The Major Sources of Oils and Fats

2.1 Introduction

One market analyst reports that in the harvest year 2006/07 (*i.e.* harvests from the Northern hemisphere in 2006 and from the Southern hemisphere in 2007) 153 million tonnes of oils and fats were produced from 17 commodity sources. These comprise four major oils (palm, sunflower, rape or canola, and sunflower), four minor oils (cottonseed, groundnut or peanut, olive, and corn), two lauric oils (palm kernel and coconut are rich in lauric acid – 12:0), three oils produced at only low levels (sesame, linseed, and castor), and four animal fats (tallow, lard, butter, and fish oil). These are listed in that order in Table 2.1. It is clear that supplies are dominated by four vegetable oils (palm, soybean, rapeseed, and sunflower) and increasingly by palm oil (from Malaysia and Indonesia) and soybean oil (from Argentina, Brazil, and USA).

A part of this total supply is used by the oleochemical industry as starting material for a range of industrial products. This holds for all the castor oil, most of the linseed oil, a significant proportion of the lauric oils and of tallow, and some of the remaining oils.

Table 2.1 Production (million tonnes) of 17 commodity oils and fats in 2006/07

Palm	38.0	Olive	3.0	Castor	0.5
Soybean	36.7	Corn	2.3	Tallow	8.5
Rapeseed	18.4	Palm kernel	4.4	Lard	8.0
Sunflower	11.4	Coconut	2.9	Butter	6.9
Cottonseed	5.0	Sesame	0.9	Fish oil	1.0
Groundnut	4.2	Linseed	0.7	*Total*	152.7

Note: Forecasts for 2007/08 are for 160.4 million tonnes.
Source: Adapted from Oil World Annual (2007), ISTA Mielke GmbH, Hamburg.

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Some is also used for animal feed but the rest of these commodity oils form the basis of the food industry. For many years it has been assumed that these 17 oils and fats were used for food, feed, and the oleochemical industry in the ratio 80:6:14 but this is changing, mainly through the rapidly growing demand for biodiesel. At the end of 2007 it is probably close to 74:6:20. It has been suggested that by 2020 it could be 68:6:26 though recent evidence suggests that the shift may be greater than this. This revised ratio does not mean that less will be consumed as food but that this will represent a smaller proportion of a larger total. In 2007/08 one half of the year's additional supply will probably be used for non-food purposes (mainly biodiesel) and the other half for food purposes. During 2007 and perhaps for some time to come demand exceeds supply and demand will be restricted through price rationing.

It is worth noting that this arbitrary list of commodity oils does not include cocoa butter nor many minor oils now available on the market such as camelina oil, almond oil, and evening primrose and borage oils to mention only a few. In dietary terms further significant quantities of fat are ingested which do not appear in the listings of oil and fat market analysts. For example, dairy produce (other than butter) such as milk, cream, and cheese and fats ingested when meat or fish is consumed or when nuts are eaten.

With the burgeoning demand for oils and fats as a source of biodiesel, concern has been expressed that there will not be enough for food purposes as the demand for this also increases with growth in population and income. It is known that with increasing income, particularly in developing countries, there is a growing demand for meat and fat. Total production of oils and fats is likely to increase through harvesting larger areas and through improved yields. Nevertheless, oil and fat prices are already under pressure, and this will influence the demand for both food and non-food purposes until a new equilibrium is reached.

After a period of below-trend prices about 10 years ago, reaching a nadir in 1997/98, prices of oilseeds and of oils and fats have risen very sharply in recent years. This reflects enhanced demand both for food purposes, especially in China and other developing countries and for conversion to biodiesel. At the same time there is a tightened supply situation arising from unfavourable weather conditions in many producing countries.

Over the past 10 years (1997–2006) annual production of oils and fats has risen on average by around five million tonnes. Over the last 3 years the figure has been close to eight. It has been estimated that in the next 5 years (2008 onwards) demand for food and for non-food purposes could each rise by about 4–5 million tonnes. Can supplies increase by 8–10 million tonnes in the near future to meet the demand for food and fuel? The figures cited above allow for a pessimistic or an optimistic conclusion. The closeness of the supply and demand figures will operate a rationing system through stocks and prices. Of course other factors will be relevant, in particular the supply/demand/price situation for wheat and other cereals and the cost of (mineral) oil.

