REVIEW

Nutritional aspects of oilseeds

B. McKevith
British Nutrition Foundation, London, UK

Summary

Oilseeds, such as soybean, cottonseed, rapeseed (canola), sunflower seed and peanut, are annual plants (O'Brien *et al*. 2000). They are the largest source of vegetable oils even though most oil-bearing tree fruits provide the highest oil yields (*e.g.* olive, coconut and palm trees) (Gunstone 2002). Oilseeds are also used in animal feed because of their high protein content. Their seeds contain energy for the sprouting embryo mainly as oil, compared with cereals, which contains the energy in the form of starch (Lucas 2000). This article reviews the main types of oilseeds; their production and processing into oil. It focuses on the role of oilseeds and their by-products in human health and disease, and highlights new developments that may provide even more benefits for health in the future.

Keywords: fat, health, oilseeds, *n*-3 polyunsaturated fatty acids, processing, production

Introduction

According to Lucas (2000), there are five major annual edible oilseeds:

1. Soybean (*Glycine max* (L.) Merr.)

Soybeans and soya products have played an important part in Asian cuisine for centuries. However, there was little use of soybean oil prior to World War II because of problems with flavour reversion. Once a technique was developed to solve this, the use of soybean oil expanded rapidly (O'Brien *et al*. 2000) and it is now the dominant oilseed produced in the world (Wang 2002).

Correspondence: Ms Brigid McKevith, Nutrition Scientist, British Nutrition Foundation, High Holborn House, 52–54 High Holborn, London WC1V 6RQ, UK.
E-mail: b.mckevith@nutrition.org.uk

2. Cottonseed (*Gossypium hirstum* L.)

Although cotton was grown primarily for its use in the textile industry, cottonseed dominated the world oil market prior to World War II, when soybean oil took over. It still contributes ~4% to the world's vegetable oil production but its production is linked to the demand for cotton fibre (Bruinsma 2003).

3. Rapeseed/Canola (*Brassica napus* L. B. rapa L. & *B. juncea*)

Rapeseed is produced by the rape plant which has bright yellow flowers and is a member of the turnip family. Rapeseed used to have high levels of the fatty acid erucic acid but due to reported toxicity, new varieties were bred with oleic acid replacing erucic acid (BNF 1992). These new varieties are referred to as canola in the USA and Canada, while within the EU the original name of rapeseed is still used. Rapeseed is rich in monounsaturated fatty acid (MUFA) and alpha linolenic acid (ALNA) (see Tables 1 and 2).

Table 1 Nutrient content of selected oilseeds (per 100 g)

	Cottonseed kernel*	Linseed/ flaxseed*	Peanut (plain)	Rapeseed**	Sesame seed	Soya (boiled in unsalted water)	Safflower seed	Sunflower seed	Olives (in brine)
Energy (kcal/kJ)	506/2117	492/2059	563/2337	452/1900	598/2470	141/590	517/2163	581/2410	103/422
Fat (g)	36.3	34.0	46.0	N	58.0	7.3	38.5	47.5	11
Saturated fatty acids	9.7	3.2	8.7	N	8.3	0.9	3.7	4.5	1.7
Monounsaturated fatty acids	6.9	6.9	22.0	N	21.7	1.4	4.8	9.8	5.7
Polyunsaturated fatty acids	18.1	22.4	13.1	N	25.5	3.5	28.2	31.0	1.3
Carbohydrate (g)	21.9	34.3	12.5	8.3	0.9	5.1	34.3	18.6	Tr
Protein (g)	32.6	19.5	25.6	22.0	18.2	14.0	16.2	19.8	0.9
Fibre (as NSP unless specified) (g)	5.5	27.9	6.2	7.2 (crude fibre)	7.9	6.1	N	6.0	2.9
Vitamin E (mg)	N	0.3	10.1	N	2.53	1.13	N	37.77	1.99
Niacin equivalent (mg)	3.01	1.4	19.3	N	10.4	2.7	2.3	9.1	0.1
Folate (microgram)	233	278	110		97	54	160	N	Tr
Sodium (mg)	25	34	2	5	20	1	3	3	2250
Potassium (mg)	1350	681	670	800	570	510	687	710	91
Calcium (mg)	100	199	60	400	670	83	78	110	61
Phosphorus (mg)	800	498	430	800	720	250	644	640	17
Iron (mg)	5.4	6.2	2.5	N	10.4	3.0	4.9	6.4	1.0
Magnesium (mg)	440	362	210	250	370	63	353	390	22
Zinc (mg)	6	4.2	3.5	N	5.3	0.9	5.1	5.1	N

NSP, non-starch polysaccharides; Tr, trace

Source: Food Standards Agency and Institute of Food Research (2002) except * where information is from US Department of Agriculture, Agricultural Research Service (2003) and ** where information is from Ewing (1997).

N, the nutrient is present in significant quantities but there is no reliable information about the amount.

Table 2 Fatty acid composition of selected vegetable oils and butter for comparison

Fatty acid (g/100 g oil)	Cottonseed	Linseed/Flaxseed*	Peanut	Rapeseed	Safflower	Sesame	Soya	Sunflower	Olive	Palm	Butter
Saturated											
8:0	0	0	0	0	0	0	0	0	0	0	1.09
10:0	0	0	0	0	0	0	0	0	0	0	2.34
12:0	Tr	0	Tr	0	0	0	0	0	0.1	0.1	2.69
14:0, mystric	0.8	0	Tr	Tr	0.1	Tr	0.1	0.1	0.1	1.0	8.37
16:0, palmitic	22.4	1.8	10.9	4.2	6.6	8.6	10.7	6.2	10.1	41.8	22.04
18:0, stearic	2.5	1.4	3.2	1.5	2.3	0	3.8	4.3	3.0	4.6	8.56
20:0	0.3	N	1.3	0.6	0.3	5.1	0.4	0.3	0.4	0.3	0.13
22:0	0.1	N	3.2	0.3	0.3	0.3	0.5	0.8	0.1	0	0.05
24:0	0	N	1.4	Tr	0.1	0.1	0.1	0.3	0.4	0	0.01
Monounsaturated											
16:1, palmitoleic	0.8	0	Tr	0.2	0.1	0.1	0.1	0.1	0.7	Tr	1.24
18:1, oleic	17.4	6.9	43.3	57.6	11.4	37.2	20.8	20.2	71.9	37.1	15.80
Polyunsaturated											
n-6 18:2, linoleic	50.1	22.4	31.0	19.7	73.9	43.1	51.5	63.2	7.5	10.1	0.95
18:3, γ-linolenic	0	(undifferentiated)	0	0	0	0	0	0	0	0	0.02
n-3 18:3, α-linolenic	0.1		0	9.6	0.1	0.3	7.3	0.1	0.7	0.3	0.46

Tr, trace

Source: Ministry of Agriculture Fisheries and Food (1998), except *where information is from US Department of Agriculture, Agricultural Research Service (2003).

4. Sunflower seed (*Helianthus annus* L. var *marcocarpus* DC)

The fatty acid composition of sunflower seed oil is dependent on where the crop is grown. Cooler climates produce higher amounts of the *n*-6 polyunsaturated fatty acid (PUFA) linoleic acid (an essential fatty acid, EFA) compared with warmer climates, where the MUFA oleic acid is more dominant (Morrison *et al*. 1995). As well as the normal variety, a high oleic sunflower has also been developed. These fatty acids have different properties and different health effects (see p. 19).

