 16:1 | 18:1 | 18:2 | 18:3 |
|------|------|------|------|------|------|
| 6.1  | 3.2  | 0.1  | 16.6 | 14.2 | 59.8 |

**Table 3.61** Fatty acid composition<sup>a</sup> (wt%) of oil from *E. anfractuosum* (Blanchini *et al.*, 1981)

| 16:0 | 18:0 | 18:1 | 18:2 | M | MH <sub>2</sub> | S | SH <sub>2</sub> | Others |
|------|------|------|------|---|-----------------|---|-----------------|--------|
| 22   | 3    | 21   | 37   | 8 | 1               | 4 | 1               | 3      |

<sup>a</sup> This oil contains malvinic (M), dihydromalvinic (MH<sub>2</sub>), sterculic (S) and dihydrosterculic (SH<sub>2</sub>) acids.

Table 3.64 Characteristics of raw linseed oil (ASTM specification D234-48)

|                                            |                                                                                                                    |
|--------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| Relative density, $d_{15}^{15.5}$          | 0.931–0.936                                                                                                        |
| Refractive index, $n_D^{20}$               | 1.400–1.4835 <sup>a</sup>                                                                                          |
| Saponification value                       | 189–195                                                                                                            |
| Iodine value, minimum                      | 177                                                                                                                |
| Unsaponifiable matter, maximum (%)         | 1.50                                                                                                               |
| Acid number                                | 4.0                                                                                                                |
| Loss on heating at 105–110 °C, maximum (%) | 0.3                                                                                                                |
| Appearance                                 | Clear and transparent at 65 °C                                                                                     |
| Colour                                     | Not darker than a freshly prepared solution of 1.0 g of $K_2Cr_2O_7$ in 100 ml of pure $H_2SO_4$ (rel. dens. 1.84) |
| Foots, max. (%)                            |                                                                                                                    |
| heated oil                                 | 1.0                                                                                                                |
| chilled oil                                | 4.0                                                                                                                |

<sup>a</sup> Not part of the ASTM specification, a British Standard.

Table 3.65 Fatty acid composition (wt%) of linseed oil (*L. usitatissimum*)

| Fatty acid | Variety                     |      |                                |                      |                             |         |
|------------|-----------------------------|------|--------------------------------|----------------------|-----------------------------|---------|
|            | Krupnosemganny <sup>a</sup> |      | Abyssinian yellow <sup>b</sup> | Cawpore <sup>b</sup> | Low-linolenate <sup>c</sup> |         |
|            | 1961                        | 1962 |                                |                      | Glenelg                     | Croxton |
| 14:0       | tr                          |      | tr                             | tr                   | —                           | —       |
| 16:0       | 6.8                         | 6.3  | 7.0                            | 7.0                  | 8                           | 8       |
| 16:1       | tr                          | tr   | tr                             | tr                   | —                           | —       |
| 18:0       | 5.8                         | 4.1  | 4.0                            | 4.0                  | 5                           | 3       |
| 18:1       | 23.5                        | 14.7 | 15.0                           | 39.0                 | 21                          | 18      |
| 18:2       | 15.0                        | 18.8 | 18.0                           | 15.0                 | 64                          | 69      |
| 18:3       | 48.9                        | 56.1 | 56.0                           | 35.0                 | 2                           | 2       |

<sup>a</sup> Grown in Russia; 1962 crop grown from 1961 seeds (Vereshchagin and Novitskaya, 1965).

<sup>b</sup> Data from Yermanos (1966).

<sup>c</sup> Green (1988).

close correlation between refractive index and iodine value (Zeleny and Coleman, 1936) (see also Von Schuster and Marquard, 1974).

The major triglycerides of linseed are given in Table 3.159. The sterols, methylsterols and tri-terpene alcohols of linseed are given in Tables 3.163–3.166. The technical application of linseed in paints is described in Chapter 5.

Flaxseed and flaxseed cake contain the cyanogenic glucoside linamarin, which, when hydrolysed by the endogenous enzyme linase, yields hydrogen cyanide. This can be prevented by denaturing the enzyme by heat.

Plant breeding via genetic modification has produced a low-linolenate variety of flax, which is more suitable for edible purposes (Table 3.65) (Green, 1988, *IFORM*, 1990).

### 3.3.20 Mowrah butter (*bassia*, *illipe*)

[*Madhuca latifolia* (*M. indica*, *Bassia latifolia*), *M. longifolia* (*B. longifolia*); Sapotaceae]  
confused with Borneo tallow;  
see Illipe butter

World production was reported as 37 000 tonnes in 1977. Fatty acid data and characteristics are shown in Tables 3.66 and 3.67. The seeds are obtained from tropical trees growing in India. *M. longifolia* is an evergreen found in southern India. *M. latifolia* is deciduous and grows in northern India. Although they are botanically distinct, the trade does not distinguish between them. Confusion can occur because the seeds of *Shorea stenoptera* are also called illipe (Kaufmann and Thieme, 1954).

## Occurrence and characteristics

**Table 3.66** Fatty acid composition (wt%) of mowrah butter (Tropical Products Institute, 1971)

|                      | 16:0 | 18:0 | 18:1 | 18:2 |
|----------------------|------|------|------|------|
| <i>M. latifolia</i>  | 24   | 19   | 43   | 14   |
| <i>M. longifolia</i> | 28   | 14   | 49   | 9    |

**Table 3.67** Characteristics of mowrah butter

|                                  |             |
|----------------------------------|-------------|
| Relative density, $d_{15}^{100}$ | 0.856–0.870 |
| Refractive index, $n_D^{40}$     | 1.458–1.462 |
| Saponification value             | 188–200     |
| Iodine value                     | 53–70       |
| Unsaponifiable matter (%)        | 1–3         |
| Oil content of seed (%)          | 55–60       |

Commercial quantities of mowrah butter are obtained by expelling. The oil is used for soap-making and to a lesser extent as an edible oil. The meal contains a poisonous saponin, mowrin, which has been used to kill worms.

The oil is of significant commercial importance in India and is used for both edible and industrial purposes. The oil, either hydrogenated or not, has been proposed as a confectionery fat. Many crystallizations from solvent are apparently required to obtain a suitable fraction with the right melting properties.

A wide variation in the composition of the oil has been noted (Sen Gupta *et al.*, 1982): 15–32% palmitic, 16–26% stearic, 32–45% oleic, 14–18% linoleic and traces of 14:0 and 20:0.

Other minor oils produced from seeds of trees in India include neem, karanja and kusum. Typical fatty acid compositions of these oils are given in Table 3.68, and the triglycerides in mowrah are given in Table 3.69. For a detailed review, see Bringi (1987).

### 3.3.21 Mustard seed oil

[*Brassica alba* (white mustard), *B. hirta* (yellow m.), *B. nigra* (black m.), *B. juncea* (brown m.), *B. carinata* Braun (Ethiopian m.); Cruciferae]  
see also Rapeseed oil

World production: there are no comprehensive data available; approximately 100 000 tonnes were traded in 1980. Other data are shown in Tables 3.70 and 3.71.

Mustard seed is normally associated in the West with table mustard, its taste arising from sulphur-based essential oils. *Brassica juncea* (brown mustard) is, however, grown for its oil in India, Pakistan and Bangladesh. Other species of Cruciferae grown for oil in southern Asia are *B. tournefortii* Gouan and rocket (*Eruca sativa* Hill).

Mustard is grown as both a summer and a winter

**Table 3.68** Fatty acid composition of minor seed oils of India (wt%)

|                                    | 14:0 | 16:0 | 18:0 | 20:0 | 22:0 | 18:1 | 18:2 | 18:3 | Others          |
|------------------------------------|------|------|------|------|------|------|------|------|-----------------|
| Karanja ( <i>Pongamia glabra</i> ) | 0.3  | 10.7 | 7.2  | 1.0  | 6.7  | 47.9 | 23.6 | –    | 1.6             |
| Kusum <i>Schleichera trijuga</i>   | 1    | 7    | 6    | 26   | –    | 42   | 4    | tr   | 14 <sup>a</sup> |
| Neem ( <i>Melia azadirachta</i> )  | 2    | 14   | 18   | 2    | –    | 55   | 9    | –    | –               |

<sup>a</sup> Includes 12% 20:1.

**Table 3.69** The triglyceride composition<sup>a</sup> of mowrah butter (Bringi, 1987)

| S <sub>3</sub> | S <sub>2</sub> U | SU <sub>2</sub> | U <sub>3</sub> | POP  | POSt  | StOSt | POO  | StOO |
|----------------|------------------|-----------------|----------------|------|-------|-------|------|------|
| 1–2            | 42–56            | 36–44           | 6–12           | 7–12 | 12–16 | 4–7   | 8–12 | 7–10 |

<sup>a</sup> S, saturated; U, unsaturated; P, palmitic (16:0); O, oleic (18:1); St, stearic (18:0).

**Table 3.70** Fatty acid composition (wt%) of *Brassica alba*

| 16:0 | 18:0 | 20:0 | 16:1 | 18:1 | 18:2 | 18:3 | 20:1 | 22:1 | Others |
|------|------|------|------|------|------|------|------|------|--------|
| 2.6  | 0.8  | 0.7  | 0.1  | 23.2 | 8.9  | 10.4 | 8.1  | 43.1 | 2.1    |

**Table 3.71** Characteristics of mustard seed oil, from draft Codex (Codex, 1970b, see Table 3.157)

|                                                  |                 |
|--------------------------------------------------|-----------------|
| Relative density, $d_{20}^{20}$                  | 0.910–0.921     |
| Refractive index, $n_D^{40}$                     | 1.461–1.469     |
| Saponification value                             | 170–184         |
| Iodine value                                     | 92–125          |
| Unsaponifiable matter (g/kg)                     | 15              |
| Allylisothiocyanate (g/kg)<br>(method specified) | Not more than 4 |

crop. The oil content of the seed varies (24–40%). The yield is approximately 1000 kg/ha of seed. The oil, in some cases unrefined, is used for edible purposes in a number of countries. There is increasing interest in the crop as a source of erucic acid for the chemical industry (Knowles *et al.*, 1981). At the present time there is no edible oil market for mustard oils in the USA. Rapeseed oil (low-erucic acid) has recently been permitted as an edible oil.

The relationship between the six brassica species has been described by Downey *et al.* (1975). Commercially grown high-erucic acid rape and mustard seed oil are similar in composition and are characterized by their high erucic acid content (McPherson, 1978; Tsunoda *et al.*, 1980).

The glyceride composition of mustard oil has not been reported but presumably is similar to that of high-erucic acid rape (Table 3.100).

As with rape, the oil contains large amounts of brassicasterol, a 'unique' component used for identifying the presence of Cruciferae oils (Matsumoto *et al.*, 1982). Minor amounts of brassicasterol have, however, been reported in other vegetable oils.

### 3.3.22 Oiticica oil

[*Licania rigida*; Rosaceae]

Comprehensive data on world production are not readily available; 14 000 tonnes reported in 1981. Brazil exported 3000 tonnes in 1981. Other information is summarized in Tables 3.72 and 3.73.

The oil comes from the kernels of the nuts of the oiticica tree, which grows in Brazil. The tree is large and spreading, similar to the mango tree. The seeds, contained in a tough fibrous shell (2.5–5 cm long), are readily split to provide the long reddish kernel. The seed must be decorticated, as the outer husk contains significant amounts of chlorophyll, which can transfer to the oil. The Mexican oiticica tree, *Licania arborea*, yields an oil of similar composition and is called Mexican oiticica or cacahuanache oil.

The oil is extracted by either expelling or solvent extraction or a combination of both. The crude oil is

**Table 3.72** Fatty acid composition (wt%) of oiticica oil

| 16:0 | 18:0 | 18:1 | oxo 18:3 | OH 18 |
|------|------|------|----------|-------|
| 7    | 5    | 6    | 78       | 4     |

**Table 3.73** Characteristics of oiticica oil (typical values)

|                                 |        |
|---------------------------------|--------|
| Relative density, $d_{20}^{40}$ | 0.970  |
| Refractive index, $n_D^{25}$    | 1.5140 |
| Saponification value            | 190    |
| Iodine value                    | 148    |
| Unsaponifiable matter (%)       | 0.5    |
| Oil content of seed (%)         | 62     |

freed from mucilage at 120°C with 5% water and filtered hot. The extracted oil isomerizes and gradually solidifies on standing at room temperature. This is prevented by heating the oil to 210–220°C for 30 min.

The major fatty acid in oiticica, Mexican oiticica and poyoak (*Parinarium sherbroense*) oils is  $\alpha$ -licanic acid, a conjugated trienoic  $C_{18}$  fatty acid with a keto function at  $C_4$  (4-keto 9c,11t,13t-18:3) (Morrell and Davis, 1936). Hydroxy fatty acids (4%) have also been detected by GLC. Prior to GLC  $\alpha$ -eleostearic acid had been reported (sections 1.4 and 3.2.12).

The oil superficially resembles tung oil, but oiticica dries more slowly and has poorer water- and chemical-resistance properties. The oil is used in paints and enamels and in the linoleum, oil cloth and printing ink industries.

Oiticica oil triglycerides have been separated by silica column chromatography into four fractions: a monoketo fraction (27.3%), diketo fraction (32.1%), a more polar triglyceride fraction (12.9%) and others (15.9%). The level of licanic acid was reported to be lower than that previously reported, i.e. 46% instead of 70–80% (Evans *et al.*, 1967).

The neutral unsaponifiables of Brazilian oiticica oil have also been characterized (Fedeli *et al.*, 1966).

### 3.3.23 Olive oil (aceituna, oliva, olivier)

[*Olea europea*; Oleaceae]

Data are summarized in Tables 3.74–3.79. Today, olive oil is the major edible vegetable oil of the Mediterranean countries (including Spain, Greece and Italy) and Portugal (Lunde, 1972; Tous, 1968). Spanish missionaries brought the olive to California in 1850 and Mediterranean immigrants brought it to South America. For recent reviews, see Kiritsakis

## Occurrence and characteristics

**Table 3.74** World production of olive oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 | 1989 | 1990 |
|---------|---------|---------|---------|---------|------|------|
| 1605    | 1760    | 1980    | 1580    | 2160    | 1911 | 1768 |

**Table 3.75** Fatty acid composition of olive oil (wt%), two examples

| 16:0 | 18:0 | 20:0 | 16:1 | 18:1 | 18:2 | 18:3 | 20:1 |
|------|------|------|------|------|------|------|------|
| 10.3 | 2.3  | 0.4  | 0.7  | 78.1 | 7.3  | 0.6  | 0.3  |
| 18.3 | 2.5  | 0.5  | 2.4  | 56.6 | 18.9 | 0.8  | —    |

**Table 3.76** Characteristics<sup>a</sup> of olive oil, from draft Codex (Codex, 1979 and 1987)

|                                                       |                  |
|-------------------------------------------------------|------------------|
| Relative density, $d_{20}^{20}$                       | 0.910–0.916      |
| Refractive index, $n_D^{20}$                          | 1.4677–1.4705    |
| Saponification value                                  | 184–196          |
| Iodine value                                          | 75–94            |
| Unsaponifiable matter (%)                             | 1.5              |
| Bellier index                                         | Not more than 17 |
| Tests for specific oils<br>(see recommended standard) | Negative         |
| GLC ranges of fatty acid<br>composition (%)           |                  |
| 14:0                                                  | <0.05            |
| 16:0                                                  | 7.5–20           |
| 16:1                                                  | 0.3–3.5          |
| 18:0                                                  | 0.5–5.0          |
| 18:1                                                  | 55–83            |
| 18:2                                                  | 3.5–21           |
| 18:3                                                  | <1.5             |
| 20:0                                                  | <0.8             |
| 20:1                                                  | tr               |
| 22:0                                                  | <0.2             |
| 24:0                                                  | <1.0             |

<sup>a</sup> The composition and quality factors of olive oil vary widely from country to country. The physical and chemical characteristics are determined for each olive crop year and published in each producing country's *National Olive Oil Index File*.

and Markakis (1987) and Kiritsakis and Min (1988). The oil is obtained from the fruit of the evergreen olive tree. Trees 100–500 years old still bear fruit. The olive fruit is a drupe consisting, when ripe, of an oily pulp enclosing an ellipsoidal stone containing a small kernel. Prior to harvesting, the oil content increases (to 15–40%) and the olive progressively turns black. The kernels contain oil in smaller proportions (1% of total) than that found in the pulp, but both oils are similar in composition.

The kernels are not separated during normal methods of oil expelling or pressing. The first pressing yields virgin olive oil, which is separated from aqueous material by prolonged settling. This oil provides the finest quality of oil for export and is used in its unrefined state.

The Codex defines virgin olive oil as 'the oil obtained from the fruit of the olive tree by mechanical or other physical means under conditions, particularly thermal, which do not lead to alterations of the oil. Virgin olive oil is an oil which is suitable for consumption in its natural state.' The International Olive Oil Council (IOOC) has defined three grades of virgin olive oil (extra, fine and ordinary) based on flavour, free fatty acid content, peroxide value and ultraviolet (UV) absorbance coefficient criteria. Virgin olive oil not for consumption as it is, i.e. that

**Table 3.77** IOOC quality standards of olive oil for international trade

| Virgin olive oils | Flavour            | Acidity<br>(%) | Peroxide value | Specific UV absorbance |            |
|-------------------|--------------------|----------------|----------------|------------------------|------------|
|                   |                    |                |                | $K_{270}$              | $\Delta K$ |
| Extra             | Absolutely perfect | 1.0            | 20             | 0.2                    | 0.010      |
| Fine              | Absolutely perfect | 1.5            | 20             | 0.2                    | 0.010      |
| Ordinary          | Good               | 3.3            | 20             | 0.25                   | 0.010      |

**Table 3.78** Fatty acid composition (%) of olive oil, from different origins

| Acid | Libya <sup>a</sup> | Iran <sup>b</sup> | Italy <sup>c</sup> | Turkey <sup>c</sup> | Portugal <sup>c</sup> |
|------|--------------------|-------------------|--------------------|---------------------|-----------------------|
| 16:0 | 17.8               | 10.0              | 7-17               | 11.1                | 12.1                  |
| 17:0 | 0.1                | tr                | —                  | —                   | —                     |
| 18:0 | 2.2                | 2.6               | 1.5-4.0            | 2.5                 | 2.5                   |
| 20:0 | 0.4                | 0.2               | 0-0.7              | 0.4                 | 0.1                   |
| 22:0 | —                  | —                 | 0-0.3              | 0.1                 | 0.1                   |
| 24:0 | —                  | —                 | 0-0.5              | 0.4                 | 0.4                   |
| 16:1 | 2.5                | 0.8               | 0.3-3.0            | 0.7                 | 1.5                   |
| 17:1 | 0.1                | tr                | —                  | —                   | —                     |
| 18:1 | 43.7               | 78.2              | 63-83              | 74.1                | 75.3                  |
| 18:2 | 32.3               | 7.9               | 5-13.5             | 9.4                 | 6.1                   |
| 18:3 | 0.8                | 0.2               | 0-1.5              | 0.2                 | 1.0                   |
| 20:1 | 0.2                | 0.1               | 0-0.5              | 0.2                 | —                     |

<sup>a</sup> Rana and Ahmed (1981).<sup>b</sup> Paganuzzi (1979).<sup>c</sup> Fedeli (1983).**Table 3.79** Minor components in olive oil (Tous, 1968)

| Component                   | Level        |
|-----------------------------|--------------|
| Hydrocarbons (total)        | 0.125-0.750% |
| Squalene                    | 0.125-0.700% |
| Sterols (total)             | 0.125-0.250% |
| Triterpene alcohols (total) | 500 ppm      |
| Chlorophyll                 | 0.6-2.2 ppm  |
| Carotenoids as:             |              |
| $\beta$ -carotene (total)   | 0.6-9.5 ppm  |
| tocopherols (total)         | 175-200 ppm  |

requires refining, is defined as virgin olive oil lampante.

The residual pulp is subjected to a second pressing with hot water. The oil is usually refined and blended with virgin olive oil. The pomace can be pressed a third time and the residue extracted with solvent (olive residue oil, ORO).

Inedible 'sulphur olive oil' or 'olive foots' are the names given to very low grades of olive oil obtained by extraction. The name 'sulphur' originates from the use of carbon disulphide, which is now rarely used as an extraction solvent. Higher grades of extracted oil are refined and used for edible purposes.

The oil is used almost solely for edible purposes, e.g. cooking oil, salad oil, but inedible grades are used for soap-making, in wool-combing and in cosmetics.

In a number of countries legal and commercial pressures have encouraged olive oil adulteration. Similarly, low-grade olive oils are 'blended' off with groundnut, cottonseed and soybean oil, etc. The practice of adulterating olive oil was highlighted in

the tragic events in Spain in 1981 when it was reported that rapeseed oil denatured with aniline was used as an adulterant (Pastana and Munoz, 1982; Toxic Oil Syndrome References Archive, 1990).

Olive oil is unusual because it contains such a high proportion of oleic acid, 65-85%. The compositions of oils from various origins are given in Table 3.78. The triglyceride composition of a typical olive oil is given in Tables 3.158 and 3.160, and the positional distribution of fatty acids in Table 3.161. See also the paper by Santinelli *et al.* (1992). Numerous minor components in olive oil have been characterized (Table 3.79).

Detailed analyses of the sterols, 4-methylsterols and triterpene alcohols are given in Tables 3.163-3.166. A detailed analysis of the minor components of Iranian olive oil has been reported (Paganuzzi, 1979).

Refined olive oil was found to contain (Muller-Mulot, 1976)  $\alpha$ -tocopherol (93 mg/kg) and  $\gamma$ -tocopherol (7 mg/kg). Other tocopherols and tocotrienols were not detected (see also Carpenter, 1979). The level of polyphenols has been related to oxidative stability (Gutfinger, 1981). The oil also contains the highest amount of squalene amongst vegetable oils (Table 3.80).

The phospholipid content varies from 40 to 135 ppm (Vitagliano and Turri, 1958; Vitagliano, 1960). Phosphatidylcholine and phosphatidylethanolamine are present in the kernel (Vioque and Maza, 1973).

The flavour components are reported (Fedeli, 1977) to consist of hydrocarbons, aliphatic hydroxy compounds, aldehydes, ketones, ethers, furan derivatives, thiophene derivatives, esters and terpene alcohols.

## Occurrence and characteristics

**Table 3.80** Squalene content of some vegetable oils (Kiritakis and Min, 1988)

| Oil        | Squalene (mg/100 g) |
|------------|---------------------|
| Olive      | 136-708             |
| Corn       | 19-36               |
| Cottonseed | 4-12                |
| Groundnut  | 13-49               |
| Soybean    | 7-17                |
| Sunflower  | 8-19                |
| Teaseed    | 8-16                |

Detection of the adulteration of olive oil is a special topic in itself. Numerous specific tests have been proposed (Tous, 1968). The polyunsaturated fraction isolated by silver-ion chromatography has been used to detect adulteration with linoleate-rich oils (Kapoulas and Passaloglou-Emmanouilidou, 1981).

The flavour chemistry has been reviewed (Kiritakis and Min, 1988).

### 3.3.24 Palm oil

[*Elaeis guineensis* (African oil palm),  
*E. oleifera* (American oil palm);  
Palmae]

Summary data are shown in Tables 3.81-3.86. The oil palm *E. guineensis* is the source of two major edible oils: palm oil from the mesocarp, and palmkernel oil from the kernel. The composition and properties of palm oil have been widely described (Cornelius, 1977; Hartley, 1977; Jacobsberg, 1975; *Palm Oil*, 1977; Raymond, 1961).

There is strong evidence that the oil palm originated in Africa. Palm oil trade between Africa and Europe began in the eighteenth century. The introduction of *E. guineensis* to the East Indies occurred in 1848. The progeny of these palms were transferred to Deli in Sumatra and gave rise to the Deli palms, which now provide the basis for the palm oil industry in the Far East (Hartley, 1977).

*E. guineensis* now exists in Africa, South-East Asia and America, and of all the oil-bearing plants it is the highest yielding (5-10 tonnes/ha in plantations).

**Table 3.81** World production of palm oil from *E. guineensis* (1000 tonnes)<sup>a</sup>

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 | 1989/90 |
|---------|---------|---------|---------|---------|---------|
| 1745    | 2845    | 4625    | 5370    | 5340    | 10917   |

<sup>a</sup> In 1982 Malaysia produced 3512, Nigeria 838, Indonesia 950 and the Ivory Coast 525 (× 1000 tonnes).

**Table 3.82** Fatty acid compositions (wt%) for whole palm oil and fractions (Rossell *et al.*, 1985)

| Origin<br>(number of samples) | 12:0             | 14:0    | 16:0      | 16:1    | 18:0    | 18:1      | 18:2      | 18:3             | 20:0             |
|-------------------------------|------------------|---------|-----------|---------|---------|-----------|-----------|------------------|------------------|
| Malaysia (21)                 | nd-0.1           | 0.9-1.1 | 43.1-45.3 | 0.1-0.3 | 4.0-4.8 | 38.4-40.8 | 9.4-11.1  | 0.1-0.4          | 0.1-0.4          |
| Mainland Malaysia (11)        | nd-0.1           | 0.9-1.0 | 43.1-45.0 | 0.1-0.3 | 4.0-4.8 | 39.2-40.8 | 9.4-10.8  | 0.1-0.4          | 0.1-0.4          |
| Sabah (8)                     | nd-0.1           | 0.9-1.1 | 43.2-45.3 | 0.1-0.3 | 4.3-4.7 | 38.4-40.1 | 10.1-11.1 | 0.2-0.4          | 0.1-0.4          |
| Sarawak (2)                   | nd <sup>a</sup>  | 0.9-1.0 | 43.5-45.0 | 0.2-0.3 | 4.5-4.8 | 38.5-39.4 | 10.4-10.5 | 0.2-0.3          | 0.2-0.4          |
| Ivory Coast (8)               | 0.1-0.2          | 0.8-1.0 | 43.4-45.2 | 0.1-0.2 | 4.9-5.5 | 37.1-39.9 | 9.6-10.9  | 0.2-0.4          | 0.2-0.4          |
| Sumatra (4)                   | nd-0.2           | 1.1-1.3 | 44.6-46.3 | 0.1-0.2 | 4.1-4.6 | 36.7-38.6 | 10.1-11.5 | 0.2-0.3          | 0.2-0.4          |
| Papua New Guinea (3)          | nd-0.1           | 0.9-1.0 | 43.4-45.4 | tr-0.1  | 4.4-4.6 | 37.5-39.4 | 11.0-11.1 | 0.3 <sup>a</sup> | 0.2-0.4          |
| Solomon Islands (4)           | nd-0.1           | 1.0-1.1 | 44.4-44.7 | tr-0.1  | 4.4-4.8 | 37.6-38.9 | 10.3-11.0 | 0.3-0.4          | 0.4 <sup>a</sup> |
| New Britain (4)               | 0.1 <sup>a</sup> | 1.0-1.3 | 43.5-44.1 | tr-0.2  | 4.6-5.0 | 37.4-38.3 | 11.8-11.9 | 0.2-0.3          | 0.4 <sup>a</sup> |
| Nigeria (1)                   | 0.2              | 1.0     | 45.4      | 0.1     | 4.6     | 37.7      | 10.6      | 0.2              | 0.3              |
| Overall range (45)            | nd-0.2           | 0.8-1.3 | 43.1-46.3 | tr-0.3  | 4.0-5.5 | 36.7-40.8 | 9.4-11.9  | 0.1-0.4          | 0.1-0.4          |
| Mean                          | 0.1              | 1.0     | 44.3      | 0.15    | 4.6     | 38.7      | 10.5      | 0.3              | 0.3              |
| Stearins (8)                  | 0.1-0.2          | 1.0-1.3 | 46.5-68.9 | tr-0.2  | 4.4-5.5 | 19.9-38.4 | 4.1-9.3   | 0.1-0.2          | 0.1-0.3          |
| (mainland Malaysia)           |                  |         |           |         |         |           |           |                  |                  |
| Oleins (5) (Malaysia)         | 0.1-0.2          | 0.9-1.0 | 39.5-40.8 | tr-0.2  | 3.9-4.4 | 42.7-43.9 | 10.6-11.4 | nd-0.4           | 0.1-0.3          |

<sup>a</sup> All samples had the same value within experimental error. nd = not detected. tr = trace (unquantified level of less than 0.05%).

The fruit of the oil palm grows in bunches, which weigh 4–20 kg and contain 200–2000 individual fruits varying in size and shape. Three main fruits have been characterized, *dura*, *tenera* and *pisifera*. These forms are distinguished by both size of the kernel and thickness of shell. *Tenera* is a hybrid of *dura* and *pisifera*. The variability of fatty acid composition within bunches has been determined (Rajanaidu and Tan, 1983).

The nature and type of cultivated palm is likely to

**Table 3.83** Characteristics of palm oil, from draft Codex (Codex, 1979 and 1993)

|                                          |                  |
|------------------------------------------|------------------|
| Relative density, $d_{20}^{50}$          | 0.891–0.899      |
| Refractive index, $n_D^{50}$             | 1.449–1.455      |
| Saponification value                     | 190–209          |
| Iodine value                             | 50–55            |
| Unsaponifiable matter (g/kg)             | Not more than 12 |
| GLC ranges in fatty acid composition (%) |                  |
| 12:0                                     | 0–0.4            |
| 14:0                                     | 0.5–2.0          |
| 16:0                                     | 40.1–47.5        |
| 16:1                                     | 0–0.6            |
| 18:0                                     | 3.5–6.0          |
| 18:1                                     | 36–44            |
| 18:2                                     | 6.5–12           |
| 18:3                                     | 0–0.5            |
| 20:0                                     | 0–1.0            |

**Table 3.84** Carotenoids of palm oil (%)<sup>a</sup>

| Compounds          | Percentage of total carotenoids |
|--------------------|---------------------------------|
| $\alpha$ -Carotene | 29–36                           |
| $\beta$ -Carotene  | 55–62                           |
| $\gamma$ -Carotene | 3–4                             |
| Xanthophylls       | 2–3                             |
| Lycopene           | 2–4                             |

<sup>a</sup> Range in palm oil, 500–700 mg/kg.

**Table 3.85** Tocopherols in palm oil (mg/kg)<sup>a</sup> (Rossell *et al.*, 1983; Gapor *et al.*, 1981)

| Tocol                 | Range   | Mean |
|-----------------------|---------|------|
| $\alpha$ -Tocopherol  | 3–185   | 85   |
| $\beta$ -Tocopherol   | tr      | 0    |
| $\gamma$ -Tocopherol  | 4–36    | 18   |
| $\alpha$ -Tocotrienol | 4–336   | 124  |
| $\gamma$ -Tocotrienol | 42–710  | 318  |
| $\delta$ -Tocotrienol | tr–148  | 72   |
| Total                 | 98–1330 | 617  |

<sup>a</sup> From 46 samples.

**Table 3.86** Sterol composition of palm oil<sup>a</sup> (Rossell *et al.*, 1983)

| Sterol                   | Range <sup>b</sup> (%) | Mean <sup>b</sup> (%) |
|--------------------------|------------------------|-----------------------|
| Cholesterol              | 2.2–6.7                | 4.1                   |
| Brassicasterol           | 0.0                    | 0.0                   |
| Campesterol              | 19.8–29.1              | 22.8                  |
| Stigmasterol             | 8.3–13.0               | 11.3                  |
| $\beta$ -Sitosterol      | 50.2–62.1              | 57.5                  |
| $\Delta^5$ -Avenasterol  | 0.0–2.8                | 1.5                   |
| $\Delta^7$ -Stigmasterol | 0.0–2.8                | 1.0                   |
| $\Delta^7$ -Avenasterol  | 0.0–4.0                | 1.5                   |

<sup>a</sup> From 15 samples.

<sup>b</sup> Total sterol 326–627 mg/kg.

change dramatically in the coming years as genetic manipulation and cloning techniques are applied to optimize palm characteristics (Corley *et al.*, 1981; Jones, 1974, 1984; Paranjothy, 1989).

The American oil palm *Elaeis oleifera* (also called corozo or *E. melanococca*) has a procumbent habit. The oil is relatively unsaturated, which has encouraged its hybridization with *E. guineensis* to produce experimental palms. The native Amazonian palm, *Jessenia bataua*, has a fatty acid composition similar to olive oil (Balick, 1981).

Crude palm oil is obtained from the mesocarp (Berger, 1983) either by centrifugation or by hydraulic pressing of the fruit after it has been 'digested'. Digestion involves mashing and sterilizing the stripped fruit in a steam-jacketed vessel at 95 °C. Unless the damaged fruit is quickly sterilized, fungal lipases rapidly hydrolyse the oil (Tombs and Stubbs, 1982). In West Africa many hand-operated screw and hydraulic presses are in operation.

The crude oil is deep red in colour owing to the presence of carotenoids (500–700 ppm) and is sometimes referred to in the trade as either hard or soft depending on whether the free fatty acid content is high or low. The taste of oil with a high free fatty acid content is preferred in many local parts of West Africa. Oils from plantations with good bleachability and oxidative stability are marketed under the name Zaire Special Prime Bleach (SPB) from West Africa and Special Quality (SQ) from Malaysia. These oils have low free fatty acid (2–3%) and iron contents (4–5 ppm). A 'standard bleaching test' has been devised for these oils. The anisidine test and UV absorbance at 233 and 269  $\mu$ m are also considered to be good guides to oxidative stability. The high level of carotenoids mitigates against easy bleachability during refining, but refined oils of low residual colour can be obtained when starting with SPB or SQ oils.

The oil is bleached after neutralization using

bleaching earth or by heat bleaching at temperatures of 240–270°C. In this latter case fatty acid stripping, bleaching and deodorization can be carried out in a single step. Partial hydrogenation also bleaches the oil.

The processing of palm oils in the countries of origin has increased immensely over the last 20 years to the extent that virtually no crude palm oil is now exported from Malaysia. Dry fractionation, approximately 2M tonnes/annum capacity in Malaysia 1994, is carried out on a large scale (Symposium, 1985). Under certain circumstances, it has been commercially attractive to reblend palm fractions to produce simulated palm oils or 'cocktails'. These cocktails can be distinguished in many cases from crude palm oil by determining their triglyceride composition and carotenoid and tocopherol contents.

Palm oil is widely used in food products (Berger, 1987). The nutritional aspects of palm oil have received increasing attention with suggestions that there may be beneficial effects, but current evidence is difficult to interpret unambiguously (Cottrell, 1991; Elson, 1992).

Palm fractions containing high levels (*ca* 70%) of SOS, produced by solvent fractionation (Bernardini, 1978; Berger, 1977), are used as components of cocoa butter equivalents (Best *et al.*, 1956; Thomas and Paulicka, 1976; Gordon *et al.*, 1979; Willems and Padley, 1985).

The characteristics of palm oils from various sources, including Malaysian oils and their fractions are given in Table 3.82. See also data on fatty acid, triglyceride compositions and solid fat contents of palm oil products (Siew *et al.*, 1992). The triglyceride composition of commercial palm oil (Table 3.158) is interesting in that it contains not only high levels of the symmetrical triglyceride SOS (30–36%) but also significant amounts of the unsymmetrical disaturated glyceride SSO (*ca* 7%) and trisaturated triglycerides, mainly tripalmitin. Unlike other vegetable oils, the 2 position of palm oil triglycerides contains approximately 10% of saturated acid.

The minor components of palm oil include carotenoids (Table 3.84), tocopherols (Table 3.85), sterols (Tables 3.86 and 3.163), triterpene alcohols (Table 3.165) and methylsterols (Table 3.164). Average figures for the minor components in plantation oils are given in Tables 3.84–3.86.

The major phospholipids of *E. guineensis* palm oil expressed as a mole percentage of the total phospholipid are phosphatidylcholines (36%), phosphatidylethanolamines (24%), phosphatidylinositols (22%), phosphatidylglycerols (9%) and others (9%). The total phospholipid content in crude palm oil depends on the method of extraction. Values ranging from 20 to 2000 ppm are reported; the lower values are for normal commercially extracted Malaysian oils. The high values are for laboratory solvent-extracted oils (Goh *et al.*, 1982).

The lipids and minor components present in palm leaflets from fronds of different ages have been determined (Gapor *et al.*, 1991). On a dry basis the leaflets contained on average 0.20–0.4%  $\alpha$ -tocopherol, 0.05–0.22% carotenoids, 0.006–0.2% squalene for young and old leaflets respectively. Chlorophyll, 0.48–0.62%, reaches a maximum (0.62%) at an intermediate stage.

### 3.3.25 Palmkernel oil

[*Elaeis guineensis*; Palmae]

Relevant data are shown in Tables 3.87 to 3.92. The background to the oil palm is given in the preceding section (Cornelius, 1977; Hartley, 1977). After the palm oil has been recovered from the fruit, the residual cake from the hydraulic or screw presses is further separated to recover the nuts from which the palmkernels are obtained. The first step is to separate the nuts from the fibre in a stream of air. The nuts are dried, cracked and the kernel separated from the shells either by flotation or by hydrocyclones. Traditional hand methods are still used in certain

Table 3.87 World production of palmkernel oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 | 1985/86 | 1989/90 |
|---------|---------|---------|---------|---------|---------|---------|
| 490     | 510     | 585     | 680     | 715     | 992     | 1421    |

Table 3.88 Fatty acid composition (wt%) of palmkernel oil

| 6:0 | 8:0 | 10:0 | 12:0 | 14:0 | 16:0 | 18:0 | 20:0 | 18:1 | 18:2 |
|-----|-----|------|------|------|------|------|------|------|------|
| 0.5 | 2.5 | 4    | 49   | 16   | 9    | 2    | 1    | 14   | 2    |

**Table 3.89** Characteristics of palmkernel oil, from draft Codex (Codex, 1979 and 1993)

|                                          |                  |
|------------------------------------------|------------------|
| Relative density, $d_{20}^{40}$          | 0.899–0.914      |
| Refractive index, $n_D^{40}$             | 1.448–1.452      |
| Saponification value                     | 230–254          |
| Iodine value                             | 13–23            |
| Unsaponifiable matter (g/kg)             | Not more than 10 |
| Reichert value                           | 4–7              |
| Polenske value                           | 8–12             |
| GLC ranges of fatty acid composition (%) |                  |
| 6:0                                      | 0–0.8            |
| 8:0                                      | 2.4–6.2          |
| 10:0                                     | 2.6–5.0          |
| 12:0                                     | 41–55            |
| 14:0                                     | 14–18            |
| 16:0                                     | 6.5–10           |
| 18:0                                     | 1.3–3.0          |
| 18:1                                     | 12–19            |
| 18:2                                     | 1.0–3.5          |
| $\Sigma 18:3-24:1$                       | 0–1.0            |

parts of Africa. Mechanical cracking can lead to a greater proportion of broken kernels.

The kernels are dried to a moisture content of approximately 7% after separation. A rapid reduction in moisture content is important to ensure that the oil is not hydrolysed by yeasts or by fungal attack. Reduction in moisture content also inhibits the production of toxic fungal metabolites such as *Aspergillus flavus*.

Mature kernels, which contain 46–57% oil (moisture-free), vary widely in size and shape. Those from *tenera*, a hybrid of *dura* and *pisifera*, are smaller with a thinner shell than the *dura* (Hartley, 1977). The kernels mature earlier than the mesocarp oil.

The kernel oil is obtained by expelling, usually followed by solvent extraction. The oil superficially resembles coconut oil in chemical and physical properties. The free fatty acid of the crude oil varies from 0.5 to 10%, plantation oils normally having the lowest values. The refined oil keeps well but has a tendency to form soapy rancid off-flavours under conditions in which microbial or lipolytic activity has not been controlled. The off-flavours are from two sources, first the short-chain acids released by hydrolysis of the fat and secondly from methyl ketones, one carbon atom less than the parent acid, generated by fungal action (*Penicillium crustosum*) on the short-chain acids (Kinderlerer and Hatton, 1991).

A major use is in soaps because lauric acid imparts excellent solubility and lathering properties. Palmkernel acids are also used to produce short-chain alcohols and their derivatives for detergents. Edible uses include margarine, ice cream and biscuit cream

fillings (Timms, 1986). The melting behaviours of palmkernel and coconut oils are compared in Table 3.32.

The oil foams badly when used in mixtures with other oils for frying. The oil can be fractionated and the high-melting point stearin fraction used as a chocolate substitute fat (Rossell, 1985; Timms, 1985, 1986). The melting point of the oil and its fractions can be further raised by hydrogenation. The effect is greater for palmkernel than coconut oil because the latter contains only low levels of unsaturated acids.

The high lauric acid content in palmkernel oil is typical of numerous species of palm (Tables 3.90 and 3.91). Kernel oils of intermediate composition have been obtained from hybrids of *E. oleifera* and *E. guineensis*. In the longer term we may therefore encounter commercial palmkernel oils of very different character to those of today (Tan and Berger, 1982).

Analyses of Brazilian palmkernel oils showed a similar range of fatty acid compositions as reported in Table 3.88 (Tavares *et al.*, 1990).

The complex fatty acid composition of palmkernel oil is reflected in its triglyceride composition. Gas-liquid chromatography is a convenient method of characterizing the triglycerides of both palmkernel and coconut oils (Bezard, 1971; Bezard *et al.*, 1971; Kuksis and McCarthy, 1962) according to carbon number. These two oils are compared in Table 3.92. The distribution of the major acids follows slightly different patterns in the two oils. Lauric acid is enriched at the 2 position in coconut oil (47% overall, 79% at the 2 position) but only slightly in palmkernel oil (54% overall, 59% at the 2 position). Conversely oleic acid is enriched at the 2 position (9% overall, 15% 2 position) in palmkernel oil but in coconut oil there is no appreciable difference (4.7% and 3.9% respectively) (Table 3.162).