The question of vegetable oils derived from genetically modified seeds is still an issue in Europe and in some other countries. Over one half (and increasing) of soybean oil comes from genetically modified seeds in both North and South America and also increasing proportions of canola oil from Canada. Non-GM material must be sourced from appropriate areas and be identity preserved (IP). The first GM oilseeds were modified to be resistant to certain herbicides and to pests leading to more efficient farming. The second generation of GM oilseeds have been modified to have different fatty acid composition and/or enhanced levels of minor components. There may be pressure for Europeans to accept oil from GM plants for industrial (biodiesel) purposes.

When oilseeds are extracted by pressing and/or use of solvent (Section 3.1) they furnish differing proportions of oil (lipid) and meal, rich in protein and used mainly for animal feed. The lipids from the different vegetable and animal sources vary in fatty acid composition. They consist mainly (around 95%) of triacylglycerols based on component acids which are chiefly palmitic (16:0), oleic (18:1), and linoleic (18:2) with other acids such as stearic (18:0) and linolenic (18:3) at lower levels and yet other acids occurring only occasionally. The native oils also contain free acids, and mono- and diacylglycerols (at low levels), phospholipids (up to 3%), free sterols and sterol esters (0.1–2.2%), tocopherols (up to 0.2%), and other minor components (Chapter 1). After refining, the triacylglycerol content is usually above 99% and the other components are correspondingly reduced. Several of the minor commodities have potential value and may be recovered from side streams in the refining processes. Sometimes they are added back into the oil or meal or into a food.

Some of the more important oils are discussed in the following sections and are presented in alphabetical order.

2.2 Animal fats (butter, lard, tallow, chicken fat, and fish oils)

(Cow) milk fat is a significant product of the agricultural industry and is consumed as milk, cream, butter, or cheese. Data on the annual production of butterfat is given in Table 2.2. Butter has some disadvantages (see below) but it is appreciated for its superior flavour. It is used mainly as a spread but also as a baking and frying fat. Its fatty acid composition is different from that of any other commodity oil with over 500 components already identified. These are mainly saturated acids (4:0 to 18:0, 65–70% wt) with some 18:1 which is mainly oleic acid but also vaccenic acid (11*t*-18:1) and other *trans* isomers resulting from biohydrogenation within the rumen. The content of PUFA is low (~3%). Also present at low levels are conjugated linoleic acids (CLA, mainly rumenic acid 9*c*11*t*-18:2), branched-chain acids, oxo (keto) acids, hydroxy acids, and lactones some of which are responsible for the characteristic flavour of butter. The composition of milk fat depends on the cows' diet and in some parts of the world this leads a slightly different composition in the summer (pasture-fed) and winter (fed indoors). The disadvantages of butter are considered to be its high fat level (80–82% – required by legal definition) in comparison with the lower levels now present in most spreads, its high level of saturated acids, its content of cholesterol, and the fact that it does not spread easily when taken directly from

Table 2.2 Typical fatty acid composition (%wt) of major animal fats

	14:0	16:0	16:1	18:0	18:1[a]	18:2	Other
Butter[b]	12	26	3	11	28	2	18
Lard	2	26	5	11	44	11	1
Beef tallow	3	27	11	7	48	2	2
Mutton tallow	6	27	2	32	31	2	0
Chicken fat	1	22	6	7	40	20	4

Notes
[a]Including *trans* isomers.
[b]Also 4:0 (3%), 6:0 (2%), 8:0 (1%), 10:0 (3%), and 12:0 (4%).
These figures are cited as wt%. Different figures result when the results are given on a molar basis, particularly when the fatty acids have a wide range of molecular weight as in butter. In a typical example the figures for butterfat were given as: 4:0 (3.7% wt and 9.6% mol), 6:0 (2.4% and 4.8%), 8:0 (1.4% and 2.2%), 10:0 (2.9% and 3.9%), 18:0 (13.9% and 11.4%), and *cis*-18:1 (28.0% and 23.0%).

the refrigerator. Some of these disadvantages have been circumvented but since butter is defined legally some of the modified products cannot be described as 'butter'. Butter contains CLA and other minor components (*e.g.* sphingolipids) for which nutritional benefits have been claimed. Anhydrous butterfat can be fractionated to give higher and lower melting fractions which find specific uses in the baking industry. In the Indian sub-continent milk fat is converted to ghee. This is a butter-like product with more fat and less water ($<$0.2%) that keeps better in hot countries.