5. Peanut (*Arachis hypogae* L.)

Also known as groundnuts, peanuts are grown for oil (sometimes referred to as arachis oil) and as a food commodity. More than a third of the peanuts grown on a worldwide basis are used as food (Sanders 2002).

In addition to the oilseeds described above, there are a number of other seeds that are also used to produce oil, including (O'Brien *et al*. 2000):

- Linseed (*Linum usitatissimum*), which is also known as flaxseed and has a very high ALNA content (35–60%) (see Table 2). ALNA is also an EFA and is a member of the *n*-3 family (Fig. 1). Linseed oil is used in a variety of industrial applications (*e.g.* resin and plastic, varnish and paint), while the plant's fibre is used in the preparation of high-quality products in the paper and textile industries.

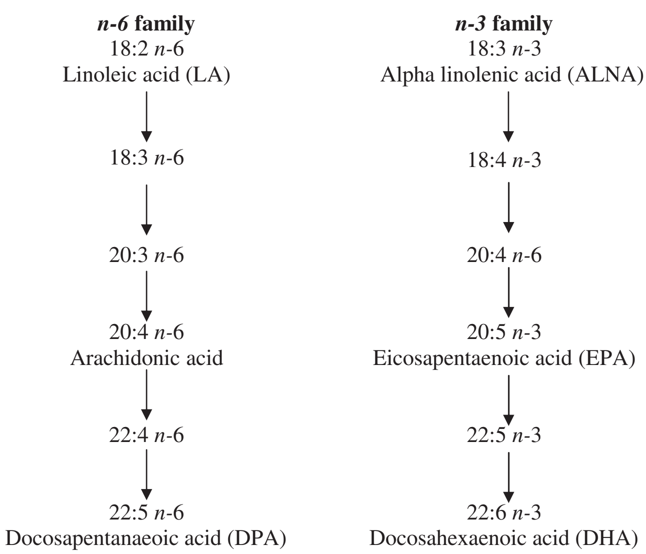

Figure 1 The families of polyunsaturated fatty acids produced from linoleic and alpha linolenic acids by the human body.

- Safflower (*Carthamus tinctorius*), which has the highest level of PUFAs (more than 70% as linoleic acid) (see Table 1). A high oleic oil has also been developed with a 77% oleic acid content.
- Sesame seed (*Sesamum indicun* L), which contains MUFA and PUFA in roughly equal amounts (see Table 1). Sesame seeds can be eaten whole (*e.g.* in Asian cuisine, decoration on bread), used to produce a paste (tahini) or to produce oil (which is used in particular, in Asia and the Middle East).

A number of other seed oils are also produced and used as supplements, *e.g.* evening primrose oil and borage oil. Evening primrose oil is made from the seeds of the plant *Oenithera biennis* and although claims are made that evening primrose oil is beneficial in the treatment of menopausal symptoms, a recent systematic review found there was inconclusive evidence (Huntley & Ernst 2003). Similarly, there is inconclusive evidence on the role of borage oil on atopic eczema (Takwale *et al.* 2003) and rheumatoid arthritis (Belch & Hill 2000).

Production

Oilseeds are grown in a range of countries (see Table 3). World oilseed stocks have been estimated at 39.8 million tons for 2003/2004 (USDA 2004). Increases in a small number of crops, including soybean, sunflower and rapeseed, account for the increase in world production of oil. However, according to the Food and Agriculture Organization (FAO), more traditional oil crops like groundnut and sesame seeds continue to be important in the food supply and food security of many countries, *e.g.* Sudan and Myanmar (Bruinsma 2003).

Oilseeds are also important in animal nutrition as they are used in animal feed. Because of economic and nutritional reasons (*e.g.* a better price can be obtained by making the oilseeds available to the human food market, and the presence of naturally occurring toxic compounds and antinutrients), only a small proportion of oilseeds are fed to animals as whole seeds. However, oilseed meal, which is a by-product of processing the seeds for oil, is used extensively in animal feeds and is therefore an important economic aspect of oilseed production.

Within the EU, oilseeds account for 2% of the total output value of agriculture. Rape seed, sunflower seed and soya are the most important oilseeds in the EU. The main producers are France (rape seed and sunflower seed), Germany (rape seed), Spain (sunflower seed) and Italy (soya) (Table 4) (Verhoog 2002).

Table 3 Oilseed production areas, with information on olive and palm oil for comparison

Plant	Examples of producing areas
Rapeseed/canola	Austria, Canada, China, Czech Republic, Denmark, France, Germany, India, Poland, UK
Cottonseed	Brazil, China, Egypt, India, Pakistan, Russia, Turkey, USA
Peanut	Argentina, China, India, Senegal, South Africa, USA
Soybean	Argentina, Austria, France, Germany, Italy, Spain, Russia, UK
Sunflower	Russia, Argentina, Austria, France, Italy, Germany, Spain, UK
Olive	Spain, Italy, Greece, Tunisia, Turkey, Morocco, Portugal, Syria, Algiers, Cyprus, Egypt, Israel, Libya, Jordan, Lebanon, Argentina, Chile, Mexico, Peru, USA and Australia
Palm	Malaysia, Indonesia, China, Philippines, Pakistan, Mexico, Bangladesh, Colombia, Nigeria, Ivory Cost

Reproduced from O'Brien *et al.* (2000) *Introduction to Fats and Oil Technology*, with permission from AOCS Press.

Table 4 Total areas (1000 hectares) of oilseeds in the EU Member States in 2000

	Total area with oilseeds	Area with rape seed	Area with sunflower seed	Area with soybeans	Area with other oilseeds
EU (15 countries)	5610	3036	1883	350	341
Austria	101	52	22	16	11
Belgium	19	5	–	–	14
Denmark	100	100	–	–	–
Finland	54	53	–	–	1
France	2031	1225	710	80	16
Germany	1215	1078	26	–	112
Greece	18	–	17	–	1
Ireland	3	3	–	–	–
Italy	505	36	217	253	–
Luxembourg	3	3	–	–	–
Netherlands	6	1	–	–	5
Spain	971	31	841	3	96
Sweden	58	48	–	–	10
UK	478	402	2	–	74

Source: Verhoog (2002).

Storage

Oilseeds can be stored for a long time before being processed (Macrae *et al.* 1993). As with cereals (McKevith 2004), oilseeds are dried after harvesting. Appropriate humidity and moisture is required during storage to prevent spoilage and maintain mechanical stability of the seed, with a moisture content target of 7.5%.

Processing

Although oilseeds can be eaten whole, the majority are crushed to produce oil. About one-sixth of production is retained as seed for planting and for food (animal and human) (Gunstone 2002).

Most oils are obtained from oilseeds using a two-step process (extraction and refining). The aim is to obtain a clean product consisting mainly of triglycerides (a glycerol molecule backbone with three fatty acid molecules branched off it). Before extraction, the seeds are cleaned using sieves, aspirators and magnets to remove foreign matter. Some oilseeds are then dehulled or decorticated –, *e.g.* sunflower seeds and cottonseed – before being conditioned (cooked) and ground. Conditioning inactivates enzymes and gives the seeds an optimal plasticity, while grinding reduces the size of the oilseed particles.