The sterols, 4-methylsterols and triterpene alcohols are reported in Tables 3.163–3.166. Free and bound lactones were detected in Asiatic palmkernel oils (Van der Ven and de Jong, 1970). Data on tocopherols are given in Tables 3.167 and 3.170 but for phospholipids are not readily available.

### 3.3.26 Poppy seed oil

[*Papaver somniferum*; Papavaraceae]

World production: comprehensive data are not readily available; 12 000 tonnes were reported in 1981/82, excluding the former USSR. Other data are summarized in Tables 3.93 and 3.94.

The poppy grows in various climates, but is cultivated for oil as an annual crop mainly in warm temperate zones, e.g. the former USSR, South-East

**Table 3.90** Distribution of fatty acid compositions with sample origin for palmkernel oil (Rossell *et al.*, 1985)

| Origin<br>(number of samples) | Fatty acid composition (wt%) |         |         |           |           |          |         |           |         |         |         |         |
|-------------------------------|------------------------------|---------|---------|-----------|-----------|----------|---------|-----------|---------|---------|---------|---------|
|                               | 6:0                          | 8:0     | 10:0    | 12:0      | 14:0      | 16:0     | 18:0    | 18:1      | 18:2    | 18:3    | 20      | 20:1    |
| Nigeria (7)                   | 0.1-0.2                      | 3.2-3.5 | 3.4-3.8 | 46.6-48.5 | 16.5-16.9 | 8.5-9.3  | 2.7-2.9 | 14.1-15.7 | 1.4-2.2 | tr-0.1  | 0.1-0.3 | tr-0.5  |
| Sierra Leone (2)              | 0.2-0.4                      | 3.1-3.4 | 3.4     | 45.6-45.7 | 16.7-16.8 | 8.9      | 2.7     | 16.0-16.7 | 2.2-2.6 | tr-0.2  | 0.1     | 0.1     |
| Ivory Coast (7)               | 0.2-0.3                      | 2.6-3.4 | 3.0-3.5 | 46.4-47.6 | 16.0-16.9 | 8.5-9.0  | 2.3-2.8 | 15.3-16.7 | 1.9-2.5 | tr-0.2  | 0.1     | tr-0.1  |
| Guinea Bissau (4)             | 0.1-0.2                      | 2.5-3.0 | 2.8-3.2 | 43.6-46.8 | 16.9-17.2 | 9.0-10.0 | 2.3-2.9 | 16.4-18.5 | 1.4-1.9 | tr      | 0.2     | nd-0.1  |
| Malaysia (8)                  | 0.2-0.8                      | 3.0-4.4 | 3.3-4.0 | 46.2-49.6 | 15.9-16.8 | 7.9-8.6  | 1.9-2.2 | 13.7-16.1 | 1.9-2.9 | tr-0.2  | 0.1-0.3 | 0.1-0.4 |
| Honduras (2)                  | 0.2                          | 3.4-3.6 | 3.6     | 48.5-49.8 | 15.3-16.1 | 7.8-8.4  | 2.0-2.4 | 13.9-15.6 | 1.9-2.5 | 0.1-0.7 | 0.1     | 0.1     |
| New Britain (3)               | 0.2-0.3                      | 3.0-3.8 | 3.4-3.7 | 48.0-49.3 | 15.7-16.0 | 7.8-8.1  | 2.2-2.3 | 14.7-15.0 | 2.8-3.3 | tr-0.1  | 0.1     | 0.1-0.3 |
| Solomon Islands (1)           | 0.2                          | 3.3     | 3.3     | 49.2      | 16.1      | 8.6      | 2.2     | 14.2      | 2.7     | tr      | 0.1     | 0.1     |
| Sumatra (5)                   | nd-0.5                       | 3.3-4.7 | 3.5-4.5 | 47.3-50.2 | 15.6-15.9 | 7.3-8.1  | 1.9-2.1 | 13.8-15.0 | 2.4-2.7 | tr-0.1  | 0.1     | 0.1     |
| Camerouns (6)                 | 0.2-0.5                      | 2.8-3.8 | 3.0-3.8 | 46.2-51.4 | 16.0-17.1 | 7.2-9.4  | 2.3-2.6 | 11.9-16.0 | 2.3-3.2 | tr-0.3  | 0.1-0.2 | tr-0.2  |
| Costa Rica (1)                | 0.2                          | 3.4     | 3.5     | 48.8      | 16.0      | 8.3      | 2.8     | 14.4      | 2.4     | tr      | 0.1     | 0.1     |
| Togo (4)                      | 0.2-0.3                      | 3.0-3.5 | 3.2-3.7 | 46.2-47.8 | 16.3-16.8 | 8.6-9.4  | 2.7-3.0 | 14.8-16.5 | 1.9-2.3 | tr-0.2  | 0.1-0.2 | 0.1     |
| Liberia (1)                   | 0.5                          | 3.5     | 3.5     | 46.6      | 16.4      | 8.5      | 2.7     | 15.7      | 2.4     | tr      | 0.1     | 0.1     |
| Papua New Guinea (1)          | 0.1                          | 3.4     | 3.5     | 47.9      | 16.3      | 8.3      | 2.1     | 15.5      | 2.7     | tr      | 0.1     | 0.1     |
| Sarawak (1)                   | 0.2                          | 3.0     | 3.3     | 46.9      | 15.7      | 8.9      | 2.3     | 16.0      | 3.2     | 0.1     | 0.2     | 0.2     |
| Sabah (1)                     | 0.2                          | 3.3     | 3.4     | 47.7      | 15.8      | 8.9      | 2.2     | 15.2      | 2.9     | tr      | 0.2     | 0.2     |
| Overall range (54)            | nd-0.8                       | 2.5-4.7 | 2.8-4.5 | 43.6-51.4 | 15.3-17.2 | 7.2-10.0 | 1.9-3.0 | 11.9-18.5 | 1.4-3.3 | tr-0.7  | 0.1-0.3 | nd-0.5  |
| Mean                          | 0.3                          | 3.3     | 3.5     | 47.5      | 16.4      | 8.5      | 2.4     | 15.3      | 2.4     | 0.1     | 0.1     | 0.1     |

tr = trace (unquantified level of less than 0.05%), nd = Not detected.

Table 3.91 Fatty acid composition of palmkernel triglycerides (Litchfield, 1970)

|                                        | 6:0 | 8:0  | 10:0 | 12:0 | 14:0 | 16:0 | 18:0 | 18:1 | 18:2 |
|----------------------------------------|-----|------|------|------|------|------|------|------|------|
| <b>Cocoideae</b>                       |     |      |      |      |      |      |      |      |      |
| <i>Astrocaryum murumuru</i> (murumuru) | —   | 2.3  | 1.9  | 55.6 | 27.3 | 4.8  | 1.8  | 4.4  | 1.9  |
| <i>Astrocaryum vulgare</i> (tucum)     | —   | 1.3  | 4.4  | 48.9 | 21.6 | 6.4  | 1.7  | 13.2 | 2.5  |
| <i>Cocos nucifera</i>                  | 0.6 | 10.1 | 6.8  | 47.7 | 18.8 | 7.9  | 2.0  | 4.7  | 1.4  |
| <i>Elaeis guineensis</i>               | 0.4 | 5.9  | 4.8  | 53.9 | 16.2 | 6.6  | 1.7  | 8.9  | 1.6  |
| <i>Orbignya oleifera</i>               | 0.5 | 8.3  | 7.3  | 49.5 | 13.9 | 6.8  | 2.7  | 9.9  | 1.1  |
| <i>Elaeis oleifera</i>                 | —   | 1.0  | 0.8  | 29.5 | 25.9 | 10.1 | 1.8  | 26.4 | 4.5  |
| <b>Coryphoideae</b>                    |     |      |      |      |      |      |      |      |      |
| <i>Chamaerops humilis</i>              | —   | 3.2  | 3.7  | 26.5 | 9.6  | 9.6  | 2.0  | 31.4 | 14.0 |
| <i>Livistona chinensis</i>             | —   | 0.5  | 0.6  | 22.2 | 9.3  | 13.8 | 3.0  | 28.6 | 22.0 |
| <i>Sabal palmetto</i>                  | —   | 0.5  | 0.4  | 21.7 | 10.2 | 9.1  | 1.4  | 31.2 | 25.5 |
| <i>Trachycarpus fortunei</i>           | —   | 0.2  | 0.2  | 14.6 | 12.4 | 9.5  | 2.3  | 28.3 | 32.5 |
| <i>Washingtonia robusta</i>            | —   | 0.8  | 0.5  | 17.7 | 12.7 | 9.7  | 1.9  | 37.5 | 19.2 |
| <b>Phoenicoideae</b>                   |     |      |      |      |      |      |      |      |      |
| <i>Phoenix reclinata</i>               | —   | 0.6  | 0.6  | 29.2 | 13.5 | 8.9  | 1.4  | 34.3 | 11.5 |
| <b>Arecpodeae</b>                      |     |      |      |      |      |      |      |      |      |
| <i>Archontophoenix cunninghamiana</i>  | —   | 0.2  | 0.3  | 23.9 | 14.2 | 12.6 | 2.7  | 15.1 | 31.0 |
| <i>Howeia fosteriana</i>               | —   | 1.5  | 1.9  | 45.8 | 12.2 | 5.9  | 2.7  | 21.1 | 8.9  |

Table 3.92 Triglyceride composition (%) of coconut and palmkernel oils (Bezard, 1971; Bezard *et al.*, 1971)

| Carbon no. | Mol% in oil |            | Major glyceride type <sup>a</sup> | Mol% in oil |            |
|------------|-------------|------------|-----------------------------------|-------------|------------|
|            | Coconut     | Palmkernel |                                   | Coconut     | Palmkernel |
| 28         | 0.9         | —          | 6,10,12                           | 0.3         | —          |
|            |             |            | 8,8,12                            | 0.4         | —          |
| 30         | 4.2         | 1.3        | 6,12,12                           | 1.6         | 0.6        |
|            |             |            | 8,10,12                           | 1.8         | 0.3        |
| 32         | 15.8        | 8.6        | 6,12,14                           | 1.1         | 0.9        |
|            |             |            | 8,12,12                           | 11.9        | 6.4        |
| 34         | 19.0        | 9.8        | 8,12,14                           | 9.1         | 3.6        |
|            |             |            | 10,12,12                          | 5.7         | 4.7        |
| 36         | 20.3        | 25.7       | 12,12,12                          | 10.6        | 19.8       |
| 38         | 17.2        | 16.8       | 12,12,14                          | 10.8        | 14.1       |
| 40         | 9.6         | 9.5        | 12,12,16                          | 3.8         | 3.5        |
|            |             |            | 12,14,14                          | 3.1         | 3.6        |
| 42         | 6.4         | 7.8        | 8,16,18                           | 0.4         | 0.9        |
|            |             |            | 12,12,18                          | 2.8         | 3.3        |
|            |             |            | 12,12,16                          | 2.7         | 2.7        |
| 44         | 3.2         | 5.8        | 8,18,18                           | 0.3         | 1.0        |
|            |             |            | 12,14,18                          | 1.6         | 3.5        |
|            |             |            | 12,16,16                          | 0.7         | 0.8        |
| 46         | 1.5         | 4.0        | 12,16,18                          | 1.0         | 2.7        |
|            |             |            | 14,14,18                          | 0.2         | 0.6        |
| 48         | 1.0         | 4.4        | 12,18,18                          | 0.4         | 2.9        |
|            |             |            | 14,16,18                          | 0.4         | 1.2        |
| 50         | 0.5         | 2.2        | 14,18,18                          | 0.1         | 1.2        |
|            |             |            | 16,16,18                          | 0.3         | 0.9        |
| 52         | 0.2         | 2.2        | 16,18,18                          | 0.1         | 1.9        |
| 54         | —           | 1.8        | 18,18,18                          | —           | 1.3        |

<sup>a</sup> 6,10,12 signifies all glycerides with acyl chains of 6, 10 and 12 carbons.

## Occurrence and characteristics

**Table 3.93** Fatty acid composition (wt%) of poppy seed oil

| 16:0 | 18:0 | 18:1 | 18:2 | 18:3 |
|------|------|------|------|------|
| 10   | 2    | 11   | 72   | 5    |

**Table 3.94** Characteristics of poppy seed oil, reported values (Awe, 1937; Ninomiya, 1940)

|                              |         |
|------------------------------|---------|
| Density (60°C)               | 0.898   |
| Refractive index, $n_D^{60}$ | 1.4604  |
| Saponification value         | 197.5   |
| Iodine value                 | 133.4   |
| Unsaponifiable matter (%)    | 0.4–1.2 |
| Oil content of seed (%)      | 36–50   |

Asia, China, India, Turkey and the former Czechoslovakia. The main cultivated variety is the opium poppy, grown for both oil and opium.

Opium does not occur in the seed but is obtained from the juice that exudes from the unripe capsules when they are manually scarred. Morphine, the active principle, is also extracted more cheaply from the straw in the former USSR after harvesting.

The oil is extracted from the seed by expelling and solvent extraction. Cold-pressed oil, light yellow in colour, is used for edible purposes without refining. The oil is a semi-drying oil and is also used in artists' paints, in white paint in conjunction with boiled poppy seed oil and in soap after hydrogenation. Poppy seeds are used for decorating baked goods and as bird seed (Anon, 1985).

The fatty acid composition of the principle cultivars and hybrids of the opium poppy grown in Uttar Pradesh, India, gave a mean linoleic acid content of 51.6% with a range of 41–68% (Singh *et al.*, 1990).

The glyceride composition has been determined by silver-ion TLC and agrees well with the data pre-

dicted by lipolysis. The 2 position is occupied essentially by unsaturated acids. The sterols, 4-methylsterols and triterpene alcohols are described in Tables 3.163–3.166.

### 3.3.27 Rapeseed oil (colza oil)

[*Brassica napus*, *B. rapa*, *B. campestris*, turnip, mustard; Cruciferae]

Relevant data are given in Tables 3.95–3.101. Over the past two decades, the nature of commercial rapeseed and rapeseed oil has changed dramatically (Andersson, 1981). Rape, mustard (*B. alba*, *B. nigra*) and crambe (*Crambe abyssinica*) seed oils all belong to the same family, the Cruciferae. In the past, they have been grouped together because they all contained significant quantities of erucic acid. Some commercial rapeseed oils are now very different because of their low erucic acid content. The classification of rapeseed is given in Table 3.98.

*Brassica napus* and *B. campestris* both occur in winter and spring/summer forms. The first is sown in autumn and requires a vernalization period of some weeks below 5°C. The spring variety (45–75 cm high) requires a relatively short growth period and is used particularly in Canada because of the very harsh winters. The winter (biennial) varieties (up to 140 cm high) give the highest yields, 2.7 t/ha (tonnes/hectare) in Europe, compared to 0.9–1.1 t/ha in Canada for the summer variety.

Plant breeders have developed strains that are not only low in erucic acid but also more disease-resistant, less prone to shattering (casting of seeds from the pod at maturity) and contain less glucosinolates (Rakow and McGregor, 1973; Downey *et al.*, 1969; Craig *et al.*, 1973; Grami and Stefansson, 1977).

Rape seeds are small, round (0.1–0.2 mm diameter) and can be yellow, brown or black. The oil content usually lies within the range of 40–60%. The

**Table 3.95** World production of rapeseed oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 | 1985/86 | 1989/90 |
|---------|---------|---------|---------|---------|---------|---------|
| 2220    | 2650    | 3675    | 4060    | 5000    | 6426    | 8025    |

**Table 3.96** Fatty acid composition of rapeseed oil (two examples) (wt%)

|                       | 16:0 | 18:0 | 20:0 | 22:0 | 18:1 | 18:2 | 18:3 | 20:1 | 22:1 |
|-----------------------|------|------|------|------|------|------|------|------|------|
| High-erucic-acid rape | 3    | 1    | 1    | tr   | 16   | 14   | 10   | 6    | 49   |
| Low-erucic-acid rape  | 4    | 2    | tr   | tr   | 56   | 26   | 10   | 2    | tr   |

Table 3.97 Characteristics of rapeseed oil<sup>a</sup> (Codex, 1979 and 1993)

|                                                          | Low-erucic rape                                         | Rape             |
|----------------------------------------------------------|---------------------------------------------------------|------------------|
| Relative density, $d_{20}^{20}$                          | 0.914–0.917                                             | 0.910–0.920      |
| Refractive index, $n_D^{40}$                             | 1.465–1.467                                             | 1.465–1.469      |
| Saponification value                                     | 188–193                                                 | 168–187          |
| Iodine value                                             | 110–126                                                 | 94–120           |
| Crismar value                                            | 67–70                                                   | 71–85            |
| Unsaponifiable matter (g/kg)                             | Not more than 20                                        | Not more than 20 |
| Brassicasterol                                           | Not less than 5%<br>of total sterols                    |                  |
| Erucic acid                                              | Not more than 5 mol%<br>of the component<br>fatty acids |                  |
| GLC ranges of fatty acid<br>composition (%) <sup>b</sup> |                                                         |                  |
| <14:0                                                    | nd                                                      | <0.1             |
| 14:0                                                     | <0.2                                                    | <0.2             |
| 16:0                                                     | 3.3–6.0                                                 | 1.5–6.0          |
| 16:1                                                     | 0.1–0.6                                                 | 0–3.0            |
| 18:0                                                     | 1.1–2.5                                                 | 0.5–3.1          |
| 18:1                                                     | 52–66.9                                                 | 8–60             |
| 18:2                                                     | 16.1–24.8                                               | 11–23            |
| 18:3                                                     | 6.4–14.1                                                | 5–13             |
| 20:0                                                     | 0.2–0.8                                                 | 0–3.0            |
| 20:1                                                     | 0.1–3.4                                                 | 3–15             |
| 20:2                                                     | 0.0–0.1                                                 | 0–1.0            |
| 22:0                                                     | 0.0–0.5                                                 | 0–2.0            |
| 22:1                                                     | 0.0–2.0                                                 | 5–60             |
| 22:2                                                     | 0.0–0.1                                                 | <2.0             |
| 24:0                                                     | 0.0–0.2                                                 | <2.0             |
| 24:1                                                     | 0.0–0.4                                                 | <3.0             |

<sup>a</sup> Draft Codex standards for both 'edible low-erucic-acid rape' and 'rape' have been proposed (Codex, 1993); see Table 3.157.

<sup>b</sup> 17:0 and 17:1 both 0.0–0.3.

oil can be obtained by either expelling or solvent extraction or a combination of the two. The various processing steps to achieve good-quality edible oil have been reviewed (Ohlson, 1992). The crude oil is

dark amber in colour and contains a high level of phosphatides (3.5%), pigments, especially chlorophyll from unripe seeds, and sulphur compounds (Crawford, 1982; Mag, 1983).

Table 3.98 Classification of rapeseed (Appelqvist and Ohlsen, 1972)

| Botanical name                                    | Common name        | Synonyms                         | Grown in             |
|---------------------------------------------------|--------------------|----------------------------------|----------------------|
| <i>Brassica napus</i> subsp. <i>oleifera</i>      |                    |                                  |                      |
| f. <i>biennis</i>                                 | Winter rape        | Oil rape, rapeseed, Swedish rape | Europe, Chile, China |
| f. <i>annua</i>                                   | Summer rape        | Oilseed rape                     | Canada               |
| <i>Brassica campestris</i> subsp. <i>oleifera</i> |                    |                                  |                      |
| f. <i>biennis</i>                                 | Winter turnip rape | Rapeseed                         | Sweden               |
| f. <i>annua</i>                                   | Summer turnip rape | Oil turnip                       | Canada               |
| f. <i>annua</i> var. <i>chinensis</i>             | Summer turnip rape | Chinese mustard                  |                      |
| f. <i>annua</i> var. <i>pekinensis</i>            | Summer turnip rape | Celery cabbage, Chinese kale     |                      |
| f. <i>annua</i> var. <i>dichotoris</i>            | Summer turnip rape | Toria                            | India, Pakistan      |
| f. <i>annua</i> var. <i>trilocularis</i>          | Summer turnip rape | Sarson                           | India, Pakistan      |
| <i>Brassica juncea</i>                            | Brown mustard      | Leaf mustard, Indian mustard     | India, Pakistan      |

Table 3.99 Fatty acids in old and new varieties of rape (wt%) (Kroeze, 1982; Wong *et al.*, 1990; Knutson *et al.*, 1992; Voelker and Davies, 1992)

|        | <i>Brassica napus</i> (Kroeze) |           |                 |           | <i>Brassica campestris</i> (Kroeze) |            |    |    | High-oleic<br>(Wong) | High-stearic<br>(Knutson) | High-lauric<br>(Voelker) |
|--------|--------------------------------|-----------|-----------------|-----------|-------------------------------------|------------|----|----|----------------------|---------------------------|--------------------------|
|        | Winter (French)                |           | Summer (Canada) |           | Summer (Canada)                     |            |    |    |                      |                           |                          |
|        | Old major                      | New major | Old target      | New tower | Old span                            | New candle |    |    |                      |                           |                          |
| 12:0   | —                              | —         | —               | —         | —                                   | —          | —  | —  | —                    | —                         | 29.3                     |
| 14:0   | —                              | —         | —               | —         | —                                   | —          | —  | —  | —                    | —                         | 3.5                      |
| 16:0   | 3.5                            | 4.5       | 3.0             | 3.9       | 4.0                                 | 3.8        | 4  | 4  | 4                    | 3.5                       |                          |
| 18:0   | 1.2                            | 1.5       | 0.1             | 0.3       | 0.1                                 | 0.2        | 2  | 2  | 22                   | 1.3                       |                          |
| 18:1   | 14.2                           | 60.5      | 19.5            | 65.0      | 58.0                                | 53.5       | 79 | 40 | 40                   | 41.0                      |                          |
| 20:1   | 10.9                           | 0.9       | 10.0            | 1.2       | 3.8                                 | 1.4        | 2  | 2  | —                    | —                         |                          |
| 22:1   | 46.9                           | 0.2       | 39.5            | 1.0       | 3.7                                 | 1.0        | —  | —  | —                    | —                         |                          |
| 18:2   | 13.8                           | 21.6      | 16.0            | 19.0      | 20.0                                | 23.5       | 7  | 18 | 18                   | 11.3                      |                          |
| 18:3   | 9.1                            | 10.3      | 11.0            | 8.6       | 14.0                                | 14.0       | 5  | 13 | 13                   | 10.1                      |                          |
| Others | 0.4                            | 0.5       | 0.9             | 1.0       | 0.4                                 | 0.6        | 1  | 3  | 3                    | —                         |                          |

**Table 3.100** Triglyceride composition (mol%) of high-erucic-acid rapeseed oil<sup>a</sup> (Adapted from Jurriens, 1968)

|                    |      |                    |      |
|--------------------|------|--------------------|------|
| One double bond    |      | Five double bond   |      |
| SOS                | 0.2  | ErLL               | 4.5  |
| SSEr               | 0.2  | OLeEr              | 0.8  |
|                    |      | ErOLe              | 2.2  |
| Two double bonds   |      | ErLeEr             | 16.3 |
| SOEr               | 3.9  | Others             | 1.1  |
| Others             | 1.6  |                    |      |
| Three double bonds |      | Six double bonds   |      |
| OOEr               | 0.9  | ErLLe              | 3.0  |
| ErOEr              | 18.1 | ErLeL              | 3.0  |
| ErErEr             | 0.9  | Others             | 0.8  |
| SLer               | 5.2  | Seven double bonds |      |
| Others             | 0.9  | LLLe               | 0.3  |
| Four double bonds  |      | ErLeLe             | 2.0  |
| OLEr               | 1.2  | Others             | 0.6  |
| ErOL               | 3.4  |                    |      |
| ErLEr              | 24.3 |                    |      |
| SLeEr              | 3.4  |                    |      |
| Others             | 1.2  |                    |      |

<sup>a</sup> Er, erucic acid; S, saturated; L, linoleic; O, oleic; Le, linolenic.

The fully refined oil is bland, pale yellow and free from waxes and essentially free of phosphorus and sulphur.

Until the early 1970s high-erucic-acid rape had been used freely in a number of countries for edible purposes. Biological tests on animals have highlighted potential dangers to the heart in humans. As a consequence, national legislation and FAO/WHO (Food and Agriculture Organization/World Health Organization) recommendations have all led to the use of only low-erucic-acid varieties of rape for edible purposes in numerous countries. In the EEC and Canada only oils with <5% erucic acid are permitted for edible use. The oil is used as a salad oil, for frying and in margarine and shortenings (Ackman, 1990; Ames, 1989; Kramer *et al.*, 1983).

The breeding of low-erucic-acid rape varieties means that the composition of rapeseed oil can vary enormously. Various names have been adopted commercially in an attempt to avoid confusion. 'Canbra' and 'Lear' were used by the Canadians to describe oils with <3.5% erucic acid. The tradename 'Canola' (Sebedio and Ackman, 1981; Vaisey-Genser and Eskin, 1982) has been registered in Canada to describe 'double-zero' varieties of rape, low in glucosinolates (26.5  $\mu\text{mol/g}$ ), which conform to the Codex draft standard of  $\leq 5\%$  erucic acid. 'Sinola' oil in Germany contains <2% erucic acid. Typical changes in composition are given in Table 3.99. A reduction in erucic acid (22:1) is accompanied by a major increase in oleic (18:1). This is further complicated by the development of high-oleic (Wong *et al.*, 1990), high-stearate (Knutson *et al.*, 1992) and high laurate varieties (Voelker and Davis, 1992).

The high-erucic-acid rapeseed oil has been used industrially, for example as a lubricant (erucamide) and as a source of brassylic acid ( $\text{C}_{13}$  dicarboxylic acid, tridecanedioic acid) and pelargonic acid (nonanoic acid) via ozonolysis. Low-erucic-acid rape is also used as a lubricating and cutting oil and, after hydrogenation, in soap.

Rapeseed meal contains glucosinolates, which are hydrolysed by an indigenous enzyme myrosinase, yielding toxic products such as isothiocyanates. This can be prevented by inactivating the enzymes by heat prior to seed extraction (Kramer *et al.*, 1983; Dietz and Harris, 1990). Plant breeding is also significantly reducing the levels of glucosinolates in the meal, to as low as 7  $\mu\text{mol/g}$  (Crawford, 1982; Mag, 1983; Ackman, 1990; Unger, 1990; Lange and Linow, 1987).

Analysis of minor fatty acids (Sebedio and Ackman, 1981) of Canola oil showed that erucic acid, ( $n-9$ )-22:1, is accompanied by low levels of the  $n-7$  isomer (*ca* 1% of total 22:1) (see Table 3.102).

The triglyceride compositions of high-erucic-acid varieties are given in Tables 3.100 and 3.160. Erucic

**Table 3.101** Typical values for minor components in Canola oil (Mag, 1983; Teasdale, 1975; Pritchard, 1983)

| Component           | Crude water degummed | Alkali refined | Bleached and deodorized |
|---------------------|----------------------|----------------|-------------------------|
| Free fatty acid (%) | 0.1–1                | 0.05           | 0.05                    |
| Phosphorus (ppm)    | 150–250              | 0–5            | 5                       |
| Sulphur (ppm)       | 3–15                 | 2–7            |                         |
| Chlorophyll (ppm)   | 5–25                 | 1–25           | No visual green         |
| Soap (ppm)          | –                    | 0–50           | tr                      |
| Moisture (%)        | 0.05                 | 0.05           | –                       |
| Fe (ppm)            | 1–3                  | 0.1            | 0.1                     |
| Cu (ppm)            | –                    | 0.1            | 0.01                    |

## Occurrence and characteristics

acid is enriched at the 1,3 positions in the glyceride (Table 3.161). Positional distribution of the acids is given in Table 3.102.

The major pigments of rapeseed oil are the chlorophylls a and b (Table 3.101) (Canola Council of Canada, 1981; Niewiadomski *et al.*, 1965) and their decomposition products pheophytin a and b.

The crude degummed oil contains 10–300 ppm of phosphorus depending on the type of degumming (acid or water) operation used (Table 3.101).

The sterols, 4-methylsterols and triterpene alcohols in rapeseed are given in Tables 3.163–3.166. Rapeseed oils contain brassicasterol and little or no stigmasterol (Matsumoto *et al.*, 1982).

The major phospholipids in low-erucic-acid varieties of rape are phosphatidylcholine (48%), phosphatidylinositol (19.5%) and phosphatidylethanolamine (8.9%). The major fatty acids in the phospholipids are palmitic, stearic and oleic acids (Sosulki *et al.*, 1981; Lawsson *et al.*, 1978).

The following tocopherols (mg/kg) in high-erucic-

acid rapeseed oil were determined (Slover, 1971; Whittle and Pennock, 1967):  $\alpha$ -tocopherol (18–24),  $\gamma$ -tocopherol (38–42),  $\delta$ -tocopherol (1.1–1.2) and total tocopherol (67) (see Tables 3.167–3.170).

The effect of reducing the content of erucic acid on the crystallization behaviour of hydrogenated rapeseed oil is to slow down the crystallization rate and for the products to have a greater tendency to form large crystals in the  $\beta$ -polymorphic form (Persmark and Bengtsson, 1976). Margarine developed a grainy texture when manufactured solely from rapeseed and hydrogenated rapeseed oil. The phase behaviour of unhydrogenated rapeseed oils depends on their erucic acid content (Ruijter, 1970).

### 3.3.28 Rice bran oil

[*Oryza sativa*; Graminae]

World production: there are no comprehensive data available; 370 000 tonnes were reported in 1981. Other information is summarized in Tables 3.103 and 3.104.

Rice is the main cereal crop of Asia and is the basis of the diet of half the world's population (Gaydou and Raonizafinimanana, 1980; Rao and Murthi, 1961; Grist, 1961; Terstage, 1972; Vaccarino, 1977).

Rice grain has an outer siliceous hull, which is removed to give 'brown' rice. Brown rice is further milled to remove the bran and the germ, leaving the endosperm whole (white or polished rice).

The bran, 6–8% of the rice grain, contains about 15–20% oil, 0.4–1.5% wax, 5–8% protein, 40–50% soluble carbohydrate and 5–8% fibre. The rice-bran-oil industry has been hampered by various technical and logistic problems. The bulk of rice bran oil is wasted in a number of countries. The oil is quickly hydrolysed if it remains in the bran. Good-quality oil is therefore only obtained by extracting the oil immediately after milling (Saunders, 1985; Fellers, 1991). The increase in free fatty acid can also be reduced by heating and drying the bran prior to extraction. Hexane and isopropanol have been used as extraction solvents. Rice sugar is a by-product obtained when bran is extracted with isopropanol.

Good-quality oil has excellent oxidative stability arising from a number of naturally occurring anti-

**Table 3.102** Stereospecific analysis of rapeseed triacyl-*sn*-glycerols (Takagi and Ando, 1991)

| Acyl group           | Composition (mol%) |                 |              |              |
|----------------------|--------------------|-----------------|--------------|--------------|
|                      | Total              | <i>sn</i> -1    | <i>sn</i> -2 | <i>sn</i> -3 |
| 14:0                 | 0.1                | 0.1             | 0.2          | 0.1          |
| 16:0                 | 3.9                | 5.6             | 1.6          | 4.5          |
| ( <i>n</i> - 9)-16:1 | 0.1                | nd <sup>a</sup> | 0.1          | 0.6          |
| ( <i>n</i> - 7)-16:1 | 0.3                | 0.3             | 0.3          | 0.2          |
| ( <i>n</i> - 8)-17:1 | 0.1                | nd              | 0.3          | nd           |
| 18:0                 | 1.3                | 1.9             | 0.4          | 1.7          |
| ( <i>n</i> - 9)-18:1 | 17.2               | 13.7            | 32.4         | 5.1          |
| ( <i>n</i> - 7)-18:1 | 1.4                | 2.8             | 1.0          | 0.5          |
| ( <i>n</i> - 6)-18:2 | 16.1               | 1.2             | 39.3         | 7.4          |
| ( <i>n</i> - 3)-18:3 | 8.7                | 3.3             | 21.3         | 1.3          |
| 20:0                 | 0.8                | 0.6             | 0.3          | 1.5          |
| ( <i>n</i> - 9)-20:1 | 8.9                | 15.5            | 1.5          | 10.0         |
| ( <i>n</i> - 7)-20:1 | 1.5                | 1.9             | 0.4          | 2.0          |
| ( <i>n</i> - 6)-20:2 | 0.5                | 1.2             | 0.1          | 0.2          |
| 22:0                 | 0.7                | nd              | nd           | 2.1          |
| ( <i>n</i> - 9)-22:1 | 37.4               | 50.2            | 0.8          | 61.3         |
| ( <i>n</i> - 7)-22:1 | 0.6                | 0.9             | nd           | 1.0          |
| ( <i>n</i> - 6)-22:2 | 0.5                | 0.9             | nd           | 0.7          |

<sup>a</sup> ND = not detected.

**Table 3.103** Fatty acid composition (wt%) of rice bran oil from *O. sativa* var. *japonica* from Malagasy, Madagascar (Gaydou and Raonizafinimanana, 1980)

| 14:0 | 16:0 | 18:0 | 20:0 | 16:1 | 18:1 | 18:2 | 18:3 | 20:1 |
|------|------|------|------|------|------|------|------|------|
| 0.4  | 16.4 | 1.8  | 0.4  | 0.1  | 42.3 | 37.1 | 1.3  | 0.2  |

**Table 3.104** Characteristics of rice bran oil

|                                 |             |
|---------------------------------|-------------|
| Relative density, $d_{25}^{25}$ | 0.916–0.921 |
| Refractive index, 25 °C         | 1.470–1.473 |
| Saponification value            | 181–189     |
| Iodine value                    | 99–108      |
| Unsaponifiable matter (%)       | 3–5         |
| Oil content of bran (%)         | 15–20       |

oxidants including tocopherols and esters of ferulic acid. Rice bran lipids include glycolipids, phospholipids, ceramides and waxes (Nasirullah and Nagaraja, 1987). The sterols, 4-methylsterols and triterpene alcohols are given in Tables 3.163–3.166. The fatty acid and sterol compositions of six Malagasy varieties have been reported (Gaydou and Raonizafimanana, 1980).

### 3.3.29 Safflower oil (safflowerseed, *carmanthus*, *kurdee*) [*Carthamus tinctorius*; Compositae]

Data are summarized in Tables 3.105–3.108. The plant (false saffron, dyers' saffron) has been grown since antiquity as an oil seed crop and for its flowers, from which the dye (carthamin and safflower yellow) is produced. The plant is a spiny erect herb resembling the thistle (30–100 cm high). There are two distinct varieties, one very spiny, the other moderately spiny or spineless. The seeds resemble sunflower seeds but are approximately half the size; oil content is 36–43% when dehulled. The hull can form a large proportion of the seed (35–65%). The higher-oil-containing commercial seeds are low in hull content. Early commercial data are scanty.

The oil is obtained either by expelling or by solvent extraction (Knowles, 1955; US Department of

**Table 3.105** World production of safflower oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 |
|---------|---------|---------|---------|---------|
| 170     | 330     | 265     | 260     | 245     |

Agriculture, 1965) and oil is refined in the conventional way. The oil is normally associated with very high levels of linoleic acid, but a commercial variety of high-oleic-acid safflower was introduced into the USA in 1968 (Fuller, 1966; Fuller *et al.*, 1967; Knowles, 1965; Kuemmel, 1964; Knowles, 1975).

The high-linoleic safflower is used as an edible oil and as a component of paints, giving fast-drying non-yellowing properties (no linolenic acid). High-oleic-acid safflower is used as a salad oil, as a stable cooking oil and in certain pharmaceutical and industrial applications.

The fatty acid compositions of both commercial and experimental oils are summarized in Table 3.108.

Statistical analysis of a large number of analyses has shown a strong negative correlation between oleic and linoleic acid (Yermanos *et al.*, 1967). The oil content of the seed is controlled by several genes, none of which is dominant.

The major glycerides of safflower (high-linoleic) are trilinolein, oleodilinolein and monosaturated dilinolein (Table 3.159). The minor components in

**Table 3.107** Characteristics of high-linoleic safflower oil, from draft Codex (Codex, 1969, 1979 and 1987)

|                                            |                    |
|--------------------------------------------|--------------------|
| Relative density, $d_{20}^{20}$            | 0.992–0.927        |
| Refractive index, $n_D^{40}$               | 1.467–1.470        |
| Saponification value                       | 186–198            |
| Iodine value                               | 135–150            |
| Unsaponifiable matter (g/kg)               | Not more than 15   |
| GLC ranges of fatty acid composition (wt%) |                    |
| 14:0                                       | 0–0.2              |
| 16:0                                       | 5.3–8.0            |
| 16:1                                       | 0–0.2              |
| 18:0                                       | 1.9–2.9            |
| 18:1                                       | 8.4–21.3           |
| 18:2                                       | 67.8–83.2          |
| 18:3                                       | 0–0.1              |
| 20:0                                       | 0.2–0.4            |
| 20:1                                       | 0.1–0.3            |
| 22:0                                       | 0.2–0.8            |
| 22:1                                       | 0–1.8 <sup>a</sup> |
| 24:0                                       | 0–0.2              |
| 24:1                                       | 0–0.2              |

<sup>a</sup> One sample only. Thirty samples had  $\leq 0.4$ .

**Table 3.106** Fatty acid composition (wt%) of safflower oil

|                            | 14:0 | 16:0 | 18:0 | 20:0 | 22:0 | 16:1 | 18:1 | 18:2 |
|----------------------------|------|------|------|------|------|------|------|------|
| High-oleic <sup>a</sup>    | 0.1  | 5.7  | 2.3  | 0.7  | 0.3  | –    | 73.6 | 15.8 |
| High-linoleic <sup>b</sup> | 0.1  | 6.5  | 2.9  | 0.4  | 0.2  | 0.1  | 13.8 | 75.3 |

<sup>a</sup> Others 1.5%.

<sup>b</sup> Others 0.7%.

## Occurrence and characteristics

**Table 3.108** Fatty acid composition (wt%) of safflower oils

| Fatty acid | Commercial oils                  |                               | Experimental oils                                |                             |
|------------|----------------------------------|-------------------------------|--------------------------------------------------|-----------------------------|
|            | High-linoleic<br>(Kuemmel, 1964) | (Jurriens, 1968) <sup>a</sup> | High-linoleic<br>(Yermanos <i>et al.</i> , 1967) | High-oleic<br>(Craig, 1953) |
| 12:0       | 0.1                              | 0.2                           |                                                  |                             |
| 14:0       | 0.1                              | 0.1                           |                                                  |                             |
| 16:0       | 6.5                              | 6.9                           | 7.6                                              | 4-8                         |
| 18:0       | 2.9                              | 3.1                           | 2.1                                              | 4-8                         |
| 20:0       | 0.4                              | 0.1                           |                                                  |                             |
| 22:0       | 0.2                              | —                             |                                                  |                             |
| 24:0       | 0.1                              | —                             |                                                  |                             |
| 16:1       | 0.1                              | 0.1                           |                                                  |                             |
| 18:1       | 13.8                             | 12.9                          | 33.1                                             | 74-79                       |
| 18:2       | 75.3                             | 76.5                          | 57.2                                             | 11-19                       |
| 20:1       | 0.3( <i>n</i> - 8)               | 0.1                           |                                                  |                             |
| 22:1       | 0.1( <i>n</i> - 8)               | —                             |                                                  |                             |
| 24:1       | 0.1( <i>n</i> - 8)               | —                             |                                                  |                             |

<sup>a</sup> Triglyceride composition is shown in Table 3.159.

**Table 3.109** Tocopherols in safflower oil (mg/kg)

| $\alpha$ -T | $\beta$ -T | $\gamma$ -T <sup>a</sup> | $\delta$ -T | $\alpha$ -T <sub>3</sub> | $\beta$ -T <sub>3</sub> | $\gamma$ -T <sub>3</sub> |
|-------------|------------|--------------------------|-------------|--------------------------|-------------------------|--------------------------|
| 223         | 7          | 33                       | 3.9         | —                        | —                       | —                        |

<sup>a</sup>  $\beta$ -T<sub>3</sub> is included in the  $\gamma$ -T values.

safflower include sterols, methylsterols and tri-terpene alcohols (Tables 3.163–3.166). The most recent data show that the main tocopherol in safflower oil is  $\alpha$ -tocopherol (Tables 3.109, 3.169 and 3.170).

### 3.3.30 Sal fat

[*Shorea robusta*; Dipterocarpaceae]

World production of sal fat was 35 000 tonnes reported in 1978. Other data are given in Tables 3.110–3.112.

Sal fat was commercially unknown until the mid-1970s (Bringi, 1987). The seed is the fruit of large subtropical trees growing in the natural forests of northern India. The tree is used mainly for its timber. Deforestation has to some extent been halted with

the growing commercialization of seed collection (May–July). The winged seed consists of 60% kernel, 12–20% shell and 20–30% wings. The oil content of the kernel is 14–18%.

The oil is extracted with hexane to give a deep-green semi-solid fat. The quality of the oil depends upon a number of factors, but mainly on whether the seed is harvested before or after the monsoon and on the storage conditions of the seed. The oil is difficult to bleach by conventional refining methods; partial hydrogenation or hydrobleaching has been used.

The oil is used both as an edible oil, in the formulation of cocoa butter equivalents (Yella Reddy and Prabhakar, 1989) and also for soap-making. Certain grades of oil contain epoxy or dihydroxyoctadecanoic acids (Bringi *et al.*, 1972; Bringi, 1987; Yella Reddy and Prabhakar, 1987, 1989). The reason for the occurrence of these components is not fully understood and is probably related to either indigenous lipoxygenase or fungal enzymes modifying the unsaturated acids. Methods of determining these components by TLC and GLC have been reported (Bringi *et al.*, 1972; Belvadi *et al.*, 1979).