Lard is the fat produced by pigs and tallow is the fat from cattle (and sheep). The fatty acid composition of lard and tallow differ mainly because tallow comes from ruminants and is a harder fat because of biohydrogenation. Both fats contain cholesterol (3000–4000 mg/kg) and are deficient in polyunsaturated acids and in antioxidants. Only the highest grades of tallow can be used for food purposes. Lower grades are used as animal feed, for surfactants, and as a source of biodiesel. Lard is unusual among fats in that much of its palmitic acid is attached to the *sn*-2 position in glycerol. The only other important fat displaying this property is human milk fat. Because of this unusual distribution of fatty acids lard has changed physical properties after interesterification and is thereby converted to an improved shortening.

Despite the high level of poultry meat now consumed only limited quantities of chicken fat are available. This comes from food companies processing and cooking chickens on an industrial scale.

Fish oils differ from vegetable oils and from other animal fats in the wider range of chain length of their component fatty acids (C_{14} to C_{24}) including the very important omega-3 acids such as eicosapentaenoic acid (EPA 20:5) and docosahexaenoic acid (DHA 22:6). Fish oil is now a by-product in the production of fish meal and both meal and oil are used mainly in the diets of farmed fish. The human need for omega-3 LC-PUFA is met in part by eating fish and in part by consuming high-quality fish oil. This last may be taken in capsules, be incorporated into animal diets to enhance the levels of EPA and DHA in milk or eggs or flesh, or be added to prepared foods such as spreads, bread, and fruit drinks, often as a free-flowing microencapsulated powder. Encapsulation also provides some protection from oxidation (Williams and Buttriss, 2006). Fish oils enriched in EPA and/or DHA are available, usually in encapsulated form, as food additives or as dietary supplements.

2.3 Cocoa butter and cocoa butter alternatives

The cocoa bean provides cocoa powder and a solid fat (cocoa butter) both of which are important ingredients of chocolate. Cocoa butter (mp 32–35°C) is characterised by its high content (70–90%) of triacylglycerols of the type SOS where S stands for any saturated acid. Cocoa butter is rich in POP, POSt, and StOSt as a consequence of the presence of near-equal quantities of palmitic, stearic, and oleic acids (Table 2.3). Glycerol esters of this type are hard and brittle at ambient temperatures giving chocolate its characteristic snap and its steep melting curve with virtually complete melting at mouth temperature. This provides a cooling sensation and a smooth creamy texture. See also Sections 5.1 and 8.7.

Because cocoa butter carries a premium price cheaper fats with similar physical properties have been produced. In the EU cocoa butter can be replaced only in part by one or more solid vegetable fats confined to a prescribed list if the name chocolate is to be retained. These materials are described as cocoa butter equivalents (CBE). European chocolate may contain around 25–35% of cocoa butter and up to 5% (maximum) of the fats listed in Table 2.3. The only processes allowed in the production of these fats are refining and fractionation. This excludes hydrogenation and interesterification even when the latter is enzymatic. If fats outside this

Table 2.3 Major triacylglycerols in cocoa butter and in tropical fats that may partially replace cocoa butter in chocolate according to the EU Chocolate Directive

Common name	Botanical name	Major triacylglycerols (%wt)		
		POP	POSt	StOSt
Cocoa butter	*Theobroma cacoa*	16	38	23
Palm mid-fraction	*Elaies guinensis*	57	11	2
Borneo tallow (Illipe)	*Shorea stenoptera*	6	37	49
Kokum butter	*Garcinia indica*	1	5	76
Mango kernel stearin	*Mangifera indica*	2	13	55
Sal stearin	*Shorea robusta*	1	10	57
Shea stearin	*Butyrospermum parkii*	1	7	71