Oil can be extracted from seeds either by pressing (using a screw press) or by the use of solvents (mainly by percolating the solvent through the prepared seeds). The oil produced then goes through a series of refining processes to remove unwanted components which may affect taste, smell, appearance or storage stability. Examples include:

• Degumming, which removes a range of substances from the oil which would separate out on storage.

- Neutralisation, which reduces free fatty acids (FFA) and the oxidation products of FFA.
- Deodorisation, which reduces the level of FFA and removes odours, off-flavours and other volatile components from the oil to ensure the oil has an acceptable taste and shelf-life.

Crude oil can also be refined using physical methods but this is not suitable for all oilseeds, *e.g.* cottonseed contains a thermally unstable compound called gossypol which would turn the oil black.

Refining removes most of the contaminants that might be in the oil, including pesticides and aflatoxins (see section below on food safety for more on aflatoxins). If the refining process is carried out correctly, there is almost no change in the fatty acid composition of the oil.

Three main processes can be used to modify the composition of oils:

- Fractionation can be used to provide more functional products, *e.g.* high-stability oils. This physical process makes use of the different melting points or solubility of triglycerides to separate them into fractions.
- Hydrogenation, sometimes called hardening, is used to reduce the degree of unsaturation by the addition of hydrogen. During the process hydrogen is added to the vegetable oil in the presence of a catalyst; some of the *cis* double bonds in the oils are isomerised to *trans* double bonds. Hydrogenation is used to either change the physical form of the oil to improve product functionality or to improve oxidative stability (O'Brien *et al.* 2000). Margarine can be made using hydrogenation, although many of the high PUFA margarines are produced using emulsifier technology (Gurr 2000).
- Interesterification changes the physical properties of the oil (*e.g.* different melting and crystallisation characteristics) by changing the order of distribution of the three fatty acids within the triglyceride molecules. This process does not change the fatty acid composition. Commercially this process is used for the production of confectionary fats, cooking oils, frying fats and shortenings.

Post-processing deterioration

After processing, oxidation is the main problem affecting oils, leading to aldehyde production which imparts strong disagreeable flavours and odours, referred to as rancidity. Generally, the rate of oxidation will depend on the degree of unsaturation of the oil and its temperature as well as the presence of antioxidants. Oxidation will occur at varying rates throughout the life of the oil: during storage and distribution of the oil, during food preparation and storage of the final food product.

During heating some changes may occur in the structure of oils, depending on the temperature to which the oil is heated, the length of time the oil is heated and the amount of air to which it is exposed. For example, in deep-fat frying, the production of steam carries volatile compounds out of the oil and oxidation over time can reduce the concentration of PUFA. The oil used for deep-fat frying should therefore be replaced regularly.

Food safety

Mycotoxins are toxic chemical substances produced by certain forms of mould under specific conditions. Oilseeds, along with cereals, nuts, dried fruit, coffee, cocoa, spices, dried peas and beans, are among the major food commodities that can be affected by mycotoxins. Mycotoxins pose a potential threat to human and animal health through the ingestion of food products prepared from contaminated commodities. The first mycotoxins to be identified were aflatoxins. These are produced by a particular type of mould, *Aspergillus,* and can appear on a number of foods including peanuts. A range of preventative strategies are used to reduce the formation of mycotoxins before and after harvest in oilseeds and other susceptible crops.

The nutritional value of oilseeds and their oils

As can be seen from Table 1, oilseeds are energy dense foods; for example, sesame seeds provide ~600 kcal or 2470 kJ/100 g. Although oilseeds contain protein (~14–32 g/100 g) and carbohydrate (ranging from less than 1 g/100 g to more than 34 g/100 g), most of the food energy they provide is as fat (which provides 9 kcal or 37 kJ/g). Oilseeds vary widely in their fatty acid composition but tend to be rich in MUFA (*e.g.* peanuts) or PUFA (*e.g.* sunflower seeds) (Table 2). Some seed oils contain significant amounts of the EFA ALNA, an *n*-3 fatty acid, and linoleic acid (LA), an *n*-6 fatty acid. From these two fatty acids, the body can make all the fatty acids it needs (Fig. 1). From LA, arachidonic acid can be produced, and from ALNA the long chain *n*-3 eicosapentaenoic acid (EPA) and docosahaexanoic acid (DHA) can be made. The latter two fatty acids are the ones present in fish oils in large quantities. More details can be found in the BNF's (1999) Briefing Paper n-*3 Fatty Acids and Health*.

Generally, whole oilseeds are a source of fibre, phosphorus, iron and magnesium; many oilseeds are also a source of vitamin E (an antioxidant), niacin and folate (Table 1). Whole oilseeds also contain phytoestrogens, a group of substances including lignans and isoflavones. Phytoestrogens have a structure similar to the oestrogen hormone oestradiol and can bind to oestrogen receptors. Phytoestrogens may provide a protective effect against coronary heart disease as they have been shown to have a lowering effect on blood cholesterol. Additionally, some phytoestrogens may have antioxidant properties (Goldberg 2003).

In Britain oilseeds are usually consumed, following processing, as oils and margarines. As can be seen from Table 2, the fatty acid composition of oils produced from oilseeds varies widely. Vegetable oils do not contain the same levels of macronutrients, vitamins and minerals as whole oilseeds. In fact, apart from fat itself, vitamin E is the only nutrient present in appreciable amounts (Fig. 2). Vegetable oils do, however, contain a range of phytohemicals, *e.g.* they are the main source of natural plant sterols in the diet. Plant sterols have a structure similar to cholesterol and hence reduce cholesterol absorption, therefore reducing the circulating levels of total and low density lipoprotein (LDL) cholesterol. Plant sterols can be present as free or esterified forms and the proportions vary, *e.g.* free sterols dominate in soybean, olive and sunflower oil, while in rapeseed and corn oil free sterols account for only 30% of the plant sterols. Refining vegetable oils decreases the content of sterols (from 10 to 70% depending on the oil and processing conditions used), thus decreasing their potential to lower serum cholesterol (Goldberg 2003).

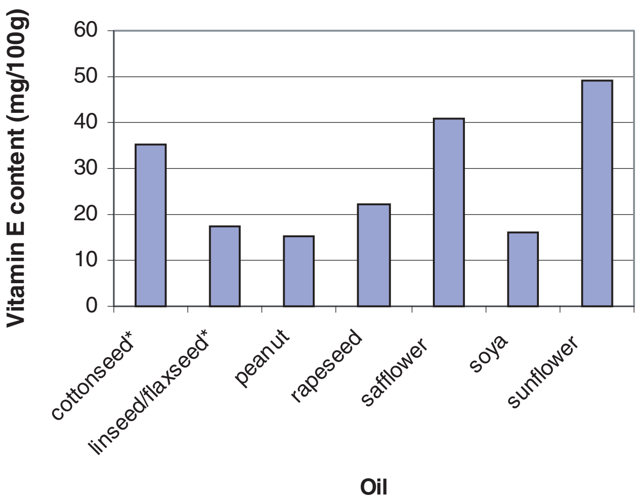

Figure 2 Vitamin E content of selected oils (mg/100 g). Source: Food Standards Agency & Institute of Food Research (2002), except * where information is from US Department of Agriculture, Agricultural Research Service (2003).