The fatty acid compositions of oils extracted from different Indian States in 1979 are given in Table 3.111 (Chakrabarty, 1979). A reported triglyceride composition is given in Table 3.112.

**Table 3.110** Fatty acid composition (wt%) of sal fat (Bringi *et al.*, 1972)

| 14:0 | 16:0 | 18:0 | 20:0 | 22:0 | 18:1 | 18:2 | 18:3 |
|------|------|------|------|------|------|------|------|
| tr   | 5.2  | 42.8 | 7.0  | tr   | 40.4 | 3.8  | 0.8  |

**Table 3.111** Fatty acid composition of sal oils extracted from sal seeds from various States of India (Chakrabarty, 1979)

| State          | Fatty acid (wt%) |           |           |         |         |          | Epoxy acid <sup>a</sup> |
|----------------|------------------|-----------|-----------|---------|---------|----------|-------------------------|
|                | 16:0             | 18:0      | 18:1      | 18:2    | 18:3    | 20:0     |                         |
| Bihar          | 4.6–7.3          | 32.6–49.3 | 36.9–48.2 | 0.6–3.1 | 0.5–1.2 | 4.1–8.5  | 0.6–7.0                 |
| Orissa         | 4.6–6.7          | 39.6–49.0 | 34.7–44.5 | 1.2–2.7 | 0.5–0.9 | 3.6–8.7  | 0.6–5.4                 |
| Madhya Pradesh | 3.6–10.5         | 38.4–48.1 | 34.0–44.5 | 1.1–3.1 | 0.3–1.2 | 3.1–10.0 | 0.8–5.2                 |
| Uttar Pradesh  | 4.6–7.0          | 35.2–48.6 | 36.5–45.2 | 1.2–2.6 | 0.5–0.9 | 4.4–8.8  | 0.4–2.1                 |
| West Bengal    | 4.1–4.9          | 42.8–48.9 | 32.9–38.8 | 1.5–3.1 | 0.5–1.2 | 7.3–7.8  | 0.3–6.8                 |

<sup>a</sup> As epoxystearic (chemical method).

**Table 3.112** Triglyceride composition of a sal fat (Bringi *et al.*, 1972)

| Triglyceride <sup>a</sup> | Content (%) |
|---------------------------|-------------|
| SSS                       | 2           |
| SSU                       | 1           |
| SUS                       | 55          |
| SEpS                      | 9           |
| SUU                       | 26          |
| SEpU                      | 3           |
| USU                       | 1           |
| UUU                       | 3           |
| UEpU                      | 1           |

<sup>a</sup> S, total saturated acids; U, total unsaturated acids; Ep, *cis*-9,10-epoxystearic acid; SUS, etc., represents the total of all triglycerides of each type.

The minor components, i.e. sterols and triterpene alcohols, are given in Tables 3.163–3.166.

A number of investigations have demonstrated the wholesomeness of the oil (Gandhi *et al.*, 1976; Sundaravalli *et al.*, 1978).

### 3.3.31 Sesame oil

[*Sesamum indicum*, *S. orientale* is subsp.; Pedaliaceae]

Data are summarized in Tables 3.113–3.115. The plant is an annual herb 0.3–2 m high, of which there are many varieties, including shattering and non-shattering types. It grows in tropical, subtropical and warm-temperate regions.

The main producing countries are China (40%), India (30%), Sudan and Mexico. The seed contains 40–60% oil (Yermanos *et al.*, 1972), which is obtained by either expelling or solvent extraction. Cold-pressed oil is used directly for edible purposes. The colour of the crude oil depends on the type of seed and the extraction method used. Light-coloured oils

are obtained by conventional refining methods. High-quality oils can be used in place of olive oil and also in margarine. The oil has an unusually high oxidative stability, until recently attributed to the presence of sesamol (see below). Lower grades are used in the perfumery industry, as a carrier fat for pharmaceuticals and insecticides and for soap-making. The seeds are used in confectionery and bakery products.

The mean fatty acid composition of 721 different samples of sesame seed obtained on a worldwide basis was palmitic 9.5%, stearic 4.4%, oleic 39.6% and linoleic 46.0%, with a range of 32.7–53.9% for oleic acid and 39.3–59.0% for linoleic (Yermanos *et al.*, 1972). There is a significant negative correlation between oleic and linoleic acid content. A more limited range has been observed by others (El Tinay *et al.*, 1976). Wide variations in compositions are observed within countries (Budowski and Markley, 1951).

The triglycerides of a sesame oil are given in Tables 3.159 and 3.160. The fatty acids follow the normal distribution pattern for vegetable oils.

Sesame oil contains two unusual components, sesamin (0.5–1.1%) and sesamol (0.3–0.6%) (Budowski and Markley, 1951; Beroza and Kinman, 1955; Tashiro *et al.*, 1991). Both are based on a 2,7-dioxabicyclo[3.3.0]octane nucleus. Concentrates of these have been used for their synergistic effect with pyrethrum as an insecticide (Lyon, 1972), but this use has been superseded by synthetic alternatives. Only trace amounts of free sesamol are detected in the oil.

The sterols, 4-methylsterols and triterpene alcohols are given in Tables 3.163–3.166.

**Table 3.113** World production of sesame oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 |
|---------|---------|---------|---------|---------|
| 755     | 645     | 615     | 730     | 630     |

**Table 3.114** Fatty acid composition (wt%) of sesame oil

| 16:0 | 18:0 | 20:0 | 22:0 | 16:1 | 18:1 | 18:2 | 18:3 | 20:1 |
|------|------|------|------|------|------|------|------|------|
| 9.2  | 5.8  | 0.5  | tr   | 0.1  | 38.2 | 45.0 | 0.6  | 0.6  |

**Table 3.115** Characteristics of sesame oil, from draft Codex (Codex, 1979) (See also Table 3.157)

|                                                          |                  |
|----------------------------------------------------------|------------------|
| Relative density, $d_{20}^{20}$                          | 0.915–0.923      |
| Refractive index, $n_D^{40}$                             | 1.465–1.469      |
| Saponification value                                     | 187–195          |
| Iodine value                                             | 104–120          |
| Unsaponifiable matter (g/kg)                             | Not more than 20 |
| Modified Villavecchia test or sesame oil test (Baudouin) | Positive         |

The unusually high oxidative stability of the oil has until recently been attributed to the presence of small amounts of sesamol, which is usually present. Sesamol is released from sesamolin by hydrogenation, acid or acid bleaching earths or certain conditions of processing or storage (Budowski and Markley 1951; Budowski, 1964). Sesamolin, sesamin and sesamol have been separated by HPLC (Kikugawa *et al.*, 1983). Studies on the oxidative stability of the oil to which has been added controlled amounts of sesamol showed that the high oxidative stability could not be ascribed to sesamol but to another unknown powerful antioxidant (Kikugawa *et al.*, 1983).

### 3.3.32 Shea nut oil (shea butter, bambuk butter, karite)

[*Butyrospermum parkii*; Sapotaceae]

World production: the approximate trading volume in 1979 was 35 000 tonnes. Other data are shown in Tables 3.116 and 3.117.

The tree grows in the drier parts of equatorial central Africa, roughly in a belt from the equator to 15°N latitude (Adomako, 1985). The trees bear fruit 10–15 years after planting and reach maturity after 20–30 years. The fruit, 5 cm long, is shaped like a plum and has an edible yellow-green outer pulp enclosing the nut. The nuts are normally dried by sun and fire after the pulp has rotted away. The oil content of the nut is 45–55%. The fruit is available from June to September (Cobley, 1956; Ruysen, 1957).

The oil is extracted locally, but inefficiently, by grinding the nut to a paste, boiling in water and skimming off the oil. It is extracted commercially

by a combination of expelling and extraction. Commercial samples of shea nuts were shown to be very heterogeneous regarding moisture and oil content (Kershaw and Hardwick, 1981).

The oil is used in baking, in other edible applications and also in soap-making (locally). When fractionated from the solvent it yields a stearin, rich in 2-oleodistearin, used in producing cocoa butter equivalents (Soeters, 1970).

The triglyceride composition of shea nut oil is given in Table 3.158.

The oil contains a polyisoprenoid hydrocarbon. This is a gum-like material (3–4%), which can interfere with oil processing (Wolf, 1978; Paquot *et al.*, 1952).

Other minor components (Badifu, 1989) characterized include: tocopherols (90 mg/kg), triterpenol alcohols and cinnamic acid esters, sterols and 4-methylsterols. These are characteristic of the oil (Derbesy and Richert, 1979; Peers, 1977; Itoh *et al.*, 1974). The major triterpene alcohols are  $\alpha$ - and  $\beta$ -amyrin, butyrospermol and lupeol. The major sterols are  $\alpha$ -spinasterol, previously confused with  $\beta$ -sitosterol and  $\Delta^7$ -stigmasterol (Derbesy and Richert, 1979; Itoh *et al.*, 1974) (Tables 3.163–3.166).

The selective extraction of shea components using supercritical CO<sub>2</sub> has been described (Turpin *et al.*, 1992).

**Table 3.116** Fatty acid composition (wt%) of shea nut oil (Sawadogo and Bezard, 1982)

| 16:0 | 18:0 | 20:0 | 18:1 | 18:2 |
|------|------|------|------|------|
| 3.3  | 44.3 | 1.3  | 45.6 | 5.5  |

**Table 3.117** Characteristics of shea nut oil, from draft Codex (Codex, 1970b)

|                                  |             |
|----------------------------------|-------------|
| Relative density, $d_{15}^{100}$ | 0.859–0.869 |
| Refractive index, $n_D^{40}$     | 1.463–1.467 |
| Saponification value             | 178–190     |
| Iodine value <sup>a</sup>        | 53–65       |
| Unsaponifiable matter (%)        | 2–11        |

<sup>a</sup> The oil contains 3–4% of polyisoprenoid gums with iodine value ~350.

**3.3.33 Soybean oil**[*Sofa max*, *Glycine max*; Leguminosae]

Data relevant to soybean oil are summarized in Tables 3.118–3.121.

Soybean is one of the oldest crops cultivated by humans and was grown in China as far back as 2338 BC. Subsequently, it has been grown in Asia, Europe and America. The commercial production of soybean (*Glycine max*) started to expand significantly in the early 1940s, particularly in the USA, and it is now the major world oil seed crop. It is grown in over 50 countries, notably the USA, China, Brazil and Argentina. Papers (Soybean, 1981) and a book (Erikson *et al.*, 1980) review most aspects of the soybean and soybean oil. The chemical, biochemical and nutritional aspects have been reviewed (Lundberg, 1972).

The breeding of different strains of soybean relies in part on germplasm banks in India, Japan, South Korea and the USA (USDA, Soybean germplasm collection).

Soybeans (oil content 18–22%) can be safely stored at 12% moisture without any noticeable increase in free fatty acids. Long-term storage leads to slow but perceptible changes in oil composition, notably the formation of oxygenated fatty acids by the action of lipoxygenase (Barger, 1981; List and Erickson, 1980; Sen Gupta, 1972).

Crude soybean oil can be obtained from the bean by pressing but more normally by hexane extraction. Good-quality oil is light amber in colour with a free fatty acid content of 0.5%. Oil from damaged beans is darker, higher in free fatty acids and modified lipids and is more difficult to bleach. The residual meal is a major source of animal feed and is being increasingly used in human nutrition (Slavin, 1991).

The crude oil is 'degummed' by the controlled addition of water (2%), which precipitates the

**Table 3.120** Characteristics of soybean oil, from draft Codex (Codex, 1979 and 1993)

|                                          |                  |
|------------------------------------------|------------------|
| Relative density, $d_{20}^{20}$          | 0.919–0.925      |
| Refractive index, $n_D^{40}$             | 1.466–1.470      |
| Saponification value                     | 189–195          |
| Iodine value                             | 120–143          |
| Unsaponifiable matter (g/kg)             | Not more than 15 |
| GLC ranges of fatty acid composition (%) |                  |
| <14                                      | 0–0.1            |
| 14:0                                     | 0–0.2            |
| 16:0                                     | 8–13.3           |
| 16:1                                     | 0–0.2            |
| 18:0                                     | 2.4–5.4          |
| 18:1                                     | 17.7–26.1        |
| 18:2                                     | 49.8–57.1        |
| 18:3                                     | 5.5–9.5          |
| 20:0                                     | 0.1–0.6          |
| 20:1                                     | 0–0.3            |
| 20:2                                     | 0–0.1            |
| 22:0                                     | 0.3–0.7          |
| 22:1                                     | 0–0.3            |
| 24:0                                     | 0–0.4            |

hydratable phosphatide (1.5–2.5%) to give a valuable by-product. The fully refined oil is used in margarine, salad and frying oils. The oil has a tendency to oxidative flavour reversion, which is largely associated with the linolenic acid in the oil. Its stability for edible purposes is enhanced by partial hydrogenation. Hydrogenation is also applied to soybean oil and other liquid oils to raise their melting range so that they can be used in products that require a certain level of solid fat.

*(a) Fatty acid and triglyceride composition*

Soybean oil shows a wide variation in composition (Tables 3.120 and 3.121). Strong interrelationships

**Table 3.118** World production of soybean oil (1000 tonnes)<sup>a</sup>

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 | 1985/86 | 1989/90 |
|---------|---------|---------|---------|---------|---------|---------|
| 7700    | 11 000  | 13 275  | 14 015  | 15 395  | 14 326  | 16 123  |

<sup>a</sup> In the period 1980/81, the following amounts of *soybean* were grown (1000 tonnes): USA 48 772; Brazil 15 500; Republic of China 7880; Argentina 3500; Europe 656; former USSR 525.

**Table 3.119** Fatty acid composition (wt%) of normal and high-stearate soybean oils (Graef *et al.*, 1985; Knauf, 1987)

|               | 16:0 | 18:0 | 20:0 | 16:1 | 18:1 | 18:2 | 18:3 | 20:1 |
|---------------|------|------|------|------|------|------|------|------|
| Normal        | 11   | 4    | 1    | 0.5  | 22   | 53   | 7.5  | 1    |
| High-stearate | 8    | 30   | –    | –    | 21   | 35   | 6    | –    |

Table 3.121 Fatty acid composition for soybean oil according to origin<sup>a</sup> (Rossell, 1991)

| Origin<br>(number of samples)     | Fatty acids compositions (wt% methyl esters) |                  |                  |           |           |         |                  |                  |                  |                 |                  |  |
|-----------------------------------|----------------------------------------------|------------------|------------------|-----------|-----------|---------|------------------|------------------|------------------|-----------------|------------------|--|
|                                   | 16:0                                         | 16:1             | 18:0             | 18:1      | 18:2      | 18:3    | 20:0             | 20:1             | 22:0             | 22:1            | 24:0             |  |
| Argentina (6)                     | 10.7-11.9                                    | tr-0.2           | 3.7-4.3          | 17.7-19.1 | 55.0-56.8 | 7.9-9.5 | 0.2-0.5          | 0.2 <sup>b</sup> | 0.5-0.6          | tr-0.2          | nd-0.2           |  |
| Brazil (6)                        | 10.7-11.8                                    | tr-0.2           | 3.7-4.2          | 21.9-23.9 | 53.1-54.7 | 5.9-7.3 | 0.4-0.5          | 0.2-0.3          | 0.5-0.7          | tr-0.3          | tr-0.2           |  |
| Paraguay (4)                      | 11.3-12.2                                    | tr-0.2           | 3.7-3.9          | 22.5-22.7 | 54.0-54.4 | 5.6-6.4 | 0.3-0.5          | 0.2 <sup>b</sup> | 0.5-0.6          | 0.2-0.3         | 0.2 <sup>b</sup> |  |
| Uruguay (2)                       | 11.4-11.7                                    | tr-0.1           | 4.2 <sup>b</sup> | 19.8-20.4 | 53.7-54.6 | 8.3-8.8 | 0.4 <sup>b</sup> | 0.2 <sup>b</sup> | 0.4-0.5          | tr-0.1          | 0.2 <sup>b</sup> |  |
| USA (8)                           | 10.4-11.9                                    | 0.1-0.2          | 3.9-4.8          | 22.3-25.5 | 50.5-53.6 | 5.5-8.1 | 0.3-0.6          | 0.2-0.3          | 0.3-0.6          | nd-0.1          | nd-0.4           |  |
| Canada (3)                        | 10.8-10.9                                    | 0.1 <sup>b</sup> | 3.6-4.0          | 21.9-24.7 | 51.2-52.9 | 8.4-9.3 | 0.3 <sup>b</sup> | 0.2 <sup>b</sup> | 0.3-0.4          | nd-tr           | 0.1 <sup>b</sup> |  |
| S. Africa (3)                     | 9.9-10.7                                     | 0.1-0.2          | 4.0-5.4          | 18.8-21.9 | 53.2-55.8 | 7.9-9.1 | 0.4-0.5          | 0.2 <sup>b</sup> | 0.4-0.5          | tr <sup>b</sup> | 0.1-0.2          |  |
| Australia (2)                     | 11.1-11.7                                    | tr <sup>b</sup>  | 3.4-3.8          | 21.7-21.9 | 54.2-54.8 | 7.5-8.0 | 0.2-0.3          | tr-0.1           | 0.4 <sup>b</sup> | nd-0.1          | 0.1 <sup>b</sup> |  |
| India (3)                         | 9.7-11.7                                     | tr-0.2           | 3.5-4.3          | 22.4-26.1 | 49.8-54.7 | 6.8-7.1 | 0.3-0.4          | 0.2-0.3          | 0.4-0.5          | 0.1-0.2         | 0.1-0.2          |  |
| France (1)                        | 10.9                                         | tr               | 3.0              | 19.8      | 57.1      | 8.4     | 0.1              | 0.1              | 0.3              | nd              | 0.1              |  |
| China (1)                         | 13.3                                         | tr               | 4.0              | 20.4      | 51.9      | 9.1     | 0.5              | 0.3              | 0.4              | nd              | nd               |  |
| Overall range (39)                | 9.7-13.3                                     | tr-0.2           | 3.0-5.4          | 17.7-26.1 | 49.8-57.1 | 5.5-9.5 | 0.1-0.6          | tr-0.3           | 0.3-0.7          | nd-0.3          | nd-0.4           |  |
| Mean (39)                         | 11.2                                         | 0.1              | 4.0              | 21.8      | 53.9      | 7.6     | 0.4              | 0.2              | 0.5              | 0.1             | 0.1              |  |
| Coefficient of variation (%) (39) | 6.0                                          | 68.4             | 9.9              | 9.3       | 2.9       | 15.7    | 26.1             | 25.6             | 19.2             | 124.6           | 61.1             |  |
| Codex range <sup>c</sup>          | 7-14                                         | 0-0.5            | 3.0-5.5          | 18-26     | 50-57     | 5.5-10  | 0-0.6            | 0-0.5            | 0-0.5            | -               | 0-0.5            |  |

<sup>a</sup> tr = trace (unquantified level of less than 0.05%); nd = not detected.<sup>b</sup> Where single values are given and more than one sample was analysed, all samples had the same value within experimental error.<sup>c</sup> Codex Standard 20-1981, as revised February 1987.

exist between the fatty acids. Linolenic and linoleic acids are directly correlated; linolenic and oleic acids are negatively correlated. Saturated acids range from 11 to 26% and are virtually independent of the iodine value (Howell and Collins, 1957; Singh, 1976; White *et al.*, 1961).

The most interesting developments relate to the breeding of varieties that have very different compositions to those associated with conventional soybean oil (Hammond and Fehr, 1984; Graef *et al.*, 1985; Knauf, 1987).

Epoxy fatty acids occur at levels between 0.08 and 1.04% in crude oils depending to a large extent on the quality of the beans (Sen Gupta, 1972; Spencer, 1973).

As with most vegetable oils, the saturated acids hardly occur at the 2 position of the triglyceride. The glyceride composition calculated by the 1,3-random, 2-random distribution agrees well with experimentally determined values. Typical figures are given in Table 3.159. The stereospecific distribution of fatty acids in soya does not show strong differences in the composition of the 1 and 3 positions (Tables 3.122 and 3.161).

#### (b) Minor components

Perhaps the most important from the refining point of view are the phospholipids (400–700 ppm phosphorus in crude oil). Hydratable phosphatides are removed by degumming with water, but the oil still contains varying amounts of residual phosphatides depending

on the quality of the beans. The non-hydratable phospholipids complex with metal ions, notably iron and copper. These are normally removed by treatment with dilute phosphoric acid. Failure to remove phosphatides adversely influences the colour of the oil and hinders hydrogenation.

Soybean phospholipids (Chapman, 1980) contain phosphatidic acid (5%), phosphatidylinositol (20%), phosphatidylethanolamine (23%), phosphatidylcholine (39%) and unidentified components (13%). The phosphatides in crude and degummed soybean oil are given in Table 3.123 (Racicot and Handel, 1983).

Typical tocopherol, sterol, triterpene alcohol, chlorophyll and hydrocarbon levels in soybean oil are given in Table 3.124. Many of these compounds are at least partially removed during refining, bleaching and deodorization. More detailed analyses of the sterols, 4-methylsterols and triterpene alcohols are given in Tables 3.163–3.166, and for tocopherols in Tables 3.167–3.170.

The partial hydrogenation of soybean oil, apart from saturating a proportion of the double bonds, results in the isomerization and migration of double bonds along the fatty acid chain (Dutton and Emken, 1979; Coenen, 1976). The composition of partially hydrogenated soya oil appears in Table 3.125 (D'Alonzo *et al.*, 1981). A US Select Committee on GRAS substances concluded that there was no evidence to demonstrate or suggest that the current levels of partially hardened soya oil used in the USA should be reduced in food (Food and Drug Administration, 1976; Applewhite, 1981). However, recent

**Table 3.122** Comparison of stereospecific distributions of acyl groups in soybean oil triacyl-*sn*-glycerols obtained by HPLC and enzymatic methods (Takagi and Ando, 1991)

| Acyl group           | Composition (mol%) |                 |              |               |              |              |
|----------------------|--------------------|-----------------|--------------|---------------|--------------|--------------|
|                      | HPLC method        |                 |              | Enzyme method |              |              |
|                      | <i>sn</i> -1       | <i>sn</i> -2    | <i>sn</i> -3 | <i>sn</i> -1  | <i>sn</i> -2 | <i>sn</i> -3 |
| 14:0                 | 0.1                | 0.1             | 0.1          | 0.3           | 0.3          | –0.2         |
| 16:0                 | 16.7               | 2.2             | 16.1         | 16.9          | 1.4          | 16.6         |
| ( <i>n</i> – 7)-16:1 | 0.1                | 0.1             | 0.1          | 0.1           | 0.1          | 0.0          |
| 17:0                 | 0.1                | 0.0             | 0.1          | 0.1           | 0.0          | 0.0          |
| 18:0                 | 5.4                | 0.3             | 4.6          | 5.2           | 0.3          | 4.7          |
| ( <i>n</i> – 9)-18:1 | 22.2               | 23.0            | 22.9         | 20.3          | 22.6         | 25.1         |
| ( <i>n</i> – 7)-18:1 | 2.1                | 0.4             | 1.7          | 2.0           | 0.4          | 1.8          |
| ( <i>n</i> – 6)-18:2 | 46.4               | 68.1            | 47.0         | 47.4          | 69.2         | 45.2         |
| ( <i>n</i> – 6)-18:3 | 6.4                | 5.7             | 7.0          | 7.5           | 5.7          | 5.9          |
| 20:0                 | 0.5                | nd <sup>a</sup> | 0.4          | 0.2           | nd           | 0.7          |

<sup>a</sup> nd, not detected.

**Table 3.123** Individual phosphorus compounds of crude and degummed soybean oil (Racicot and Handel, 1983)

| Compound <sup>a</sup> | Phosphorus content <sup>b</sup> |                   |                        |                   |
|-----------------------|---------------------------------|-------------------|------------------------|-------------------|
|                       | Crude                           |                   | Degummed               |                   |
|                       | (ppm)                           | (% of total P)    | (ppm)                  | (% of total P)    |
| LPC                   | 10.5 ± 4.1                      | 2.4               | 1.9 ± 1.2              | 4.4               |
| PC                    | 143.7 ± 11.4                    | 32.7 <sup>e</sup> | 4.5 ± 2.6              | 10.5 <sup>e</sup> |
| LPE                   | 6.3 ± 2.4                       | 1.4               | 2.2 ± 1.5 <sup>c</sup> | 5.1               |
| PI                    | 67.2 ± 15.3                     | 14.3              | 4.5 ± 3.8 <sup>d</sup> | 10.5 <sup>d</sup> |
| PA                    | 73.7 ± 53.0                     | 16.8              | 4.3 ± 3.0 <sup>d</sup> | 10.1 <sup>d</sup> |
| PE                    | 109.1 ± 25.3                    | 24.8              | 8.5 ± 4.2 <sup>d</sup> | 19.9 <sup>d</sup> |
| Unknown 1             | 6.0 ± 4.2                       | 1.4 <sup>e</sup>  | 8.9 ± 0.5              | 20.8 <sup>e</sup> |
| Unknown 2             | 23.0 ± 10.7                     | 5.2 <sup>e</sup>  | 8.0 ± 5.2              | 18.7 <sup>e</sup> |

<sup>a</sup> LPC, lysophosphatidylcholine; PC, phosphatidylcholine; LPE, lysophosphatidylethanolamine; PI, phosphatidylinositol; PA, phosphatidic acid; PE, phosphatidylethanolamine.

<sup>b</sup> Average of four companies unless otherwise noted.

<sup>c</sup> Average of three companies.

<sup>d</sup> Average of eight samples from one company.

<sup>e</sup> Significantly different at the 1% level.

comparisons between *trans* acids and saturated acids may influence future policy.

Soybean oil is widely used in the chemicals industry (Erickson *et al.*, 1980). In the drying-oil industry it is used mainly in alkyd resins. The skipped methylene

unsaturated acids can be conjugated by the action of catalysts, e.g. nickel, sulphur dioxide or iodine (Johnson, 1979), to produce faster-drying coatings.

Epoxidation is carried out with performic acid, peracetic acid or hydrogen peroxide in the presence of a strong acid or ion-exchange resin. The epoxidized oil is used as both a stabilizer and a plasticizer (Erickson *et al.*, 1980).

Dimerized fatty acids are used in adhesives, coatings, lubricants, printing inks and iron corrosion inhibitors. They are produced by condensing two unsaturated fatty acids in the presence of a catalyst, e.g. clay (Johnson, 1979; Pryde and Cowan, 1972; Berman and Loeb, 1975). They are further converted to polyamides for applications in adhesives, coatings and inks.

**Table 3.124** Some minor components in soybean oil

|                     |                                |
|---------------------|--------------------------------|
| Tocopherols (total) | 530–1500 mg/kg                 |
| α-Tocopherol        | 90–120 mg/kg                   |
| γ-Tocopherol        | 740–1020 mg/kg                 |
| δ-Tocopherol        | 240–300 mg/kg                  |
| Chlorophyll         | 1500 µg/kg                     |
| Hydrocarbons        | 300 mg/kg (squalene 150 mg/kg) |
| Sterols             | 1000–3500 mg/kg                |
| Triterpene alcohols | 600 mg/kg                      |

**Table 3.125** Fatty acid composition (wt%) of a partially hydrogenated soybean oil (D'Alonzo *et al.*, 1981)

|                     | 12:0          | 14:0         | 16:0         | 18:0         | 20:0         | Total        |
|---------------------|---------------|--------------|--------------|--------------|--------------|--------------|
| Saturated           | 0.2           | 0.2          | 9.2          | 4.2          | tr           |              |
| Monoenes (18:1)     | <i>n</i> – 10 | <i>n</i> – 9 | <i>n</i> – 8 | <i>n</i> – 7 | <i>n</i> – 6 | <i>n</i> – 5 |
| <i>cis</i>          | 0.6           | 21.9         | 0.9          | 3.6          | 12.0         | –            |
| <i>trans</i>        | 0.8           | 1.7          | 3.9          | 3.2          | 1.7          | 0.7          |
| Dienes              |               |              |              |              |              |              |
| <i>cis, cis</i>     |               |              |              |              |              | 29.4         |
| <i>cis, trans</i>   |               |              |              |              |              | 3.0          |
| <i>trans, trans</i> |               |              |              |              |              | 0.0          |
| Trienes             |               |              |              |              |              | 3.5          |

The main aspects of soybean oil chemistry and processing have been reviewed (Erickson *et al.*, 1980; Soybean, 1981).

### 3.3.34 *Stillingia* oil

[*Sapium sebiferum*; Euphorbiaceae]

This is dealt with alongside Chinese vegetable tallow in section 3.3.6).

### 3.3.35 Sunflower oil

[*Helianthus annuus*; Compositae]

Data are summarized in Tables 3.126–3.130. The sunflower is native to the Americas, but was introduced into Europe in the sixteenth century (Putt, 1978). It is now widely exploited (Table 3.129) as an annual field crop taking four months to mature, 70 days for dwarf varieties.

There are numerous varieties of sunflower, which are identifiable in part on the basis of height but also on the basis of oil composition, i.e. linoleic acid rich and oleic acid rich. The flower heads are harvested mechanically, ideally when the moisture content has dropped to approximately 9–10%. Mechanical drying is frequently necessary. Yields of 1300–2000 kg/ha are obtained. Oil content of seed: 20–32% old strains, 40% new strains.

The seed has a hard woody pericarp, often white with black streaks, which is removed using a decorticator. The oil is extracted by cold and hot pressing followed by solvent extraction. Most of the oil is used for edible purposes, the best quality as table or cooking oil and in margarine. For certain applications, e.g. table oil, the oil is winterized to remove waxes. Sunflower seeds are used as bird seed and are also roasted and salted for confectionery.

**Table 3.128** Characteristics of sunflower oil, from draft Codex (Codex, 1979 and 1993)

|                                            |                  |
|--------------------------------------------|------------------|
| Relative density, $d_{20}^{20}$            | 0.918–0.923      |
| Refractive index, $n_D^{40}$               | 1.467–1.469      |
| Saponification value                       | 188–194          |
| Iodine value                               | 110–143          |
| Unsaponifiable matter (g/kg)               | Not more than 15 |
| GLC ranges of fatty acid composition (wt%) |                  |
| 12:0                                       | 0–0.1            |
| 14:0                                       | 0–0.2            |
| 16:0                                       | 5.6–7.6          |
| 16:1                                       | 0–0.3            |
| 18:0                                       | 2.7–6.5          |
| 18:1                                       | 14–39.4          |
| 18:2                                       | 48.3–74.0        |
| 18:3                                       | 0–0.2            |
| 20:0                                       | 0.2–0.4          |
| 20:1                                       | 0–0.2            |
| 22:0                                       | 0.5–1.3          |
| 22:1                                       | 0–0.2            |
| 22:2                                       | 0–0.3            |
| 24:0                                       | 0.2–0.3          |

**Table 3.129** Major sunflower-producing countries, 1981/82

| Country     | Tonnage of seeds ( $\times 1000$ ) |
|-------------|------------------------------------|
| Former USSR | 5 150                              |
| USA         | 2 120                              |
| Argentina   | 1 450                              |
| PR China    | 1 050                              |
| Rumania     | 740                                |
| Turkey      | 575                                |
| Hungary     | 520                                |
| S. Africa   | 495                                |
| France      | 380                                |
| Others      | 1 820                              |
| Total       | 14 300                             |

**Table 3.126** World production of sunflower oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 | 1985/86 | 1989/90 |
|---------|---------|---------|---------|---------|---------|---------|
| 3335    | 3575    | 4695    | 5250    | 5910    | 6894    | 7767    |

**Table 3.127** Fatty acid composition (wt%) of sunflower oil (Earle *et al.*, 1968; Knauf, 1987)

|             | 14:0 | 16:0 | 18:0 | 20:0 | 22:0 | 24:0 | 16:1 | 18:1 | 18:2 | 18:3 | 20:1 |
|-------------|------|------|------|------|------|------|------|------|------|------|------|
| Russian     | 0.2  | 6.0  | 5.6  | 0.3  | 0.8  | 0.1  | 0.1  | 17.8 | 68.7 | 0.2  | 0.1  |
| American    | 0.1  | 5.5  | 4.7  | 0.3  | 0.9  | 0.2  | 0.1  | 19.5 | 68.5 | 0.1  | 0.1  |
| High-oleate | 0.1  | 3.6  | 4.9  | 0.4  | 1.2  | 0.3  | 0.1  | 80.6 | 8.4  | 0.1  | 0.3  |

**Table 3.130** Component glycerides (mol%) of maturing sunflower seed oil (Gunstone and Padley, 1967)

| Glyceride <sup>a</sup> | 38-day          |                |                | 55-day |    |    | 90-day |    |    |
|------------------------|-----------------|----------------|----------------|--------|----|----|--------|----|----|
|                        | Ag <sup>b</sup> | L <sup>b</sup> | T <sup>b</sup> | Ag     | L  | T  | Ag     | L  | T  |
| 222                    | 21              | 20             | 20             | 41     | 44 | 45 | 37     | 41 | 41 |
| 221                    | 22              | 27             | 27             | 24     | 28 | 28 | 25     | 26 | 25 |
| 220                    | 20              | 16             | 16             | 19     | 14 | 13 | 20     | 18 | 18 |
| 211                    | 7               | 12             | 12             | 8      | 6  | 6  | 7      | 5  | 5  |
| 210                    | 9               | 14             | 15             | 5      | 6  | 6  | 9      | 7  | 8  |
| 111                    | 5               | 2              | 2              | 0      | 0  | 0  | 0      | 0  | 0  |
| 200                    | 5               | 4              | 3              | 2      | 1  | 1  | 1      | 2  | 2  |
| 110                    | 6               | 3              | 3              | 1      | 1  | 1  | 1      | 1  | 1  |
| 100                    | 5               | 2              | 2              | 0      | 0  | 0  | 0      | 0  | 0  |

<sup>a</sup> These figures indicate the number of double bonds in the three acyl chains. Each glyceride category includes all positional isomers.

<sup>b</sup> Ag, results from silver-ion chromatography; L, results from lipolysis calculated according to Coleman; T, results from component acids calculated according to Gunstone.

Low grades are used for industrial purposes: in soap (after hydrogenation), in blends with linseed oil, etc., in paints and varnishes and in alkyd resins. Paints based solely on sunflower oil have a good resistance to yellowing because of the low linolenic acid content. The use of the oil as a diesel fuel is also being explored (Zimmerman, 1981).

The composition of sunflower oil varies as a consequence of climate and type (Kinman, 1972; Putt, 1978; Von Schuster *et al.*, 1980; Sunflower Oil Today, 1987). The temperature during maturation correlates inversely with linoleic acid content, an observation made with many types of oil seed. The oil is normally renowned for its high linoleic acid content, but there is increasing interest in high-oleic varieties, which are already being grown commercially in the former USSR and the USA (Ficke, 1983; Knauf, 1987).

The triglyceride composition of normal sunflower oil is given in Table 3.159 and of maturing sunflower seed oil (Gunstone and Padley, 1967) in Table 3.130. Carbon-number data are given in Table 3.160.

*cis*-9,10-Epoxy- and 9,10-dihydroxystearic and -octadecenoic (12c) acids have been detected in sunflower oil extracted from seed stored for prolonged periods (Mikolajczak *et al.*, 1968). Only trace amounts of oxygenated acids were found in certain high-oil Russian varieties.

The major phospholipids (0.5–1.2% of crude sunflower oil) are phosphatidic acid (2.2% of total phospholipid), phosphatidylinositol (27.9%), phosphatidylethanolamine (21.2%) and phosphatidylcholine (48.7%) (Chapman, 1980).

The sterols, 4-methylsterols and triterpene

alcohols of sunflower oil are given in Tables 3.163–3.166.

The presence of hydrocarbons (0.025–0.031%), sterols (0.542–0.584%) and waxes (0.008–0.044%) has been reported (Morrison and Robertson, 1975). The waxes are frequently removed by winterization to obtain oils with improved cloud points (Rivarola *et al.*, 1985).

$\alpha$ -Tocopherol (608 mg/kg),  $\beta$ -tocopherol (17 mg/kg) and  $\gamma$ -tocopherol (11 mg/kg) are present in sunflower oil (Muller-Mulot, 1976) (Table 3.167).

### 3.3.36 Tall oil

World production: comprehensive data are not readily available. Production capacity is currently estimated to be 1490 000 tonnes. Data are shown in Tables 3.131 and 3.132. Tall oil is a by-product of the pulping of pine wood using the sulphate or Kraft process.

Crude tall oil is a mixture of fatty acids (45%), rosin acids (42%) and unsaponifiables (triterpenes 13%). The characterization of the fatty and resin acids has been described by a number of workers including

**Table 3.131** Fatty acid composition (wt%) of tall oil

| 16:0 | 18:0 | 20:0 | 18:1 | 18:2 | 18:3 |
|------|------|------|------|------|------|
| 5    | 3    | 2    | 46   | 41   | 3    |

**Table 3.132** ASTM specifications for tall oil fatty acids

| Properties            | Type I |      | Type II |      | Type III |      |
|-----------------------|--------|------|---------|------|----------|------|
|                       | Min.   | Max. | Min.    | Max. | Min.     | Max. |
| Iodine value          | 125    | 135  | —       | —    | —        | —    |
| Acid value            | 197    | —    | 192     | —    | 190      | —    |
| Unsaponifiables (wt%) | —      | 1.0  | —       | 2.0  | —        | 10   |
| Resin acids (wt%)     | —      | 1.0  | —       | 2.0  | —        | 10   |
| Fatty acids (wt%)     | 98     | —    | 96      | —    | 90       | —    |
| Colour (Gardner)      | —      | 4    | —       | 5    | —        | 10   |

Holmbom (1977, 1978). The resin acids include abietic, dehydroabietic, palustic, pimaric and isopimaric acids.

Most of the crude tall oil is fractionally distilled to separate the resin and fatty acids, which are present in approximately equal amounts. The specifications for different grades of tall oil fatty acids are given in Table 3.132.

A food-grade oleic acid has been produced commercially from tall oil. The main uses of tall oil fatty acids are as intermediates in the production of oleochemicals and as components of alkyd resins. The absence of linolenic acid conveys good colour retention and non-yellowing properties for protective coatings.

### 3.3.37 Tea seed oil

{*Thea sasanqua*, *Camellia sasanqua*;  
Theaceae}

Comprehensive information is not readily available on world production; 100 000 tonnes were recorded in 1979, excluding India and parts of China. Other data are given in Tables 3.133 and 3.134.

Tea seed oil is obtained from the woody evergreen shrubs or small trees of *Thea sasanqua* growing in tropical and subtropical climates (oil content of seed 56–70%). The tea leaves used as a beverage normally come from *Thea sinensis* (*Camellia sinensis*), but this is not used to any extent as a source of tea seed oil (oil

**Table 3.134** Characteristics of tea seed oil

|                              |             |
|------------------------------|-------------|
| Relative density             | —           |
| Refractive index, $n_D^{25}$ | 1.467–1.469 |
| Saponification value         | 193–196     |
| Iodine value                 | 83–89       |
| Unsaponifiable matter (%)    | ~0.9        |
| Oil content of seed (%)      | 56–70       |

content of seeds 16–20%). The fatty acids in tea leaf have been determined (Bhuyan and Mahanta, 1989).

Japanese tea seed oil, tsubaki, comes from *Thea japonica*. The oil is obtained either by pressing or by a combination of expelling and solvent extraction. The fully refined oil is virtually colourless and is very similar to olive oil in composition (Owuor *et al.*, 1985).

The oil is mainly used for edible purposes and only the very low grade oils are used for soap or other industrial purposes. Commercial data are very scarce.

The meal is reported to contain saponins; it has astringent properties and cannot be used in animal feeds.

The presence of tea seed oil in olive oil is 'detected' by the Fitelson test.

The sterols (0.6%) are mainly  $\beta$ -sitosterol, campesterol and stigmasterol. The triterpenes (0.04%) include cycloartenol, cycloartanol, 24-methylenecycloartenol and probably  $\alpha$ -amyirin (Fedeli *et al.*, 1966).

**Table 3.133** Fatty acid composition (wt%) of tea seed oil (Sengupta *et al.*, 1976; Cloughley, 1983)

|                                       | 14:0 | 16:0 | 18:0 | 18:1 | 18:2 | 20:1 | 22:1 |
|---------------------------------------|------|------|------|------|------|------|------|
| <i>Camellia sasanqua</i>              | —    | 16.1 | 0.4  | 59.0 | 22.3 | —    | —    |
| <i>Camellia sinensis</i> <sup>a</sup> | 0.2  | 27.5 | 5.5  | 45.5 | 19.5 | 0.9  | 0.9  |

<sup>a</sup> The 'tea plant'.

## Occurrence and characteristics

### 3.3.38 Tobacco seed oil

[*Nicotiana tabacum* and *N. rustica*;  
Solanaceae]

World production: data are not readily available. Other information is summarized in Tables 3.135–3.137.

Tobacco (*Wealth of India*, 1966) is grown in both temperate and tropical zones primarily for its leaf, which forms the basis of the tobacco industry. The seed heads are in many cases removed from the plant before they reach maturity as a method of controlling the quality of the tobacco. In many parts of India and to a lesser extent in Greece and Bulgaria, however, the seed is allowed to ripen and is harvested. Relatively small amounts of oil are produced in the USA and Turkey.

The oil is obtained by pressing or solvent extraction. The refined oil is used for edible purposes. It is also widely used as a drying oil because of its non-yellowing characteristics and as a component of alkyd resins. Both the seed and the oil are free of nicotine. The meal is rich in protein and is used in cattle feed. The triglyceride composition determined by silver-nitrate TLC and lipase hydrolysis is detailed in Table 3.138.

Detailed analyses of tobacco seed meal, fatty acid, sterol and triglyceride composition of the oil have been made (Frega *et al.*, 1991). Sterol composition is given in Table 3.137.