Note: The chocolate directive, agreed after about 30 years of negotiation, is based on political compromise rather than technical necessity and there are other regions of the world with a more liberal attitude as to what constitutes chocolate.

prescribed list with similar melting properties are used the confections cannot be described as 'chocolate'. Cocoa butter replacers (CBR) and cocoa butter substitutes (CBS) are generally lauric fats or vegetable oils (soybean, cottonseed, palm) that have been fractionated and partially hydrogenated (thereby producing higher melting *trans* acids). These materials can be used to make confectionery fats but products containing them cannot be described as chocolate in Europe. The EU rules represent a political-economic rather than a technical compromise and do not apply on a global scale. Cocoa beans yield more cocoa powder than is needed for the cocoa butter also produced. It is therefore desirable to find other uses for cocoa powder or to extend supplies of cocoa butter with alternative fats having the required physical properties.

2.4 Lauric oils (coconut, palm kernel)

Coconut and palm kernel oil (Tables 2.1 and 2.4) differ from other commodity oils in that they are rich in medium-chain saturated acids (8:0 to 14:0, especially lauric acid – 12:0) and have correspondingly less oleic and linoleic acid. They have iodine values of only 7–10 (coconut oil) and 14–21 (palm kernel oil). They are extensively used to produce surface-active compounds in addition to their wide use in the food industry as components of spreads, of non-dairy creams and coffer whiteners, and as alternatives to cocoa butter. To extend their range of usefulness they may be fractionated and/or hydrogenated. After hydrogenation both oils have iodine values around 2 and slip melting points of 32–34°C. The C_8 and C_{10} acids can be separated and reconverted to triacylglycerols. These 'medium-chain triglycerides' (MCT) are used as safe lubricants in food-making equipment or as easily metabolised fats for invalids and athletes.

The triacylglycerols of these lauric oils are usually reported by carbon number which is the sum of the carbon atoms in the three

Table 2.4 Typical fatty acid composition (%wt) of coconut and palm kernel oils

	8:0	10:0	12:0	14:0	16:0	18:0	18:1	18:2
Coconut	8	7	48	16	9	2	7	2
Palm kernel	3	4	45	18	9	3	15	2

acyl groups. They range from 28 to 54 and are predominantly in the range 32–44. The C_{36} group will be mainly, but not entirely, trilaurin (12,12,12).

2.5 Olive oil

Olive oil comes almost entirely from Mediterranean countries. It has a high reputation as a healthy oil based on its fatty acid composition, its minor components, and its method of extraction. It is available in several grades tightly specified by several EU directives that relate to its isolation procedure and subsequent treatment. Oil is obtained from the olive mesocarp (soft fleshy fruit) by pressing. The first pressings are of highest quality and are designated as virgin oils. This extraction procedure requires no solvent and avoids high temperature. The oil is not refined and so retains important minor components that add to its nutritional value.

There are nutritional and technical reasons why, for many purposes, oils should be low in saturated and polyunsaturated acids and high in oleic (or other monounsaturated) acid. This is one of the reasons for the status of olive oil (Table 2.5). Because of the high level of oleic acid olive oil consist mainly of triacylglycerols with two or three oleic chains (OOO 40–59%, POO 12–20%, and LOO 12–20%). The importance of this type of fatty acid composition is reflected in the fact that high-oleic varieties have been developed for most of the commodity oils such as soybean, rape, sunflower, and safflower (see following sections and Table 2.5). Sometimes these have been obtained through conventional seed breeding: sometimes they have resulted from genetic modification. Even those seeds whose fatty acid composition may have been modified by conventional seed breeding may also be genetically modified to add desirable agricultural traits. Until genetically modified crops are more widely accepted it is necessary to know the detailed origin of vegetable oils used in the food industry.

A number of minor oils also fall into the category of oleic-rich such as almond oil with 65–70% oleic acid, hazelnut (74–80%), macadamia (55–65% along with 16–25% of 16:1) and moringa oil (77%). Hazelnut is sometimes added to olive oil as an adulterant, exploiting the very similar fatty acid composition of these two oils. Rapeseed/canola oil (Section 2.7) is also an oleic-rich oil.