Whole oilseeds

Relatively small amounts of whole oilseeds are eaten in Britain – only about 20% of men and women consumed *nuts and seeds* during the 7-day survey period of the recent National Diet and Nutrition Survey (NDNS). The average weekly intake of nuts and seeds, including non-consumers, was 17 g for men and 12 g for women (Henderson *et al.* 2002). Nuts and seeds did, however, contribute a small proportion of the total PUFA intake, providing 3% of *cis n*-3 PUFA intake in men and 2% of *cis n*-3 in women; and 2% of *cis n*-6 intake of men and women (Henderson *et al.* 2003a). In the NDNS of children aged 5–18 years, about 15% of children consumed nuts and seeds during the survey period (7 days) (Gregory *et al.* 2000).

Oilseed meals

Oilseed meals are important in animal nutrition as they are used in feed compounds. Oilseed meals are high in protein, with most being over 40% (Young 1982). They also contain about 10% carbohydrate and some fat (the amount of which is dependent on the efficiency of oil extraction, but values range from ~1% to 6% depending on the oilseed and method used for extraction) (Young 1982).

Vegetable oil and spreads

Margarines and cooking fats are the major foods produced from vegetable oils. Although information is available on UK intakes of fats and oils from the NDNS and National Food Surveys (NFS), it is difficult to estimate what proportion of these come from oilseeds. Historical NFS data show that household consumption of total fats and oils has decreased from 245 g/person/week in 1942 to 186 g/person/week in 2000 (although intakes did increase in the mid-1960s to around 340 g/person/week). Household consumption of lard, margarine and butter have decreased over time (*e.g.* butter has decreased from 115 g/person/week in 1980 to 39 g/person/week in 2000), with concomitant increases in vegetable oils (from 30 g/person/week in 1980 to 47 g/person/week in 2000), low-fat spreads (from 12 g/person/week in 1984 to 20 g/person/week in 2000) and reduced-fat spreads (from 11 g/person/week in 1987 to 48 g/person/week in 2000, DEFRA & National Statistics 2001).

Products containing vegetable oils and spreads

Margarines and cooking fats are used in a variety of foods including bread, cakes, biscuits, pastry, snack foods, mayonnaise and dressings. Vegetable oils provide a number of specific functions, including batter aeration, emulsifying properties, flavour provision and improvement in keeping properties (Macrae *et al.* 1993).

Vegetable oils are also used for frying. In shallow or pan frying, the cooking oil prevents the food from sticking to the hot cooking surface as well as contributing to the colour and flavour of the food. As the oil is only used once, resistance to oxidation is not critical. This is in contrast to deep-fat frying, where the oil is reused. When there is high turnover, highly unsaturated vegetable oils such as soybean or rapeseed can be used but when turnover is low, improved stability to oxidation is needed and hydrogenated vegetable oils may be more appropriate. Hydrogenated vegetable oils may, however, contain *trans* fatty acids (see p. 14 for more on *trans* fatty acids).

The contribution of oilseeds and their products to the UK diet

From oilseeds a range of oils and spreads are produced. These products are used as an ingredient in a range of other foods; oils are also used to cook of a number of other foods. It is therefore difficult to estimate the total intake of oilseeds and foods containing vegetable oils or fats produced from oilseeds.

Table 5 shows the average contribution fat spreads make to the energy, macronutrient and micronutrient intakes of the British population. Table 6 shows the average contribution a range of other foods make to nutrient intake, a proportion of which may be due to vegetable oil or margarines they contain.

Fat spreads are an important source of vitamin E, being the main contributor of adult vitamin E intake among British adults and the second most important source among British children and young people. Excluding butter, they contribute 14% of total vitamin E intake in adults (Henderson *et al.* 2003b), 17% in boys and 16% in girls (Gregory *et al.* 2000). Fat spreads also contribute a significant proportion of vitamin D, with margarines and low-fat spreads contributing to 16% of intake in adults (Henderson *et al.* 2003b), 19% in boys and 19% in girls (Gregory *et al.* 2000). Fat spreads contribute to total vitamin A intake, but to a smaller extent. In Britain, margarines are required by law to be fortified with vitamins A and D to levels comparable with or higher than those found in butter. These vitamins are also added voluntarily to many reduced-fat and low-fat spreads.

Fat and health

Fat is an essential nutrient with a number of important functions. It carries fat-soluble vitamins and supplies EFA which are vital for the formation of signalling substances in the body known as eicosanoids. EFA and their long-chain derivatives are important structural elements of cell membranes and are essential for the formation of new tissues, *e.g.* in pregnancy (Nettle 1993). They are particularly important for the development of the brain, nervous system and retina (BNF 1999). Body fat is an energy store and more recently it has been recognised as an endocrine gland, producing signalling molecules which play an important role in preventing the accumulation of body fat in tissues other than the usual fat stores (*e.g.* muscle, pancreas, and heart) (Nugent 2004b).

The total amount of fat in the diet and the amount of the different fatty acids in the diet can influence health. The UK dietary reference values (DRV) were published in 1991 (Department of Health 1991). The figures are intended as population averages, not as targets for individuals. Additional recommendations were made for the long-chain *n*-3 PUFA by the Committee on Medical Aspects of Food in 1994 during a review of the nutritional aspects of cardiovascular disease (CVD) (Department of Health 1994) (Table 7).

The recent NDNS of UK adults showed that the average daily total fat intakes were close to UK recommendations, but average intakes for men in all age groups and women in the two youngest age groups remained above the DRV. Although average intakes of saturated fatty acids have decreased since the 1986/87 survey (16.5% food energy and 17.0% food energy, respectively, for men and women), intakes from the 2000/2001 survey still exceeded the DRV of 11%, highlighting the need to decrease further the saturated fatty acid intake of the population. With regard to *trans* fatty acids, despite recent media attention, current UK intakes are now well below the population target set, as can be seen from Table 7.

It has been suggested that the balance between the intakes of *n*-6 and *n*-3 fatty acids is more important than levels of intake of individual fatty acids. Changing dietary patterns have led to a substantial rise in intake of *n*-6 fatty acids, as vegetable oils have been used to replace traditional sources of fat (*e.g.* lard and butter) in the food industry. Changes in animal feeding practices

Table 5 Contribution of fats and oils to average nutrient in the UK (% total intake)