**Table 3.135** Fatty acid composition (wt%) of *N. rustica* (Sengupta and Mazumbar, 1976)

| 16:0 | 18:0 | 20:0 | 18:1 | 18:2 | 18:3 |
|------|------|------|------|------|------|
| 8.4  | 3.8  | 0.1  | 15.7 | 71.2 | 0.8  |

**Table 3.136** Analytical characteristics of *N. rustica* (AOCS values)

|                                 |              |
|---------------------------------|--------------|
| Relative density, $d_{15}^{15}$ | 0.923–0.925  |
| Refractive index, 25 °C         | 1.474–1.483  |
| Saponification value            | 186–197      |
| Iodine value                    | 129–197      |
| Unsaponifiable matter (%)       | Not over 1.5 |
| Oil content of seed (%)         | 30–43        |

**Table 3.137** Triglycerides (wt%) of tobacco seed oil (all isomers)

| 002 <sup>a</sup> | 012 | 022 | 211 | 221 | 222 |
|------------------|-----|-----|-----|-----|-----|
| 3                | 10  | 20  | 5   | 24  | 38  |

<sup>a</sup> 0, 1, 2 indicate number of double bonds in fatty acid chains, e.g. 2 = linoleic (18:2).

**Table 3.138** Composition<sup>a</sup> of the sterol fraction of tobacco seed oils (as trimethylsilyl (TMS) derivatives), compared to those of other oil-bearing seeds (Frega *et al.*, 1991)

| RRT <sup>b</sup> | Identification <sup>c</sup>     | Kentucky 104 | Bright Italia | Bright V | Safflower | Grape seed | Tomato |
|------------------|---------------------------------|--------------|---------------|----------|-----------|------------|--------|
| 0.62             | Unknown                         | tr           | tr            | 0.4      | –         | –          | –      |
| 0.67             | Cholesterol                     | 8.6          | 7.3           | 9.8      | tr        | 0.3        | 20.6   |
| 0.69             | Cholestanol                     | 0.4          | 0.2           | tr       | tr        | tr         | 1.0    |
| 0.74             | Brassicasterol                  | 1.1          | 0.1           | 1.0      | –         | –          | 1.1    |
| 0.77             | 24-Methylencholesterol          | 0.5          | 0.9           | 0.4      | 1.3       | –          | 0.9    |
| 0.78             | Unknown                         | tr           | 0.5           | 0.7      | 0.1       | –          | –      |
| 0.83             | Campesterol                     | 13.0         | 13.4          | 13.6     | 13.6      | 9.5        | 4.8    |
| 0.84             | Campestanol                     | 0.3          | 0.3           | tr       | –         | –          | –      |
| 0.88             | Stigmasterol                    | 9.3          | 10.2          | 9.6      | 5.5       | 11.3       | 9.6    |
| 0.90             | Stigmastenol                    | 0.6          | 0.6           | 0.6      | –         | –          | –      |
| 0.92             | $\Delta^7$ -Campestanol         | 1.5          | 0.9           | 1.9      | 4.2       | –          | –      |
| 0.98             | Clerosterol                     | 0.7          | 0.8           | 1.3      | –         | –          | 0.5    |
| 1.00             | $\beta$ -Sitosterol             | 39.5         | 43.8          | 39.5     | 48.9      | 75.0       | 49.8   |
| 1.03             | $\Delta^5$ -Avenasterol         | 22.7         | 19.3          | 19.2     | 4.0       | 1.7        | 10.2   |
| 1.06             | Unknown                         | tr           | 0.2           | 0.3      | –         | –          | –      |
| 1.08             | $\Delta^{3,2}$ -Stigmastadienol | 1.0          | 0.8           | 0.8      | –         | –          | –      |
| 1.11             | $\Delta^7$ -Stigmastenol        | 0.1          | 0.1           | 0.2      | 18.5      | 1.4        | 1.0    |
| 1.16             | $\Delta^7$ -Avenasterol         | 0.7          | 0.6           | 0.7      | 2.1       | 0.8        | 0.5    |

<sup>a</sup> Calculated on the basis of the areas found in high-resolution gas chromatography (HRGC), expressed as a percentage.

<sup>b</sup> Relative retention time, referred to  $\beta$ -sitosterol(TMS) = 1.00.

<sup>c</sup> Tentative identification on the basis of data reported in literature.

### 3.3.39 Tung oil (China wood oil)

[*Aleurites fordii* Hemsl., *A. montana* Willd.; Euphorbiaceae]

Data relating to tung oil are summarized in Tables 3.139–3.141. *A. fordii* is a small tree (up to 12 m high) and *A. montana* a larger (20 m high) deciduous tree. *A. fordii* probably originated in western China and grows under warm-temperate and subtropical conditions. *A. montana* is more suited to a tropical climate. The oils from the two species are virtually identical and trade under the same name.

The fruit is about the size of a large walnut, with a fibrous outer hull inside which are usually four or five seeds. In China the fruit is reported to be harvested unripe, whereas in the USA the ripe fruit is collected after being allowed to fall naturally. The fruit is normally dried immediately. After dehulling and decortication, the kernels are ground, heated to 80°C and either pressed or solvent extracted. The yield of air-dried seed varies from 1000 to 3000 kg/ha depending on the age of the tree and type of stock (Foster, 1963).

The meal is unsuitable as an animal feed because of the presence of a toxic protein (Mann, 1954).

**Table 3.139** World production of tung oil (1000 tonnes)

| 1970/71 | 1975/76 | 1980/81 | 1981/82 | 1982/83 |
|---------|---------|---------|---------|---------|
| 120     | 110     | 105     | 95      | 100     |

**Table 3.140** Fatty acid composition (wt%) of tung oil (Gunstone *et al.*, 1965)

| 16:0 | 18:0 | 18:1 | 18:2 | 18:3 conj. |
|------|------|------|------|------------|
| 3.1  | 2.1  | 11.2 | 14.6 | 69         |

**Table 3.141** Characteristics of tung oil

|                                     |               |
|-------------------------------------|---------------|
| Relative density, $d_{15}^{15}$     | 0.938–0.945   |
| Refractive index, $n_D^{25}$        | 1.5165–1.5200 |
| Saponification value                | 189–195       |
| Iodine value                        | 160–175       |
| Unsaponifiable matter (%)           | 0.5           |
| Oil content of seed (% of dry seed) | 16–25         |

Tung oil contains high levels of  $\alpha$ -eleostearic acid (*cis*-9-*trans*-11-*trans*-13-octadecatrienoic) and is therefore inedible. It is used mainly as a component of quick-drying enamels and varnishes. Tung oil is normally liquid down to 7°C but traces of catalysts such as sulphur, iodine, selenium or light will isomerize  $\alpha$ -eleostearic acid to  $\beta$ -eleostearic acid (the all-*trans* isomer), thus raising the melting point (sections 1.4 and 3.2.12). The oil thickens and gels when heated and thus forms the basis for the Browne and Worstall tests.

The gelation time for *A. montana* is longer than that of *A. fordii*. Surprisingly, the oil is 'permanently' prevented from elaidinizing by heating to 200–225°C for a short time. No explanation has been offered.

The contamination of edible oils with tung oil has been detected using a variety of colorimetric tests (Kitamara *et al.*, 1984).

Tung oil is reported to contain small amounts of 9,14-dihydroxyoctadeca-10,12-dienoic acid (Davies *et al.*, 1950). The estimation of unsaturation by the Wijs iodine method is not quantitative as a result of the relative inactivity of the conjugated system.

The drying of tung oil is reported to require less oxygen (5% absorbed) than the drying of non-conjugated oils such as linseed (12% oxygen adsorbed).

### 3.3.40 Ucuhuba

[*Virola surinamensis*, *V. sebeteia*; Myristacaceae]

Data on world production are not readily available. Other data are given in Tables 3.142 and 3.143.

Both varieties are trees of medium height, the former growing along the swampy coast of northern Brazil and the Guianas, the latter growing inland near the Amazon and its tributaries. The fruits have a spherical hull enclosing a kernel the size of a hazelnut.

The oil is obtained by expelling. Earlier work (Steger and van Loon, 1935) showed that the commercial oil was not completely soluble in petrol. An ether-soluble 'resin fraction' (6.5%) has been isolated from the seed after extraction with petrol. This fraction is apparently largely removed by alkali refining owing to its acidic nature.

**Table 3.142** Fatty acid composition (wt%) of ucuhuba (Culp *et al.*, 1965)

| 10:0 | 12:0 | 14:0 | 16:0 | 18:0 | 18:1 | 18:2 |
|------|------|------|------|------|------|------|
| 0.5  | 13   | 68.5 | 7    | 1    | 8    | 2    |

**Table 3.143** Characteristics of ucuhuba

|                                  | Crude fat          | Resin-free fat |
|----------------------------------|--------------------|----------------|
| Relative density, $d_{15}^{100}$ | 0.8715             |                |
| Refractive index, $n_D^{25}$     | 1.4525             | 1.4502         |
| Saponification value             | 221                | 229            |
| Iodine value                     | 17.0               | 12.3           |
| Unsaponifiable matter (%)        | 1–3                |                |
| Acid value                       | 26.5               | 20.7           |
| Oil content of seed (%)          | 65–76 <sup>a</sup> |                |

<sup>a</sup> Including resins.**Table 3.144** Fatty acid composition (wt%) of vernonia oil

|                         | 14:0 | 16:0 | 18:0 | 18:1 | 18:2  | 18:3 | V <sup>a</sup> | Others |
|-------------------------|------|------|------|------|-------|------|----------------|--------|
| <i>V. anthelmintica</i> | tr   | 2    | 1    | 2    | 9     | 0.5  | 79.5           | 6      |
| <i>V. roxburghii</i>    | tr   | 3.0  | 3.5  | 4.5  | 13.5  | tr   | 75.2           | 0.3    |
| <i>V. galamensis</i>    | tr   | ~3   | 3–4  | 4–6  | 13–14 | tr   | 72–78          | tr     |

<sup>a</sup> Vernolic (cis-12,13-epoxyoleic) acid.

The major triglycerides found (Culp *et al.*, 1965) were laurodimyristin (31%), trimyristin (43%), lauromyristopalmitin (10%) and lauromyristoolein (12%).

### 3.3.41 Vernonia oil

[*Vernonia anthelmintica*, Indian iron weed, purple fleabane; Compositae]

World production of this oil is non-commercialized. Other data are shown in Tables 3.144 and 3.145.

The extracted oil is viscous and green. The oil is of interest because of the unusually high level of cis-12,13-epoxy-cis-9-octadecanoic acid (vernolic acid), the first of this type to be discovered (Gunstone, 1954). Epoxyoleic acids have also been identified in okra (*Hibiscus esculentis*) and in several species of Malvaceae. Oils of this type have been viewed with fresh interest as a natural source of epoxy fatty acids for industrial use (see sections 1.9 and 3.2.9).

**Table 3.145** Characteristics of vernonia oil

|                                 |               |
|---------------------------------|---------------|
| Relative density, $d_{25}^{25}$ | 0.905–0.973   |
| Refractive index, $n_D^{25}$    | 1.4742–1.4860 |
| Saponification value            | 165–210       |
| Iodine value                    | 103.7–107.5   |
| Unsaponifiable matter (%)       | 6.7           |
| Optical rotation, 25 °C         | +2.5          |
| $[\alpha]_D^{25}$               | +18.4         |
| Oil content of seed (%)         | 24            |

Other species of *Vernonia* have been studied (Osman and Ahmad, 1981; Carlson *et al.*, 1981), and *V. roxburghii* (75.2% epoxy content) and *V. galamensis* (72–78% vernolic acid) have been proposed as being more commercially attractive than *V. anthelmintica* as sources of epoxy acids. *V. galamensis* seed oil has been studied in some detail (Carlson *et al.*, 1981). High enzymic activity was noted in many seeds and the enzyme has to be inactivated before the oil is extracted. Encouraging results were obtained when the oil was evaluated as an epoxy coating.

Detailed compositions of fatty acid and sterols have been determined (Ologunde *et al.*, 1992).

### 3.3.42 Wheat germ oil

[*Triticum aestivum*; Graminae]

World production: commercial information on oil is not readily available. Other information is shown in Tables 3.146 to 3.148.

Wheat is a monocotyledon. The grain consists of a starchy endosperm surrounded by a protective layer of bran. The germ is located at the proximal end of the grain. The bran and germ are separated from the endosperm in the production of white flour. The germ is isolated by suitable mechanical processing and is stabilized against rancidity by wet or dry heat treatment to inactivate lipases and lipoxygenases.

Wheat germ typically contains 10% fat (Al-Saleh *et al.*, 1986). Commercial oil is produced by expelling

**Table 3.146** Fatty acid composition (wt%) of wheat germ oil (Barnes and Taylor, 1980)

|                       | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 |
|-----------------------|------|------|------|------|------|
| Pressure expelled (1) | 13.7 | 1.5  | 21.8 | 57.9 | 5.1  |
| Pressure expelled (2) | 12.3 | 2.0  | 19.3 | 61.2 | 5.2  |
| Solvent extracted     | 7.1  | 4.1  | 22.7 | 66.1 | tr   |

**Table 3.147** Characteristics of wheat germ oil

|                                 |             |
|---------------------------------|-------------|
| Relative density, $d_{25}^{25}$ | 0.900–0.933 |
| Refractive index, $n_D^{20}$    | 1.470–1.480 |
| Saponification value            | 184–185     |
| Iodine value                    | 120–130     |
| Unsaponifiable matter (%)       | 2–6         |
| Free fatty acid (%)             | 2.6–6.0     |

under pressure. Solvent extraction is reported to produce oils with higher iodine values and lower free fatty acid. The oil resembles corn oil and there is increasing interest in its use as a health food because of its high content of vitamin E (Kahlon, 1989).

The lipids of wheat germ and wheat germ oil have been reviewed (Barnes, 1982). The sterols, methylsterols and triterpene alcohols are reported in Tables 3.163–3.166. The oil contains unusually high levels of tocopherols (Table 3.148).

Recent work shows that the tocotrienols are not present in the germ. Pericarp/aleurone fractions contain predominantly  $\beta$ -T<sub>3</sub> and  $\alpha$ -T<sub>3</sub>. The endosperm contains  $\beta$ -T<sub>3</sub> (Barnes and Taylor, 1980).

Other minor components include squalene and a range of n-, iso- and anteiso-hydrocarbons. Ferulic and vanillic acids have been extracted from wheat germ, and esters of ferulic acid with dihydro- $\gamma$ -sitosterol have been detected in the oil.

Both wheat germ and corn oil contain higher levels of gramisterol than other oils. These two oils may be distinguished from each other by means of the higher  $\beta$ -amyryn content in wheat germ oil (Kornfeldt and Croon, 1981).

Detailed compositions of the phospholipids have not been published.

### 3.3.43 Unclassified oils of interest and new oil seed crops

It is widely accepted that in many parts of the developed world there is a surplus of most traditional crops and consequently there is a search for new crops and for break crops. Unless a new vegetable oil has some specific property (like the oils containing  $\gamma$ -linolenic acid), it will have to compete with existing supplies of oils available at bulk prices. This exerts several constraints:

1. The new crops should be easily cultivated, harvested, processed and marketed. Even when these requirements are met, additional costs may result from the need to have separate and distinct harvesting, processing and marketing facilities.
2. The new crop must quickly become available in good and reliable yields, at appropriate volumes, and at acceptable prices.
3. The demand for and interest in new crops may come more from the oleochemical industry than from the food industry, though, traditionally, the oleochemical industry has used lower-grade and cheaper oils than the food industry.
4. The demand must be market-led (or at least market-maintained after the first few years), and there is an interest in new crops that produce high concentrations of a single acid such as lauric, oleic, erucic, petroselinic, or acids with hydroxy or epoxy groups.
5. Whilst agronomists must help to produce oils meeting these requirements, chemists and technologists must assist in the substitution of existing oils by new oils and in the development of new uses for new oils.

**Table 3.148** Tocopherols in wheat germ oil (mg/kg) (Barnes, 1982)

|                          | $\alpha$ -T | $\beta$ -T | $\gamma$ -T | $\delta$ -T | $\alpha$ -T <sub>3</sub> | $\beta$ -T <sub>3</sub> |
|--------------------------|-------------|------------|-------------|-------------|--------------------------|-------------------------|
| Laboratory extracted (1) | 2238        | 803        | 44          | —           | —                        | 80                      |
| (2)                      | 1088        | 292        | 25          | —           | 63                       | 323                     |
| Commercial (1)           | 1845        | 739        | 213         | —           | —                        | —                       |
| (2)                      | 984         | 386        | 681         | 105         | —                        | —                       |

## Occurrence and characteristics

New crops or existing crops with changed fatty acid composition can be obtained by domestication of wild plants (e.g. *Cuphea*) or by the modification of existing crops either by the traditional methods of plant breeders (e.g. Canola, low-erucic rape, or Linola, low-linolenic linseed; see sections 3.3.27 and 3.3.19, respectively) or by the application of gene splitting techniques (e.g. production of a lauric oil from rapeseed).

### (a) Lauric oils

Glycerides rich in lauric and other medium-chain fatty acids are used extensively both in the food industry and in the production of surfactants, usually in the form of derivatives of the  $C_{12}$  alcohol. Whilst the availability of palmkernel oil should rise along with increasing supplies of palm oil, the supply and price of coconut oil has been sufficiently uneven in recent years to arouse interest in other ways of providing lauric acid. Three approaches have been tried: the domestication of *Cuphea* species (section 3.3.12); the production of petroselinic acid-containing oils, which can be oxidized to adipic and lauric acids (see section 3.3.43(c) below); and the application of gene-splitting techniques to rape to make it produce an oil rich in medium-chain acids.

### (b) Oleic oils

Oleic acid is a very important source material for the oleochemical industry. It is usually obtained from tall oil (about 45%, section 3.3.36), palm oil (about 40%, section 3.3.24), or tallow (about 50%, section 3.4.2). These are cheap sources, but the oleic acid level is not very high and the proportion of oleic acid has to be increased by some fractionation process. Richer sources of oleic acid include rapeseed oil (56%, section 3.3.27), macadamia oil (56%, and 22% of 16:1), almond oil (61%), high-oleic safflower oil (74%, section 3.3.29), olive oil (78%, section 3.3.23), *Jessenia* palm (78%), high-oleic sunflower oil (sun oil, 82%, section 3.3.35) and *Euphorbia lathyris* seed oil (84%). Of these, almond and rape also contain significant amounts of linoleic acid (25–30%), which is undesirable in a source of oleic acid for non-food use.

*E. lathyris* (caper spurge) is a Mediterranean annual containing about 50% oil in its seed and 80–90% of oleic acid in the oil. At present it suffers from a number of deficiencies, especially seed shattering and the presence of a co-carcinogenic milky sap, but it is hoped to get rid of these problems by plant breeding.

Attempts are also being made to raise the level of oleic acid in rapeseed oil to around 80%.

### (c) Oils containing petroselinic acid

Seed oils of the Umbelliferae are characterized by the presence of petroselinic acid, often at high levels. Oil content is frequently in the range of 30–60% with petroselinic acid at the 50–90% level. Many plants from this family are already cultivated for other purposes, so it should be possible to develop strains optimized for oil yield and petroselinic acid level. This acid melts at 33°C in contrast to its common isomer (oleic acid, 12°C). It is also less soluble in organic solvents and the two acids can be separated by crystallization. It can be oxidized to adipic and lauric acids and may have useful properties for cosmetic and pharmaceutical applications. Attempts are being made in Europe to develop coriander (80% petroselinic acid) into a useful oil crop.

### (d) Oils containing higher monoene acids ( $C_{20}$ – $C_{24}$ )

Erucic acid, available in industrial rapeseed oil (high-erucic rapeseed, HEAR), is used extensively in the form of its amide as an antiblock and slip-promoting agent for polyolefins. It can also serve as a source of tridecanedioic acid for the production of nylon-13,13. Attempts are being made to raise the level of erucic acid to about 70%. Other potential sources of erucic acid include *Crambe* (section 3.3.12), honesty (containing 22:1 43% and 24:1 25%), nasturtium (20:1 25% and 22:1 65%) and mustard (section 3.3.21).

Another source of higher monoene compounds is jojoba oil, which has already been developed as a marketable but low-level commodity. It is produced by a drought-tolerant plant that withstands desert heat. This takes 3–5 years to harvest first, 10–17 years to full yield and has a lifespan of around 100 years. It is grown in south-west USA and Mexico mainly, but also in Latin America, Israel, South Africa and Australia. Yields are reported to be 1 tonne of oil/acre.

Jojoba oil is not a typical triacylglycerol but a mixture of wax esters containing mainly 20:1 and 22:1 acids and alcohols. It is thus a mixture of  $C_{40}$ ,  $C_{42}$  and  $C_{44}$  esters with two isolated double bonds. The oil is a replacement for sperm whale oil, which is now prohibited in most countries because the sperm whale is an endangered species. At present it is a high-priced oil used mainly in cosmetics, but it has good lubricating properties and could be used extensively for that purpose if available in sufficient quantity at an appropriate price. The oil is fairly pure as extracted, has a light colour and, since the double bonds are well separated, it is resistant to oxidation.

The oil can be chemically modified by reaction (hydrogenation, stereomutation, epoxidation, sulphochlorination) of the double bonds in both the acid and alcohol portions of the esters.

Meadowfoam oil (*Limnanthes alba*) is another oil rich in  $C_{20}$  and  $C_{22}$  acids. It comes from a herbaceous annual grown in the Pacific coastal regions of North America. More than 95% of its component acids are  $C_{20}$  or  $C_{22}$  and include 5c-20:1 (63%), 5c-22:1 (12%), 13c-22:1 (3%) and 5c,13c-22:2 (18%). The double bond is mainly  $\Delta 5$ , which is an unusual position. The oil remains clear at refrigerator temperature and is fairly stable to oxidation. Potential uses of the oil include conversion to a liquid wax, hydrogenation to a solid ester, use of the isopropyl ester as a cosmetic, use of its glycerol (mono)ester and propylene glycol esters as surface-active compounds, vulcanization to a factice (i.e. a rubber substitute generated by reaction with sulphur), and conversion to amide and dimer acid.

#### (e) Oils containing $C_{18}$ polyene acids

New interest in linseed oil and in a new low-linolenic variety of this oil (Linola) is discussed in section 3.3.19.

A potential new crop is calendula oil (marigold), which contains about 55% of calendic acid (8t,10t,12c-18:3). This oil with its conjugated triene acid will be a drying oil like tung oil but is being used for cosmetic purposes.

There is a small but growing and thriving industry based on oils containing  $\gamma$ -linolenic acid (6c,9c,12c-18:3). This  $n-6$  acid is an isomer of  $\alpha$ -linolenic acid and an intermediate in the important bioconversion of linoleic acid to arachidonic. Claims have been made that oils containing this acid are beneficial in the treatment of diseases such as multiple sclerosis, arthritis, atopic eczema and premenstrual tension (section 11.1). This acid is present in a number of seed oils, but commercial exploitation is restricted to evening primrose oil (8–12%, section 3.3.13), borage (19–25%) and blackcurrant (15–19%).  $\gamma$ -Linolenic acid also occurs in a number of microbiological lipids, and products have been developed in Japan and in Britain (oil of javanicus, about 18%) (Gunstone, 1992; Horrobin, 1992).

#### (f) Oils containing epoxy acids

The use of epoxidized soybean oil as a stabilizer-plasticizer for PVC provides a basis for the interest in natural epoxy acids, of which the best-known is vernolic acid (12,13-epoxyoleic, section 3.2.41). The

acid occurs at high levels in the seed oils of *Vernonia galamensis* (73–78%), *Euphorbia lagascae* (62%) and *Stokes aster* (65–79%), and attempts are being made to make the first two into commercial crops. In addition to the possibility of epoxidizing them further, they can also be used as a source of  $C_9$  and  $C_{12}$  dibasic acids.

#### (g) Oils containing hydroxy acids

*Lesquerella fendleri* produces 25% of oil in its seed and this contains 55% of lesquerolic acid (14-OH 11c-20:1), the bishomologue of the ricinoleic acid present in castor oil (section 3.3.5). These two hydroxy acids should have similar physical properties but they will give different products on pyrolysis (undecenoic and tridecenoic acids from the  $C_{18}$  and  $C_{20}$  acids, respectively) and on alkali fusion (sebacic and dodecanedioic acids).

Dimorphotheca oil contains dimorphecolic acid (9-OH 10,12-18:2). This hydroxy conjugated diene acid can easily be dehydrated to a conjugated triene.

#### (h) Other unusual acids

Still other examples are known of seed oils rich in a single acid of unusual structure. For example, *Picramnia* species contain the acetylenic acid tariric (6a-18:2) in their seed oils up to 90% level, and *Santalum album* (the sandalwood tree) contains over 90% of santalbic (ximenynic) acid (9a,11t-18:2) in its seed oil. There is no report that these are being developed for commercial purposes.

#### (i) Specialty (exotic, gourmet) oils

Specialty oils (also described as exotic or gourmet oils) are available in Europe and in the USA. They include low-volume oils such as almond, apricot, avocado, grapeseed (section 3.3.14), hazelnut, macadamia, mustard (section 3.3.21), pecan, passionflower, pistachio, pumpkin, sesame (section 3.3.31), walnut and wheat germ (section 3.3.42) in addition to some of the bulk oils such as coconut, corn, cottonseed, olive, groundnut, palmkernel, rape, safflower, soya and sunflower (Hancock and Houghton, 1990).

These are sold as food oils, in some cases on account of their distinctive flavour, and are also used in toiletries, cosmetics and pharmaceuticals. Careful sourcing of seeds or nuts is necessary to obtain products of the highest quality. The oil must then

be extracted under appropriate conditions (cold-pressed, hot-pressed, solvent-extracted) and refined (if desired) using stainless-steel equipment and nitrogen blanketing. In order to achieve low or zero levels of pesticides, it may be necessary to grow the seeds or nuts under organic farming conditions.

The fatty acid compositions of these newer oils are given in Tables 3.150–3.153. These data include the compositions of a range of tree nuts, fruit pulp, fruit seeds and kernels, many of which have not been commercialized as a source of oil.

Some of these oils are also available after chromatographic purification carried out on a multi-kilogram scale. This removes impurities more and less polar than the triacylglycerols to give products that are >99% triacylglycerols.

#### (j) Crops of potential interest from India

A significant research effort has been devoted in India to the study and development of indigenous oil seed crops. These include sal, mowrah, mango, kokum, neem, pisa and a host of others. A number of these crops have been commercialized to varying degrees depending on ease of collecting the seed and the ability to convert the extracted oil into a suitable material for either soap-making or edible purposes. A detailed description of the major oils of interest has been written (Bringi, 1987).

The compositions of some typical Indian oils are

given in Tables 3.149 and 3.154 (mango) and Table 3.155 (others).

#### (k) Oats and lupin

The relevance of oats in the diet has been highlighted. The fatty acid compositions of 12 strains are given in Table 3.156 (Sahasrabudhe, 1979).

Various varieties of lupin are being considered as a source of protein. The seeds contain approx. 10% oil. See Table 3.156 for fatty acid composition of *Lupinus polyphyllus* (Anizewski, 1993; Feldheim, 1991).

**Table 3.149** Fatty acid composition in triglyceride (TG) fraction of mango fat (mol%)<sup>a</sup> (Ali *et al.*, 1985)

| Variety     | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 |
|-------------|------|------|------|------|------|------|
| Brindaboni  | 9.2  | 39.1 | 41.1 | 7.6  | 0.7  | 2.3  |
| Fazli       | 8.4  | 39.4 | 42.5 | 7.3  | 0.7  | 1.7  |
| Kalabau     | 8.1  | 40.2 | 41.5 | 7.3  | 0.6  | 2.2  |
| Kanchamitha | 9.1  | 38.2 | 43.0 | 6.3  | 0.9  | 2.5  |
| Kuipahari   | 10.0 | 38.3 | 41.3 | 7.1  | 0.9  | 2.5  |
| Lakhanvoge  | 9.7  | 38.3 | 41.7 | 6.9  | 0.7  | 2.6  |
| Lengra      | 8.5  | 39.3 | 42.4 | 6.8  | 0.7  | 2.2  |
| Mohanvoge   | 9.0  | 38.6 | 41.4 | 7.6  | 0.9  | 2.4  |
| Misrakanta  | 7.9  | 39.2 | 43.8 | 6.0  | 1.0  | 2.0  |
| Ranipasand  | 7.9  | 39.9 | 42.0 | 7.4  | 0.6  | 2.2  |

<sup>a</sup> Mean results of three experiments.

Table 3.150 Fatty acid composition (%)<sup>a</sup> of fruit pulp fatty acids (Kamel and Kakuda, 1992)

| Common name          | Scientific name             | Lipid (%) | 14:0 | 16:0 | 16:1 | 18:0 | 18:1 | 18:2 | 18:3 | Sat. | Unsat. |
|----------------------|-----------------------------|-----------|------|------|------|------|------|------|------|------|--------|
| Apple <sup>b</sup>   | <i>Malus sylvestris</i>     | 0.4       | 1.2  | 26.7 | 0.6  | 3.9  | 7.9  | 48.9 | 10.1 | 32.4 | 67.5   |
| Apricot              | <i>Prunus armeniaca</i>     | 0.4       | —    | 8.8  | —    | 1.1  | 62.0 | 28.1 | —    | 9.9  | 90.1   |
| Avocado              | <i>Persea americana</i>     | 6.5–25.5  | —    | 9.0  | 1.8  | 0.5  | 77.7 | 8.5  | 0.9  | 9.5  | 88.9   |
| Banana               | <i>Musa paradisiaca</i>     | 0.2       | —    | 41.9 | 2.1  | 3.8  | 14.4 | 16.1 | 21.7 | 45.7 | 54.3   |
| Blueberry            | <i>Vaccinium corymbosum</i> | 0.43–0.55 | 2.1  | 7.38 | —    | 2.8  | 24.0 | 38.7 | 27.1 | 12.2 | 89.8   |
| Cherry (sour)        | <i>Prunus cerasus</i>       | 0.3       | 0.8  | 20.0 | 0.4  | 6.7  | 33.8 | 19.2 | 18.3 | 27.5 | 71.7   |
| Cherry (sweet)       | <i>Prunus avium</i>         | 1.0       | 0.7  | 19.8 | 0.4  | 6.8  | 33.8 | 19.2 | 18.5 | 27.3 | 71.9   |
| Chironji fruit       | <i>Buchanania lanzan</i>    | —         | —    | 34.4 | —    | 2.0  | 62.3 | 1.2  | 0.2  | 36.4 | 63.7   |
| Currant              | <i>Ribes nigrum</i>         | 0.4       | —    | 7.4  | 0.4  | 2.6  | 20.7 | 39.5 | 26.6 | 10.0 | 87.2   |
| Durian               | <i>Durio zibethinus</i>     | 4–5       | 0.5  | 39.8 | 8.5  | 0.8  | 45.8 | 1.8  | 2.7  | 41.1 | 58.8   |
| Fig                  | <i>Citrus ficus carica</i>  | 0.3       | 0.8  | 17.0 | —    | 4.4  | 24.4 | 53.3 | —    | 22.2 | 77.7   |
| Gooseberry           | <i>Ribes spp.</i>           | 0.6       | —    | 4.7  | —    | 3.2  | 12.6 | 66.7 | 11.3 | 7.9  | 90.6   |
| Grapefruit           | <i>Citrus paradisi</i>      | 0.1       | —    | 23.5 | 2.0  | 1.9  | 23.5 | 37.3 | 9.8  | 25.4 | 72.6   |
| Grape                | <i>Vitis vinifera</i>       | 0.6       | 3.4  | 42.5 | —    | 5.8  | 6.0  | 34.1 | 10.2 | 51.7 | 50.3   |
| Guava                | <i>Psidium guajava</i>      | 0.6       | 2.5  | 30   | 0.6  | 3.3  | 10.8 | 37.9 | 14.8 | 35.8 | 64.1   |
| Lemon                | <i>Citrus limon</i>         | 0.3       | 0.7  | 25.2 | 0.7  | 1.4  | 7.2  | 45.3 | 18.7 | 27.3 | 71.9   |
| Loquats <sup>c</sup> | <i>Eriobotrya japonica</i>  | 0.2       | 0.7  | 23.0 | —    | 2.8  | 5.7  | 55.4 | 9.3  | 27.2 | 70.4   |
| Mango                | <i>Mangifera indica</i>     | 0.1–0.4   | 2.4  | 23.6 | 27.4 | 1.3  | 26.4 | 1.8  | 16.7 | 27.3 | 72.3   |
| Nabk <sup>d</sup>    | <i>Zizyphus jujuba</i>      | 4         | —    | 11.3 | 1.1  | 6.7  | 53.8 | 20.6 | —    | 19.9 | 79.1   |
| Olive <sup>e</sup>   | <i>Olea europea</i>         | 35–70     | —    | 12.0 | 0.4  | 4.0  | 72.0 | 10.0 | 0.5  | 16.4 | 83.0   |
| Orange               | <i>Citrus sinensis</i>      | 0.3       | —    | 20.6 | 4.7  | —    | 31.7 | 28.6 | 11.1 | 20.6 | 76.1   |
| Papaya <sup>f</sup>  | <i>Carica papaya</i>        | 0.14      | 6.3  | 28.6 | 17.8 | 1.8  | 16.1 | 5.3  | 22.3 | 37.6 | 61.5   |
| Peach                | <i>Prunus persica</i>       | 0.9       | —    | 10.1 | 1.1  | 1.1  | 38.0 | 49.4 | 1.1  | 11.2 | 89.6   |
| Pear <sup>g</sup>    | <i>Pyrus communis</i>       | 0.4       | —    | 8.5  | 1.0  | 1.5  | 40.5 | 46.5 | 0.5  | 10.0 | 89.0   |
| Pineapple            | <i>Ananas comosus</i>       | 0.43      | —    | 8.4  | 1.3  | 4.8  | 19.9 | 37.2 | 27.4 | 13.2 | 85.8   |
| Plum                 | <i>Prunus spp.</i>          | 0.62      | —    | 7.0  | 0.84 | 1.5  | 67.9 | 22.7 | —    | 8.5  | 91.4   |
| Quince <sup>h</sup>  | <i>Cydonia oblonga</i>      | 0.1       | —    | 7.29 | —    | 2.1  | 37.5 | 51.1 | —    | 9.4  | 89.6   |
| Raspberry            | <i>Rubus spp.</i>           | 0.55      | —    | 3.4  | —    | 0.8  | 12.7 | 54.0 | 27.3 | 4.2  | 94.0   |
| Strawberry           | <i>Fragaria xananassa</i>   | 0.37      | —    | 5.4  | 0.4  | 1.5  | 19.8 | 41.9 | 30.2 | 6.9  | 92.3   |
| Tangerine            | <i>Citrus reticulata</i>    | 0.2       | 1.1  | 21.5 | 4.4  | 1.1  | 32.3 | 29.0 | 10.7 | 23.7 | 76.4   |
| Tamarind             | <i>Tamarindus indica</i>    | 0.6       | 1.3  | 32.8 | —    | 11.7 | 35.3 | 11.5 | —    | 45.8 | 46.8   |

<sup>a</sup> For references, see original publication.<sup>b</sup> 0.6% 12:0; <sup>c</sup> 0.7% 12:0; <sup>d</sup> 1.9% 20:0, 1.1% 20:1, 1.4% 20:2, 1.1% 20:4; <sup>e</sup> 0.4% 20:0, 0.2% 20:1; <sup>f</sup> 0.9% 12:0; <sup>g</sup> 0.5% 20:1; <sup>h</sup> 1.0% 20:1.

Table 3.151 Fatty acid composition of oils from tree nuts<sup>a</sup> (Beuchat and Worthington, 1978)

| Common name      | Botanical name                            | Oil (%) | Fatty acid (wt%) |      |      |      |      |      |      |      |      |      |      |        |
|------------------|-------------------------------------------|---------|------------------|------|------|------|------|------|------|------|------|------|------|--------|
|                  |                                           |         | 16:0             | 16:1 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 22:0 | 22:1 | 24:0 | Others |
| Almond           | <i>Prunus amygdalus</i>                   | 52.7    | 6.7              | 0.5  | 1.2  | 66.3 | 22.3 | tr   | tr   | tr   | tr   | —    | —    | 3.0    |
| Butternut        | <i>Juglans cinerea</i>                    | 60.0    | 1.6              | tr   | 0.8  | 19.0 | 61.9 | 16.0 | —    | —    | —    | —    | —    | 0.7    |
| Brazil           | <i>Bertholletia myriaceae</i>             | 68.7    | 14.1             | 0.3  | 8.6  | 29.0 | 46.6 | tr   | 0.3  | tr   | tr   | —    | —    | 1.1    |
| Cashew           | <i>Anacardium occidentale</i>             | 47.7    | 10.2             | 0.4  | 8.5  | 60.9 | 18.3 | —    | 0.8  | tr   | tr   | —    | —    | 0.9    |
| Chestnut         | <i>Castanea mollissima</i>                | 2.5     | 14.6             | 0.7  | 1.1  | 54.0 | 24.9 | 2.7  | —    | 1.0  | 0.2  | —    | —    | 0.8    |
| Filbert/hazelnut | <i>Corylus avellana</i>                   | 62.3    | 4.7              | 0.2  | 1.6  | 76.4 | 16.3 | 0.1  | 0.1  | 0.2  | —    | —    | —    | 0.4    |
| Hickory          | <i>Carya ovata ovata</i>                  | 70.4    | 8.8              | 0.5  | 2.3  | 52.0 | 33.5 | 1.7  | 0.2  | tr   | —    | —    | —    | 1.0    |
| Macadamia        | <i>Macadamia tetraphylla</i> <sup>b</sup> | 73.2    | 8.3              | 21.8 | 2.1  | 56.4 | 2.8  | —    | 2.4  | 3.1  | 0.8  | 0.3  | 0.5  | 1.3    |
| Pecan            | <i>Carya illinoensis</i>                  | 70.3    | 5.7              | 0.1  | 2.2  | 66.9 | 22.1 | 1.1  | 0.2  | 0.4  | —    | —    | —    | 1.3    |
| Pignolia         | <i>Pinus</i> sp.                          | 48.1    | 5.8              | 0.2  | 3.8  | 38.1 | 46.4 | 0.8  | 0.7  | 0.9  | —    | —    | —    | 3.3    |
| Pistachio        | <i>Pistachia vera</i>                     | 57.0    | 8.6              | 0.7  | 2.3  | 68.8 | 17.8 | 0.3  | 0.3  | 0.6  | tr   | —    | —    | 0.6    |
| Walnut, black    | <i>Juglans nigra</i>                      | 59.0    | 3.1              | tr   | 2.6  | 29.1 | 58.3 | 4.9  | tr   | tr   | tr   | —    | tr   | 2.0    |
| Walnut, English  | <i>Juglans regia</i>                      | 67.4    | 7.3              | 0.2  | 2.3  | 19.1 | 57.4 | 13.1 | tr   | —    | —    | —    | —    | 0.6    |

<sup>a</sup> All fats contained tr (trace) of 17:0.<sup>b</sup> 0.1% 17:1.