Table 2.5 Typical fatty acid composition (%wt) of selected vegetable oils

Oil	Major acids			Other acids		
	Palmitic	Oleic	Linoleic	Stearic	Linolenic	Other
Palm						
Oil	44	39	11	4		
Olein	41	41	12	4		
Stearin	47–74	16–37	3–10	4–6		
Mid-fraction	41–55	32–41	3–11	5–7		
Soybean						
Oil	11	23	54	4	8	
Low-len	10	41	41	5	2	
High oleic	6	86	2	1	2	
High sat	24	9	38	19	10	
Oil IV 132[a]	11	22	55	4	7	
Oil IV 110[a]	10	42	40	4		9[b]
Oil IV 97[a]	13	48	30	6		13[b]
Oil IV 81[a]	11	73	11	5		32[b]
Oil IV 65[a]	11	75	–	14		40[b]
Rapeseed/canola						
High erucic	4	15	14	1	9	20:1 10 22:1 45
Low erucic	4	62	22	1	10	
High oleic	3	78	10	3	3	
Low linolenic	4	61	28	1	2	
Sunflower						
Regular	11–13[c]	20–30	60–70			
High oleic	9–10[c]	80–90	5–9			
Mid-oleic (Nu-sun)	<10[c]	55–75	15–35			

Notes

[a] Soybean of IV 132 and after hydrogenation to the iodine value indicated.

[b] Content of *trans* acids.

[c] Total saturated acids.

Similar data are given in Table 8.4.

2.6 Palm oil

The oil palm produces two different oils (palm oil and palm kernel oil) in a ratio of around 8.5:1. Palm oil is now produced in larger quantities than any other fatty oil (Table 2.1, 38.0 million tonnes in 2006/07) and is even more dominant among traded commodity oils. It is grown mainly in Malaysia and Indonesia and is exported from these countries (total exports 30.4 million tonnes) to virtually all oil-importing nations and particularly to China (5.7 million tonnes), EU-27 (4.9 million tonnes), and the Indian sub-continent (India, Pakistan, and Bangladesh together 6.1 million tonnes). Imports to the USA are small (0.71 million tonnes) but have increased in recent years following attempts to reduce the levels of *trans* acids in processed fats. The oil palm produces more lipid/hectare than any commodity oilseed. Palm oil is exported as crude oil, as refined oil, and as fractionated palm olein and palm stearin. Red palm oil is deodorised at below 150°C so that it retains about 80% of its original carotene and is used as a dietary source of important compounds required to combat blindness. β-Carotene is the biological precursor of vitamin A. Palm oil is generally the cheapest of the commodity oils and is produced entirely without genetic modification and without solvent extraction. The major export from Malaysia is RBD (refined, bleached, and deodorised) palm olein and it may be necessary to check whether the oil being used is palm oil or palm olein.

The range of use of palm oil is extended through fractionation (Section 3.5). In its simplest form this affords stearin, olein, and mid-fractions but the process has been improved and extended to give sub-fractions ranging in iodine value from 17 to 72 compared with a value of 51–53 for palm oil itself. Palm olein (IV 56–59) is used mainly as a frying oil, palm stearin (IV 40–42) as hardstock, and palm mid-fraction (range of iodine values between 32 and 47) in confectionery fats.

Palm oil contains roughly equal amounts of saturated and unsaturated acids (Table 2.5). Depending on the presence or absence of palm itic acid palm oil triacylglycerols have 48–54 carbon atoms (excluding the three glycerol carbon atoms) and are mainly C_{50} (16, 16, and 18) and C_{52} (16, 18, and 18). The major triacylglycerol species are POP (29%), POO (23%), PLO (10%), and PLP (10%) (average values from a large survey of Malaysian samples). Palm oil contains ~5% of diacylglycerols. The crude oil is low in phospholipids (5–130 ppm) and contains carotenes (500–700 ppm), sterols (200–600 ppm), and tocopherols and tocotrienols (together 700–1100 ppm).