Nutrient	Food	Boys (4–18 years)	Girls (4–18 years)	Adults
Energy	Fat spreads	3	3	4
Fat	Fat spreads	9	9	12
	Including margarine			1
	PUFA reduced-fat spread	5	4	5
	Other reduced-fat spreads			
	Low-fat spreads	–	–	1
Saturates	Fat spreads	8	8	11
	Including margarine	–	–	1
	PUFA reduced-fat spread	3	3	1
	Other reduced-fat spreads			2
	Low-fat spreads	–	–	1
Trans fatty acids	Fat spreads	13	13	18
	Including margarine	4	4	5
	PUFA reduced-fat spread	2	2	1
	Other reduced-fat spreads	3	3	7
	Low-fat spreads	–	–	2
Cis MUFA	Fat spreads	8	8	11
	Including margarine	2	2	2
	PUFA reduced-fat spread	2	2	1
	Other reduced-fat spreads	2	2	4
	Low-fat spreads	–	–	1
Cis n-3 PUFA	Fat spreads	6	6	7
	Including margarine	2	2	2
	PUFA reduced-fat spread	1	1	0
	Other reduced-fat spreads	3	2	3
	Low-fat spreads			1
	Nuts & seeds	8	4	3
Vitamin A	Fat spreads	13	12	10
	Including margarine	–	–	1
	PUFA reduced-fat spread	3	3	1
	Other reduced-fat spreads	–	–	2
	Low-fat spreads	–	–	1
Vitamin D	Fat spreads	21	22	17
	Including margarine	3	4	3
	PUFA reduced-fat spread	12	11	–
	Other reduced-fat spreads			8
	Low-fat spreads	4	4	5
Vitamin E	Fat spreads	23	22	18
	Including margarine	–	–	–
	PUFA reduced-fat spread	13	13	8
	Other reduced-fat spreads	–	–	3
	Low-fat spreads	4	3	3

MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

have also led to a small fall in the concentration of ALNA in beef and lamb, and coupled with this, there has been a fall in the consumption of red meat from the 1950s. Currently, targets for *n*-6 fatty acid intake are being met, but the recommendations for very long-chain *n*-3 fatty acids (a weekly intake of 1.5 g of the very long-chain *n*-3 fatty acids, EPA/DHA), set by the Cardiovascular Review Group Committee on Medical Aspects of Food and Nutrition Policy, are not met (Department of Health 1994).

Table 6 Other foods contributing to intake (% total intake) which may contain vegetable oil or margarines

Nutrient	Food	Boys (4–18 years)	Girls (4–18 years)	Adults
Energy	Biscuits, buns, cakes & pastries	10	10	6
	Meat pies & pastries	2	2	2
	Potato chips	6	6	4
	Savoury snacks	4	5	1
Fat	Biscuits	5	6	3
	Buns, cakes & pasties	5	5	4
	Meat pies & pasties	4	3	4
	Roasted & fried potatoes & chips	10	8	
Saturates	Biscuits	7	7	4
	Buns, cakes & pastries	5	5	4
Trans fatty acids	Biscuits	12	12	9
	Buns, cakes & pastries	9	9	8
Cis MUFA	Biscuits	5	5	3
	Buns, cakes & pastries	5	5	4
	Meat & pastries	4	4	4
	Roast & fried potatoes & chips	10	10	7
	Savoury snacks	8	10	4
Cis n-3 PUFA	Buns, cakes & pastries	3	3	2
	Meat pies & pastries	2	1	2
	Roast & fried potatoes & chips	24	25	14
	Savoury snacks	3	4	1
Vitamin A	Buns, cakes & pastries	5	4	2
Vitamin D	Buns, cakes & pastries	8	9	4
	Vegetables, potatoes & savoury snacks	2	2	2 (1% potato & savoury snacks)
Vitamin E	Biscuits	4	4	2
	Buns, cakes & pastries	4	4	3
	Roast & fried potatoes & chips	11	10	9
	Savoury snacks	10	11	4

MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

Fat and heart health

Generally, high intakes of saturated fatty acids and *trans* fatty acids have been associated with raised blood cholesterol levels, one of the risk factors associated with CVD. In comparison, MUFA decrease the 'bad cholesterol' LDL-cholesterol (LDL-C). While PUFA also decrease LDL-C, intakes of *n*-6 PUFA above 10% energy may have adverse effects on 'good cholesterol' high density lipoprotein-cholesterol (HDL-C) (Clarke *et al*. 1997).

Although *n*-3 fatty acids have little or no effect on total blood cholesterol levels, a substantial amount of work has recently focused on their ability to reduce blood triacylglycerol levels (*e.g.* Rivellese *et al*. 2003). This, together with evidence that long-chain *n*-3 fatty acids reduce the risk of having a fatal heart attack, indicates an important role for long-chain *n*-3 fatty acids in maintaining heart health. A number of mechanisms have been proposed, including protection against blood clot formation (thrombosis), protection against heart arrhythmias and a beneficial impact on blood pressure. There has also been recent interest of PUFA to influence insulin sensitivity, a key factor in the development of metabolic syndrome (a 'clustering' of several risk factors for CVD, namely obesity (particularly abdominal obesity), abnormal blood lipids (dyslipidemia), insulin resistance and high blood pressure). But to date, there is little support for a role in healthy people. There is also interest in the potential of fatty acids to influence endothelial function (endothelial dysfunction is associated with atherosclerosis and other CVD risk factors).

The majority of the work on heart health and *n*-3 fatty acids has focused on long-chain *n*-3 fatty acids found in fish oils rather than the shorter chain fatty acids found in oilseeds and their oils. In theory, ALNA can be elongated and desaturated to the long-chain *n*-3 fatty acids, but the extent and regulation of this conversion in man is unclear. In dietary studies, ALNA-rich oils do not appear to reproduce fish-oil-like effects on CVD

Table 7 Population targets for the percentage contribution of fats and fatty acids to daily food energy intake (UK DRV) and current UK intakes

	DRV (Department of Health 1991)	Current UK intakes (Henderson *et al.* 2003a)	
		Men	Women
Total Fat (% food energy)	35	35.8	34.9
Saturated fatty acid (% food energy)	11	13.4	13.2
Trans fatty acids (% food energy)	2	1.2	1.2
MUFA (% food energy)	13	12.1	11.5
Cis PUFA (% food energy)	6.5		
n-3 PUFA (% food energy)	– Minimum intake for individuals, 0.2%; Long-chain 1.5 g/week (Department of Health 1994)	1.0	1.0
n-6 PUFA (% food energy)	– Minimum intake for individuals, 1%; Maximum intake for individuals 10%	5.4	5.3

DRV, dietary reference values; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

risk factors, including blood lipids, haemostatic factors, or immune, inflammatory and endothelial function or platelet function (Sanderson *et al.* 2002). For example, a placebo-controlled, parallel study in 150 moderately hyperlipidemic subjects given plant-derived *n*-3 PUFA for 6 months found no affect on blood coagulation or fibrinolytic factors (Finnegan *et al.* 2003). Nonetheless, a recent World Health Organization (WHO)/FAO report on diet and chronic disease listed ALNA as a probable factor decreasing the risk of CVD (WHO/FAO 2003).

Plant stanols and sterols have been shown to have cholesterol-lowering effects at a daily intake of up to 2 g/day, reducing LDL-C by ~0.3 mmol/L to ~0.5 mmol/L depending on the subject's age. However, as usual intakes from the diet are only about 140–400 mg/day, a range of functional foods have been developed containing higher amounts of sterol or stanol esters (Goldberg 2003).

In addition, soya protein has been associated with decreased cholesterol levels (a meta-analysis of 38 studies providing an average of 47 g/day of soya protein was able to achieve an average reduction in total and LDL-C of 0.6 mmol/L and 0.56 mmol/L respectively (Anderson *et al.* 1995)) and in a recent 3-month randomised study the isoflavone genistein was found to decrease blood pressure in subjects with mild hypertension (Rivas *et al.* 2002). However, it is unlikely that soya oil will have these effects as these components are removed during processing.