Table 3.152 Fatty acid content (%) of fruit seeds and kernels<sup>a</sup> (Kamel and Kakuda, 1992)

| Common name                  | Scientific name                | Lipid (%)       | 8:0 | 10:0 | 12:0 | 14:0 | 16:0 | 16:1 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 22:0 | 24:0 | Sat. | Unsat. |
|------------------------------|--------------------------------|-----------------|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|--------|
| Apple seed                   | <i>Malus sylvestris</i>        | 25.7            | -   | -    | -    | -    | 9.0  | -    | 2.3  | 41.3 | 45.6 | 0.7  | 1.1  | -    | -    | 12.4 | 87.6   |
| Apricot kernel               | <i>Prunus armeniaca</i>        | 49.50           | -   | -    | -    | -    | 4.8  | 0.42 | 0.23 | 69.2 | 25.4 | -    | -    | -    | -    | 5.0  | 95.0   |
| Avocado seed                 | <i>Persea americana</i>        | 1-1.5           | -   | -    | -    | 0.8  | 22   | 3.2  | 0.8  | 25   | 41.5 | 4.5  | tr   | tr   | -    | 23.6 | 74.2   |
| Cantaloupe seed              | <i>Cucumis melo</i>            | 36 <sup>m</sup> | -   | -    | -    | 34   | 27.4 | -    | 6.4  | 12.9 | 17.7 | 1.6  | -    | -    | -    | 67.8 | 32.2   |
|                              |                                | 34 <sup>n</sup> | -   | -    | -    | -    | 26.7 | -    | 6.7  | 16.7 | 46.6 | 3.3  | -    | -    | -    | 33.4 | 66.6   |
| Cherry kernel                | <i>Prunus avium</i>            | 30-38           | -   | -    | -    | -    | 7.7  | -    | 2.4  | 60.8 | 30.8 | tr   | -    | -    | -    | 10.0 | 91.6   |
| Coffee seed <sup>b</sup>     | <i>Coffea arabica</i>          | 11.8            | -   | -    | -    | 2.0  | 28.8 | -    | 4.5  | 18.9 | 44.0 | -    | 1.6  | -    | -    | 36.9 | 62.9   |
| Currant seed                 | <i>Ribes nigrum</i>            | 30.5            | -   | -    | -    | -    | 6.4  | -    | 1.3  | 10.3 | 46.5 | 13.6 | -    | -    | -    | 7.7  | 92.3   |
| (black) <sup>c</sup>         |                                |                 |     |      |      |      |      |      |      |      |      |      |      |      |      |      |        |
| Currant seed                 | <i>Ribes rubrum</i>            | 25.2            | -   | -    | -    | -    | 4.5  | -    | 1.5  | 15   | 42   | 29   | -    | -    | -    | 6.0  | 95     |
| (red) <sup>d</sup>           |                                |                 |     |      |      |      |      |      |      |      |      |      |      |      |      |      |        |
| Date seed                    | <i>Phoenix dactylifera</i>     | 10.4            | -   | 2.8  | 17.3 | 11.4 | 10.3 | 0.17 | 2.8  | 44.2 | 8.4  | 0.6  | 0.6  | 0.3  | 0.2  | 45.8 | 53.4   |
| Durian seed <sup>e</sup>     | <i>Durio zibethinus</i>        | 0.5             | -   | -    | -    | 0.12 | 12.2 | 1.1  | 1.4  | 8.4  | 6.5  | 11.3 | -    | 1.2  | -    | 14.9 | 81.5   |
| Egusi seed                   | <i>Colocynthis citrullus</i>   | 52              | -   | -    | -    | 0.02 | 10.4 | 0.14 | 9.8  | 15.9 | 62.8 | 0.41 | -    | -    | -    | 22.4 | 77.6   |
| Fig seed                     | <i>Ficus carica</i>            | 30              | -   | -    | -    | -    | 7.2  | -    | 2.6  | 14.9 | 30.6 | 44.7 | -    | -    | -    | 9.8  | 90.2   |
| Gooseberry seed <sup>f</sup> | <i>Ribes uva crista</i>        | 18.3            | -   | -    | -    | -    | 7    | -    | 1    | 17   | 40   | 19.5 | -    | -    | -    | 8.0  | 92     |
| Grape seed                   | <i>Vitis vinifera</i>          | 13-18.4         | -   | -    | -    | 0.05 | 7.0  | -    | 3.9  | 15.6 | 72.2 | 0.24 | -    | -    | -    | 10.9 | 88.1   |
| Grapefruit seed              | <i>Citrus paradisi</i>         | 41.4            | 8.4 | -    | -    | -    | 42.6 | -    | 0.83 | 12.2 | 34.5 | 1.5  | -    | -    | -    | 51.8 | 48.2   |
| Guava seed                   | <i>Psidium guajava</i> L.      | 10.1            | -   | -    | -    | 1.2  | 8.9  | -    | 4.8  | 53.9 | 29.2 | 1.1  | -    | -    | -    | 14.9 | 84.2   |
| Jack fruit <sup>g</sup>      | <i>Artocarpus integrifolia</i> | 6.1             | -   | -    | -    | 3.3  | 30.2 | -    | 3.3  | 6.4  | 40.2 | 9.4  | -    | -    | -    | 38.8 | 63.2   |
| Lime seed                    | <i>Citrus aurantifolia</i>     | 42.7            | 0.8 | -    | 0.99 | -    | 19.1 | 0.28 | 0.84 | 17.1 | 18.0 | 42.3 | -    | -    | -    | 21   | 78.5   |
| Mandarin seed <sup>h</sup>   | <i>Citrus reticulata</i>       | 40.2            | 3.1 | 4.5  | 4.4  | 4.9  | 25.7 | 2.9  | 11.1 | 23.9 | 19.2 | -    | -    | -    | -    | 53.7 | 46.0   |
| Mango kernel                 | <i>Mangifera indica</i>        | 6-12            | -   | -    | -    | -    | 9.2  | -    | 39.1 | 41.1 | 7.6  | 0.7  | 2.3  | -    | -    | 50.6 | 49.4   |
| Melon seed <sup>i</sup>      | <i>Citullus vulgaris</i>       | 23.1            | -   | -    | -    | 0.55 | 12.2 | 0.13 | 11.2 | 11.1 | 54.7 | 0.18 | -    | -    | -    | 23.9 | 66.1   |
| Melon seed <sup>j</sup>      | <i>Colocynthis vulgaris</i>    | -               | -   | -    | -    | 1.5  | 20   | 0.3  | 7.1  | 21.6 | 24.5 | 15.9 | -    | -    | -    | 28.6 | 67.4   |
| Orange seed <sup>k</sup>     | <i>Citrus sinensis</i>         | 45.5            | -   | 5.4  | -    | -    | 28.8 | 0.65 | 2.6  | 23.7 | 30.9 | 6.5  | -    | -    | -    | 36.8 | 61.7   |
| Papaya kernel                | <i>Carica papaya</i>           | 50.1            | -   | -    | -    | 0.2  | 17.2 | 1.3  | 3.6  | 77.3 | 0.4  | -    | -    | -    | -    | 21.0 | 79.0   |
| Passion fruit                | <i>Passiflora edulis</i> f.    | 20              | -   | -    | -    | -    | 8    | -    | 2.2  | 12.6 | 77.2 | -    | -    | -    | -    | 10.2 | 89.8   |
| Peach kernel                 | <i>Prunus persica</i>          | 45.1-54.5       | -   | -    | -    | 0.88 | 13.4 | 0.16 | 6.4  | 63.8 | 15.4 | tr   | -    | -    | -    | 20.7 | 79.3   |
| Prune kernel                 | <i>Prunus domestica</i>        | 28.6            | -   | -    | -    | -    | 8.0  | -    | 1.7  | 61.2 | 29.1 | -    | -    | -    | -    | 9.7  | 90.3   |
| Pumpkin seed                 | <i>Cucurbita mixta</i>         | 36              | -   | -    | -    | tr   | 16.4 | -    | 7.7  | 33.8 | 42.0 | -    | -    | -    | -    | 24.7 | 75.8   |
| Soursop seed                 | <i>Annona muricata</i>         | 24              | -   | -    | -    | 0.34 | 17.0 | -    | 5.8  | 61.0 | 12.1 | -    | -    | -    | -    | 23.1 | 73.1   |
| Tamarind seed                | <i>Tamarindus indica</i>       | 7.4             | -   | -    | tr   | tr   | 14.8 | -    | 5.9  | 27.0 | 7.5  | 5.6  | 4.5  | 12.2 | 22.3 | 59.7 | 40.1   |
| (India)                      |                                |                 |     |      |      |      |      |      |      |      |      |      |      |      |      |      |        |
| Tamarind seed                | <i>Tamarindus indica</i> L.    | 6-8             | -   | -    | -    | 0.2  | 17.4 | 0.3  | 6.7  | 19.5 | 42.4 | 0.1  | 2.8  | 4.0  | 5.5  | 36.8 | 63.2   |
| (Madagascar) <sup>k</sup>    |                                |                 |     |      |      |      |      |      |      |      |      |      |      |      |      |      |        |
| Tomato seed <sup>l</sup>     | <i>Lycopersicon esculentum</i> | 22.4            | -   | -    | -    | 0.4  | 14.4 | 0.5  | 3.9  | 21.7 | 54.8 | 3.2  | 0.5  | -    | -    | 19.8 | 80.2   |
|                              | <i>Calodendrum capense</i>     | 60              | -   | -    | -    | -    | 23.6 | -    | 4.5  | 33.7 | 35.6 | 1.4  | -    | -    | -    | 29.1 | 70.7   |

<sup>a</sup> For references, see original publication.<sup>b</sup> 0.2% behenic, 4.5% 18:4.<sup>c</sup> 18.2%  $\gamma$ -18:3.<sup>d</sup> 4%  $\gamma$ -18:3.<sup>e</sup> 15.7% malvalic acid, 38.5% steric acid.<sup>f</sup> 11%  $\gamma$ -18:3.<sup>g</sup> 7.2% ricinoleic acid.<sup>h</sup> 2.4% 15:0, 3.2% 15:1.<sup>i</sup> 5% 21:0.<sup>j</sup> 0.43% 15:1.<sup>k</sup> 0.9% 20:1.<sup>l</sup> 0.6% 17:0.<sup>m</sup> Var. Malti Bahtim, 3.7% 18:4.<sup>n</sup> Var. King Bahtim.

Table 3.153 Fatty acid composition (%) of fruit nuts<sup>a</sup> (Kamel and Kakuda, 1992)

| Common name                  | Scientific name                 | Lipid (%) | 14:0 | 16:0 | 16:1 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | Sat. | Unsat. |
|------------------------------|---------------------------------|-----------|------|------|------|------|------|------|------|------|------|------|--------|
| Acorn                        | <i>Quercus</i> spp.             | 23.8      | -    | 12.5 | -    | 1.1  | 66.2 | 20.1 | -    | -    | -    | 13.6 | 86.3   |
| Almond                       | <i>Prunus amygdalus</i>         | 50-65     | 0.1  | 12.2 | 1.5  | 0.1  | 44.5 | 40.5 | 0.6  | -    | -    | 12.8 | 87.2   |
| Beechnut                     | <i>Sylvatica fagus</i> spp.     | 50        | 0.13 | 7.6  | 0.6  | 2.5  | 40.3 | 39.1 | 3.6  | -    | 5.9  | 10.2 | 89.5   |
| Black walnut                 | <i>Juglan nigra</i>             | 56-59     | -    | 2.8  | -    | 2.8  | 32.7 | 57.6 | 3.9  | -    | -    | 5.6  | 94.2   |
| Brazil                       | <i>Bertholletia myrtaceae</i>   | 68.7      | -    | 14.1 | -    | 0.3  | 8.6  | 29.0 | 46.6 | 0.3  | -    | 22.7 | 76.2   |
| Butternut                    | <i>Juglans cinerea</i>          | 60        | -    | 1.6  | -    | 0.8  | 19.0 | 61.9 | 16.0 | -    | -    | 2.4  | 96.9   |
| Cashew                       | <i>Anacardium occidentale</i>   | 47.7      | -    | 10.4 | 0.6  | 8.4  | 62.6 | 18.1 | -    | -    | -    | 18.7 | 81.2   |
| China chestnuts <sup>b</sup> | <i>Sterculia monosperma</i>     | 3.1       | 0.15 | 23.4 | 1.3  | 2.5  | 24.9 | 18.2 | -    | -    | -    | 26.1 | 74.4   |
| English walnut               | <i>Juglan regia</i>             | 67.4      | -    | 7.3  | 0.2  | 2.3  | 19.1 | 57.4 | 13.1 | -    | -    | 9.6  | 89.8   |
| European chestnuts           | <i>Castanea mollissima</i>      | 2.5       | -    | 14.6 | 0.7  | 1.1  | 54.0 | 24.9 | 2.7  | -    | -    | 15.7 | 82.3   |
| Faveleira nut <sup>c</sup>   | <i>Chidocolus phyllacanthus</i> | 32        | -    | 17.4 | -    | 9.4  | 15.1 | 55.4 | 1.0  | 0.4  | 0.2  | 27.6 | 71.7   |
| Filbert                      | <i>Corylus avellana</i>         | 62.3      | -    | 4.7  | 0.2  | 1.6  | 76.4 | 16.3 | 0.15 | 0.1  | -    | 6.4  | 93.0   |
| Ginkgo                       | <i>Ginkgo biloba</i>            | 1.68      | 0.4  | 19.1 | 5.2  | 1.0  | 33.9 | 38.3 | 1.4  | -    | 0.7  | 20.5 | 79.5   |
| Hickory                      | <i>Carya ovata ovata</i>        | 70.4      | -    | 8.8  | 0.5  | 2.3  | 52.0 | 33.5 | 1.7  | 0.2  | -    | 11.3 | 87.7   |
| Macadamia                    | <i>Macadamia tetraphylla</i>    | 73.2-78   | 0.7  | 10.1 | 20.1 | 4.3  | 57.4 | 2.5  | -    | 2.8  | 1.9  | 17.8 | 81.5   |
| Mafura                       | <i>Trichilia emetica</i>        | 55-56     | -    | 38.6 | -    | 2.2  | 48.0 | 10.2 | 1.0  | -    | -    | 40.8 | 59.2   |
| Pecan                        | <i>Carya illinoensis</i>        | 70.3      | -    | 5.7  | 0.11 | 2.2  | 66.9 | 22.1 | 1.1  | 0.21 | 0.4  | 8.1  | 90.6   |
| Pine nut                     | <i>Pinus pinea</i>              | 50.7      | -    | 8.0  | 0.45 | 3.6  | 39.2 | 45.2 | 1.4  | -    | 2.1  | 11.6 | 88.3   |
| Pistachio                    | <i>Pistachia vera</i>           | 54-57     | -    | 8.6  | 0.7  | 2.3  | 68.8 | 17.8 | 0.3  | 0.3  | 0.6  | 11.2 | 87.7   |

<sup>a</sup> For references, see original paper.<sup>b</sup> 3.2% 18:3 + 20:0.<sup>c</sup> 0.4% 20:4.

Table 3.154 Physical and chemical characteristics of mango fats<sup>a</sup> (Ali *et al.*, 1985)

| Variety     | Moisture in fresh kernel (%) | Fat content (%) | Iodine value | Melting point (°C) | Saponification value | Unsaponifiable matter (%) | Peroxide value |
|-------------|------------------------------|-----------------|--------------|--------------------|----------------------|---------------------------|----------------|
| Brindaboni  | 62.0                         | 9.3             | 51.2         | 27-28              | 195                  | 1.7                       | 0.1            |
| Fazli       | 68.0                         | 7.1             | 55.0         | 38-39              | 190                  | 1.8                       | 0.5            |
| Kalabau     | 50.0                         | 9.0             | 44.0         | 27-28              | 192                  | 1.8                       | 0.1            |
| Kanchamitha | 50.0                         | 7.5             | 50.4         | 26-27              | 194                  | 1.8                       | 0.1            |
| Kuipahari   | 61.0                         | 8.0             | 50.3         | 44-45              | 193                  | 1.7                       | 0.5            |
| Lakhanovoge | 52.6                         | 10.0            | 46.8         | 28-29              | 191                  | 1.5                       | 0.1            |
| Lengra      | 48.5                         | 9.7             | 46.0         | 46-47              | 195                  | 1.5                       | 0.5            |
| Mohanvoge   | 50.0                         | 7.8             | 55.0         | 25-26              | 188                  | 1.9                       | 0.2            |
| Misrakanta  | 48.5                         | 8.9             | 50.6         | 25-26              | 191                  | 1.7                       | 0.1            |
| Ranipasad   | 56.0                         | 9.4             | 51.2         | 34-35              | 197                  | 1.9                       | 0.1            |

<sup>a</sup> Mean results of three experiments.

## Occurrence and characteristics

**Table 3.155** Fatty acid compositions of some Indian oils (Bringi, 1987)

| Name               | Source                            | 16:0 | 18:0 | 20:0 | 22:0 | 18:1 | 18:2 | 18:3 | Others |
|--------------------|-----------------------------------|------|------|------|------|------|------|------|--------|
| Dhupa              | <i>Vateria indica</i>             | 9    | 47   | 1    | —    | 42   | 1    | —    | —      |
| Karanja            | <i>Pongamia glabra</i>            | 10   | 7    | 4    | 5    | 49   | 19   | —    | 6      |
| Kusum <sup>a</sup> | <i>Schleichera trijuga</i>        | 8    | 2    | 21   | 2    | 43   | 5    | —    | 19     |
| Mango              | <i>Mangifera indica</i>           | 10   | 38   | 1    | tr   | 45   | 5    | 1    | —      |
| Mowrah             | <i>Madhuca indica</i>             | 25   | 22   | —    | —    | 36   | 17   | —    | —      |
| Neem               | <i>Azadirachta indica juss</i>    | 19   | 21   | 2    | —    | 42   | 16   | —    | —      |
|                    |                                   | 8:0  | 10:0 | 12:0 | 14:0 | 16:0 | 18:0 | 18:1 |        |
| Pilu               | <i>Salvadora oleoides persica</i> | 2    | 4    | 45   | 32   | 10   | 5    | 2    |        |
| Pisa               | <i>Actinodaphne hooker</i>        | —    | 2    | 92   | 3    | 1    | —    | 2    |        |

<sup>a</sup> Chemistry very complex; cyanolipids form a significant part of the oil.

**Table 3.156** Moisture, protein, lipid and fatty acid composition of 12 strains of oats (*Avena sativa*) (Sahasrabudhe, 1979) and Lupin (*Lupinus polyphyllus*) (Aniszewski, 1993)

| Strain                | Moisture (%) | Protein <sup>a</sup> (%) | Lipid <sup>b</sup> (%) | Fatty acids (%) |      |      |      |      |      |                    |
|-----------------------|--------------|--------------------------|------------------------|-----------------|------|------|------|------|------|--------------------|
|                       |              |                          |                        | 14:0            | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | Other <sup>c</sup> |
| Oats                  |              |                          |                        |                 |      |      |      |      |      |                    |
| Exeter                | 8.4          | 13.2                     | 4.2                    | 1.0             | 25.8 | 2.9  | 25.8 | 40.6 | 3.7  | 0.2                |
| Garry                 | 7.7          | 20.4                     | 5.4                    | 0.6             | 22.4 | 2.6  | 30.0 | 41.0 | 3.3  | 0.1                |
| Hinoat                | 7.4          | 24.4                     | 5.5                    | 3.1             | 19.6 | 2.5  | 32.8 | 36.9 | 2.8  | 2.2                |
| OA-290-5              | 7.8          | 18.8                     | 5.5                    | 3.6             | 23.1 | 3.0  | 39.8 | 38.0 | 2.5  | nd <sup>d</sup>    |
| Gemini                | 7.4          | 16.4                     | 5.9                    | 1.1             | 21.3 | 2.0  | 32.0 | 40.3 | 3.2  | 0.1                |
| Random                | 8.0          | 17.9                     | 6.3                    | 0.5             | 21.0 | 2.2  | 36.1 | 37.4 | 2.4  | 0.3                |
| Terra                 | 7.7          | 16.2                     | 6.5                    | 4.9             | 19.7 | 2.4  | 35.6 | 32.3 | 2.0  | 3.1                |
| Elgin                 | 7.8          | 19.3                     | 6.8                    | 1.0             | 23.0 | 3.9  | 30.8 | 37.6 | 3.6  | tr <sup>e</sup>    |
| Dal                   | 7.8          | 19.1                     | 7.9                    | 0.5             | 23.6 | 2.8  | 33.7 | 37.7 | 1.7  | tr                 |
| CI-3387               | 7.7          | 14.1                     | 11.0                   | 2.7             | 16.5 | 1.6  | 40.2 | 35.5 | 2.2  | 1.3                |
| Lodi                  | 7.8          | 19.9                     | 11.3                   | 1.4             | 14.9 | 2.4  | 41.0 | 36.0 | 2.1  | 2.2                |
| CI-4492               | 8.0          | 14.2                     | 11.8                   | 4.9             | 15.6 | 2.7  | 41.3 | 31.3 | 1.7  | 2.4                |
| Lupin                 |              |                          |                        |                 |      |      |      |      |      |                    |
| <i>L. polyphyllus</i> |              | 43.0                     | 9.1                    | 0.1             | 14.3 | 1.2  | 33.4 | 39.0 | 11.3 | 0.7                |

<sup>a</sup> Percentage N × 5.7.

<sup>b</sup> Lipid extracted by hexane.

<sup>c</sup> Includes fatty acids C<sub>20</sub> and C<sub>22</sub>.

<sup>d</sup> Not detected.

<sup>e</sup> Indicates less than 0.1%.

### 3.3.44 Summary tables relating to vegetable oils and fats

The data given in this section have been compiled on the basis that in most cases the work has been done by a single research group. This gives the data some element of consistency. In some instances there may be more up-to-date analyses that can support the information supplied here. Triglyceride, sterol and tocopherol analyses present their own particular problems, in the first case because of the varied techniques used to quantify these components and in the second because of the natural variability that is known to occur.

The summary tables that are given here are as follows:

Codex ranges of fatty acid compositions of fats and oils (3.157);

Triglycerides of palmitic/stearic/oleic-rich fats (3.158);

Triglycerides of seed oils rich in linolenic and/or linoleic acid (3.159);

Free fatty acids, mono-, di- and triglycerides of fats according to carbon number (3.160);

Stereospecific positional distribution of fatty acids in triglycerides of seed oils (3.161);

Vegetable oils – fatty acid composition of triglycerides and of fatty acids at the 2 position (3.162);

Sterol composition of some commonly occurring vegetable oils (3.163);

4-methylsterols of some commonly occurring vegetable oils (3.164);

Triterpene alcohols of some commonly occurring vegetable oils (3.165);

Sterols in vegetable oils (3.166);

Ranges of tocopherol and tocotrienol levels in vegetable oils (3.167);

Vitamin E activity of tocopherols/ tocotrienols in vegetable oils (3.168);

Tocopherols determined in vegetable oils (3.169);

Tocopherol content and vitamin E activity of oils and fats (3.170);

World production of oils and fats (3.171);

Major oils and fats, summary of world supply and demand (3.172);

Oil-producing nations (3.173);

Fatty acid composition and lipid content of edible vegetables, cruciferae (3.174) and Asteraceae and Apiaceae (3.175). See also tables in section 3.3.43 (unclassified oils of interest and new oil seed crops).

**Table 3.157** GLC fatty acid ranges in Codex standards for individual fats and oils (revised in 1993 at 14th Session CCFO, Al inorm 95/17) (per cent of total fatty acids). Ranges refer to typical commercial samples of *bona fide* fats and oils

| Fatty acid | Arachis         | Babassu   | Coconut   | Cottonseed | Grapeseed | Maize     | Mustard seed          | Olive oil | Palm      | Palm kernel | Palm steari |
|------------|-----------------|-----------|-----------|------------|-----------|-----------|-----------------------|-----------|-----------|-------------|-------------|
| C6:0       | nd <sup>c</sup> | nd        | 0.0-0.6   | nd         | nd        | nd        | 0.0-0.5* <sup>d</sup> | nd        | ns        | 0.0-0.8     | nd          |
| C8:0       | nd              | 2.6-7.3   | 4.6-9.4   | nd         | nd        | nd        |                       | nd        | ns        | 2.4-6.2     | nd          |
| C10:0      | nd              | 1.2-7.6   | 5.5-7.8   | nd         | nd        | nd        |                       | nd        | ns        | 2.6-5.0     | nd          |
| C12:0      | 0.0-0.1         | 40.0-55.0 | 45.1-50.3 | 0.0-0.2    | 0.0-0.5   | 0.0-0.3   |                       | nd        | 0.0-0.4   | 41.0-55.0   | 0.1-0       |
| C14:0      | 0.0-0.1         | 11.0-27.0 | 16.8-20.6 | 0.6-1.0    | 0.0-0.3   | 0.0-0.3   | 0.0-1.0               | <0.05     | 0.5-2.0   | 14.0-18.0   | 1.1-1       |
| C16:0      | 8.3-14.0        | 5.2-11.0  | 7.7-10.2  | 21.4-26.4  | 5.5-11    | 8.6-16.5  | 0.5-4.5               | 7.5-20    | 40.1-47.5 | 6.5-10.0    | 48.4        |
| C16:1      | 0.0-0.2         | nd        | nd        | 0.0-1.2    | 0.0-1.2   | 0.0-0.4   | 0.0-0.5               | 0.3-3.5   | 0.0-0.6   | ns          | 0.05-       |
| C17:0      | nd              | nd        | nd        | nd         | nd        | nd        | nd                    | nd        | ns        | ns          | nd          |
| C17:1      | nd              | nd        | nd        | nd         | nd        | nd        | nd                    | nd        | ns        | ns          | nd          |
| C18:0      | 1.9-4.4         | 1.8-7.4   | 2.3-3.5   | 2.1-3.3    | 3.0-6.0   | 1.0-3.3   | 0.5-2.0               | 0.5-5.0   | 3.5-6.0   | 1.3-3.0     | 3.9-5       |
| C18:1      | 36.4-67.1       | 9.0-20.0  | 5.4-8.1   | 14.7-21.7  | 12-28     | 20.0-42.2 | 8.0-23                | 55-83     | 36.0-44.0 | 12.0-19.0   | 15.6-       |
| C18:2      | 14.0-43.0       | 1.4-6.6   | 1.0-2.1   | 46.7-58.2  | 58-78     | 39.4-62.5 | 10-24                 | 3.5-21    | 6.5-12.0  | 1.0-3.5     | 3.2-5       |
| C18:3      | 0.0-0.1         | nd        | 0.0-0.2   | 0.0-0.4    | 0.0-1.0   | 0.5-1.5   | 6.0-18                | <1.5      | 0.0-0.5   |             | 0.1-        |
| C20:0      | 1.1-1.7         | nd        | 0.0-0.2   | 0.2-0.5    | 0.0-1.0   | 0.3-0.6   | 0.0-1.5               | <0.8      | 0.0-1.0   |             | 0.3-        |
| C20:1      | 0.7-1.7         | nd        | 0.0-0.2   | 0.0-0.1    | nd        | 0.2-0.4   | 5.0-13                | tr        | ns        | 0.0-1.0%    | nd          |
| C20:2      | nd              | nd        | nd        | 0.0-0.1    | nd        | 0.0-0.1   | 0.0-1.0               | nd        | ns        |             | nd          |
| C22:0      | 2.1-4.4         | nd        | nd        | 0.0-0.6    | 0.0-0.3   | 0.0-0.5   | 0.2-2.5               | <0.2      | ns        |             | nd          |
| C22:1      | 0.0-0.3         | nd        | nd        | 0.0-0.3    | nd        | 0.0-0.1   | 22-50                 | nd        | ns        |             | nd          |
| C22:2      | nd              | nd        | nd        | 0.0-0.1    | nd        | nd        | 0.0-1.0               | nd        | ns        |             | nd          |
| C24:0      | 1.1-2.2         | nd        | nd        | 0.0-0.1    | 0.0-0.1   | 0.0-0.4   | 0.0-0.5               | <1.0      | ns        |             | nd          |
| C24:1      | 0.0-0.3         | nd        | nd        | nd         | nd        | nd        | 0.5-2.5               | nd        | ns        |             | nd          |

<sup>a</sup> Revised 13th Session CCFO, Alinorm 87/17; 14:1 <0.2; 15:0, 15:iso, 22:0, each <0.1; 20:4 <1.0.

<sup>b</sup> Revised 13th Session CCFO, Alinorm 87/17; 14:iso <0.3; 14:1, 0.5-1.5; 15:0, 0.5-1.0; 15:iso + anteiso <0.5; 16:2 <1.0; 16:iso <0.5; 17:iso and anteiso <1.5; 20:4 <0.5.

<sup>c</sup> nd, not detected; ns, not specified.

<sup>d</sup> Total value for the fatty acids indicated.

<sup>e</sup> 1.8% 22:1 found in only one out of 31 samples. 25 samples ≤0.2%.

95/17

| Im<br>mel | Palm<br>stearin | Rapeseed | Rapeseed<br>(low erucic<br>acid) | Safflower<br>seed    | Sesame<br>seed | Soya bean | Sunflower<br>seed | Lard <sup>a</sup> and<br>rendered<br>pork fat | Premier jus <sup>b</sup><br>and edible<br>tallow |
|-----------|-----------------|----------|----------------------------------|----------------------|----------------|-----------|-------------------|-----------------------------------------------|--------------------------------------------------|
| 1-0.8     | nd              | 0.1      | nd                               | nd                   | nd             | nd        | nd                | <0.5                                          | <2.5                                             |
| 1-6.2     | nd              |          | nd                               | nd                   | nd             | nd        | nd                |                                               |                                                  |
| 5-5.0     | nd              |          | nd                               | nd                   | nd             | nd        | nd                |                                               |                                                  |
| 0-55.0    | 0.1-0.4         |          | nd                               | nd                   | nd             | 0.0-0.1   | 0.0-0.1           |                                               |                                                  |
| 0-18.0    | 1.1-1.8         | 0.2      | 0.0-0.2                          | 0.0-0.2              | 0.0-0.1        | 0.0-0.2   | 0.0-0.2           | 0.5-2.5                                       | 1.4-7.8                                          |
| 5-10.0    | 48.4-73.8       | 1.5-6.0  | 3.3-6.0                          | 5.3-8.0              | 7.9-10.2       | 8.0-13.3  | 5.6-7.6           | 20-32                                         | 17-37                                            |
|           | 0.05-0.2        | 0.0-3.0  | 0.1-0.6                          | 0.0-0.2              | 0.1-0.2        | 0.0-0.2   | 0.0-0.3           | 1.7-5                                         | 0.7-8.8                                          |
|           | nd              | nd       | 0.0-0.3                          | nd                   | 0.0-0.2        | nd        | nd                | <0.5                                          | 0.5-2.0                                          |
|           | nd              | nd       | 0.0-0.3                          | nd                   | 0.0-0.1        | nd        | nd                | <0.5                                          | <1.0                                             |
| 3-3.0     | 3.9-5.6         | 0.5-3.1  | 1.1-2.5                          | 1.9-2.9              | 4.8-6.1        | 2.4-5.4   | 2.7-6.5           | 5-24                                          | 6.0-40                                           |
| 0-19.0    | 15.6-36.0       | 8-60     | 52.0-66.9                        | 8.4-21.3             | 35.9-42.3      | 17.7-26.1 | 14.0-39.4         | 35-62                                         | 26-50                                            |
| 3-3.5     | 3.2-9.8         | 11-23    | 16.1-24.8                        | 67.8-83.2            | 41.5-47.9      | 49.8-57.1 | 48.3-74.0         | 3-16                                          | 0.5-5.0                                          |
|           | 0.1-0.6         | 5-13     | 6.4-14.1                         | 0.0-0.1              | 0.3-0.4        | 5.5-9.5   | 0.0-0.2           | <1.5                                          | <2.5                                             |
|           | 0.3-0.6         | 0.0-3.0  | 0.2-0.8                          | 0.2-0.4              | 0.3-0.6        | 0.1-0.6   | 0.2-0.4           | <1.0                                          | <0.5                                             |
|           | nd              | 3-15     | 0.1-3.4                          | 0.1-0.3              | 0.0-0.3        | 0.0-0.3   | 0.0-0.2           | <1.0                                          | <0.5                                             |
|           | nd              | 0.0-1.0  | 0.0-0.1                          | nd                   | nd             | 0.0-0.1   | nd                | <1.0                                          |                                                  |
|           | nd              | 0.0-2.0  | 0.0-0.5                          | 0.2-0.8              | 0.0-0.3        | 0.3-0.7   | 0.5-1.3           | <0.1                                          |                                                  |
| 0-1.0%    | nd              | 5-60     | 0.0-2.0                          | 0.0-1.8 <sup>c</sup> | nd             | 0.0-0.3   | 0.0-0.2           |                                               |                                                  |
|           | nd              | 0.0-2.0  | 0.0-0.1                          | nd                   | nd             | nd        | 0.0-0.3           |                                               |                                                  |
|           | nd              | 0.0-2.0  | 0.0-0.2                          | 0.0-0.2              | 0.0-0.3        | 0.0-0.4   | 0.2-0.3           |                                               |                                                  |
|           | nd              | 0.0-3.0  | 0.0-0.4                          | 0.0-0.2              | nd             | nd        | nd                |                                               |                                                  |

1 anteiso

Table 3.158 Triglycerides (mol%) of palmitic/stearic/oleic-rich fats (Jurriens, 1968)

| Triglyceride <sup>a</sup>    | Cocoa butter | Illipe fat | Palm oil |         | Shea butter | Olive oil |
|------------------------------|--------------|------------|----------|---------|-------------|-----------|
|                              |              |            | Congo    | Sumatra |             |           |
| No double bonds              |              |            |          |         |             |           |
| PPP                          | 0.1          | 0.1        | 4.3      | 6.1     | —           | —         |
| PPSt                         | 0.5          | 0.4        | 1.1      | 0.9     | 0.3         | —         |
| PStP                         | —            | 0.1        | 0.4      | 0.3     | —           | —         |
| StPSt                        | 0.8          | 0.5        | } 0.3    | } 0.3   | 1.2         | —         |
| PStSt                        | 0.3          | 0.8        |          |         | 0.4         | —         |
| StStSt                       | 0.4          | 1.2        |          |         | 1.8         | —         |
| Others                       | 0.1          | —          | 0.5      | 0.9     | —           | 0.1       |
| One double bond              |              |            |          |         |             |           |
| MOP                          | 0.9          | —          | 1.2      | 1.3     | —           | } 4.3     |
| MOS <sub>t</sub>             | 1.3          | —          | —        | —       | —           |           |
| POP                          | 12.0         | 6.6        | 24.1     | 25.9    | 0.5         |           |
| POSt                         | 34.8         | 34.3       | 7.0      | 3.1     | 6.4         |           |
| StOS <sub>t</sub>            | 25.2         | 44.5       | 0.5      | —       | 29.6        | } 0.2     |
| PPO                          | 0.6          | —          | 3.6      | 6.0     | 0.1         |           |
| StPO                         | 0.9          | 0.1        | 0.5      | 0.3     | 1.1         |           |
| PStO                         | 0.8          | 0.1        | } 1.2    | 0.5     | 0.2         |           |
| StStO                        | 1.1          | 0.2        |          | —       | 1.7         |           |
| Others                       | 0.7          | —          |          | 0.8     | —           |           |
| Two double bonds             |              |            |          |         |             |           |
| POO                          | 3.7          | 2.2        | 18.9     | 18.9    | 3.2         | } 26.0    |
| StOO                         | 4.9          | 6.0        | 2.8      | 2.6     | 29.8        |           |
| OPO                          | —            | —          | 1.0      | 1.2     | 0.3         | 0.3       |
| PLP                          | 1.2          | 0.1        | 7.8      | 6.8     | —           | } 0.5     |
| StLP                         | 3.1          | 0.3        | 2.3      | 1.9     | 0.8         |           |
| Others                       | 3.1          | 0.4        | 2.2      | 3.6     | 4.6         |           |
| Three double bonds           |              |            |          |         |             |           |
| OOO                          | 0.5          | 0.4        | 2.7      | 3.2     | 7.4         | 39.2      |
| POL                          | 0.4          | 0.4        | 4.0      | 2.6     | 0.3         | } 4.5     |
| StOL                         | 0.4          | 1.1        | 0.6      | —       | 2.2         |           |
| MLO                          | —            | —          | 0.3      | —       | —           | —         |
| PLO                          | 0.3          | —          | 4.5      | 4.3     | 0.4         | } 3.0     |
| StLO                         | 0.3          | 0.1        | 0.6      | 0.5     | 4.0         |           |
| Others                       | 1.6          | 0.1        | 7.1      | 7.8     | 3.9         | 0.6       |
| More than three double bonds |              |            |          |         |             |           |
| LOO                          | —            | —          | —        | —       | —           | 13.7      |
| OLO                          | —            | —          | 0.5      | 0.2     | —           | 4.6       |
| Others                       | —            | —          | —        | —       | —           | 3.0       |

<sup>a</sup> P, palmitic; St, stearic; M, myristic; O, oleic; L, linoleic.

Table 3.159 Triglycerides of seed oils rich in linolenic acid and/or linoleic acid

| Component glycerides <sup>a</sup> |       | Seed oils (mol%)       |                   |                         |                        |                      |                        |                     |                   |                        |                        |
|-----------------------------------|-------|------------------------|-------------------|-------------------------|------------------------|----------------------|------------------------|---------------------|-------------------|------------------------|------------------------|
|                                   |       | Candlenut <sup>b</sup> | Corn <sup>c</sup> | Cottonseed <sup>c</sup> | Groundnut <sup>d</sup> | Linseed <sup>b</sup> | Safflower <sup>c</sup> | Sesame <sup>d</sup> | Soya <sup>b</sup> | Sunflower <sup>c</sup> | Wild rose <sup>b</sup> |
| LeLeLe                            | (333) | 2                      | -                 | -                       | -                      | 24                   | -                      | -                   | -                 | -                      | 5                      |
| LeLeL                             | (332) | 10                     | -                 | -                       | -                      | 14                   | -                      | -                   | 1                 | -                      | 17                     |
| LeLeO                             | (331) | 6                      | -                 | -                       | -                      | 15                   | -                      | -                   | -                 | -                      | 6                      |
| LeLeS                             | (330) | 3                      | -                 | -                       | -                      | 12                   | -                      | -                   | 1                 | -                      | 4                      |
| LeLL                              | (322) | 13                     | -                 | -                       | -                      | 3                    | -                      | -                   | 7                 | -                      | 21                     |
| LeLO                              | (321) | 14                     | -                 | -                       | -                      | 5                    | -                      | -                   | 5                 | -                      | 10                     |
| LeLS                              | (320) | 8                      | -                 | -                       | -                      | 5                    | -                      | -                   | 4                 | -                      | 4                      |
| LeOO                              | (311) | 5                      | -                 | -                       | -                      | 5                    | -                      | -                   | 2                 | -                      | 1                      |
| LeOS                              | (310) | 4                      | -                 | -                       | -                      | 7                    | -                      | -                   | 3                 | -                      | 1                      |
| LeSS                              | (300) | -                      | -                 | -                       | -                      | 1                    | -                      | -                   | 2                 | -                      | -                      |
| LLL                               | (222) | 6                      | 15                | 11                      | 4                      | 1                    | 47                     | 10                  | 15                | 14                     | 13                     |
| LLO                               | (221) | 8                      | 21                | 9                       | 20                     | 2                    | 19                     | 20                  | 16                | 39                     | 8                      |
| LLS                               | (220) | 6                      | 17                | 27                      | 12                     | -                    | 18                     | 9                   | 13                | 14                     | 4                      |
| LOO                               | (211) | 5                      | 14                | 5                       | 17                     | 1                    | 5                      | 22                  | 8                 | 19                     | 2                      |
| LOS                               | (210) | 5                      | 17                | 20                      | 22                     | 3                    | 7                      | 17                  | 12                | 11                     | 2                      |
| LSS                               | (200) | 1                      | 5                 | 17                      | 6                      | -                    | 2                      | 3                   | 4                 | 1                      | 1                      |
| OOO                               | (111) | 1                      | 6                 | 2                       | 6                      | 1                    | 1                      | 8                   | 2                 | -                      | 1                      |
| OOS                               | (110) | 2                      | 4                 | 3                       | 10                     | 2                    | 1                      | 8                   | 5                 | 1                      | -                      |
| OSS                               | (100) | 1                      | 1                 | 6                       | 3                      | -                    | -                      | 3                   | -                 | 1                      | -                      |
| SSS                               | (000) | -                      | -                 | -                       | -                      | -                    | -                      | -                   | -                 | -                      | -                      |

<sup>a</sup> All isomers: linolenic (Le, 3); linoleic (L, 2); oleic (O, 1); saturated (S, 0).<sup>b</sup> Gunstone and Padley (1965).<sup>c</sup> Gunstone and Qureshi (1965).<sup>d</sup> Jurriens (1968).

Table 3.160 Free fatty acids and mono-, di- and triglycerides (wt%) of fats according to carbon number<sup>a</sup> (D'Alonzo *et al.*, 1982)

|                   | Cocoa<br>butter | Corn oil | Cottonseed<br>oil | Lard | Olive<br>oil | Palm<br>oil | Peanut<br>oil | Rapeseed oil<br>(high-erucic) | Tallow | Safflower<br>oil | Sesame<br>oil | Soybean<br>oil | Sunflower<br>oil |
|-------------------|-----------------|----------|-------------------|------|--------------|-------------|---------------|-------------------------------|--------|------------------|---------------|----------------|------------------|
| Fatty acid        | 0.6             | -        | -                 | 0.2  | 0.1          | 0.1         | -             | 0.1                           | 2.3    | -                | 0.1           | -              | 0.1              |
| Monoglyceride     | 0.2             | -        | -                 | -    | 0.2          | -           | -             | 0.1                           | -      | -                | -             | -              | -                |
| Diglyceride       | 2.2             | 2.8      | 3.1               | 1.3  | 5.5          | 5.8         | 2.2           | 0.8                           | 3.8    | 2.1              | 2.6           | 1.0            | 2.0              |
| Triglyceride      | 96.0            | 95.8     | 95.0              | 97.9 | 93.3         | 93.1        | 93.3          | 96.8                          | 89.6   | 96.0             | 95.0          | 97.9           | 95.6             |
| Other             | 0.9             | 1.4      | 1.9               | 0.6  | 0.9          | 1.0         | 4.5           | 2.2                           | 4.3    | 1.9              | 2.3           | 1.1            | 2.3              |
| Fatty acid        |                 |          |                   |      |              |             |               |                               |        |                  |               |                |                  |
| C <sub>16</sub> A | 0.2             | -        | -                 | 0.1  | -            | -           | -             | -                             | 1.0    | -                | -             | -              | -                |
| C <sub>18</sub> A | 0.4             | -        | -                 | 0.1  | 0.1          | 0.1         | -             | 0.1                           | 1.3    | -                | 0.1           | -              | 0.1              |
| Monoglyceride     |                 |          |                   |      |              |             |               |                               |        |                  |               |                |                  |
| C <sub>16</sub> M | -               | -        | -                 | -    | -            | -           | -             | 0.1                           | -      | -                | -             | -              | -                |
| C <sub>18</sub> M | 0.1             | -        | -                 | -    | 0.2          | -           | -             | -                             | -      | -                | -             | -              | -                |
| C <sub>20</sub> M | -               | -        | -                 | -    | -            | -           | -             | -                             | -      | -                | -             | -              | -                |
| C <sub>22</sub> M | -               | -        | -                 | -    | -            | -           | -             | -                             | -      | -                | -             | -              | -                |
| Diglyceride       |                 |          |                   |      |              |             |               |                               |        |                  |               |                |                  |
| C <sub>30</sub> D | -               | -        | -                 | -    | -            | -           | -             | -                             | -      | -                | -             | -              | -                |
| C <sub>32</sub> D | 0.1             | -        | 0.1               | 0.1  | 0.1          | 0.6         | -             | -                             | 0.3    | -                | -             | -              | -                |
| C <sub>34</sub> D | 0.8             | 0.7      | 1.0               | 0.6  | 1.4          | 3.0         | 0.5           | 0.1                           | 1.6    | 0.3              | 0.5           | 0.1            | 0.2              |
| C <sub>36</sub> D | 1.3             | 2.1      | 2.0               | 0.6  | 4.0          | 2.2         | 1.7           | 0.7                           | 1.9    | 1.8              | 2.1           | 0.9            | 1.8              |
| C <sub>38</sub> D | -               | -        | -                 | -    | -            | -           | -             | -                             | -      | -                | -             | -              | -                |
| C <sub>40</sub> D | -               | -        | -                 | -    | -            | -           | -             | -                             | -      | -                | -             | -              | -                |
| Triglyceride      |                 |          |                   |      |              |             |               |                               |        |                  |               |                |                  |
| C <sub>46</sub> T | -               | 0.2      | 0.1               | 0.4  | 0.1          | 0.6         | 0.1           | 0.7                           | 1.1    | 0.2              | 0.5           | 0.2            | -                |
| C <sub>48</sub> T | 0.3             | 1.2      | 1.7               | 1.9  | 0.3          | 6.6         | 0.1           | 0.9                           | 5.2    | 0.3              | 0.1           | 0.1            | 0.6              |
| C <sub>50</sub> T | 16.9            | 3.0      | 14.4              | 13.4 | 6.2          | 35.0        | 3.0           | 1.5                           | 16.4   | 1.6              | 2.7           | 2.2            | 2.0              |
| C <sub>52</sub> T | 43.2            | 25.2     | 39.7              | 59.1 | 33.2         | 37.6        | 22.2          | 4.5                           | 43.4   | 16.8             | 21.3          | 24.2           | 16.9             |
| C <sub>54</sub> T | 32.7            | 63.4     | 35.7              | 20.7 | 51.1         | 12.3        | 52.4          | 11.8                          | 21.3   | 73.9             | 66.6          | 68.2           | 72.0             |
| C <sub>56</sub> T | 2.3             | 2.5      | 2.8               | 2.4  | 2.1          | 1.0         | 9.3           | 13.3                          | 2.2    | 2.5              | 3.2           | 2.2            | 2.6              |
| C <sub>58</sub> T | 0.6             | 0.3      | 0.6               | -    | 0.3          | 0.1         | 6.2           | 17.4                          | -      | 0.7              | 0.6           | 0.8            | 1.5              |
| C <sub>60</sub> T | -               | -        | -                 | -    | -            | -           | -             | 19.0                          | -      | -                | -             | -              | -                |
| C <sub>62</sub> T | -               | -        | -                 | -    | -            | -           | -             | 26.4                          | -      | -                | -             | -              | -                |
| C <sub>64</sub> T | -               | -        | -                 | -    | -            | -           | -             | 1.3                           | -      | -                | -             | -              | -                |

<sup>a</sup> Determination by capillary gas chromatography.