2.7 Rapeseed (canola) oil

Traditionally rapeseed oil (known formerly as colza oil) was characterised by high levels of erucic acid (22:1) and high-erucic oils (HEAR) still find use as a source of the valuable erucamide ($RCONH_2$) for use in plastic film. For food purposes HEAR has been replaced almost entirely by a low-erucic variety developed first in Canada and designated canola oil. This oil contains only low levels of erucic acid in the oil (<2%) and low levels of glucosinolates in the meal (<30 μM/g). The high demand for rapeseed oil for food purposes is now augmented, in Europe particularly, by its use as a source of biodiesel in the form of rapeseed oil methyl esters. It is a high-quality food oil with the lowest level of saturated acids among all commodity oils, a high level of oleic acid, and useful levels of linoleic and linolenic acid in a very good ratio (Table 2.5). However, the presence of linolenic acid means that for frying and some other purposes the oil will be subject to brush hydrogenation (Section 3.6) to reduce the level of this triene acid before use. The major triacylglycerols are LOO (23%), OOO (22%), LnOO (10%), LLO (9%), and LnLO (8%). The rapeseed plant lends itself to modification by traditional seed breeding or by genetic modification and many potentially valuable modified oils have been reported including high-oleic, low-linolenic, and other mutants.

2.8 Soybean oil

Soybeans are grown more than any other oilseed, mainly in USA, Argentina, Brazil, and China. When extracted, the beans furnish oil (18%) and a high-quality protein meal (79%). The latter is extensively used as animal feed and also in many processed human foods. Most of the soybeans now grown are genetically modified (mainly for agricultural reasons) and non-GM beans (or products) are only available as IP material. Soybean oil (36.7 million tonnes in 2006/07) is now second to palm oil in annual production. It is an unsaturated oil rich in linoleic acid (54%) and containing some linolenic acid (11%). As a consequence of this fatty acid composition around one half of the triacylglycerol molecules contain two or three linoleic acid chains. Typical values are LLO 16%, LLL 16%, LLP 12%, LLLn 7%, and LLSt 3%. Other triacylglycerols at levels exceeding 5% include LOP 9%, LOO 8%, and LOLn 6%. These three letter symbols include all isomeric triacylglycerols with the acyl chains indicated. Linolenic acid is easily oxidised (Section 6.2) thereby reducing the shelf life of foods containing this oil. This difficulty is reduced by 'brush hydrogenation' – a very light hydrogenation in which the level of linolenic acid is halved (Sections 3.3 and 6.1). An alternative is to use soybean varieties (some of which are non-GM) with lower levels of this acid (3–4%) that are now increasingly available, at least in North America (Table 2.5). Subjected to further hydrogenation regular soybean oil furnishes products suitable for spreads and cooking fats. Concerns about the undesirable effects of *trans* acid that are known to increase LDL and reduce HDL levels have led to the US requirement (perhaps to be followed elsewhere) for the labelling of *trans* content. Since most of the *trans* acids are formed during partial hydrogenation of PUFA attempts have been made to use alternative technologies such as interesterification (Section 3.7) to avoid or limit partial hydrogenation without at the same time raising the content of saturated acids (Table 2.5). Because of its dependence on soybean oil the problem of *trans* acids formed during partial hydrogenation is greater in the USA than in Europe. Crude soybean oil contains several minor components. Insofar as these are removed during refining they can be recovered and serve as valuable starting points for other purposes. Degumming removes most of the phospholipids (~3%) and gives lecithin which is a crude mixture of phospholipids with triacylglycerols and glycolipids (Section 1.4). Deodorisation produces soybean deodoriser distillate enriched in sterols (~18% from an original level of 0.33%) and tocols (~11% from an original level of 0.15–0.21%) and a valuable source of phytosterols and of vitamin E. Attempts are being made to produce soybean oils with changed fatty acid composition or with different levels of minor components. Some of these are detailed in Table 2.5.