Fat and cancer

Some studies have indicated that there may be an association between fat intake and risk of certain types of cancer. For example:

- Franceschi (1999) compared the diets of people with colorectal cancer ($n = 1953$) with hospital controls ($n = 4154$) using a food frequency questionnaire. A high intake of saturated fatty acids seemed to be associated with an increased risk of colorectal cancer while high intake of PUFA (chiefly olive oil and seed oils) showed a marginal inverse association with colorectal cancer risk.
- Another Italian case–control study found a reduced risk of ovarian cancer with a high intake of olive oil [odds ratio (OR) = 0.68] and for a group of specific seed oils (*i.e.* sunflower, peanut and soya) (OR = 0.59) (Bosetti *et al.* 2002).
- In the Norfolk component of the European Prospective Investigation into Cancer and Nutrition (EPIC) study, a relationship was found between saturated fatty consumption and breast cancer when consumption was assessed with a 7-day food diary (hazard ratio 1.22, $P = 0.005$, per quintile increase in energy-adjusted fat intake), but not when measured with the Food Frequency Questionnaire (FFQ) (1.10 [0.94–1.29], $P = 0.23$) (Bingham *et al.* 2003).

Although these studies may suggest a role for fatty acids in cancer, findings from such case–control studies are weak and need to be verified by randomised controlled trials.

Fat and overweight/obesity

Fat is a concentrated source of energy, providing twice as much energy per gram as protein or carbohydrate. It has been suggested that it may be easier to consume an excess of energy when eating a high-fat diet, as fat-rich foods have a poor satiating power compared to protein- and carbohydrate-rich foods. If energy intake and expenditure are unbalanced, then the excess energy is stored in the body as fat, potentially leading to an individual becoming overweight or obese. In the Postdam cohort of the EPIC study, consumption of high-fat foods significantly predicted weight gain in women, *e.g.* fats (butter, margarine, oil) were associated with an OR of 1.75. Consumption of nuts and seeds was associated with a small weight loss (OR = 0.33) (Schulz *et al.* 2002). Although the replacement of saturated fatty acids with carbohydrates has been the standard advice for weight loss, high carbohydrate diets have been shown to increase plasma triacylglycerol and decrease beneficial HDL-C levels.

There is currently considerable debate about the most effective balance between carbohydrate and fatty acid profile and a number of large studies are underway. It may be that different advice is needed depending on whether type 2 diabetes and/or metabolic syndrome is present.

Other roles of fat in health

There has also been interest in the role of fatty acids in a number of functions and conditions, for example:

Diabetes

Because of reported effects of *n*-3 fatty acids on blood insulin levels, there has been some interest in the potential of *n*-3 fatty acids to influence type 2 diabetes and associated risks (Lovejoy 1999). Work in animal models has shown that long-chain *n*-3 fatty acids improve insulin sensitivity compared with *n*-6 PUFA (Storlein *et al.* 1991), although work in obese patients with impaired glucose tolerance given fish oil supplements for 2 weeks did not affect fasting concentrations of glucose and insulin nor induced glycaemia and insulin response (Fasching *et al.* 1991).

Inflammatory conditions

Essential fatty acids are used in the body to produce eicosanoids which participate in inflammatory and immune responses. As *n*-3 fatty acid derived eicosanoids are generally less potent than those derived from *n*-6, it has been suggested that decreasing the dietary *n*-6/*n*-3 ratio may be beneficial in a number of conditions that involve abnormal immune responses, such as asthma, Crohn's disease, psoriasis and rheumatoid arthritis. The evidence of a benefit of *n*-3 fatty acids in most of these conditions remains conflicting and/or weak (Prescott & Calder 2004). However, a recent review on the nutritional management of rheumatoid arthritis concluded that long-chain *n*-3 PUFA consistently demonstrated an improvement in symptoms and allowed a reduction in the use of non-steroidal anti-inflammatory drugs (Rennie *et al.* 2003). Although no evidence of a specific benefit of *n*-3 PUFA rich plant oils for patients with rheumatoid arthritis was found, there was some evidence of a possible benefit of plant oils rich in gamma-linolenic acid (GLA) (produced from *n*-6 linoleic acid) (*e.g.* evening primrose oil and borage seed oil). The authors identified a need for more studies, preferably using a randomised control design and of longer duration, to explore the long-term effects of GLA supplementation.

Cognitive function

Work in France studying the relationship between the fatty acid composition of erythrocyte membranes and cognitive decline in free-living volunteers found that a higher proportion of total *n*-3 fatty acids was associated with a lower risk of cognitive decline (OR = 0.59, for 1-SD differences in fatty acid proportions) (Heude *et al.* 2003). Several studies have found an association between dietary fat and fatty acids and cognitive function and risk of dementia, with a reduced risk of cognitive decline or dementia associated with intakes of *n*-3 PUFA, particularly the long-chain *n*-3 PUFA associated with fish consumption (Kalmijn 2000; Morris *et al.* 2003; Kalmijn *et al.* 2004). However, these observations do not equate to causality and need to be verified in clinical trials.

In summary, although there appears to be a role for long-chain *n*-3 fatty acids in heart health, the benefits of shorter chain *n*-3 PUFA are still unclear. There may be other health benefits from *n*-3 PUFA, especially for rheumatoid arthritis, but again little evidence exists for shorter chain PUFA. Several researchers have not found an effect of foods enriched with plant- (or marine-) derived *n*-3 fatty acids on human immune function, suggesting that much more research is needed to understand the mechanism behind any observed benefits (see e.g. Thies *et al.* 2001; Kew *et al.* 2003).

Labelling and health claims

Currently in the UK, nutrition labelling is not mandatory but many manufacturers do provide nutrition information on a voluntary basis. If given, nutrition information must be given either in the Group 1 format (providing information on energy, protein, carbohydrate and fat) or Group 2 format (as for Group 1 plus information on sugar, saturates, fibre and sodium). There is scope to provide further information on the fatty acid composition of foods under the UK Food

Labelling Regulations. However, no legislation or guidance currently exists for *n*-3 fatty acid claims, for example the amount required to be present to enable a food to be labelled a source, or rich source, of *n*-3 fatty acids, although the proposed EU regulation on nutrient and health claims is likely to define such claims. Additionally, the level of consumer knowledge and understanding of fatty acids and their role in health is not known, making it difficult to know whether additional information on food labels would be beneficial to consumers.

Health claims are used to communicate positive health messages, and although there is no legislation specifically covering health claims in the UK, legislation at an EU level has been proposed. It is possible that the legislation will prohibit non-specific claims, claims regarding psychological and behavioural functions, and health claims on alcohol. Additionally the 'nutritional profiles' of foods may be evaluated, with a view to restricting the use of claims on some foods with high-fat, high-salt and/or high-sugar contents. A pre-approval process is planned, which will require submission of a dossier containing relevant scientific evidence, prior to use of a health claim.

Developments in nutrition labelling and health claims should be noted by those involved in development of new products. It is unlikely that resources will be spent developing new products, for example with modified fatty acid compositions, unless the benefits of this can be communicated to the consumer.