**Table 3.161** Positional distribution of fatty acids in triglycerides of seed oils (Brockerhoff and Hoyle, 1963; Brockerhoff and Yurkowski, 1966; Brockerhoff *et al.*, 1966)

| Seed oils    | Positions | Fatty acids (mol%) |      |      |      |      |      |      |                  |      |      |      |
|--------------|-----------|--------------------|------|------|------|------|------|------|------------------|------|------|------|
|              |           | 16:0               | 16:1 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1             | 22:0 | 22:1 | 24:0 |
| Cocoa butter | 1         | 34.0               | 0.6  | 50.4 | 12.3 | 1.3  | —    | 1.0  | —                | —    | —    | —    |
|              | 2         | 1.7                | 0.2  | 2.1  | 87.4 | 8.6  | —    | —    | —                | —    | —    | —    |
|              | 3         | 36.5               | 0.3  | 52.8 | 8.6  | 0.4  | —    | 2.3  | —                | —    | —    | —    |
| Linseed      | 1         | 10.1               | 0.2  | 5.6  | 15.3 | 15.6 | 53.2 | —    | —                | —    | —    | —    |
|              | 2         | 1.6                | 0.1  | 0.7  | 16.3 | 21.3 | 59.8 | —    | —                | —    | —    | —    |
|              | 3         | 6.0                | 0.3  | 4.0  | 17.0 | 13.2 | 59.4 | —    | —                | —    | —    | —    |
| Maize        | 1         | 17.9               | 0.3  | 3.2  | 27.5 | 49.8 | 1.2  | —    | —                | —    | —    | —    |
|              | 2         | 2.3                | 0.1  | 0.2  | 26.5 | 70.3 | 0.7  | —    | —                | —    | —    | —    |
|              | 3         | 13.5               | 0.1  | 2.8  | 30.6 | 51.6 | 1.0  | —    | —                | —    | —    | —    |
| Olive        | 1         | 13.1               | 0.9  | 2.6  | 71.8 | 9.8  | 0.6  | —    | —                | —    | —    | —    |
|              | 2         | 1.4                | 0.7  | —    | 82.9 | 14.0 | 0.8  | —    | —                | —    | —    | —    |
|              | 3         | 16.9               | 0.8  | 4.2  | 73.9 | 5.1  | 1.3  | —    | —                | —    | —    | —    |
| Peanut       | 1         | 13.6               | 0.3  | 4.6  | 59.2 | 18.5 | —    | 0.7  | 1.1 <sup>a</sup> | 1.3  | —    | 0.7  |
|              | 2         | 1.6                | 0.1  | 0.3  | 58.5 | 38.6 | —    | —    | 0.3 <sup>a</sup> | 0.2  | —    | 0.5  |
|              | 3         | 11.0               | 0.3  | 5.1  | 57.3 | 10.0 | —    | 4.0  | 2.7 <sup>a</sup> | 5.7  | —    | 2.8  |
| Rapeseed     | 1         | 4.1                | 0.3  | 2.2  | 23.1 | 11.1 | 6.4  | —    | 16.4             | 1.4  | 34.9 | —    |
|              | 2         | 0.6                | 0.2  | —    | 37.3 | 36.1 | 20.3 | —    | 2.0              | —    | 3.6  | —    |
|              | 3         | 4.3                | 0.3  | 3.0  | 16.6 | 4.0  | 2.6  | —    | 17.3             | 1.2  | 51.0 | —    |
| Soybean      | 1         | 13.8               | —    | 5.9  | 22.9 | 48.4 | 9.1  | —    | —                | —    | —    | —    |
|              | 2         | 0.9                | —    | 0.3  | 21.5 | 69.7 | 7.1  | —    | —                | —    | —    | —    |
|              | 3         | 13.1               | —    | 5.6  | 28.0 | 45.2 | 8.4  | —    | —                | —    | —    | —    |

<sup>a</sup> Together with 18:3.**Table 3.162** Vegetable oils – fatty acid composition (mol%) of whole triglycerides and of fatty acids at the 2 position (Adapted from Mattson and Volpenheim, 1963)

| Oil                      |              | 6:0 | 8:0 | 10:0 | 12:0 | 14:0 | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 |
|--------------------------|--------------|-----|-----|------|------|------|------|------|------|------|------|
| Acorn                    | Triglyceride | —   | —   | —    | —    | —    | 9    | 1    | 70   | 20   | —    |
|                          | 2 Position   | —   | —   | —    | —    | —    | 1    | 0    | 68   | 31   | —    |
| Almond                   | Triglyceride | —   | —   | —    | —    | —    | 7    | 2    | 70   | 21   | —    |
|                          | 2 Position   | —   | —   | —    | —    | —    | 1    | 0    | 65   | 34   | —    |
| Brazil nut               | Triglyceride | —   | —   | —    | —    | —    | 17   | 12   | 33   | 38   | —    |
|                          | 2 Position   | —   | —   | —    | —    | —    | 1    | 1    | 40   | 58   | —    |
| Cashew nut               | Triglyceride | —   | —   | —    | —    | —    | 13   | 9    | 60   | 18   | —    |
|                          | 2 Position   | —   | —   | —    | —    | —    | 2    | 0    | 56   | 42   | —    |
| Chinese veg. tallow      | Triglyceride | —   | —   | —    | —    | —    | 71   | 1    | 28   | —    | —    |
|                          | 2 Position   | —   | —   | —    | —    | —    | 14   | 1    | 85   | —    | —    |
| Coconut                  | Triglyceride | 0.6 | 9.4 | 7.0  | 50.0 | 17.4 | 7.6  | 2.0  | 4.7  | 1.3  | —    |
|                          | 2 Position   | —   | 0.3 | 3.0  | 80.4 | 8.6  | 1.6  | 0.6  | 3.5  | 1.5  | —    |
| Corn                     | Triglyceride | —   | —   | —    | —    | —    | 12   | 2    | 29   | 57   | —    |
|                          | 2 Position   | —   | —   | —    | —    | —    | 2    | 0    | 26   | 72   | —    |
| Cotton seed (gland-free) | Triglyceride | —   | —   | —    | —    | —    | 27   | 3    | 17   | 53   | —    |
|                          | 2 Position   | —   | —   | —    | —    | —    | 2    | 0    | 22   | 76   | —    |
| Cotton seed              | Triglyceride | —   | —   | —    | —    | —    | 26   | 2    | 17   | 55   | —    |
|                          | 2 Position   | —   | —   | —    | —    | —    | 2    | 1    | 20   | 77   | —    |

(Continued)

Table 3.162 Continued

| Oil                           |              |     |     |     |      |      | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 |
|-------------------------------|--------------|-----|-----|-----|------|------|------|------|------|------|------|
| Cucumber seed                 | Triglyceride | —   | —   | —   | —    | —    | 16   | 5    | 7    | 72   | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 2    | 1    | 4    | 93   | —    |
| Dunkwa<br><i>Allanblackia</i> | Triglyceride | —   | —   | —   | —    | —    | 2    | 53   | 45   | —    | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 2    | 5    | 93   | —    | —    |
| Filbert nut                   | Triglyceride | —   | —   | —   | —    | —    | 7    | 2    | 83   | 8    | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 87   | 12   | —    |
| Kokum butter                  | Triglyceride | —   | —   | —   | —    | —    | 2    | 61   | 37   | —    | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 2    | 2    | 96   | —    | —    |
| Linseed                       | Triglyceride | —   | —   | —   | —    | —    | 6    | 4    | 22   | 15   | 53   |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 27   | 23   | 49   |
| Olive                         | Triglyceride | —   | —   | —   | —    | —    | 12   | 2    | 78   | 8    | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 89   | 10   | —    |
| Onion seed                    | Triglyceride | —   | —   | —   | —    | —    | 8    | 2    | 26   | 64   | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 25   | 74   | —    |
| Palm fruit                    | Triglyceride | —   | —   | —   | —    | —    | 45   | 6    | 40   | 9    | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 11   | 2    | 65   | 22   | —    |
| Palmkernel                    | Triglyceride | 0.4 | 5.7 | 4.7 | 52.8 | 16.2 | 7.6  | 2.2  | 9.2  | 1.2  | —    |
|                               | 2 Position   | —   | 2.7 | 2.5 | 62.7 | 15.8 | 2.9  | 0.3  | 11.8 | 1.3  | —    |
| Pecan                         | Triglyceride | —   | —   | —   | —    | —    | 9    | 3    | 58   | 30   | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 57   | 42   | —    |
| Poppy seed                    | Triglyceride | —   | —   | —   | —    | —    | 10   | 2    | 11   | 77   | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 9    | 90   | —    |
| Rice bran                     | Triglyceride | —   | —   | —   | —    | —    | 18   | 1    | 41   | 38   | 2    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 2    | 0    | 43   | 53   | 2    |
| Safflower seed                | Triglyceride | —   | —   | —   | —    | —    | 8    | 3    | 14   | 75   | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 13   | 86   | —    |
| Sesame seed                   | Triglyceride | —   | —   | —   | —    | —    | 10   | 6    | 40   | 44   | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 1    | 43   | 55   | —    |
| Soybean                       | Triglyceride | —   | —   | —   | —    | —    | 12   | 4    | 25   | 51   | 8    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 22   | 69   | 8    |
| Spinach seed                  | Triglyceride | —   | —   | —   | —    | —    | 12   | 1    | 24   | 61   | 2    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 2    | 1    | 21   | 74   | 2    |
| Squash seed                   | Triglyceride | —   | —   | —   | —    | —    | 17   | 7    | 16   | 60   | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 1    | 17   | 81   | —    |
| Sunflower seed                | Triglyceride | —   | —   | —   | —    | —    | 6    | 3    | 27   | 64   | —    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 23   | 76   | —    |
| Tomato seed                   | Triglyceride | —   | —   | —   | —    | —    | 11   | 5    | 21   | 60   | 3    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 22   | 74   | 3    |
| Walnut                        | Triglyceride | —   | —   | —   | —    | —    | 8    | 3    | 15   | 62   | 12   |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | 0    | 17   | 71   | 11   |
| Wheat flour                   | Triglyceride | —   | —   | —   | —    | —    | 4    | 4    | 27   | 58   | 7    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 2    | 0    | 22   | 70   | 6    |
| Wheat germ                    | Triglyceride | —   | —   | —   | —    | —    | 20   | —    | 18   | 55   | 7    |
|                               | 2 Position   | —   | —   | —   | —    | —    | 1    | —    | 18   | 77   | 6    |

Table 3.163 Sterol composition (mg/kg) of some commonly occurring vegetable oils (Adapted from Itoh *et al.*, 1973a, b, 1974)

| Vegetable oil          | Cholesterol | Brassicasterol | Campesterol | Stigmasterol | $\beta$ -Sitosterol | $\Delta^5$ -Avenasterol | $\Delta^7$ -Stigmasterol | $\Delta^7$ -Avenasterol | Unknown |
|------------------------|-------------|----------------|-------------|--------------|---------------------|-------------------------|--------------------------|-------------------------|---------|
| Castor oil             | —           | —              | 285         | 627          | 1254                | 599                     | 57                       | 28                      | —       |
| Cocoa butter           | 59          | —              | 266         | 769          | 1746                | 88                      | 29                       | —                       | —       |
| Coconut                | 23          | —              | 18          | 296          | 1322                | 319                     | 136                      | —                       | —       |
| Coffee seed            | —           | —              | 3488        | 3672         | 9914                | 1101                    | 183                      | —                       | —       |
| Corn oil               | —           | —              | 2691        | 702          | 7722                | 468                     | 117                      | —                       | —       |
| Cottonseed             | —           | —              | 170         | 42           | 3961                | 85                      | —                        | —                       | —       |
| Illipe butter          | —           | —              | 739         | 323          | 3234                | 227                     | 46                       | —                       | —       |
| Kapok                  | —           | —              | 256         | 57           | 2451                | 57                      | 28                       | —                       | —       |
| Linseed                | 42          | —              | 1218        | 378          | 1932                | 546                     | 84                       | —                       | —       |
| Olive (France)         | —           | —              | 28          | 14           | 1310                | 29                      | 58                       | —                       | —       |
| Palm                   | 26          | —              | 358         | 204          | 1894                | 51                      | 25                       | —                       | —       |
| Palmkernel             | 40          | —              | 118         | 145          | 924                 | 79                      | 13                       | —                       | —       |
| Peanut                 | —           | —              | 360         | 2160         | 1536                | 192                     | 72                       | 24                      | —       |
| Poppy                  | —           | —              | 605         | 83           | 1870                | 55                      | 55                       | —                       | 83      |
| Rapeseed               | —           | 612            | 1530        | —            | 3549                | 122                     | 306                      | —                       | —       |
| Rice bran              | —           | —              | 5056        | 2709         | 8849                | 903                     | 180                      | 361                     | —       |
| Safflower              | —           | —              | 452         | 313          | 1809                | 35                      | 696                      | 104                     | 69      |
| Safflower (oleic-rich) | —           | —              | 576         | 384          | 1996                | 38                      | 576                      | 192                     | 77      |
| Sal                    | —           | —              | 1469        | 918          | 3427                | 306                     | —                        | —                       | —       |
| Sesame                 | —           | —              | 1170        | 616          | 3819                | 431                     | 123                      | —                       | —       |
| Shea butters           | —           | —              | —           | —            | —                   | —                       | 944                      | 281                     | 132     |
| Soybean                | —           | —              | 720         | 720          | 1908                | 108                     | 108                      | 36                      | —       |
| Sunflower              | —           | —              | 313         | 313          | 2352                | 156                     | 588                      | 156                     | 39      |
| Wheat germ             | —           | —              | 5702        | —            | 17336               | 1555                    | 777                      | 518                     | —       |

Table 3.164 4-Methylsterols (mg/kg) of some commonly occurring vegetable oils (Adapted from Itoh *et al.*, 1973a, b, 1974)

| Oil                    | Relative retention time <sup>a</sup> |      |      |      |      |                   |      |                   |      |      |      |                   |      |     | Others |
|------------------------|--------------------------------------|------|------|------|------|-------------------|------|-------------------|------|------|------|-------------------|------|-----|--------|
|                        | 0.64                                 | 0.71 | 0.79 | 0.86 | 0.91 | 0.95 <sup>b</sup> | 0.99 | 1.13 <sup>c</sup> | 1.29 | 1.36 | 1.46 | 1.52 <sup>d</sup> | 1.62 |     |        |
| Castor                 | -                                    | -    | -    | 4    | -    | 70                | 16   | 54                | 4    | 10   | -    | 34                | -    | 8   |        |
| Cocoa butter           | -                                    | 8    | -    | 19   | -    | 25                | 16   | 19                | 1    | 24   | -    | 46                | -    | -   |        |
| Coconut                | -                                    | -    | -    | -    | -    | 19                | -    | 61                | -    | 35   | -    | 38                | 6    | -   |        |
| Coffee seed            | -                                    | -    | -    | 57   | -    | 1503              | -    | 2485              | -    | 173  | -    | 1502              | -    | 58  |        |
| Corn                   | 1                                    | -    | -    | -    | 1    | 39                | -    | 44                | 1    | 1    | 1    | 39                | -    | 1   |        |
| Cottonseed             | -                                    | -    | -    | -    | -    | 113               | 33   | 76                | 8    | 12   | -    | 172               | -    | 4   |        |
| Illipe                 | -                                    | -    | -    | -    | -    | 132               | -    | 546               | -    | -    | 18   | 26                | -    | 158 |        |
| Kapok                  | -                                    | -    | -    | 5    | -    | 32                | 10   | 45                | 7    | 27   | -    | 110               | 10   | 3   |        |
| Linseed                | -                                    | -    | -    | 83   | -    | 220               | 9    | 1078              | 5    | 4    | -    | 58                | -    | -   |        |
| Olive (France)         | -                                    | -    | -    | -    | -    | 18                | -    | 38                | 3    | 25   | 5    | 57                | 5    | 1   |        |
| Palm                   | -                                    | -    | -    | -    | -    | 61                | 10   | 241               | 7    | 3    | -    | 32                | -    | 4   |        |
| Palmkernel             | -                                    | 4    | -    | 4    | -    | 52                | -    | 80                | 12   | 40   | 40   | 126               | 8    | 40  |        |
| Peanut                 | 4                                    | -    | -    | -    | -    | 40                | 11   | 44                | 1    | 14   | 3    | 38                | -    | 2   |        |
| Poppy                  | -                                    | -    | -    | 6    | -    | 96                | -    | 108               | -    | 18   | -    | -                 | -    | 72  |        |
| Rapeseed               | -                                    | 2    | 75   | 29   | -    | 78                | -    | 59                | -    | -    | 2    | 18                | -    | 3   |        |
| Rice                   | -                                    | -    | -    | -    | -    | 294               | -    | 252               | 1638 | -    | 336  | -                 | 1680 | -   |        |
| Safflower              | -                                    | -    | -    | -    | -    | 96                | 29   | 55                | 12   | 19   | -    | 28                | -    | -   |        |
| Safflower (oleic-rich) | -                                    | -    | -    | -    | -    | 129               | 33   | 75                | 6    | 12   | 6    | 30                | -    | 9   |        |
| Sal                    | -                                    | -    | -    | 12   | -    | 60                | -    | 192               | 6    | 6    | 12   | 60                | -    | 252 |        |
| Sesame                 | -                                    | -    | -    | -    | -    | 812               | 568  | 1421              | -    | -    | -    | 1258              | -    | -   |        |
| Shea butter            | -                                    | -    | -    | -    | -    | 224               | -    | 41                | 51   | 31   | -    | -                 | -    | 673 |        |
| Soybean                | -                                    | -    | -    | -    | -    | 53                | 13   | 158               | 6    | 66   | -    | 349               | -    | 13  |        |
| Sunflower              | -                                    | -    | -    | -    | -    | 336               | -    | 224               | 22   | 145  | -    | 347               | 45   | -   |        |
| Wheat germ             | -                                    | -    | -    | -    | -    | 70                | 34   | 475               | -    | 46   | -    | 533               | -    | -   |        |

<sup>a</sup> Retention time relative to  $\beta$ -sitosterol.<sup>b</sup> Obtusifoliosol.<sup>c</sup> Gramisterol.<sup>d</sup> Citrostadienol.

Table 3.165 Triterpene alcohols (mg/kg) of some commonly occurring vegetable oils (Adapted from Itoh *et al.*, 1973a, b, 1974)

| Oil                    | Relative retention time <sup>a</sup> |                   |      |                   |                   |                   |                   |                    |                   |      |      |                   |        |
|------------------------|--------------------------------------|-------------------|------|-------------------|-------------------|-------------------|-------------------|--------------------|-------------------|------|------|-------------------|--------|
|                        | 0.73                                 | 1.02 <sup>b</sup> | 1.06 | 1.13 <sup>c</sup> | 1.17 <sup>d</sup> | 1.23 <sup>e</sup> | 1.27 <sup>f</sup> | 1.32 <sup>g</sup>  | 1.38 <sup>h</sup> | 1.50 | 1.65 | 1.68 <sup>i</sup> | Others |
| Castor                 | —                                    | —                 | 9    | —                 | 203               | 144               | —                 | 27                 | 32                | 6    | —    | 5                 | 27     |
| Cocoa butter           | 26                                   | 10                | —    | —                 | —                 | 411               | —                 | —                  | 57                | 16   | —    | —                 | —      |
| Coconut                | —                                    | 14                | 20   | —                 | —                 | 503               | —                 | —                  | 122               | —    | 20   | —                 | —      |
| Coffee seed            | 44                                   | 88                | 177  | —                 | —                 | 1635              | —                 | —                  | 2387              | —    | —    | 44                | 44     |
| Corn                   | —                                    | 3                 | —    | 5                 | 49                | —                 | —                 | —                  | 69                | 1    | —    | 3                 | 1      |
| Cottonseed             | —                                    | —                 | —    | 19                | 96                | —                 | —                 | 187                | 158               | —    | —    | —                 | 19     |
| Illipe                 | —                                    | 11                | —    | 330               | —                 | —                 | 231               | —                  | 385               | —    | —    | —                 | 143    |
| Kapok                  | 124                                  | 19                | —    | 10                | —                 | 266               | —                 | —                  | 437               | 29   | —    | 57                | 10     |
| Linseed                | —                                    | 15                | —    | 123               | —                 | 1063              | —                 | —                  | 339               | —    | —    | —                 | —      |
| Olive (France)         | —                                    | —                 | 29   | 216               | 101               | 130               | —                 | 302                | 475               | —    | —    | 144               | 43     |
| Palm                   | 6.4                                  | 6.4               | —    | —                 | —                 | 192               | —                 | —                  | 109               | —    | —    | —                 | —      |
| Palmkernel             | —                                    | —                 | —    | 29                | 65                | 295               | 209               | 94                 | 29                | —    | —    | —                 | —      |
| Peanut                 | 14                                   | 7                 | —    | 25                | —                 | 119               | —                 | —                  | 166               | —    | —    | 29                | —      |
| Poppy                  | —                                    | 4                 | —    | 63                | —                 | 67                | —                 | (60 <sup>j</sup> ) | 126               | —    | —    | —                 | 32     |
| Rapeseed               | —                                    | 16                | 38   | —                 | —                 | 324               | —                 | —                  | 157               | —    | —    | —                 | 5      |
| Rice bran              | 823                                  | 1058              | —    | —                 | —                 | 4822              | —                 | —                  | 4939              | —    | —    | —                 | —      |
| Safflower              | —                                    | 7                 | —    | 72.6              | —                 | 337               | 119               | —                  | 66                | —    | 26   | 20                | 13     |
| Safflower (oleic-rich) | 6                                    | —                 | —    | 84                | —                 | 360               | 78                | —                  | 36                | —    | 12   | 24                | —      |
| Sal                    | —                                    | —                 | —    | 624               | —                 | 1416              | —                 | 192                | —                 | —    | —    | —                 | 168    |
| Sesame                 | —                                    | 36                | —    | 36                | —                 | 619               | —                 | —                  | 1074              | 55   | —    | —                 | —      |
| Shea butter            | —                                    | —                 | —    | 3060              | 9945              | —                 | 17595             | 6120               | —                 | —    | —    | 383               | 1148   |
| Soybean                | 8                                    | —                 | 42   | 126               | 139               | 168               | —                 | 235                | 76                | —    | 17   | —                 | 34     |
| Sunflower              | 7                                    | —                 | —    | 49                | —                 | 294               | —                 | 119                | 161               | —    | —    | 63                | 7      |
| Wheat germ             | —                                    | 67                | —    | 403               | —                 | 381               | 179               | —                  | 986               | 45   | —    | 45                | —      |

<sup>a</sup> Retention time relative to  $\beta$ -sitosterol (30 min) taken as 1.0.<sup>b</sup> Cycloartanol.<sup>c</sup>  $\beta$ -Amyrin.<sup>d</sup> Butyrospermol.<sup>e</sup> Cycloartenol.<sup>f</sup>  $\alpha$ -Amyrin.<sup>g</sup> Lupeol.<sup>h</sup> 24-Methylenecycloartenol.<sup>i</sup> Cyclobranol.<sup>j</sup> Cycloaudenol.

**Table 3.166** Ranges (means) of sterol compositions<sup>a</sup> in vegetable oils (percentage of sterol fraction; totals in mg/kg) determined on an OV-17 column in GLC stage of analysis (Rossell and Pritchard, 1990)<sup>b</sup>

| Sterol                   | Oils analysed       |                     |                     |                     |                       |                     |                     |                         |
|--------------------------|---------------------|---------------------|---------------------|---------------------|-----------------------|---------------------|---------------------|-------------------------|
|                          | Palmkernel          | Coconut             | Cottonseed          | Soybean             | Maize                 | Groundnut           | Palm                | Sunflower Rapeseed seed |
| Cholesterol              | 1.0-3.7<br>(1.7)    | 0.6-3.0<br>(1.7)    | 0.7-2.3<br>(1.0)    | 0.6-1.4<br>(0.9)    | 0.2-0.6<br>(0.4)      | 0.6-3.8<br>(1.5)    | 2.7-4.9<br>(3.5)    | 0.2-1.3<br>(0.5)        |
| Brassicasterol           | nd-0.3<br>(0.1)     | nd-0.9<br>(0.5)     | 0.1-0.9<br>(0.3)    | nd-0.3<br>(0.1)     | nd-0.2<br>(0.05)      | nd-0.2<br>(0.0)     | nd<br>(nd)          | nd-0.2<br>(0.5)         |
| Campesterol              | 8.4-12.7<br>(10.0)  | 7.5-10.2<br>(8.7)   | 7.2-8.4<br>(7.9)    | 15.8-24.2<br>(19.5) | 18.6-24.1<br>(21.3)   | 12.3-19.8<br>(17.0) | 20.6-24.2<br>(23.0) | 7.4-12.9<br>(9.5)       |
| Stigmasterol             | 12.3-16.1<br>(13.7) | 11.4-13.7<br>(12.5) | 1.2-1.8<br>(1.4)    | 15.9-19.1<br>(17.5) | 4.3-7.7<br>(5.5)      | 5.4-13.3<br>(8.7)   | 11.4-11.8<br>(11.7) | 8.6-10.8<br>(9.4)       |
| Sitosterol               | 62.6-70.4<br>(67.0) | 42.0-52.7<br>(46.7) | 80.8-85.1<br>(83.2) | 51.7-57.6<br>(54.3) | 54.8-66.6<br>(63.4)   | 48.0-64.7<br>(58.5) | 56.7-58.4<br>(57.7) | 56.2-62.8<br>(59.9)     |
| $\Delta^5$ -Avenasterol  | 4.0-9.0<br>(6.2)    | 20.4-35.7<br>(26.6) | 1.9-3.8<br>(2.6)    | 1.9-3.7<br>(2.4)    | 4.2-8.2<br>(5.7)      | 8.3-18.8<br>(12.3)  | 2.1-2.7<br>(2.5)    | 1.9-6.9<br>(3.4)        |
| $\Delta^7$ -Stigmasterol | nd-2.1<br>(0.6)     | ns-3.0<br>(2.4)     | 0.7-1.4<br>(1.0)    | 1.4-5.2<br>(2.9)    | 1.0-4.2<br>(1.8)      | nd-5.2<br>(2.1)     | 0.4-0.8<br>(0.7)    | 7.0-13.4<br>(10.4)      |
| $\Delta^7$ -Avenasterol  | nd-1.4<br>(0.1)     | 0.6-3.0<br>(1.1)    | 1.4-3.3<br>(0.7)    | 1.0-4.6<br>(0.6)    | 0.7-2.7<br>(0.5)      | nd-5.5<br>(1.2)     | 0.4-2.5<br>(1.0)    | 3.1-6.5<br>(4.8)        |
| Others                   | nd-2.7<br>(0.7)     | nd-3.6<br>(1.1)     | nd-1.5<br>(0.7)     | nd-1.8<br>(0.6)     | nd-2.4<br>(0.5)       | nd-1.4              |                     | nd-5.3<br>(2.0)         |
| Total (mg/kg)            | 792-1187<br>(1025)  | 470-1100<br>(807)   | 2690-5915<br>(4490) | 1837-4089<br>(3199) | 7931-22137<br>(13776) | 901-2854<br>(1575)  | 389-481<br>(446)    | 2437-4545<br>(3387)     |
|                          |                     |                     |                     |                     |                       |                     |                     | 4824-11276<br>(7516)    |

<sup>a</sup> nd = not detected; ns = not separated; tr = trace.<sup>b</sup> For additional data on sterols in a wide range of oils see Homberg and Bielefeld (1989).

Table 3.167 Ranges (means) of tocopherol and tocotrienol levels (mg/kg) in vegetable oils<sup>a</sup> (Rossell and Pritchard, 1990)

| Tocol                   | Relative retention times | Oils analysed              |                      |                |                 |                 |                 |               |                |                      |                     |
|-------------------------|--------------------------|----------------------------|----------------------|----------------|-----------------|-----------------|-----------------|---------------|----------------|----------------------|---------------------|
|                         |                          | Palm kernel <sup>b,c</sup> | Coconut <sup>b</sup> | Cottonseed     | Soybean         | Maize           | Groundnut       | Palm          | Sunflower seed | High-erucic rapeseed | Low-erucic rapeseed |
| $\alpha$ T              | 1.0                      | nd-44                      | nd-17                | 136-543 (338)  | 9-352 (99.5)    | 23-573 (282)    | 49-304 (178)    | 4-185 (89)    | 403-855 (670)  | 39-305               | 100-320 (202)       |
| $\beta$ T               | 1.5                      | nd-248                     | nd-11                | nd-29 (16.9)   | nd-36 (7.7)     | nd-356 (54)     | 0-41 (8.8)      | -             | 9-45 (27)      | 24-158               | 16-140 (65)         |
| $\gamma$ T              | 1.8                      | nd-257                     | nd-14                | 158-594 (429)  | 409-2397 (1021) | 268-2468 (1034) | 99-389 (213)    | 6-36 (18)     | nd-34 (11)     | 230-500              | 287-753 (490)       |
| $\delta$ T              | 2.7                      | -                          | nd-2                 | nd-17 (3.3)    | 154-932 (421)   | 23-75 (54)      | 3-22 (7.6)      | -             | nd-7 (0.6)     | 5-14                 | 4-22 (9)            |
| $\alpha$ T <sub>3</sub> | 1.1                      | nd-tr                      | nd-5                 | -              | -               | nd-239 (49)     | -               | 4-336 (128)   | -              | -                    | -                   |
| $\beta$ T <sub>3</sub>  | 1.7                      | -                          | -                    | -              | -               | nd-52 (8)       | -               | -             | -              | -                    | -                   |
| $\gamma$ T <sub>3</sub> | 1.95                     | nd-60                      | nd-1                 | -              | -               | nd-450 (161)    | -               | 42-710 (323)  | -              | -                    | -                   |
| $\delta$ T <sub>3</sub> | 3.2                      | -                          | -                    | -              | -               | nd-20 (6)       | -               | tr-148 (72)   | -              | -                    | -                   |
| Total                   |                          | nd-257 <sup>b</sup>        | tr-31 <sup>b</sup>   | 410-1169 (788) | 575-3320 (1549) | 331-3402 (1647) | 176-696 (407.4) | 98-1327 (630) | 447-900 (709)  | 312-928              | 424-1054 (766)      |

<sup>a</sup> Vitamin E activities are shown in Table 3.168.<sup>b</sup> Means are negligible.<sup>c</sup> High values may be due to migration of some palm oil into the palm kernels before separation.

**Table 3.168** Vitamin E activity of tocopherols and tocotrienols<sup>a</sup> found in vegetable oils (Sheppard and Pennington, 1993)

| Tocopherol                             | Activity as $\alpha$ -TE <sup>b</sup><br>(mg/mg compound) |
|----------------------------------------|-----------------------------------------------------------|
| RRR- $\alpha$ -tocopherol <sup>c</sup> | 1.0                                                       |
| RRR- $\beta$ -tocopherol               | 0.5                                                       |
| RRR- $\gamma$ -tocopherol              | 0.1                                                       |
| RRR- $\delta$ -tocopherol              | 0.03                                                      |
| RRR- $\alpha$ -tocotrienol             | 0.3                                                       |
| RRR- $\beta$ -tocotrienol              | 0.05                                                      |
| Synthetic $\alpha$ -tocopherol acetate | 0.74                                                      |

<sup>a</sup> The activities of  $\gamma$ -tocotrienol and  $\delta$ -tocotrienol are unknown.<sup>b</sup>  $\alpha$ -Tocopherol equivalents.<sup>c</sup> Naturally occurring  $\alpha$ -tocopherol. See Sheppard and Pennington for a definition of modern nomenclature.**Table 3.169** Tocopherols determined in vegetable oils (mg/kg) (Compiled from Carpenter, 1979; Muller-Mulot, 1976; Ong, 1993)

| Oil                            | $\alpha$ -T | $\beta$ -T | $\gamma$ -T | $\delta$ -T | $\alpha$ -T <sub>3</sub> | $\gamma$ -T <sub>3</sub> | $\delta$ -T <sub>3</sub> |
|--------------------------------|-------------|------------|-------------|-------------|--------------------------|--------------------------|--------------------------|
| Castor                         | 28          | 29         | 111         | 310         | —                        | —                        | —                        |
| Cocoa butter                   | 11          | —          | 170         | 17          | 2                        | —                        | —                        |
| Coconut <sup>a</sup>           | —           | —          | —           | 2–4         | 20                       | —                        | —                        |
| Corn <sup>a</sup>              | 134         | 18         | 412         | 39          | —                        | —                        | —                        |
| Cottonseed                     | 573         | 40         | 317         | 10          | —                        | —                        | —                        |
| Groundnut                      | 169         | 5          | 144         | 13          | —                        | —                        | —                        |
| Linseed                        | —           | —          | —           | —           | —                        | —                        | —                        |
| Mustard                        | 75          | —          | 494         | 31          | —                        | —                        | —                        |
| Olive                          | 93          | —          | 7           | —           | —                        | —                        | —                        |
| Palm, from fibres <sup>b</sup> | 1662        | —          | —           | —           | 456                      | 485                      | 142                      |
| Palm <sup>b</sup>              | 150         | —          | —           | —           | 117                      | 297                      | 80                       |
| Palm                           | 279         | —          | 61          | —           | 274                      | 398                      | 69                       |
| Rape <sup>a</sup>              | 70          | 16         | 178         | 7           | —                        | —                        | —                        |
| Rice bran <sup>b</sup>         | 324         | 18         | 53          | —           | 236                      | 349                      | —                        |
| Safflower                      | 477         | —          | 44          | 10          | —                        | —                        | —                        |
| Sesame <sup>a</sup>            | 12          | 6          | 244         | 32          | —                        | —                        | —                        |
| Soybean <sup>a</sup>           | 116         | 34         | 737         | 275         | —                        | —                        | —                        |
| Sunflower <sup>a</sup>         | 608         | 17         | 11          | —           | —                        | —                        | —                        |
| Wheat germ                     | 1179        | 398        | 493         | 118         | tr                       | —                        | —                        |

<sup>a</sup> Refined oils.<sup>b</sup> Ong (1993).

**Table 3.170** Tocopherol content and vitamin E activity of oils and fats (mg/kg) (Adapted from Sheppard and Pennington, 1993)

| Fats and oil         | Tocopherols   |              |               |               | Tocotrienols  |                | Vitamin E activity <sup>a</sup><br>as $\alpha$ -TE<br>(mg) |
|----------------------|---------------|--------------|---------------|---------------|---------------|----------------|------------------------------------------------------------|
|                      | $\alpha$ (mg) | $\beta$ (mg) | $\gamma$ (mg) | $\delta$ (mg) | $\alpha$ (mg) | $\beta$ (mg)   |                                                            |
| <b>Vegetable</b>     |               |              |               |               |               |                |                                                            |
| Canola               | 210.0         | 1.0          | 42.0          | 0.4           | 0.4           | — <sup>b</sup> | 215.0                                                      |
| Coconut <sup>c</sup> | 5.0           | —            | —             | 6.0           | 5.0           | 0.1            | 7.0                                                        |
| Corn                 | 112.0         | 50.0         | 602.0         | 18.9          | —             | —              | 198.0                                                      |
| Cottonseed           | 389.0         | —            | 387.0         | —             | —             | —              | 428.0                                                      |
| Olive                | 119.0         | —            | 7.0           | —             | —             | —              | 120.0                                                      |
| Palm <sup>d</sup>    | 256.0         | —            | 316.0         | 70.0          | 146.0         | 3.2            | 335.0                                                      |
| Palmkernel           | 62.0          | —            | —             | —             | —             | —              | 62.0                                                       |
| Peanut               | 130.0         | —            | 214.0         | 21.0          | —             | —              | 152.0                                                      |
| Safflower            | 342.0         | —            | 71.0          | —             | —             | —              | 349.0                                                      |
| Sesame               | 136.0         | —            | 290.0         | —             | —             | —              | 165.0                                                      |
| Soybean <sup>e</sup> | 75.0          | 15.0         | 797.0         | 266.0         | 2.0           | 0.1            | 171.0                                                      |
| Sunflower            | 487.0         | —            | 51.0          | 8.0           | —             | —              | 492.0                                                      |
| Walnut               | 563.0         | —            | 595.0         | 450.0         | —             | —              | 636.0                                                      |
| Wheat germ           | 1330.0        | 710.0        | 260.0         | 271.0         | 26.0          | 18.1           | 1736.0                                                     |
| <b>Fish</b>          |               |              |               |               |               |                |                                                            |
| Cod liver            | 220.0         | —            | —             | —             | —             | —              | 220.0                                                      |
| Herring              | 92.0          | —            | —             | —             | —             | —              | 92.0                                                       |
| Menhaden             | 75.0          | —            | —             | —             | —             | —              | 75.0                                                       |
| <b>Animal</b>        |               |              |               |               |               |                |                                                            |
| Lard                 | 12.0          | —            | 7.0           | —             | 7.0           | —              | 15.0                                                       |
| Tallow               | 27.0          | —            | —             | —             | —             | —              | 27.0                                                       |

<sup>a</sup>  $\alpha$ -Tocopherol equivalents.<sup>b</sup> Dashes denote no value or trace.<sup>c</sup> Contains 19.0 mg  $\gamma$ -tocotrienol.<sup>d</sup> Contains 286.0 mg  $\gamma$ -tocotrienol.<sup>e</sup> Contains 0.3 mg  $\delta$ -tocotrienol.