2.9 Sunflower seed oil

Sunflower seed oil is the last of the four major vegetable oils. In addition to its regular high-linoleic variety it is available in high-oleic and mid-oleic varieties. None of these are GM-crops. The commodity oil has been much favoured in Europe as a constituent of soft margarines free of linolenic acid. However, this advantage could be viewed differently as the need for additional omega-3 acids in the human diet is accepted. Details are given in Table 2.5. The major triacylglycerols in the regular oil are typically LLO (30%), LLL (27%), LOO (11%), LLP (10%), and PLO/StLL (10%). Sunflower oil may contain a wax (300–600 ppm) from the seed hulls unless the oil has been dewaxed (Section 3.5).

2.10 Other vegetable oils

Supplies of vegetable oils are dominated by palm oil and soybean oil followed by rapeseed/canola and sunflower oils. These, along with olive oil, cocoa butter, and the two lauric oils (coconut and palm kernel) have been discussed in the previous sections. Other commodity oils available at lower levels are cottonseed, groundnut, and corn oil. The fatty acid composition of these and some other vegetable oils available in smaller amounts are given in Table 2.6. Many other minor oils are also available but information about these must be sought on appropriate websites or in sources provided in the Reference list.

Almond, hazelnut, macadamia, and moringa oils are rich in oleic acid. Indeed hazelnut oil is so similar to olive oil that it is used to adulterate olive oil. Macadamia oil is rich in palmitoleic acid (16:1) as well as in oleic acid so that its content of monoene acids is

Table 2.6 Typical fatty acid composition of a range of vegetable oils available at lower levels

	16:0	18:1	18:2	18:3	Other
Almond		65–70			
Avocado	10–20	60–70	10–15		
Camelina		10–20	16–24	30–40	
Corn	11	25	60		
Cottonseed	23	17	56		
Groundnut	11	53	27		C_{20-24} 6
Hazelnut		74–80	6–8		
Hemp	4–9	8–15	53–60	15–25	
Linseed	6	19	24	47	
Linola	6	16	72	2	
Macadamia		55–65			16:1 16–23
Moringa	12	72	2		C_{20-26} 11
Perilla		13–15	14–18	57–64	
Rice bran	20	42	32		
Safflower		14	75		
HO saff		74	16		

Note: 16:0, 18:2, and other acids may also be present where no values are cited.

very high. Safflower seed oil is normally a linoleic acid-rich oil but a high-oleic variety is also available. Linseed oil (and perilla oil) is a convenient rich source of linolenic acid. Most linseed oil is used industrially but some high-grade oil finds food uses as a convenient source of omega-3 acid, albeit at the C_{18} chain length. There is also some food consumption of this material as seeds. When used for food purposes the name linseed is replaced by flax. A mutant of linseed resulting from chemical mutation produces a useful high-linoleic acid oil called linola and used as an alternative to sunflower oil. Camelina oil contains useful levels of linoleic and linolenic acids and is incorporated in spreads as a source of omega-3 acid. Rice bran oil is a significant oil, particularly in rice producing countries. It contains comparable levels of oleic and linoleic acids and has its own powerful antioxidants.

2.11 Single cell oils

Oils and fats produced by the agricultural supply industry come mainly from plant sources and also to a minor extent from animals. An alternative approach is to seek new lipid sources from microorganisms. Some of these can be made to produce high levels of lipids with an interesting fatty acid composition. While it is unlikely that these will replace the more conventional commodity oils for traditional use, nevertheless, they are already providing supplies of high-quality long-chain polyunsaturated fatty acids for infant formula and other special purposes. They are useful sources of arachidonic (20:4) and docosahexaenoic acid (22:6). The major source of DHA is fish oil but supplies of these are limited and some are

Table 2.7 Fatty acid composition of two commercial single cell oils

	14:0	16:0	16:1	18:0	18:1	18:2 (ω-6)	20:3 (ω-6)	20:4 (ω-6)	22:6 (ω-3)
ARASCO[a]	0.4	8	0	11	14	7	4	49	–
DHASCO[b]	20	18	2	0.4	15	0.6	–	–	39

Notes
[a]From *Mortierella alpine*.
[b]From *Crypthecodinium cohnii*.

contaminated with undesirable environmental pollutants. The fatty acid composition of two commercial products is detailed in Table 2.7. Serious attempts are being made to produce algal oils (of different fatty acid composition) that can be used as biodiesel. One of their attractions is the very high yield per hectare compared with more conventional agricultural products.