Future developments

It seems that the UK population could benefit from increasing its consumption of *n*-3 PUFA, particularly those which are long-chained. Oil-rich fish is an excellent source of long-chain *n*-3 fatty acids but alternative ways of increasing *n*-3 fatty acids are needed for several reasons. Firstly, many people do not eat fish, *e.g.* in the NDNS, less than 50% of men and women ate oily fish during the 7-day survey period (Henderson *et al.* 2002). Secondly, as the majority of fish stocks are now being fully exploited, the recommendation to increase consumption of fish needs to be balanced against sustainability concerns (WHO/FAO Expert Consultation 2003).

Food manufacturers could use more *n*-3 rich PUFA in pre-prepared food products, as well as developing products which include *n*-3 rich oilseeds such as linseed and soya to help consumers increase their *n*-3 PUFA intake. Appropriate labelling of foods high in *n*-3 PUFA (*e.g.* rapeseed oil) would also be useful. It is also important to look at ways of increasing long-chain *n*-3 PUFA. Plant biotechnology could also be used to produce plants with long-chain *n*-3 PUFA. The LIPGENE project is investigating this possibility by using transgenic technology to reproduce in oil seeds (*e.g.* linseed), the exact metabolic pathway responsible for the production of long-chain *n*-3 PUFA, thereby increasing the levels of *n*-3 PUFA in vegetable oil (Nugent 2004a).

Another possibility is to manipulate the fatty acid composition of animal products by feeding livestock ALNA-rich oils or adding ALNA-rich seeds to feed. For example, Weil *et al.* (2002) reduced the *n*-6/*n*-3 ratio by 54% in butter, 60% in meat and 86% in eggs. Increasing PUFA levels may change flavour because of their greater susceptibility to oxidative breakdown and the generation of abnormal volatile compounds during cooking. In some, but not all studies, the meat produced from pigs fed whole linseed had abnormal odours and flavours at a concentration of 3 mg ALNA/100 mg in muscle and fat tissue fatty acids (Wood *et al.* 1999). However, it has been demonstrated that consumption of products with increased *n*-3 contents can increase the *n*-3 content of plasma in humans, leading to a decrease in the *n*-6/*n*-3 (Weill *et al.* 2002). The success of such a strategy will depend on the acceptability of the final products (as increasing the PUFA levels may change flavour due to their greater susceptibility to oxidation), the costs to industry, the willingness of the consumer to pay a premium price, and the presence of a strong scientific rationale.

Conclusions

Oilseeds and the products made from them, mainly vegetable oils and spreads, have a role in a healthy balanced diet even though they are energy dense and contain a high proportion of fat. They are particularly important sources of vitamins D and E in the UK diet, as well as contributing to vitamin A intake. Oilseeds and their products are rich sources of PUFA. While there seems to be important roles in health for PUFA (*e.g.* they can have a positive effect on decreasing LDL-C), particularly in replacing saturated fatty acids in the diet, it may be particularly important to increase the *n*-3 family of PUFA rather than those belonging to the *n*-6 family. The long-chain *n*-3 PUFA (for which most of the health benefits have been found) are found in oily fish but other ways of increasing intakes are needed to help the UK population meet the target of 1.5 g/week of the long-chain PUFA, EPA and DHA. Innovative techniques may be needed, such as increasing the levels of *n*-3 PUFA in vegetable oil using transgenic technology, as well as increasing the *n*-3 PUFA content of animal products and highlighting to consumers good sources of *n*-3 PUFA fatty acids.

References

Anderson JW, Johnstone BM & Cook-Newell ME (1995) Meta-analysis of the effects of soy protein intake on serum lipids. *New England Journal of Medicine* **333**: 276–82.

Belch JJF & Hill A (2000) Evening primrose and borage oil in rheumatologic conditions. *American Journal of Clinical Nutrition* **71**(suppl. 1): 352S–6S.

Bingham SA, Luben R, Welch A *et al.* (2003) Are imprecise methods obscuring a relation between fat and breast cancer? *Lancet* **362**: 212–14.

Bosetti C, Negri E, Franceschi S *et al.* (2002) Olive oil, seed oil and other added fats in relation to ovarian cancer (Italy). *Cancer Causes & Control* **13**: 465–70.

BNF (British Nutrition Foundation) (1992) *Unsaturated Fatty Acids. Nutritional and Physiological Significance. The Report of the British Nutrition Foundation's Task Force.* Chapman & Hall, London.

BNF (British Nutrition Foundation (1999) *n-3 Fatty Acids and Health*. British Nutrition Foundation, London.

Bruinsma J (2003) *World Agriculture: Towards 2015/2030. An FAO Perspective.* Earthscan Publications Limited, London.

Clarke R, Frost C, Collins R *et al.* (1997) Dietary lipids and blood cholesterol: quantitative meta-analysis of metabolic ward studies. *British Medical Journal* **314**: 112–17.

DEFRA & National Statistics (2001) *National Food Survey 2000*. The Stationery Office, London.

Department of Health (1991) *Report on Health Social Subjects No. 41. Dietary reference values for food energy and nutrients for the United Kingdom.* HMSO, London.

Department of Health (1994) *Report on Health Social Subjects No. 46. Nutritional Aspects of Cardiovascular Disease Report of the Cardiovascular Review Group Committee on Medical Aspects of Food and Nutrition Policy.* HMSO, London.

Ewing WN (1997) *The Feeds Directory*. Context, Packington.

Fasching P, Ratheiser K, Waldhausl W *et al.* (1991) Metabolic effects of fish-oil supplementation in patients with impaired glucose tolerance. *Diabetes* **40**: 583–9.

Finnegan Y, Howarth D, Minihane AM *et al.* (2003) Plant and marine derived (n-3) polyunsaturated fatty acids do not affect blood coagulation and fibrinolytic factors in moderately hyperlipidemic humans. *Journal of Nutrition* **133**: 2210–2213.

Food Standards Agency and Institute of Food Research (2002) *McCance and Widdowson's The Composition of Foods, Sixth Summary Edition.* Royal Society of Chemistry, Cambridge.

Franceschi S (1999) Nutrients and food groups and large bowel cancer in Europe. *European Journal of Cancer Prevention* **8**(suppl. 1): S49–52.

Goldberg G, ed. (2003) *Plants: Diet and Health. The Report of the British Nutrition Foundation Task Force.* Blackwell, Oxford.

Gregory J, Lowe S, Bates CJ *et al.* (2000) *National Diet and Nutrition Survey: Young People Aged 4 to 18 Years. Volume 1: Report of the Diet and Nutrition Survey.* HMSO, London.

Gunstone FD (2002) Production and trade of vegetable oils. In: *Vegetable Oils in Food Technology Composition, Properties and Uses*, (FD Gunstone ed.) Blackwell Publishing, Oxford.

Gurr M (2000) Fats. In: *Human Nutrition and Dietetics*, 10th edn, (JS Garrow, WRT James, A Ralph eds), pp. 97–120. Churchill Livingstone, Edinburgh.

Henderson L, Gregory J, Irving K *et al.* (2003a) *The National Diet and Nutrition Survey: Adults Aged 19–64 Years. Volume 2. Energy, Protein, Carbohydrate, Fat and Alcohol Intake.* HMSO, London.