**Table 3.171** World production of oils and fats ( $\times 10^6$  tonnes), January to December each year (*Oil World Annual*, 1991)

|                 | 1986  | 1987  | 1988  | 1989  | 1990  | Average |
|-----------------|-------|-------|-------|-------|-------|---------|
| Soya            | 14.45 | 15.56 | 15.42 | 14.99 | 16.05 | 15.29   |
| Cotton          | 3.60  | 3.30  | 3.76  | 3.83  | 3.68  | 3.63    |
| Groundnut       | 3.30  | 3.44  | 3.67  | 4.27  | 3.93  | 3.72    |
| Sunflower       | 6.89  | 6.84  | 7.49  | 7.50  | 7.88  | 7.32    |
| Rape            | 6.50  | 7.40  | 7.69  | 7.86  | 8.18  | 7.53    |
| Sesame          | 0.67  | 0.66  | 0.66  | 0.66  | 0.66  | 0.66    |
| Corn            | 1.23  | 1.24  | 1.29  | 1.27  | 1.37  | 1.28    |
| Olive           | 1.83  | 1.80  | 2.04  | 1.67  | 1.92  | 1.85    |
| Palm            | 7.74  | 8.04  | 8.86  | 10.37 | 10.64 | 9.13    |
| Palmkernel      | 1.02  | 1.04  | 1.12  | 1.29  | 1.40  | 1.17    |
| Coconut         | 3.41  | 3.14  | 2.74  | 2.69  | 3.22  | 3.04    |
| Butter (as fat) | 6.58  | 6.24  | 6.23  | 6.42  | 6.57  | 6.41    |
| Lard            | 5.15  | 5.24  | 5.46  | 5.38  | 5.51  | 5.35    |
| Fish oil        | 1.66  | 1.44  | 1.50  | 1.63  | 1.36  | 1.52    |
| Linseed         | 0.78  | 0.81  | 0.71  | 0.64  | 0.65  | 0.72    |
| Castor          | 0.39  | 0.37  | 0.34  | 0.38  | 0.43  | 0.38    |
| Tallow/grease   | 6.44  | 6.44  | 6.76  | 6.63  | 6.67  | 6.59    |
| Total           | 71.64 | 73.00 | 75.74 | 77.48 | 80.12 | 75.59   |

**Table 3.172** Seventeen major oils and fats: summary of world supply-and-demand balances (1000 tonnes) (Data provided by *Oil World*)

| Oil              | Oct.-Sept.<br>1990/91 | Oct.-Sept.<br>1989/90 | Oct.-Sept.<br>1988/89 | Oct.-Sept.<br>1987/88 | Oct.-Sept.<br>1986/87 |
|------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| <b>Soybean</b>   |                       |                       |                       |                       |                       |
| Opening stocks   | 2010                  | 1993                  | 2542                  | 2196                  | 1785                  |
| Production       | 16179                 | 16050                 | 14697                 | 15509                 | 15430                 |
| Imports          | 3812                  | 4099                  | 3770                  | 3911                  | 3783                  |
| Exports          | 3887                  | 3948                  | 3886                  | 3813                  | 3880                  |
| Disappeared      | 16310                 | 16184                 | 15131                 | 15260                 | 14922                 |
| Ending stocks    | 1804                  | 2010                  | 1993                  | 2542                  | 2190                  |
| <b>Cotton</b>    |                       |                       |                       |                       |                       |
| Opening stocks   | 244                   | 312                   | 306                   | 258                   | 369                   |
| Production       | 3896                  | 3669                  | 3874                  | 3677                  | 3220                  |
| Imports          | 350                   | 341                   | 316                   | 340                   | 264                   |
| Exports          | 357                   | 317                   | 330                   | 350                   | 249                   |
| Disappeared      | 3863                  | 3762                  | 3854                  | 3620                  | 3346                  |
| Ending stocks    | 270                   | 244                   | 312                   | 306                   | 258                   |
| <b>Groundnut</b> |                       |                       |                       |                       |                       |
| Opening stocks   | 305                   | 403                   | 392                   | 367                   | 401                   |
| Production       | 3648                  | 3787                  | 4275                  | 3561                  | 3351                  |
| Imports          | 319                   | 327                   | 376                   | 395                   | 352                   |
| Exports          | 323                   | 335                   | 373                   | 388                   | 346                   |
| Disappeared      | 3688                  | 3877                  | 4267                  | 3543                  | 3390                  |
| Ending stocks    | 262                   | 305                   | 403                   | 392                   | 367                   |
| <b>Sunflower</b> |                       |                       |                       |                       |                       |
| Opening stocks   | 1023                  | 944                   | 922                   | 767                   | 867                   |
| Production       | 7722                  | 7783                  | 7397                  | 7507                  | 6858                  |
| Imports          | 2378                  | 2508                  | 2278                  | 2310                  | 1927                  |
| Exports          | 2360                  | 2469                  | 2282                  | 2365                  | 1956                  |
| Disappeared      | 7921                  | 7743                  | 7371                  | 7297                  | 6930                  |
| Ending stocks    | 842                   | 1023                  | 944                   | 922                   | 767                   |

(Continued)

Table 3.172 *Continued*

| Oil               | Oct.-Sept.<br>1990/91 | Oct.-Sept.<br>1989/90 | Oct.-Sept.<br>1988/89 | Oct.-Sept.<br>1987/88 | Oct.-Sept.<br>1986/87 |
|-------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| <b>Rapeseed</b>   |                       |                       |                       |                       |                       |
| Opening stocks    | 759                   | 683                   | 912                   | 734                   | 805                   |
| Production        | 8231                  | 7923                  | 7684                  | 7722                  | 7250                  |
| Imports           | 1896                  | 2080                  | 1783                  | 1821                  | 1624                  |
| Exports           | 1899                  | 1948                  | 1912                  | 1867                  | 1641                  |
| Disappeared       | 8272                  | 7979                  | 7784                  | 7499                  | 7303                  |
| Ending stocks     | 715                   | 759                   | 683                   | 912                   | 734                   |
| <b>Sesame</b>     |                       |                       |                       |                       |                       |
| Opening stocks    | 45                    | 47                    | 50                    | 49                    | 47                    |
| Production        | 653                   | 623                   | 659                   | 667                   | 661                   |
| Imports           | 22                    | 20                    | 17                    | 16                    | 12                    |
| Exports           | 21                    | 20                    | 17                    | 15                    | 13                    |
| Disappeared       | 654                   | 624                   | 662                   | 667                   | 659                   |
| Ending stocks     | 45                    | 45                    | 47                    | 50                    | 49                    |
| <b>Corn</b>       |                       |                       |                       |                       |                       |
| Opening stocks    | 115                   | 92                    | 109                   | 111                   | 125                   |
| Production        | 1346                  | 1331                  | 1264                  | 1262                  | 1240                  |
| Imports           | 450                   | 404                   | 490                   | 390                   | 354                   |
| Exports           | 444                   | 421                   | 417                   | 402                   | 342                   |
| Disappeared       | 1357                  | 1291                  | 1293                  | 1253                  | 1266                  |
| Ending stocks     | 110                   | 115                   | 92                    | 109                   | 111                   |
| <b>Olive</b>      |                       |                       |                       |                       |                       |
| Opening stocks    | 837                   | 770                   | 1076                  | 763                   | 960                   |
| Production        | 1777                  | 1948                  | 1559                  | 2198                  | 1670                  |
| Imports           | 545                   | 589                   | 569                   | 519                   | 732                   |
| Exports           | 543                   | 592                   | 563                   | 515                   | 732                   |
| Disappeared       | 1867                  | 1878                  | 1870                  | 1890                  | 1867                  |
| Ending stocks     | 749                   | 837                   | 770                   | 1076                  | 763                   |
| <b>Palm</b>       |                       |                       |                       |                       |                       |
| Opening stocks    | 2223                  | 2328                  | 2015                  | 1691                  | 1640                  |
| Production        | 10760                 | 10849                 | 9718                  | 8575                  | 7918                  |
| Imports           | 8182                  | 8076                  | 7019                  | 6749                  | 6069                  |
| Exports           | 7957                  | 8264                  | 7120                  | 6463                  | 6146                  |
| Disappeared       | 11347                 | 10766                 | 9304                  | 8538                  | 7790                  |
| Ending stocks     | 1860                  | 2223                  | 2328                  | 2015                  | 1691                  |
| <b>Palmkernel</b> |                       |                       |                       |                       |                       |
| Opening stocks    | 266                   | 182                   | 201                   | 195                   | 184                   |
| Production        | 1427                  | 1419                  | 1236                  | 1126                  | 1030                  |
| Imports           | 978                   | 899                   | 799                   | 772                   | 643                   |
| Exports           | 968                   | 915                   | 837                   | 744                   | 663                   |
| Disappeared       | 1469                  | 1320                  | 1217                  | 1148                  | 1000                  |
| Ending stocks     | 234                   | 266                   | 182                   | 201                   | 195                   |
| <b>Coconut</b>    |                       |                       |                       |                       |                       |
| Opening stocks    | 528                   | 388                   | 573                   | 613                   | 519                   |
| Production        | 3073                  | 3175                  | 2052                  | 2929                  | 3229                  |
| Imports           | 1467                  | 1622                  | 1007                  | 1432                  | 1445                  |
| Exports           | 1434                  | 1596                  | 1223                  | 1449                  | 1467                  |
| Disappeared       | 3148                  | 2972                  | 2872                  | 3011                  | 3113                  |
| Ending stocks     | 485                   | 528                   | 388                   | 573                   | 613                   |

(Continued)

Table 3.172 *Continued*

| Oil               | Oct.-Sept.<br>1990/91 | Oct.-Sept.<br>1989/90 | Oct.-Sept.<br>1988/89 | Oct.-Sept.<br>1987/88 | Oct.-Sept.<br>1986/87 |
|-------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Butter, as fat    |                       |                       |                       |                       |                       |
| Opening stocks    | 1350                  | 1295                  | 1483                  | 2057                  | 2257                  |
| Production        | 6569                  | 6555                  | 6339                  | 6199                  | 6295                  |
| Imports           | 1172                  | 1062                  | 1249                  | 1640                  | 1372                  |
| Exports           | 1175                  | 1054                  | 1261                  | 1821                  | 1367                  |
| Disappeared       | 6601                  | 6508                  | 6514                  | 6792                  | 6501                  |
| Ending stocks     | 1315                  | 1350                  | 1295                  | 1483                  | 2057                  |
| Lard              |                       |                       |                       |                       |                       |
| Opening stocks    | 323                   | 320                   | 351                   | 345                   | 322                   |
| Production        | 5576                  | 5457                  | 5409                  | 5409                  | 5221                  |
| Imports           | 518                   | 518                   | 540                   | 534                   | 504                   |
| Exports           | 518                   | 519                   | 531                   | 518                   | 508                   |
| Disappeared       | 5568                  | 5453                  | 5450                  | 5420                  | 5193                  |
| Ending stocks     | 331                   | 323                   | 320                   | 351                   | 345                   |
| Fish oil          |                       |                       |                       |                       |                       |
| Opening stocks    | 359                   | 530                   | 300                   | 451                   | 457                   |
| Production        | 1439                  | 1442                  | 1717                  | 1402                  | 1488                  |
| Imports           | 758                   | 812                   | 1062                  | 734                   | 878                   |
| Exports           | 736                   | 841                   | 971                   | 822                   | 839                   |
| Disappeared       | 1479                  | 1584                  | 1579                  | 1463                  | 1534                  |
| Ending stocks     | 341                   | 359                   | 530                   | 300                   | 451                   |
| Linseed           |                       |                       |                       |                       |                       |
| Opening stocks    | 102                   | 111                   | 137                   | 154                   | 100                   |
| Production        | 675                   | 648                   | 637                   | 738                   | 830                   |
| Imports           | 228                   | 219                   | 224                   | 273                   | 297                   |
| Exports           | 230                   | 224                   | 200                   | 273                   | 305                   |
| Disappeared       | 662                   | 651                   | 688                   | 756                   | 768                   |
| Ending stocks     | 112                   | 102                   | 111                   | 137                   | 154                   |
| Castor            |                       |                       |                       |                       |                       |
| Opening stocks    | 77                    | 71                    | 91                    | 139                   | 134                   |
| Production        | 482                   | 401                   | 366                   | 331                   | 385                   |
| Imports           | 241                   | 211                   | 182                   | 168                   | 193                   |
| Exports           | 249                   | 201                   | 188                   | 159                   | 197                   |
| Disappeared       | 447                   | 404                   | 380                   | 388                   | 376                   |
| Ending stocks     | 105                   | 77                    | 71                    | 91                    | 139                   |
| Tallow and grease |                       |                       |                       |                       |                       |
| Opening stocks    | 522                   | 547                   | 537                   | 505                   | 511                   |
| Production        | 6743                  | 6657                  | 6644                  | 6743                  | 6356                  |
| Imports           | 2650                  | 2738                  | 2835                  | 2655                  | 2560                  |
| Exports           | 2700                  | 2708                  | 2770                  | 2743                  | 2543                  |
| Disappeared       | 6689                  | 6712                  | 6700                  | 6624                  | 6379                  |
| Ending stocks     | 525                   | 522                   | 547                   | 537                   | 505                   |
| GRAND TOTAL       |                       |                       |                       |                       |                       |
| Opening stocks    | 11087                 | 11016                 | 11997                 | 11394                 | 11481                 |
| Production        | 80195                 | 79717                 | 76127                 | 75556                 | 72433                 |
| Imports           | 25966                 | 26435                 | 24709                 | 24731                 | 33000                 |
| Exports           | 25800                 | 26373                 | 24880                 | 24507                 | 23193                 |
| Disappeared       | 81343                 | 79708                 | 76938                 | 75168                 | 72336                 |
| Ending stocks     | 10106                 | 11087                 | 11016                 | 11997                 | 11394                 |

| Soybean oil        | Palm oil       |        |                  | Rapeseed/Canola oil |        |                 |      |        |
|--------------------|----------------|--------|------------------|---------------------|--------|-----------------|------|--------|
| USA                | 6325           | (5898) | Malaysia         | 6560                | (6095) | China           | 2235 | (1831) |
| Brazil             | 2620           | (2974) | Indonesia        | 3000                | (2413) | India           | 1889 | (1331) |
| Argentina          | 1288           | (1080) | Nigeria          | 630                 | (580)  | Germany         | 1180 | (1042) |
| Japan              | 653            | (680)  | Colombia         | 292                 | (226)  | Japan           | 803  | (763)  |
| Netherlands        | 617            | (609)  | Ivory Coast      | 280                 | (270)  | Canada          | 647  | (488)  |
| Germany            | 482            | (477)  | Thailand         | 270                 | (226)  | UK              | 486  | (420)  |
| China              | 458            | (497)  | Papua New Guinea | 206                 | (138)  | France          | 443  | (412)  |
| Taiwan             | 425            | (407)  | Ecuador          | 147                 | (120)  | Belgium         | 311  | (263)  |
| Spain              | 382            | (418)  | Cameroon         | 107                 | (108)  | Poland          | 258  | (316)  |
| India              | 344            | (246)  | Zaire            | 105                 | (101)  | Netherlands     | 152  | (140)  |
| Sunflower seed oil | Cottonseed oil |        |                  | Peanut oil          |        |                 |      |        |
| Argentina          | 1320           | (1458) | China            | 1112                | (801)  | India           | 1580 | (1850) |
| CIS                | 1952           | (2199) | CIS              | 662                 | (708)  | China           | 1331 | (1199) |
| France             | 557            | (422)  | USA              | 623                 | (438)  | Nigeria         | 167  | (123)  |
| Spain              | 408            | (398)  | Pakistan         | 362                 | (300)  | Senegal         | 152  | (199)  |
| USA                | 364            | (217)  | India            | 314                 | (371)  | USA             | 120  | (75)   |
| Hungary            | 298            | (287)  | Brazil           | 186                 | (154)  | Myanmar (Burma) | 114  | (101)  |
| China              | 283            | (219)  | Turkey           | 132                 | (127)  | Argentina       | 91   | (27)   |
| India              | 283            | (182)  | Argentina        | 75                  | (62)   | Mali            | 72   | (24)   |
| Turkey             | 276            | (407)  | Egypt            | 66                  | (67)   | Sudan           | 72   | (77)   |
| Romania            | 206            | (223)  | Australia        | 58                  | (42)   |                 |      |        |
|                    |                |        | Paraguay         | 58                  | (54)   |                 |      |        |

**Table 3.174** Fatty acid composition and lipid content of edible vegetables<sup>a</sup>: Cruciferae (Nasirulla *et al.*, 1984)

| Fatty acid                        | Chinese cabbage<br>( <i>Brassica chinensis</i> L.) | White cabbage<br>( <i>Brassica oleracea</i> L.<br>var. <i>capitata</i> L. f. <i>alba</i> ) | Savoy<br>( <i>Brassica oleracea</i> L.<br>var. <i>sabauda</i> L.) | Kale<br>( <i>Brassica oleracea</i> L.<br>convar. <i>acephala</i> (DC.)<br>Alef. var. <i>sabellica</i> L.) |
|-----------------------------------|----------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| 10:0                              | tr                                                 | 0.1                                                                                        | 0.1                                                               | tr                                                                                                        |
| 12:0                              | 0.1                                                | 0.2                                                                                        | 0.1                                                               | tr                                                                                                        |
| 14:0                              | 0.4                                                | 0.3                                                                                        | 0.3                                                               | 0.2                                                                                                       |
| 15:0                              | 0.3                                                | 0.4                                                                                        | 0.3                                                               | 0.3                                                                                                       |
| 16:0                              | 0.1                                                | 0.2                                                                                        | 0.2                                                               | 0.2                                                                                                       |
| 16:0                              | 16.1                                               | 14.5                                                                                       | 22.1                                                              | 13.0                                                                                                      |
| 16:1                              | 0.8                                                | 0.9                                                                                        | 0.5                                                               | 0.4                                                                                                       |
| 16:2                              | 0.2                                                | 0.1                                                                                        | 0.1                                                               | —                                                                                                         |
| ( <i>n</i> - 3)-16:3              | 3.0                                                | 1.1                                                                                        | 0.9                                                               | 6.6                                                                                                       |
| 17:0                              | 1.3                                                | 0.4                                                                                        | 2.2                                                               | 4.4                                                                                                       |
| 17:0                              | 0.2                                                | 0.2                                                                                        | 0.2                                                               | 0.3                                                                                                       |
| 18:0                              | 1.9                                                | 1.1                                                                                        | 1.2                                                               | 1.2                                                                                                       |
| ( <i>n</i> - 12)-18:1             | —                                                  | —                                                                                          | —                                                                 | —                                                                                                         |
| ( <i>n</i> - 9)-18:1              | 1.3                                                | 1.3                                                                                        | 0.7                                                               | 0.7                                                                                                       |
| ( <i>n</i> - 7)-18:1              | 5.6                                                | 5.4                                                                                        | 5.7                                                               | 2.3                                                                                                       |
| ( <i>n</i> - 6)-18:2              | 7.5                                                | 14.8                                                                                       | 15.7                                                              | 18.5                                                                                                      |
| ( <i>n</i> - 3)-18:3              | 59.5                                               | 57.0                                                                                       | 46.4                                                              | 50.0                                                                                                      |
| 20:0                              | 0.6                                                | 0.3                                                                                        | 0.8                                                               | 0.3                                                                                                       |
| 20:1                              | 0.3                                                | 0.3                                                                                        | 0.3                                                               | 0.3                                                                                                       |
| ( <i>n</i> - 6)-20:2              | —                                                  | 0.2                                                                                        | 0.3                                                               | 0.1                                                                                                       |
| ( <i>n</i> - 3)-20:2              | —                                                  | 0.1                                                                                        | —                                                                 | 0.2                                                                                                       |
| 22:0                              | 0.3                                                | 0.4                                                                                        | 0.7                                                               | 0.2                                                                                                       |
| ( <i>n</i> - 9)-22:1              | —                                                  | tr                                                                                         | —                                                                 | 0.3                                                                                                       |
| 24:0                              | 0.4                                                | 0.2                                                                                        | 0.5                                                               | 0.2                                                                                                       |
| 24:1                              | 0.3                                                | 0.6                                                                                        | 0.8                                                               | 0.3                                                                                                       |
| Plant total lipids<br>(% of mass) | 0.21                                               | 0.12                                                                                       | 0.21                                                              | 0.15                                                                                                      |

<sup>a</sup> Composition of total lipid extracted from edible parts of the vegetable, i.e. roots, stems, leaves, flowers, as appropriate.

| Red cabbage<br>( <i>Brassica oleracea</i> L.<br>var. <i>capitata</i> L. f. <i>rubra</i> ) | Brussels sprouts<br>( <i>Brassica oleracea</i> L.<br>var. <i>gemmifera</i> DC.) | Cauliflower<br>( <i>Brassica oleracea</i> L.<br>convar. <i>botrytis</i><br>var. <i>botrytis</i> L.) | Kohlrabi<br>( <i>Brassica oleracea</i> L.<br>convar. <i>acephala</i><br>var. <i>gongylodes</i> L.) | Swede<br>( <i>Brassica napus</i> L.<br>var. <i>napobrassica</i> L.) |
|-------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| —                                                                                         | 0.1                                                                             | —                                                                                                   | 0.1                                                                                                | 0.1                                                                 |
| 0.1                                                                                       | 0.2                                                                             | 0.1                                                                                                 | 0.2                                                                                                | 0.4                                                                 |
| 0.2                                                                                       | 0.5                                                                             | 0.2                                                                                                 | 0.3                                                                                                | 0.4                                                                 |
| 0.5                                                                                       | 0.4                                                                             | 0.4                                                                                                 | 0.4                                                                                                | 0.6                                                                 |
| tr                                                                                        | tr                                                                              | tr                                                                                                  | 0.1                                                                                                | 0.3                                                                 |
| 18.6                                                                                      | 14.5                                                                            | 17.4                                                                                                | 20.8                                                                                               | 14.5                                                                |
| 0.6                                                                                       | 0.5                                                                             | 1.7                                                                                                 | 1.6                                                                                                | 2.3                                                                 |
| 0.1                                                                                       | —                                                                               | 0.4                                                                                                 | 0.1                                                                                                | 0.2                                                                 |
| 0.4                                                                                       | 4.1                                                                             | 0.5                                                                                                 | 0.5                                                                                                | 0.3                                                                 |
| 0.3                                                                                       | 1.8                                                                             | 0.6                                                                                                 | 0.3                                                                                                | 0.4                                                                 |
| 0.5                                                                                       | 0.2                                                                             | 0.3                                                                                                 | 0.3                                                                                                | 0.4                                                                 |
| 1.9                                                                                       | 0.9                                                                             | 1.7                                                                                                 | 1.9                                                                                                | 0.7                                                                 |
| —                                                                                         | —                                                                               | —                                                                                                   | —                                                                                                  | —                                                                   |
| 0.5                                                                                       | 0.6                                                                             | 0.8                                                                                                 | 4.2                                                                                                | 0.6                                                                 |
| 2.9                                                                                       | 3.1                                                                             | 11.9                                                                                                | 6.0                                                                                                | 6.8                                                                 |
| 29.9                                                                                      | 11.4                                                                            | 12.8                                                                                                | 17.9                                                                                               | 20.7                                                                |
| 39.8                                                                                      | 58.7                                                                            | 48.9                                                                                                | 41.9                                                                                               | 50.8                                                                |
| 1.0                                                                                       | 1.6                                                                             | 0.5                                                                                                 | 1.3                                                                                                | —                                                                   |
| 0.6                                                                                       | 0.4                                                                             | 0.4                                                                                                 | 0.3                                                                                                | 0                                                                   |
| tr                                                                                        | 0.2                                                                             | —                                                                                                   | —                                                                                                  | —                                                                   |
| 0.1                                                                                       | 0.2                                                                             | 0.2                                                                                                 | —                                                                                                  | —                                                                   |
| 0.5                                                                                       | 0.1                                                                             | 0.2                                                                                                 | 0.4                                                                                                | —                                                                   |
| —                                                                                         | —                                                                               | 0.3                                                                                                 | —                                                                                                  | —                                                                   |
| 1.0                                                                                       | 0.2                                                                             | 0.3                                                                                                 | 1.1                                                                                                | 0.2                                                                 |
| 0.5                                                                                       | 0.3                                                                             | 0.4                                                                                                 | 0.3                                                                                                | 0.1                                                                 |
| 0.15                                                                                      | 0.18                                                                            | 0.28                                                                                                | 0.12                                                                                               | 0.17                                                                |

**Table 3.175** Fatty acid composition and lipid content of edible vegetables<sup>a</sup>: Asteraceae and Apiaceae (Nasirulla *et al.*, 1984)

| Fatty acid                        | Cabbage lettuce<br>( <i>Lactuca sativa</i> L.) | Parsley<br>( <i>Petroselinum crispum</i> (Mill.)<br>Nym. subsp. <i>crispum</i> ) | Black salsify<br>( <i>Scorzonera hispanica</i> L.) |
|-----------------------------------|------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------|
| 10:0                              | tr                                             | tr                                                                               | tr                                                 |
| 12:0                              | 0.1                                            | 0.1                                                                              | tr                                                 |
| 14:0                              | 0.4                                            | 0.3                                                                              | 0.3                                                |
| 15:0                              | 0.2                                            | 0.2                                                                              | 0.7                                                |
| 16:0                              | 0.1                                            | tr                                                                               | —                                                  |
| 16:0                              | 13.9                                           | 12.8                                                                             | 34.4                                               |
| 16:1                              | 1.4                                            | 1.7                                                                              | 2.9                                                |
| 16:2                              | —                                              | —                                                                                | 0.8                                                |
| ( <i>n</i> - 3)-16:3              | 0.1                                            | 11.8                                                                             | —                                                  |
| 17:0                              | 0.1                                            | 0.3                                                                              | —                                                  |
| 17:0                              | 0.2                                            | 0.2                                                                              | 0.3                                                |
| 17:1                              | —                                              | —                                                                                | 0.1                                                |
| 18:0                              | 0.7                                            | 0.6                                                                              | 1.1                                                |
| ( <i>n</i> - 12)-18:1             | —                                              | tr                                                                               | —                                                  |
| ( <i>n</i> - 9)-18:1              | 0.6                                            | 0.6                                                                              | 0.5                                                |
| ( <i>n</i> - 7)-18:1              | 0.3                                            | 0.2                                                                              | 1.4                                                |
| ( <i>n</i> - 6)-18:2              | 23.0                                           | 25.6                                                                             | 44.4                                               |
| ( <i>n</i> - 3)-18:3              | 54.6                                           | 41.7                                                                             | 10.0                                               |
| 20:0                              | 0.4                                            | 0.6                                                                              | 0.9                                                |
| 20:1                              | 0.6                                            | 0.3                                                                              | tr                                                 |
| ( <i>n</i> - 6)-20:2              | 0.2                                            | 0.3                                                                              | 0.1                                                |
| ( <i>n</i> - 3)-20:3              | 0.2                                            | 0.1                                                                              | —                                                  |
| 22:0                              | 0.9                                            | 1.1                                                                              | 0.7                                                |
| ( <i>n</i> - 9)-22:1              | 0.1                                            | —                                                                                | tr                                                 |
| 24:0                              | 1.3                                            | 1.4                                                                              | 0.6                                                |
| 24:1                              | 0.6                                            | 0.1                                                                              | 0.8                                                |
| Plant total lipids<br>(% of mass) | 0.11                                           | 0.33                                                                             | 0.38                                               |

<sup>a</sup> Composition of total lipid extracted from edible parts of the vegetable, i.e. roots, stems, leaves, flowers, as appropriate.

| Carrot<br>( <i>Daucus carota</i> L.<br>subsp. <i>sativus</i><br>(Hoffm.) Arcang.) | Turnip-rooted parsley<br>( <i>Petroselinum crispum</i> (Mill.)<br>Nym. subsp. <i>tuberosum</i> Soo) | Florence fennel<br>( <i>Foeniculum vulgare</i> Mill.<br>var. <i>azoricum</i><br>(Mill.) Thell.) |
|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| —                                                                                 | —                                                                                                   | 0.1                                                                                             |
| 0.1                                                                               | 0.1                                                                                                 | 0.2                                                                                             |
| 0.2                                                                               | 0.1                                                                                                 | 0.2                                                                                             |
| 0.5                                                                               | 0.5                                                                                                 | 0.9                                                                                             |
| —                                                                                 | —                                                                                                   | —                                                                                               |
| 20.2                                                                              | 19.6                                                                                                | 20.6                                                                                            |
| tr                                                                                | 0.3                                                                                                 | 0.2                                                                                             |
| —                                                                                 | —                                                                                                   | —                                                                                               |
| —                                                                                 | —                                                                                                   | —                                                                                               |
| 0.2                                                                               | 0.2                                                                                                 | —                                                                                               |
| 0.5                                                                               | 0.3                                                                                                 | 0.4                                                                                             |
| 0.2                                                                               | 0.3                                                                                                 | 0.1                                                                                             |
| 1.3                                                                               | 0.4                                                                                                 | 1.4                                                                                             |
| —                                                                                 | 0.7                                                                                                 | —                                                                                               |
| 2.1                                                                               | 4.0                                                                                                 | 2.2                                                                                             |
| 0.5                                                                               | 1.5                                                                                                 | 0.3                                                                                             |
| 65.5                                                                              | 61.8                                                                                                | 62.8                                                                                            |
| 6.0                                                                               | 8.5                                                                                                 | 5.9                                                                                             |
| 0.5                                                                               | 0.3                                                                                                 | 0.8                                                                                             |
| 0.4                                                                               | 0.6                                                                                                 | 0.4                                                                                             |
| 0.2                                                                               | —                                                                                                   | 0.3                                                                                             |
| —                                                                                 | —                                                                                                   | —                                                                                               |
| 1.0                                                                               | 0.7                                                                                                 | 2.1                                                                                             |
| —                                                                                 | —                                                                                                   | —                                                                                               |
| 0.5                                                                               | tr                                                                                                  | 1.1                                                                                             |
| —                                                                                 | —                                                                                                   | —                                                                                               |
| 0.25                                                                              | 0.60                                                                                                | 0.15                                                                                            |

## References and further reading

- Abou-Donia, M.B. (1976) *Resid. Rev.*, **61**, 125.
- Abou-Donia, S.A., Lasker, J.M. and Abou-Donia, M.B. (1981) *J. Chromatogr.*, **206**, 606.
- Achaya, K.T. (1971) *J. Am. Oil Chem. Soc.*, **48**, 758.
- Achaya, K.T. and Craig, B.M. (1964) *J. Am. Oil Chem. Soc.*, **41**, 783.
- Ackman, R.G. (1990) in *Canola Rapeseed* (ed. F. Shahidi), Van Nostrand Reinhold, New York, p. 81.
- Adomako, D. (1985) *Tech. Bull. Cocoa Res. Inst. Ghana*, **11**, 12.
- Afaque, S., Rauf, A., Khan, M. and Osman, S.M. (1987) *J. Oil Technol. Assoc. India*, **19**, 78.
- Ali, M.A., Gafur, M.A., Rahman, M.S. and Ahmed, G.M. (1985) *J. Am. Oil Chem. Soc.*, **62**, 520.
- Allen, R.R. (1965) *Chem. Ind.*, 1560.
- Al-Saleh, A., Marion, D. and Gallant, D.J. (1986) *Food Microstruct.*, **5**, 131.
- Alvim, R. (1989) *Agrotropica*, **1**, 89.
- American Oil Chemists' Society (1941) *Oil Soap*, **18**, 194.
- American Oil Chemists' Society (1946) *Official and Tentative Methods*, AOCS, Chicago, p. 1, table 1.
- Ames, I.A. (1989) *J. Am. Coll. Nutr.*, **8**, 360.
- Andersson, G. (1981) *Fette Seifen Anstrichm.*, **83**, 1.
- Anizewski, T. (1993) *J. Sci. Food Agric.*, **61**, 409.
- Anon. (1985) *Zucker Suesswaren*, **38**, 19.
- Appelqvist, L.A. (1966) *Acta Agric. Scand. Suppl.*, **16**, 215.
- Appelqvist, L.A. and Ohlsen, R. (1972) *Rapeseed*, Elsevier, Amsterdam, p. 50.
- Applewhite, T.H. (1981) *J. Am. Oil Chem. Soc.*, **58**, 260.
- Archer-Daniels-Midland (1961) *Composition and Constants of Natural Fats and Oils by Gas-Liquid Chromatography*, Chart, Archer-Daniels-Midland, Minneapolis, 1961.
- Arkcoll, D. (1988) *Econ. Bot.*, **42**, 195.
- Awe, W. (1937) *Dtsch. Apoth. Ztg.*, **52**, 750.
- Ayres, J.L. (1983) *J. Am. Oil Chem. Soc.*, **60**, 357.
- Badifu, G.I.O. (1989) *J. Food Compos. Anal.*, **2**, 238.
- Bafor, M., Stobart, A.K. and Stymne, S. (1990) *J. Am. Oil Chem. Soc.*, **67**, 217.
- Bailey, A.E. (1948) *Cottonseed and Cottonseed Products*, Interscience, New York.
- Bailey, A.V., Harris, J.A. and Skau, E.L. (1966) *J. Am. Oil Chem. Soc.*, **43**, 107.
- Balick, M.J. (1981) in *New Sources of Fats and Oils* (eds E.H. Pryde, L.H. Princen and K.D. Mukherjee), American Oil Chemists' Society, Champaign, p. 141.
- Bamford, H.L., Gardiner, K.J., Howat, J.R. and Thomson, A.F. (1970) *Confect. Prod.*, 359.
- Banzon, J.A. (1980) *Phil. J. Coco. Stud.*, **5**, 47.
- Barger, W.M. (1981) *J. Am. Oil Chem. Soc.*, **58**, 154.
- Barnes, P.J. (1982) *Fette Seifen Anstrichm.*, **84**, 256.
- Barnes, P.J. and Taylor, P.W. (1980) *J. Sci. Food Agric.*, **31**, 997.
- Belvadi, V.K., Kamat, P.L., Mehta, D.T., Bhaskar, A. and Bringi, N.V. (1979) *J. Oil Tech. Assoc. India*, **11**, 3.
- Bemis, W.P., Berry, J.W., Weber, C.W. and Whitaker, T.W. (1978) *Hort. Sci.*, **13**, 235.
- Berger, K.G. (1977) *Oil Palm News*, **22**, 10.
- Berger, K.G. (1983) *J. Am. Oil Chem. Soc.*, **60**, 206.
- Berger, K.G. (1987) *Chem. Ind.*, 846.
- Berger, K.G. and Ong, S.H. (1985) *Oleagineux*, **40**, 613.
- Berman, L.U. and Loeb, M.L. (1975) in *Dimer Acids* (ed. E.C. Leonard), Humko Sheffield Chemical, Memphis, p. 9.
- Bernardini, M. (1978) *Oleagineux*, **33**, 297.
- Beroza, M. and Kinman, M.L. (1955) *J. Am. Oil Chem. Soc.*, **32**, 348.
- Best, R.L., Crossley, A., Paul, S., Pardun, H. and Soeters, J. (1956) Br. Pat. 827172.
- Beuchat, L.R. and Worthington, R.E. (1978) *J. Food Technol.*, **13**, 355.
- Bezard, J.A. (1971) *Lipids*, **6**, 630.
- Bezard, J.A., Begaut, M. and Clement, G. (1971) *J. Am. Oil Chem. Soc.*, **48**, 134.
- Bhatnagar, S., Polonsky, J., Prange, T. and Pascard, C. (1983) *Tetrahedron Lett.*, **25**, 299.
- Bhuyan, L.P. and Mahanta, P.K. (1989) *J. Sci. Food Agric.*, **46**, 325.
- Blanchini, J.P., Ralaimarivo, A. and Gaydou, E.M. (1981) *Anal. Chem.*, **53**, 2194.
- Body, D.R. and Shorland, F.B. (1965) *J. Am. Oil Chem. Soc.*, **42**, 5.
- Bolley, D.S. and McCormack, R.H. (1950) *J. Am. Oil Chem. Soc.*, **27**, 84.
- Bracco, U. (1973) *Agosto*, **2**, 145.
- Bringi, N.V. (1987) *Non Traditional Oilseeds and Oils of India*, Oxford and IBH, New Delhi.
- Bringi, N.V., Padley, F.B. and Timms, R.E. (1972) *Chem. Ind.*, 805.
- Brockhoff, H. and Hoyle, R.J. (1963) *Arch. Biochem. Biophys.*, **102**, 452.
- Brockhoff, H. and Yurkowski, M. (1966) *J. Lipid Res.*, **7**, 62.
- Brockhoff, H., Hoyle, R.J. and Wolmark, N. (1966) *Biochim. Biophys. Acta*, **116**, 67.
- Bruckner, G. (1992) in *Fatty Acids in Foods and Their Health Implications* (ed. C.K. Chow), Marcel Dekker, New York.
- Brun, J.H. and Matchett, J.R. (1963) *J. Am. Oil Chem. Soc.*, **40**, 1.
- Budowski, P. (1964) *J. Am. Oil Chem. Soc.*, **41**, 280.
- Budowski, P. and Markley, K.S. (1951) *Chem. Rev.*, **48**, 125.
- Canola Council of Canada (1981) *Canola, A New Oilseed for Canada*, Winnipeg.
- Carlson, K.D., Schneider, W.J., Chang, S.P. and Princen, L.H. (1981) in *New Sources of Oils and Fats* (eds E.H. Pryde, L.H. Princen and K.D. Mukherjee), American Oil Chemists' Society, Champaign, p. 297.
- Carlson, K.D., Baker, E.C. and Mustakas, G.C. (1985) *J. Am. Oil Chem. Soc.*, **62**, 897.
- Carpenter, A.P. (1979) *J. Am. Oil Chem. Soc.*, **56**, 668.
- Cebula, D., Dilley, K.M. and Smith, K.W. (1991) *Manuf. Confect.*, May, 131.
- Chaiseri, S. and Dimick, P.S. (1989) *J. Am. Oil Chem. Soc.*, **66**, 1772.
- Chakrabarty, M.M. (1979) Private communication.
- Chapman, G.M., Akehurst, E.E. and Wright, W.B. (1971) *J. Am. Oil Chem. Soc.*, **48**, 824.

- Chapman, G.W. (1980) *J. Am. Oil Chem. Soc.*, **59**, 299.
- Chaveron, H. and Verdoia, C. (1985) *Ann. Fals. Exp. Chim. Toxicol.*, **77**, 401.
- Cherry, J.P. (1983) *J. Am. Oil Chem. Soc.*, **60**, 312A.
- Child, R. (1964) *Coconuts*, Longmans Green, London.
- Christie, W.W. (1969) *Biochim. Biophys. Acta*, **187**, 1.
- Cloughley, J.B. (1983) *Trop. Agric. (Trinidad)*, **60**, 139.
- Cobley, L.S. (1956) *An Introduction to the Botany of Tropical Crops*, Longmans Green, London, p. 128.
- Codex (1969) Codex Alimentarius Commission, Recommended Standard, CAC/RS 27-1969.
- Codex (1970a) Codex Alimentarius Commission, Document CAC/RS 33-1970: Recommended International Standard for Olive Oil, Virgin and Refined and for Refined Olive Oil Residue.
- Codex (1970b) Codex Alimentarius Commission Report CAC/RS 34-1970.
- Codex (1979) Codex Alimentarius Commission Report, 13th Session, 3-14 December (Report of the 10th Session of the Codex Committee on Fats and Oils, London, 4-8 December 1978), Alinorm 79/17.
- Codex (1983) Codex Alimentarius Commission Report, (14th Session) (Report of the 12th Session of the Codex Committee on Fats and Oils, April 1982), Alinorm 83/17.
- Codex (1983) Codex Alimentarius Commission Report (Report of the 14th Session of the Codex Committee on Fats and Oils, September 1983, London), Alinorm 95/17.
- Coenen, J.W.E. (1976) *J. Am. Oil Chem. Soc.*, **53**, 382.
- Conte, L.S., Moschetta, M. and Capella, P. (1984) *Riv. Ital. Sost. Grasse*, **61**, 563.
- Corley, R.H.V. (1981) *J. Perak Planters' Assoc.*, **35**.
- Corley, R.H.V., Wong, C.Y., Wooi, K.C. and Jones, L.H. (1981) in *Oil Palm in Agriculture in the Eighties*, Incorporated Society of Planters, Kuala Lumpur.
- Cornelius, J.A. (1977) *Prog. Chem. Fats Other Lipids*, **15**, 5.
- Cornelius, J.A. and Raymond, W.D. (1967) *Trop. Sci.*, **9**, 75.
- Cornelius, J.A. and Simmons, E.A. (1969) *Trop. Sci.*, **11**, 17.
- Cottrell, R.C. (1991) *Am. J. Clin. Nutr.*, **53**, 989S.
- Craig, B.M. (1953) *J. Am. Oil Chem. Soc.*, **31**, 202.
- Craig, B.M., Mallard, T.M., Wight, R.E., Irvine, G.M. and Reynolds, J.R. (1973) *J. Am. Oil Chem. Soc.*, **50**, 395.
- Crawford, R.V. (1982) *Food Proc. Ind.*, **24**.
- Culp, T.W., Harlow, F.D., Litchfield, C. and Reiser, R. (1965) *J. Am. Oil Chem. Soc.*, **42**, 974.
- Curz Madueno, E. (1985) *Aliment. Equipos. Technol.*, **4**, 61.
- D'Alonzo, R.P., Kozarek, W.H. and Wharton, H.W. (1981) *J. Am. Oil Chem. Soc.*, **58**, 215.
- D'Alonzo, R.P., Kozarek, W.J. and Wade, R.L. (1982) *J. Am. Oil Chem. Soc.*, **59**, 292.
- Davies, S.B., Conroy, E.A. and Shakespeare, N. (1950) *J. Am. Chem. Soc.*, **72**, 124.
- de Jong, S., van Soest, T.C. and van Schick, M.A. (1991) *J. Am. Oil Chem. Soc.*, **68**, 371.
- de la Roche, I.A., Weber, E.J. and Alexander, D.E. (1971) *Lipids*, **6**, 531.
- Derbesy, M. and Richert, M.T. (1979) *Oleagineux*, **34**, 405.
- Dietz, H. and Harris, R.V. (1990) *Food Control*, **1**, 84.
- Dillman, A.C. and Hopper, P.H. (1943) *US Dept of Agriculture, Technical Bulletin*, No. 844.
- Downey, R.K. (1971) *J. Am. Oil Chem. Soc.*, **48**, 718.
- Downey, R.K., Craig, B.M. and Youngs, C.G. (1969) *J. Am. Oil Chem. Soc.*, **46**, 121.
- Downey, R.K., Stringham, G.R. and MacGregor, D.I. (1975) in *Oil Seed and Pulse Crops in Western Canada* (ed. J.T. Harapiak), Western Co-operative Fertilisers Ltd, Calgary, p. 157.
- Duce, S.L., Carpenter, T.A. and Hall, L.D. (1990) *Lebensm. Wiss. Technol.*, **23**, 545.
- Duck, W. (1967) *Gordian*, **67**, 28.
- du Plessis, L.M., Van Twisk, P., van Niekerk, P.J. and Steyn, M. (1981) *J. Am. Oil Chem. Soc.*, **58**, 575.
- Dupont, J., White, P.J., Carpenter, M.P., Schaefer, E.J., Meydani, S.N., Elson, C.E., Woods, M. and Gorbach, S.L. (1990) *J. Am. Coll. Nutr.*, **9**, 438.
- Dutton, H. and Emken, E.A. (1979) *Geometrical and Positional Fatty Acid Isomers*, American Oil Chemists' Society, Champaign.
- Earle, F.R. and Jones, Q. (1962) *Econ. Bot.*, **16**, 221.
- Earle, F.R., Peters, J.E. and Wolff, I.A. (1966) *J. Am. Oil Chem. Soc.*, **43**, 330.
- Earle, F.R., Vanetten, C.H., Clark, T.F. and Wolff, I.A. (1968) *J. Am. Oil Chem. Soc.*, **45**, 876.
- Eckey, E.W. (1954) *Vegetable Fats and Oils*, Reinhold, New York, p. 556.
- Eigtved, P. (1992) *Adv. Appl. Lipid Res.*, **1**, 1. (Ed. F.B. Padley), JAI Press, London, NY.
- Elson, C.E. (1992) *Crit. Rev. Food Sci. Nutr.*, **32**, 79.
- El Tinay, A.H., Khattab, A.H. and Khidir, M.O. (1976) *J. Am. Oil Chem. Soc.*, **53**, 648.
- Erickson, D.R., Pryde, E.H., Brekke, O.L., Mounts, T.L. and Falb, R.A. (eds) (1980) *Handbook of Soy Oil Processing and Utilisation*, American Soybean Association and American Oil Chemists' Society, Champaign.
- Evans, C.D., McConnell, D.G., Hoffman, R.L. and Peters, H. (1967) *J. Am. Oil Chem. Soc.*, **44**, 281.
- Fedeli, E. (1977) *Prog. Chem. Fats Other Lipids*, **15**, 57.
- Fedeli, E. (1983) *J. Am. Oil Chem. Soc.*, **60**, 356A.
- Fedeli, E., Lanzani, A., Capella, P. and Jacini, G. (1966) *J. Am. Oil Chem. Soc.*, **43**, 254.
- Feldheim, W. (1991) *Proc. 6th International Lupin Conference*, Temuco-Pucon, Chile, p. 124.
- Fellers, D.A. (1991) *Food Rev. Int.*, **7**, 445.
- Ficke, G.N. (1983) *J. Am. Oil Chem. Soc.*, **60**, 1252.
- Fincke, A. (1976) *Gordian*, **76**, 324.
- Fincke, A. (1980) *Dtsch. Lebens. Rundsch.*, **76**, 162.
- Fincke, A. (1982) *Gordian*, **82**, 246.
- Fisher, G.S. and Schuller, W.M. (1981) *J. Am. Oil Chem. Soc.*, **58**, 943.
- Flament, I., Willhelm, B. and Stoll, M. (1968) *Helv. Chim. Acta*, **50**, 2223.
- Food and Drug Administration (1976) *Evaluation of the Health Aspects of Hydrogenated Soybean Oil as a Food Ingredient*, Prepared for FDA by Federation of American Societies for Experimental Biology.

- Foster, L.J. (1963) *World Crops*, 15, 220.
- Francois, L.E. and Kleiman, R. (1990) *Agron. J.*, 82, 1110.
- Frega, N., Bocci, F., Conte, L.S. and Teta, F. (1991) *J. Am. Oil Chem. Soc.*, 68, 29.
- Fritsch, C.W., Weiss, V.E. and Anderson, R.H. (1971) *J. Am. Oil Chem. Soc.*, 48, 392.
- Froyd, D.E. (1966) *Polyamide Resins*, 2nd edn, Reinhold, New York.
- Fuller, G. (1966) *J. Am. Oil Chem. Soc.*, 43, 477.
- Fuller, G., Diamond, M.J. and Applewhite, T.H. (1967) *J. Am. Oil Chem. Soc.*, 44, 264.
- Gandhi, V.M., Cherian, K.M. and Mulky, M.J. (1976) *J. Oil Tech. Assoc. India*, 8, 65.
- Gapor, A.B., Top, M.D., Berger, K.G., Hashimoto, T., Kato, A., Tanabe, K., Mamuro, H. and Yamoaka, M. (1981) *Int. Conf. on Palm Oil Product Technology in the Eighties*, June 1981, Kuala Lumpur.
- Gapor, A.B., Akio, K. and Ong, A.S.H. (1991) *Yukagaku*, 40, 554.
- Gardner, H.A. (1943) *Natl Paint Varnish Lacquer Assoc. Circ. No. 654*, p. 28.
- Gaydou, E.M. and Raonizafinimanana, R. (1980) *J. Am. Oil Chem. Soc.*, 57, 141.
- Glumac, E. and Cowles, J. (1990) *Advances in New Crops, Proc. 1st Natl Symp. on New Crops*, Indianapolis, October 1988 (eds J. Janick and J.E. Simon), Timber Press, Portland, OR, p. 268.
- Goh, S.H., Khor, H.T. and Gee, P.T. (1982) *J. Am. Oil Chem. Soc.*, 59, 296.
- Gopalakrishna, A.G. and Prabhakar, J.V. (1983) *J. Am. Oil Chem. Soc.*, 60, 968.
- Gordon, M.H., Padley, F.B. and Timms, R.E. (1979) *Fette Seifen Anstrichm.*, 81, 116.
- Gracian, J. and Martel, J. (1969) *Grasas Aceites*, 20, 231.
- Graef, G.L., Fehr, W.R. and Hammond, E.G. (1985) *Crop Sci.*, 25, 1076.
- Graham, S.A. (1989) *Crit. Rev. Food Sci. Nutr.*, 28, 139.
- Graham, S.A., Hirsinger, F. and Robbelen, G. (1981) *Am. J. Bot.*, 68, 908.
- Grami, B. and Stefansson, B.R. (1977) *Can. J. Plant Sci.*, 57, 625.
- Green, A.G. (1988) *Proc. World Conf. on Biotechnology for the Fats and Oils Industry, 1987* (ed. T.H. Applewhite), American Oil Chemists' Society, Champaign.
- Grist, D.H. (1961) *World Crops*, 13, 154.
- Grossberger, T. and Rothschild, E. (1989) *LC-GC Int.*, 2, 44, 47-8.
- Gunstone, F.D. (1954) *J. Chem. Soc.*, 1611.
- Gunstone, F.D. (1987) *Palm Oil*, Wiley, Chichester.
- Gunstone, F.D. (1992) *Prog. Lipid Res.*, 31, 145.
- Gunstone, F.D. and Padley, F.B. (1965) *J. Am. Oil Chem. Soc.*, 42, 957.
- Gunstone, F.D. and Padley, F.B. (1967) *Chem. Phys. Lipids*, 1, 429.
- Gunstone, F.D. and Qureshi, M.I. (1965) *J. Am. Oil Chem. Soc.*, 42, 961.
- Gunstone, F.D., Hamilton, R.J., Padley, F.B. and Qureshi, M.I. (1965) *J. Am. Oil Chem. Soc.*, 42, 965.
- Gupta, S.S. and Meara, M.L. (1950) *J. Chem. Soc.*, 1337.
- Gutfinger, T. (1981) *J. Am. Oil Chem. Soc.*, 58, 966.
- Hachiya, I., Koyano, T. and Sato, K. (1989) *J. Am. Oil Chem. Soc.*, 66, 1757.
- Hageman, J.W. and Rothfus, J.A. (1992) *J. Am. Oil Chem. Soc.*, 69, 429.
- Halphen, G. (1897) *J. Pharm.*, 6, 390.
- Hammond, E.G. and Fehr, W.R. (1984) *J. Am. Oil Chem. Soc.*, 61, 1713.
- Hammons, R.O. (1981) *Proc. Am. Peanut Res. Educ. Assoc.*, 13, 12.
- Hancock, J. and Houghton, C. (1990) *Lipid Technol.*, 2, 90.
- Hartley, C.W.S. (1977) *The Oil Palm*, Longmans, London.
- Harwood, J.L. (1991) *Chem. Ind.*, 753.
- Hess, D.C. (1977) *Cereal Foods World*, 22, 98.
- Hilditch, R.P. and Williams, P.N. (1964) *The Chemical Constitution of Natural Fats*, Chapman and Hall, London.
- Hirsinger, F. (1985) *J. Am. Oil Chem. Soc.*, 62, 76.
- Holmbom, B. (1977) *J. Am. Oil Chem. Soc.*, 54, 289.
- Holmbom, B. (1978) *J. Am. Oil Chem. Soc.*, 55, 876.
- Homberg, V.E. and Bielefeld, B. (1989) *Fat Sci. Technol.*, 91, 23.
- Hopkins, D.T., Dahlgren, R.R., Davis, D., Munson, A.W. and Dupuy, H.P. (1973) *J. Am. Oil Chem. Soc.*, 50, 381.
- Hopper, T.H. and Nesbitt, L.L. (1937) *Oil Soap*, 14, 34.
- Horrobin, D.F. (ed.) (1982) *Clinical Uses of Essential Fatty Acids*, Eden, Montreal.
- Horrobin, D.F. (1992) *Prog. Lipid Res.*, 31, 163.
- Horrobin, D.F. and Manku, M.S. (1989) *Prost. Leuk. Ess. Fatty Acids*, 37, 255.
- Howell, R.W. and Collins, R.I. (1957) *Agron. J.*, 49, 593.
- Huang, A.S., Hsieh, O.A., Huang, C.L. and Chang, S.S. (1981) *J. Am. Oil Chem. Soc.*, 58, 997.
- Hudson, B.J.F. (1984) *J. Am. Oil Chem. Soc.*, 61, 540.
- Hulsker, F.H., de Jong, K. and Turksma, H. (1989) *Eur. Pat. Appl. EP0321056A*.
- Hyer, A. (1966) *Breeding for glandless cotton in California, Cotton Gin Oil Mill Press*, 67, 10, 14.
- INFORM (1990) 1, 1, 934, 944.
- INFORM (1991) 2, 692.
- Itagaki, K., Yanagihara, T., Maruzeni, S. and Yasuda, N. (1989) *Eur. Pat. Appl. EP 304493A*.
- Itoh, T., Tamura, T. and Matsumoto, T. (1973a) *J. Am. Oil Chem. Soc.*, 50, 122.
- Itoh, T., Tamura, T. and Matsumoto, T. (1973b) *J. Am. Oil Chem. Soc.*, 50, 300.
- Itoh, T., Tamura, T. and Matsumoto, T. (1974) *Oleagineux*, 29, 253.
- Jacobsberg, B. (1975) *Oleagineux*, 30, 271.
- Jeffery, M.S. (1991) *Manuf. Confect.*, 71, 76.
- Jeffrey, B.S.J. (1991) *J. Am. Oil Chem. Soc.*, 68, 289.
- Jeffrey, B.S.J. and Padley, F.B. (1991) *J. Am. Oil Chem. Soc.*, 68, 123.
- Jewell, G.G. and Bradford, L. (1981) *Manuf. Confect.*, 26.
- Johnson, R.W. (1979) in *Fatty Acids* (ed. E.H. Pryde), American Oil Chemists' Society, Champaign, chap. 17.
- Johnson, R.W. and Pryde, E.H. (1979) in *Fatty Acids* (ed. E.H. Pryde), American Oil Chemists' Society, Champaign, chap. 16.

- Jones, L.H. (1974) *Oil Palm News*, 17, 1.
- Jones, L.H. (1984) *J. Am. Oil Chem. Soc.*, **61**, 1717.
- Jones, L.H. (1989) *Biotech. Gen. Eng. Rev.*, **7**, 281.
- Jurriens, G. (1968) in *Analysis and Characterisation of Oils and Fats and Fat Production* (ed. H.A. Boekennoogen), vol. 2, Interscience, New York.
- Kabul, P. (1985) *Diss. Abs. Int. B*, **45**, 1973.
- Kahlon, T.S. (1989) *Cereal Foods World*, **34**, 872.
- Kamel, B.S. and Kakadu, Y. (1992) in *Fatty Acids in Foods and Their Health Implications* (ed. C.K. Chow), Marcel Dekker, New York.
- Kapoulas, V.M. and Passaloglou-Emmanouilidou, S. (1981) *J. Am. Oil Chem. Soc.*, **58**, 694.
- Kattenberg, H.P. (1981) *Manuf. Confect.*, **32**.
- Kaufmann, H.P. and Thieme, J.G. (1954) *Fette Seifen Anstrichm.*, **56**, 1001.
- Kershaw, S.J. (1987) *Int. J. Food Sci. Technol.*, **22**, 67.
- Kershaw, S.J. and Hardwick, E. (1981) *J. Am. Oil Chem. Soc.*, **58**, 706.
- Khoury, N.N., Dagher, S. and Sawaya, W. (1982) *J. Food Technol.*, **17**, 19.
- Kies, C. (1989) *Cereal Foods World*, **34**, 1016.
- Kikugawa, K., Arai, M. and Kurechi, T. (1983) *J. Am. Oil Chem. Soc.*, **60**, 1528.
- Kim, M.A., Matoba, T. and Hasegawa, K. (1988) *Agric. Biol. Chem. (Japan)*, **52**, 693.
- Kim, N.K. and Hung, Y.C. (1991) *J. Food Sci.*, **56**, 1378.
- Kinderlerer, J.L. and Hatton, P.V. (1991) *J. Appl. Bacteriol.*, **70**, 502.
- King, G. (1942) *J. Chem. Soc.*, 387.
- Kinman, M.L. (1972) *J. Am. Oil Chem. Soc.*, **49**, 36.
- Kircher, H.W. (1964) *J. Am. Oil Chem. Soc.*, **41**, 4.
- Kiritakis, A.K. and Markakis, P. (1987) *Adv. Food Res.*, **31**, 453.
- Kiritakis, A.K. and Min, D.B. (1988) in *Flavour Chemistry of Lipids Foods* (eds D.B. Min and T.H. Smouse), American Oil Chemists' Society, Champaign, p. 196.
- Kirk, L.D., Mustakas, G.C. and Griffin, E.L. (1966) *J. Am. Oil Chem. Soc.*, **43**, 550.
- Kitamara, K. et al. (1984) *Yukagaku*, **33**, 800.
- Kleinert, R.J. (1961) *Int. Choc. Rev.*, **16**, 201.
- Kleinert, R.J. (1970) *Int. Choc. Rev.*, **25**, 162.
- Knapp, S.J., Tagliani, L.A. and Roath, W.W. (1991) *J. Am. Oil Chem. Soc.*, **68**, 515.
- Knauf, B.V. (1987) *TIB Tech.*, **5**, 40.
- Knowles, P.F. (1955) *Econ. Bot.*, **9**, 273.
- Knowles, P.F. (1965) *Calif. Agric.*, **19**, 15.
- Knowles, P.F. (1975) *J. Am. Oil Chem. Soc.*, **52**, 374.
- Knowles, P.F., Kearney, T.E. and Cohen, D.B. (1981) in *New Sources of Fats and Oils* (ed. E.H. Pryde, L.H. Princen and K.D. Mukherjee), American Oil Chemists' Society, Champaign, p. 255.
- Knutson, D.S., Thompson, G.A., Radke, S.E., Johnson, W.B., Knauf, V.C. and Kridl, J.C. (1992) *Proc. Natl Acad. Sci. USA*, **89**, 2624.
- Kobayashi, H. and Yuyama, A. (1988) *Nippon Jui. Zasshi*, **41**, 594.
- Kornfeldt, A. and Croon, L.B. (1981) *Lipids*, **16**, 306.
- Koyano, T., Hachiya, I. and Sato, K. (1990) *Food Struct.*, **9**, 231.
- Kramer, J.K.G., Sauer, F.D. and Pigden, W.J. (eds) (1983) *High and Low Erucic Acid Rapeseed Oils*, Academic Press, London, Animal Research Centre, Ottawa.
- Kremers, F.J. (1971) *J. Am. Oil Chem. Soc.*, **48**, 314.
- Kroeze, H. (1982) Private communication.
- Kromer, G.W. (1977) in *Glanders Cotton: Its Significance, Status and Prospects, Proc. Conf.*, Dallas, Texas, Agricultural Research Service, US Department of Agriculture.
- Kuemmel, D.F. (1964) *J. Am. Oil Chem. Soc.*, **41**, 667.
- Kuksis, A. and McCarthy, M.J. (1962) *Can. J. Biochem. Physiol.*, **40**, 679.
- Lakshminarayana, G., Chandrasekhara, R.T. and Ramalingaswamy, P.A. (1983) *J. Am. Oil Chem. Soc.*, **60**, 88.
- Lakshminarayana, G., Paulose, M.M. and Kumari, B.N. (1984) *J. Am. Oil Chem. Soc.*, **61**, 1871.
- Lamer-Zarawska, E., Hojden, B. and Szymczak, J. (1989) *Herba Pol.*, **35**, 165.
- Lange, R. and Linow, F. (1987) *Lebensmittelindustrie*, **34**, 113.
- Langstraad, A. (1976) *J. Am. Oil Chem. Soc.*, **53**, 241.
- Lanzini, A., Bondiolo, P., Gasparoli, A., Mariani, C., Fedeli, E., Ponzetti, A. and Peralisi, G. (1986) *Riv. Ital. Sost. Grasse*, **63**, 325.
- Larsson, K. (1966) *Acta Chem. Scand.*, **20**, 2255.
- Latif, A. and El Daly, M.A. (1973) *Agric. Res. Rev.*, **51**, 123.
- Lawsson, I., Rydhag, L. and Wilton, I. (1978) *Proc. 5th Int. Rapeseed Conf.*, vol. 2, p. 187.
- Lee, L.S. and Timms, R.E. (1988) *ASEAN Food J.*, **3**, 11.
- Lehrian, D.W., Keeney, P.G. and Butler, D.R. (1980) *J. Am. Oil Chem. Soc.*, **57**, 61, 66.
- Leibovitz, Z. and Ruckenstein, C. (1983) *J. Am. Oil Chem. Soc.*, **60**, 347A.
- Lessman, K.J. and Anderson, W.P. (1981) *New Sources of Fats and Oils* (eds E.H. Pryde, L.H. Princen and K.D. Mukherjee), American Oil Chemists' Society, Champaign, p. 223.
- List, G.R. and Erickson, D.R. (1980) in *Handbook of Soya Oil Processing and Utilisation* (eds D.R. Erickson, E.H. Pryde, O.L. Brekke, T.L. Mounts and R.A. Falb), American Soybean Association and American Oil Chemists' Society, Champaign.
- Litchfield, C. (1970) *Chem. Phys. Lipids*, **4**, 96.
- Lognay, G., Wathélet, J.-P. and Severin, M. (1981) *Rev. Fr. Corps Gras*, **28**, 67.
- Lovell, C.R., Burton, J.L. and Horrobin, D.F. (1981) *Lancet*, **i** (8214), 278.
- Lundberg, W.O. (1972) *Fette Seifen Anstrichm.*, **74**, 557.
- Lunde, G. (1972) *J. Am. Oil Chem. Soc.*, **49**, 44.
- Lyon, C.K. (1972) *J. Am. Oil Chem. Soc.*, **49**, 245.
- Macrae, A. and Coleman, M.H. (1976) Br. Pat. 1577933.
- Macrae, A.R. (1983) *J. Am. Oil Chem. Soc.*, **60**, 291.
- Mag, T.K. (1983) *J. Am. Oil Chem. Soc.*, **60**, 380.
- Mann, G.E. (1954) *Agric. Food Chem.*, **2** (5), 258.
- Marian, J.P. (1967) *Helv. Chim. Acta*, **50**, 1509.
- Martinson, V.A., Adomako, D. and Manu, M. (1987) *Cocoa Growers Bull.*, **38**, 39.

## Occurrence and characteristics

- Matsumoto, T., Shimizu, N., Itoh, T., Iida, T. and Nishioka, A. (1982) *J. Am. Oil Chem. Soc.*, **59**, 521.
- Mattson, F.H. and Volpenheim, R.A. (1963) *J. Lipid Res.*, **4**, 392.
- May, P.H., Anderson, A.B., Balik, M.J. and Frazao, J.M.F. (1985) *Econ. Bot.*, **39**, 113.
- McKinney, R.S. and Jamieson, G.C. (1936) *Oil Soap*, **13**, 10.
- McMichael, S.C. (1959) *Agron. J.*, **51**, 630.
- McPherson, A. (1978) *Rapeseed and Mustard, a Selected Bibliography*, Rapeseed Association of Canada, Winnipeg.
- Mehlenbacher, V.C. (1936) *Oil Soap*, **13**, 136.
- Mikolajczak, K.L., Freidinger, R.M., Smith, C.R. and Wolff, I.A. (1968) *Lipids*, **3**, 489.
- Minnifie, B.W. (1980) *Chocolate, Cocoa and Confectionery: Science and Technology*, 2nd edn, Avi, Westport, CT.
- Mohr, E., Wichmann, G. and Roche, G. (1987) *Gordian*, **87**, 77.
- Morgan, R.P. and Shultz, E.B. (1981) *Chem. Eng. News*, **59**, 69.
- Morrell, R.S. and Davis, W.R. (1936) *J. Chem. Soc.*, 1481.
- Morrison, W.H. and Robertson, J.A. (1975) *J. Am. Oil Chem. Soc.*, **54**, 148.
- Muller-Mulot, W. (1976) *J. Am. Oil Chem. Soc.*, **53**, 732.
- Mustakas, G.C., Kapas, G. and Robinson, N. (1965) *J. Am. Oil Chem. Soc.*, **42**, 550A.
- Nasirulla, B., Werner, G. and Seher, A. (1984) *Fette Seifen Anstrichm.*, **86**, 264.
- Nasirullah, B. and Nagaraja, K.V. (1987) *J. Oil Tech. Assoc. India*, **19**, 2.
- Naughton, F.C. (1974) *J. Am. Oil Chem. Soc.*, **51**, 65.
- Niewiadomski, H., Bratkowska, I. and Mossakowska, E. (1965) *J. Am. Oil Chem. Soc.*, **42**, 731.
- Ninomiya, M. (1940) *Rep. Inst. Sci. Manchoukuo*, **4**, 69.
- Ohlson, R. (1992) *J. Am. Oil Chem. Soc.*, **69**, 195.
- Oil World Annual* (1991) (ed. T. Mielke), ISTA Mielke, Hamburg.
- O'Keefe, S.F., Wiley, V.A. and Knauf, D.A. (1993) *J. Am. Oil Chem. Soc.*, **70**, 489.
- Ologunde, M.O., et al. (1992) *J. Sci. Food Agric.*, **58**, 221.
- Ong, A.S.H. (1993) in *Vitamin E in Health and Disease* (eds L. Packer and J. Fuchs), Marcel Dekker, New York.
- Osman, S.M. and Ahmad, F. (1981) in *New Sources of Oil and Fats* (eds E.H. Pryde, L.H. Princen and K.D. Mukherjee), American Oil Chemists' Society, Champaign, p. 109.
- Owuor, P.O., Chavanji, A.M. and Munavu, R.M. (1985) *Tea*, **6**, 23.
- Padley, F.B. and Timms, R.E. (1980) *J. Am. Oil Chem. Soc.*, **57**, 286.
- Paganuzzi, V. (1979) *J. Am. Oil Chem. Soc.*, **56**, 925.
- Palm Oil* (1977) *International Developments in Palm Oil*, Proc. Malaysian Int. Symp., International Society of Planters, Kuala Lumpur.
- Pandey, S.N. and Suri, L.K. (1982) *J. Am. Oil Chem. Soc.*, **59**, 99.
- Paquot, C., Argoudn, S. and Querolle, M. (1952) *Oleagineux*, **7**, 397.
- Paranjothy, K. (1989) *Elaeis*, **1**, 119.
- Parker, W.A. and Melnick, D. (1966) *J. Am. Oil Chem. Soc.*, **43**, 635.
- Passwater, R.A. (1981) *Evening Primrose Oil*, Keats, New Canaan, CT, USA.
- Pastana, A. and Munoz, E. (1982) *Nature*, **298**, 608.
- Pattee, H.E., Purcell, A.E. and Jones, E.B. (1969) *J. Am. Oil Chem. Soc.*, **46**, 629.
- Pawlowski, N.E., Loveland, P.M. and Sinnhuber, R.O. (1981) *J. Am. Oil Chem. Soc.*, **58**, 692.
- Payne-Wahl, K. and Kleiman, R. (1983) *J. Am. Oil Chem. Soc.*, **60**, 1011.
- Peers, K.E. (1977) *J. Sci. Food Agric.*, **28**, 1000.
- Persmark, W. and Bengtsson, L. (1976) *Riv. Ital. Sost. Grasse*, **53**, 307.
- Phelps, R.A., Shenstone, F.S., Kemmerer, A.R. and Evans, R.J. (1965) *Poult. Sci.*, **44**, 358.
- Piggott, C.J. (1964) *Coconut Growing*, Oxford University Press, London.
- Princen, L.H. and Rothfus, J.A. (1984) *J. Am. Oil Chem. Soc.*, **61**, 281.
- Pritchard, J.R. (1983) *J. Am. Oil Chem. Soc.*, **60**, 332.
- Pryde, E.H. and Cowan, J.C. (1972) in *Condensation Monomers* (eds J.K. Stille and T.W. Campbell), Wiley, New York, p. 91.
- Putt, E.D. (1978) in *Sunflower Science and Technology*, Agronomy 19, American Society of Agronomy, Madison, WI.
- Qing, X.B. (1989) *J. Am. Oil Chem. Soc.*, **66**, 479.
- Racicot, L.D. and Handel, A.P. (1983) *J. Am. Oil Chem. Soc.*, **60**, 1098.
- Rajanaidu, N. and Tan, B.K. (1983) *Oleagineux*, **38**, 581.
- Rakow, G. and McGregor, D.I. (1973) *J. Am. Oil Chem. Soc.*, **50**, 400.
- Ramos, L.C.D.S., Tango, J.S., Savi, A. and Leal, N.R. (1984) *J. Am. Oil Chem. Soc.*, **61**, 1841.
- Rana, M.S. and Ahmed, A.A. (1981) *J. Am. Oil Chem. Soc.*, **58**, 630.
- Rao, S.D.T. and Murthi, K.S. (1961) *Indian Oilseeds*, **5**, 121.
- Rath, T. (1987) *Indian Forester*, **113**, 73.
- Raymond, W.D. (1961) *Trop. Sci.*, **3**, 69.
- Raymond, W.D. and Ward, J.B. (1956) *Colon. Plant Anim. Prod.*, **6**, 243.
- Reufels, J. (1989) *Entwickl. Landlicher Raum*, **23**, 28.
- Rijner, U. (1970) *J. Am. Oil Chem. Soc.*, **47**, 129.
- Rivarola, G., Anon, M.C. and Calvelo, A. (1985) *J. Am. Oil Chem. Soc.*, **62**, 1508.
- Röbbelin, G. (1988) *Proc. World Conf. on Biotechnology for the Fats and Oils Industry, 1987* (ed. T.H. Applewhite), American Oil Chemists' Society, Champaign, pp. 78-86.
- Rohan, T.A. (1969) *Gordian*, **69**, 443.
- Rohne, G.W. (1984) *Fette Seifen Anstrichm.*, **86**, 172.
- Rose, W.G. and Jamieson, G.S. (1943) *Oil Soap*, **20**, 227.
- Rossell, J.B. (1985) *J. Am. Oil Chem. Soc.*, **62**, 385.
- Rossell, J.B. (1991) *Fat Sci. Technol.*, **93**, 526.
- Rossell, J.B. and Pritchard, J.L.R. (eds) (1990) *Analysis of Oilseeds, Fats and Fatty Foods*, Elsevier Applied Science, London, pp. 315, 317.

- Rossell, J.B., King, B. and Downes, M.J. (1983) *J. Am. Oil Chem. Soc.*, 285A.
- Rossell, J.B., King, B. and Downes, M.J. (1985) *J. Am. Oil Chem. Soc.*, 62, 221.
- Ruyssen, B. (1957) *Agron. Trop.*, 12, 137, 273.
- Sagredos, A.N., Roy, D.S. and Thomas, A. (1988) *Fett. Wiss. Technol.*, 90, 76.
- Sahasrabudhe, M.R. (1979) *J. Am. Oil Chem. Soc.*, 56, 80.
- Sampugna, J. and Jensen, R.G. (1969) *Lipids*, 4, 444.
- Sanders, T.H. (1980) *J. Am. Oil Chem. Soc.*, 57, 12.
- Sanders, T.H. (1982) *J. Am. Oil Chem. Soc.*, 59, 346.
- Santinelli, F., Damiani, P. and Christie, W.W. (1992) *J. Am. Oil Chem. Soc.*, 69, 552.
- Sato, K. (1987) *Food Microstruct.*, 6, 151.
- Satpathi, P. (1984) *Indian Farming*, 34, 22.
- Saunders, R.M. (1985) *Food Rev. Int.*, 1, 465.
- Sawadogo, K. and Bezard, J. (1982) *Oleagineux*, 37, 69.
- Scheerens, J.C. and Berry, J.W. (1986) *Cereal Foods World*, 31, 183, 186, 190.
- Schlichter, A.J., Sarig, S. and Garti, N. (1988) *J. Am. Oil Chem. Soc.*, 65, 1140.
- Sebedio, J.L. and Ackman, R.G. (1981) *J. Am. Oil Chem. Soc.*, 58, 972.
- Sen Gupta, A.K. (1972) *Chem. Ind.*, 257.
- Sengupta, A. and Mazumbar, U.K. (1976) *J. Am. Oil Chem. Soc.*, 53, 680.
- Sengupta, C., Sengupta, A. and Ghosh, A. (1976) *J. Sci. Food Agric.*, 27, 1115.
- Sen Gupta, S., Chakrabarty, M.M. and Bhattacharyya, D.K. (1982) *Fette Seifen Anstrichm.*, 84, 226.
- Sethuraj, M.R., Rao, G.G. and Asokan, M.P. (1989) *J. Plant. Crops*, 16, 9.
- Shenstone, F.S. and Vickery, J.R. (1959) *Poult. Sci.*, 38, 1005.
- Shenstone, F.S. and Vickery, J.R. (1961) *Nature*, 190, 168.
- Sheppard, A.J. and Pennington, J.A.T. (1993) in *Vitamin E in Health and Disease* (eds L. Packer and J. Fuchs), Marcel Dekker, New York.
- Sheppard, A.J. and Rudolf, T.S. (1991) *Peanut Sci.*, 18, 51.
- Siew, W.L., Tang, T.S., Flingoh, C.H.O.H., Chong, C.L. and Tau, Y.A. (1992) *Elaeis*, 5, 38.
- Singh, B.B. (1976) PhD Thesis, University of Illinois, Urbana.
- Singh, S.P., Khanna, K.R., Dixit, B.S. and Srivastava, S.N. (1990) *Indian J. Agric. Sci.*, 60, 358.
- Singleton, J.A. and Pattee, H.E. (1981) *J. Am. Oil Chem. Soc.*, 58, 873.
- Slavin, J. (1991) *J. Am. Diet. Assoc.*, 91, 816.
- Sleeter, R.T. (1981) *J. Am. Oil Chem. Soc.*, 58, 239.
- Slover, H.T. (1971) *Lipids*, 6, 291.
- Soeters, C.J. (1970) *Fette Seifen Anstrichm.*, 72, 711.
- Sosulki, F., Zadernowski, R. and Babachowski, K. (1981) *J. Am. Oil Chem. Soc.*, 58, 561.
- Soybean (1981) *Proc. World Conf. on Soya Processing and Utilisation*; *J. Am. Oil Chem. Soc.*, 58, 121.
- Spencer, G.F. (1973) *Chem. Phys. Lipids*, 10, 191.
- Sprecher, H.W., Maier, R., Barber, M. and Holman, R.T. (1965) *Biochemistry*, 4, 1856.
- Sreenivasan, R. (1969) *J. Am. Oil Chem. Soc.*, 46, 459.
- Stalker, H.T., Young, C.T. and Jones, T.M. (1989) *Oleagineux*, 44, 419.
- Steger, A. and van Loon, J. (1935) *Rec. Trav. Chim.*, 54, 149.
- Sundaravalli, O.E., Guttikar, H.A., Desai, B.L.M., Kantha, S. and Shiurpalekar, I. (1978) *J. Oil Tech. Assoc. India*, 10, 147.
- Sunflower Oil Today (1987) *Rev. Fr. Corps Gras*, 34, 183.
- Symposium (1985) World Conference, Processing of Palm, Palmkernel and Coconut Oils, Proceedings. *J. Am. Oil Chem. Soc.*, 62, (2), 215.
- Tachibana, T. and Kambara, H. (1968) *J. Colloid Int. Sci.*, 28, 173.
- Takagi, T. and Ando, Y. (1991) *Lipids*, 26, 542.
- Tamurat, T., Sakaedani, N. and Matsumoto, T. (1958) *Nippon Kayaku Zasshi*, 79, 1011.
- Tan, B.K. and Berger, K.G. (1982) *J. Sci. Food Agric.*, 33, 204.
- Tan, B.K. and Oh, F.C.H. (n.d.) *PORIM Technology Series*, No. 4, Kuala Lumpur.
- Tashiro, T., Fukuda, Y. and Osawa, T. (1991) *Nippon Sak. Gakk. Kiji*, 60, 116.
- Tavares, M., Badolato, E.S.G., Carvalho, J.B.D. and Aued, S. (1990) *Rev. Inst. Adolfo Lutz*, 50, 307.
- Teasdale, B.F. (1975) in *Oilseed and Pulse Crops in Western Canada* (ed. J.T. Harapuk), Modern Press, Saskatoon.
- Terstage, R.G. (1972) *Oil Mill Gaset.*, 77, 9.
- Thomas, E.A. and Paulicka, F.R. (1976) *Chem. Ind.*, 774.
- Thomas, G.V., Shautaram, M.V. and Jayasankar, N.P. (1987) *J. Plant. Crops*, 15, 72.
- Thompson, A.E. (1984) *Hort. Sci.*, 19, 352.
- Thompson, A.E. (1990) in *Advances in New Crops, Proc. 1st Natl Symp. on New Crops*, Indianapolis, October 1988 (eds J. Janick and J.E. Simon), Timber Press, Portland, OR.
- Thompson, G.V. and Kleiman, R. (1988) *J. Am. Oil Chem. Soc.*, 65, 139.
- Timms, R.E. (1980) *Lebensm. Wiss. Technol.*, 13, 61.
- Timms, R.E. (1984) *Prog. Lipid Res.*, 23, 1.
- Timms, R.E. (1985) *J. Am. Oil Chem. Soc.*, 62, 241.
- Timms, R.E. (1986) *Fette Seifen Anstrichm.*, 88, 294.
- Tombs, M.P. and Stubbs, M.J. (1982) *J. Sci. Food Agric.*, 33, 892.
- Tooke, H.L., Van Etten, C.H. and Daxenbichler, M.E. (1980) in *Toxic Constituents of Plant Foodstuffs*, 2nd edn (ed. I.E. Liener), Academic Press, New York, p. 103.
- Tous, J.G. (1968) in *Analysis and Characterisation of Oils, Fats and Fat Products* (ed. H.A. Boekennoogen), Interscience, London.
- Toxic Oil Syndrome References Archive* (1990) Fondo de Investigaciones Sanitarias, Ministerio de Sanidad-consumo, Madrid.
- Traitler, H., Wille, H.J. and Studer, A. (1986) *Fette Seifen Anstrichm.*, 88, 378.
- Traitler, H., Wille, H.J. and Studer, A. (1988) *J. Am. Oil Chem. Soc.*, 65, 755.
- Treadwell, K. and Young, C.T. (1982) *Oleagineux*, 37, 477.
- Tropical Products Institute (1971) *Oils and Oil Seeds*, No. 1 in the series *Crop and Product Digests*, HMSO, London.

## Occurrence and characteristics

- Trost, V.W. (1989) *J. Am. Oil Chem. Soc.*, **66**, 325.
- Tsunoda, S., Hinata, K. and Gomez-Compo, C. (eds) (1980) *Brassica Crops and Wild Alliles*, Japan Scientific Society Press, Tokyo.
- Turpin, P.E., Coxon, D.T. and Padley, F.B. (1992) *Fat Sci. Technol.*, **5**, 179.
- Unger, E.H. (1990) in *Canola Rapeseed* (ed. F. Shahidi), Van Nostrand Reinhold, New York, p. 235.
- US Department of Agriculture (1965) *Safflower Culture in the West Central Plains*, Agric. Res. Serv., Agric. Inform. Bull. No. 300.
- Vaccarino, C. (1977) *Riv. Ital. Sost. Grasse*, **54**, 183.
- Vaisey-Genser, M. and Eskin, N.M.A. (1982) *Canola*, Canola Council of Canada, Winnipeg.
- Van der Ven, B. and de Jong, K. (1970) *J. Am. Oil Chem. Soc.*, **47**, 299.
- Van der Waal, B., Sipma, B.G., Ketenes, D.K. and Semper, A. Th. (1968) *Rec. Trav. Chim.*, **87**, 238.
- Vasconcellos, J.A. and Berry, J.W. (1982) *J. Am. Oil Chem. Soc.*, **59**, 79.
- Vasconcellos, J.A., Bemis, W.P., Berry, J.W. and Weber, C.W. (1981) in *New Sources of Fats and Oils* (eds E.H. Pryde, L.H. Princen and K.D. Mukherjee), American Oil Chemists' Society, Champaign.
- Vereshchagin, A.G. and Novitskaya, G.V. (1965) *J. Am. Oil Chem. Soc.*, **42**, 970.
- Vickery, J.R. (1980) *J. Am. Oil Chem. Soc.*, **57**, 87.
- Vioque, E. and Maza, M.P. (1973) *Grasas Aceites*, **24**, 323.
- Vitagliano, M. (1960) *Riv. Ital. Sost. Grasse*, **37**, 136.
- Vitagliano, M. and Turri, E. (1958) *Olearia*, **12**, 145.
- Voelker, T.A. and Davies, H.M. (1992) *Int. Pat. Appl.* WO 92/20236.
- Von Mikusch, J.W. (1955) *Paint Manuf.*, **25**, 386.
- Von Schuster, W. and Marquard, R. (1974) *Fette Seifen Anstrichm.*, **74**, 207.
- Von Schuster, W., Kubler, I. and Marquard, R. (1980) *Fette Seifen Anstrichm.*, **82**, 443.
- Wagner, H. and Wolff, P. (1964) *Fette Seifen Anstrichm.*, **66**, 425.
- Wang, J.P., Yu, F.L., Li, J.M. and Shan, X.Q. (1988) *Acta Bot. Sin.*, **30**, 619.
- Wealth of India - Raw Materials* (1966) Publ. Inform. Directorate, CSIR, New Delhi, vol. VII, p. 23.
- Webb, D.M. and Knapp, S.J. (1991) *Crop Sci.*, **31**, 621.
- Weyland, M. (1992) *Manuf. Confect.*, **72**, 53.
- Whipkey, A., Simon, J.E. and Janick, J. (1988) *J. Am. Oil Chem. Soc.*, **65**, 979.
- White, M.B., Quackenbush, F.W. and Probost, A.H. (1961) *J. Am. Oil Chem. Soc.*, **38**, 113.
- Whittle, K.J. and Pennock, J.F. (1967) *Analyst*, **92**, 423.
- Wille, R.L. and Lutton, E.S. (1966) *J. Am. Oil Chem. Soc.*, **43**, 491.
- Willems, M.G.A. and Padley, F.B. (1985) *J. Am. Oil Chem. Soc.*, **62**, 454.
- Wolf, J.P. (1978) *Manuel d'Analyse des Corps Gras*, Azoulay, Paris.
- Wolf, R.B., Graham, S.A. and Kleiman, R. (1983a) *J. Am. Oil Chem. Soc.*, **60**, 103.
- Wolf, R.B., Kleiman, R. and England, R.E. (1983b) *J. Am. Oil Chem. Soc.*, **60**, 1858.
- Wong, R.S., Beversdorf, W.D., James, R., Grant, I. and Patel, J.D. (1990) *Int. Pat. Appl.* WO 90/10380.
- Wood, R.D., Raju, P.K. and Reiser, R. (1965) *J. Am. Oil Chem. Soc.*, **42**, 81.
- Woodroof, J.G. (1966) *Peanuts, Production, Processing, Products*, Avi, Westport, CT.
- Woodroof, J.G. (1983) *Peanuts*, Avi, Westport, CT.
- Wright, N.G. (1988) in *Arid Lands: Today and Tomorrow* (eds E.E. Whitehead, C.F. Hutchinson, B.N. Timmerman and R.G. Varady), Belhaven, London, p. 1341.
- Wynne, J.C. (1989) *Crit. Rev. Plant Sci.*, **8**, 189.
- Yano, J., Veno, S., Sato, K., Arishima, T., Sagi, N., Kaneko, F. and Kobayashi, M. (1994) *J. Phys. Chem.*, to be published.
- Yella Reddy, S. and Prabhakar, J.V. (1987) *J. Am. Oil Chem. Soc.*, **64**, 97.
- Yella Reddy, S. and Prabhakar, J.V. (1989) *J. Am. Oil Chem. Soc.*, **66**, 805.
- Yermanos, D.M. (1966) *J. Am. Oil Chem. Soc.*, **43**, 546.
- Yermanos, D.M., Hemstreet, S. and Garber, M.J. (1967) *Crop. Sci.*, **7**, 417.
- Yermanos, D.M., Hemstreet, S., Saleeb, W. and Huszar, C.K. (1972) *J. Am. Oil Chem. Soc.*, **49**, 20.
- Young, C.C. (1984) *J. Am. Oil Chem. Soc.*, **61**, 576.
- Zarins, Z.M., White, J.L., Willich, R.K. and Feuge, R.O. (1982) *J. Am. Oil Chem. Soc.*, **59**, 511.
- Zeleny, L. and Coleman, D.A. (1936) *Oil Soap*, **13**, 253.
- Zimmerman, D.C. (1981) in *New Sources of Oils and Fats* (eds E.H. Pryde, L.H. Princen and K.D. Mukherjee), American Oil Chemists' Society, Champaign, p. 25.