Henderson L, Gregory J & Swan G (2002) *The National Diet and Nutrition Survey: Adults Aged 19 to 64 Years. Types and Quantities of Foods Consumed. Volume 1.* HMSO, London.

Henderson L, Irving K, Gregory J *et al.* (2003b) *The National Diet and Nutrition Survey: Adults Aged 19 to 64 Years. Volume 3. Vitamin and Mineral Intake and Urinary Analytes*. HMSO, London.

Heude B, Ducimetiere P, Berr C (EVA Study) (2003) Cognitive decline and fatty acid composition of erythrocyte membranes – the EVA study. *American Journal of Clinical Nutrition* **77** (4): 803–8.

Huntley AL & Ernst E (2003) A systematic review of herbal medicinal products for the treatment of menopausal symptoms. *Menopause* **10**: 465–76.

Kalmijn S (2000) Fatty acid intake and the risk of dementia and cognitive decline: a review of clinical and epidemiological studies. *Journal of Nutrition, Health and Ageing* **4**: 202–7.

Kalmijn S, van Boxtel MP, Ocke M *et al.* (2004) Dietary intake of fatty acids and fish in relation to cognitive performance at middle age. *Neurology* **62**: 275–80.

Kew S, Banerjee T, Minihane AM *et al.* (2003) Lack of effect of foods enriched with plant or marine-derived n-3 fatty acids on human immune function. *American Journal of Clinical Nutrition* **77**: 1287–95.

Lovejoy J (1999) Dietary fatty acids and insulin resistance. *Current Artherosclerosis Reports* **1**: 215–20.

Lucas EW (2000) Oilseeds and oil-bearing materials. In: *Handbook of Cereal Science and Technology, Chapter 11*, (K Kulp, JG Ponte eds). Marcel Dekker, New York.

Macrae R, Robinson RK & Sadler MJ (1993) *Encyclopaedia of Food Science, Food Technology & Nutrition*. Academic Press, London.

McKevith B (2004) Nutritional aspects of cereals. *Nutrition Bulletin* **2**: 111–42.

Ministry of Agriculture Fisheries and Food (1998) *Fatty Acids. Seventh Supplement to the Fifth Edition of McCance & Widdowson's The Composition of Foods.* The Royal Society of Chemistry and the Ministry of Agriculture, Fisheries and Food, London.

Morris MC, Evans DA, Bienias JL *et al.* (2003) Consumption of fish and *n*-3 fatty acids and risk of incident Alzheimer disease. *Archives of Neurology* **60**: 940–6.

Morrison WH, Hamilton RJ & Kaln C (1995) Sunflower seed oil. In: *Developments in Oils and Fats*, (RJ Hamilton ed.), pp. 132–51. Blackie Academic & Professional, Glasgow.

Nettleton JA (1993) Are *n*-3 fatty acids essential nutrients for fetal and infant development? *Journal of the American Dietetic Association* **93**: 58–64.

Nugent A (2004a) LIPGENE: a truly integrated approach to tackling the metabolic syndrome. *Nutrition Bulletin* **29**: 152–5.

Nugent AP (2004b) OB-AGE, an EU project to tackle the metabolic syndrome: project update. *Nutrition Bulletin* **29**: 264–5.

O'Brien RD, Farr WE & Wan PJ, eds (2000) *Introduction to Fats and Oil Technology*, 2nd edn. AOCS Press, Champagin, Illinois.

Prescott SL & Calder PC (2004) *N*-3 polyunsaturated fatty acids and allergic disease. *Current Opinion in Clinical Nutrition and Metabolic Care* **7**: 123–9.

Rennie KL, Hughes J, Lang R *et al.* (2003) Nutritional management of rheumatoid arthritis: a review of the evidence. *Journal of Human Nutrition and Dietetics* **16**: 97–109.

Rivas M, Garay RP, Escanero JF *et al.* (2002) Soy milk lowers blood pressure in men and women with mild to moderate essential hypertension. *Journal of Nutrition* **132**: 1900–2.

Rivellese AA, Maffettone A, Vessby B *et al.* (2003) Effects of dietary saturated, monounsaturated and *n*-3 fatty acids on fasting lipoproteins, LDL size, post-prandial lipid metabolism in healthy subjects. *Artherosclerosis* **167**: 149–58.

Sanders TH (2002) Groundnut (peanut oil). In: *Vegetable Oils in Food Technology Composition, Properties and Uses*, (FD Gunstone ed.). Blackwell Publishing, Oxford.

Sanderson P, Finnegan YE, Williams CM *et al.* (2002) UK Food Standards Agency alpha-linolenic acid workshop report. *British Journal of Nutrition* **88**: 573–9.

Schulz M, Kroke A, Liese AD *et al.* (2002) Food groups as predictors for shot-term weight changes in men and women of the EPIC-Potsdam cohort. *Journal of Nutrition* **132**: 1335–40.

Storlein LH, Jenkins AB, Chisholm DJ *et al.* (1991) Influence of dietary fat composition on the development of insulin resistance in rats: relationship to muscle triglyceride and ω-3 fatty acids in muscle phospholipid. *Diabetes* **40**: 2280–9.

Tawale A, Tan E, Agarwal S *et al.* (2003) Efficacy and tolerability of borage oil in adults and children with atopic eczema: randomised, double blind, placebo controlled, group trial. *British Medical Journal* **327**: 1358–9.

Thies F, Miles EA, Nebe-von-Varon G *et al.* (2001) Influence of dietary supplementation with long-chain *n*-3 or *n*-6 polyunsaturated fatty acids on blood inflammatory cell populations and functions and on plasma soluble adhesion molecules in healthy adults. *Lipids* **36**: 1183–93.

US Department of Agriculture, Agricultural Research Service (2003) *USDA National Nutrient Database for Standard Reference, Release 16*. Nutrient Data Laboratory Home Page. Available at: http://www.nal.usda.gov/fnic/foodcomp

USDA (2004) *Oilseeds: World Markets and Trade*. Circular. Series FOP 01–04 January 2004.

Verhoog AD (2002) *Statistics in Focus. Oilseed Production in the EU.* Eustostat, Luxembourg.

Wang T (2002) Soybean oil. In: *Vegetable Oils in Food Technology Composition, Properties and Uses*, (FD Gunstone ed.). Blackwell Publishing, Oxford.

Weill P, Schmitt B, Chesneau G *et al.* (2002) Effects of introducing linseed in livestock diet on blood fatty acid composition of consumers of animal products. *Annals of Nutrition and Metabolism* **46**: 182–91.

WHO/FAO (World Health Organization/Food and Agriculture Organization) (2003) *Diet, Nutrition and the Prevention of Chronic Diseases*. Report of Joint WHO/FAO Consultation. WHO, Geneva.

WHO/FAO Expert Consultation (2003) *Diet, Nutrition and the Prevention of Chronic Diseases.* WHO, Geneva.

Wood JD, Enser M, Fisher AV *et al.* (1999) Manipulating meat quality and composition. *Proceedings of the Nutrition Society* **58**: 363–70.

Young LG (1982) Effects of processing on nutritive value of feeds: oilseeds and oilseed meals. In: *CRC Handbook of Nutritive Value of Processed Food Volume II Animal Feedstuffs*, (M Recheigl Jr ed.), pp. 213–21. CRC Press, Boca Raton.