BRIEFING PAPER

Culinary oils and their health effects

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Summary

Vegetable oils are mainly produced from oilseeds (*e.g.* rapeseed and sunflower seed) as well as from legumes (*e.g.* peanut and soybean), nuts (*e.g.* walnut and almond) and the flesh of some fruits (*e.g.* olives). Vegetable oils are pressed from the plants and are then processed and refined to produce high-quality oils suitable for use as an ingredient in recipes, for frying, in salad dressings and in the production of margarines and spreads.

There has been substantial growth in the oilseeds markets over the past 30 years. This was initially driven by health concerns but, more recently, has been because of the interest in biofuels and the changing market. In 2008, the four main types of vegetable oil that dominated the world market (in terms of the quantities produced) were palm oil, soybean oil, rapeseed oil and sunflower seed oil. In the UK, the only oilseed crops harvested are rapeseed, hempseed and linseed/flaxseed. However, there are substantial imports of groundnuts, soybeans, sunflowers and palm kernels that are processed in the UK resulting in the production of a variety of different oils in the UK.

Vegetable oils mainly comprise triacylglycerides. The main nutrient they provide is fat. The only other nutrient that is present in appreciable amounts is vitamin E (tocopherols and tocotrienols). Vegetable oils are also the main source of natural plant sterols in the diet and contain minor components, such as squalene and sphingolipids, all of which may provide a range of health benefits.

The fatty acid composition of plant oils varies, and all plant oils are composed of a mixture of different fatty acids, in different proportions. Most culinary oils tend to be high in either monounsaturates or polyunsaturates, with the exception of palm kernel and coconut oils which are high in saturates. Categorising fats as 'saturated fats', 'monounsaturated fats' or 'polyunsaturated fats' (based on the predominant fatty acid) may be helpful for consumer understanding. However, this is an over-simplification of the actual situation.

The constituent fatty acids of each culinary oil are primarily responsible for the functionality of the oil, along with the minor components. The properties of the oil can be modified through technical processes including hydrogenation, fractionation and interesterification. The processes used to modify the properties of oils have become a widely debated topic. Hydrogenation was a commonly used process to increase hardness and to stabilise fats without having to increase saturates to any great extent. However, as partial hydrogenation results in the formation of *trans* fatty acids, its use in the UK for consumer products has now virtually ceased. Some food manufacturers have been using interesterification to ensure that the oil has functional properties and the desired organoleptic qualities, without the formation of *trans* fatty acids. Alternatively, manufacturers have looked for new oils with more favourable fatty acid profiles. This has been made possible through plant breeding programmes using both conventional techniques and genetic modification and will have an important impact on the fatty acid profile of the UK diet in the future.

However, overall there is little evidence to suggest that one vegetable oil should be promoted over any other oil on the basis of additional health effects as there are few good quality trials that have adequately compared the health outcomes of individuals consuming different oils. Indeed, because of the use of a variety of different vegetable-based oils in food manufacturing processes, most people are consuming a wide variety of different oils each day. Instead, the choice of the oil often depends on the functionality of the oil for a particular food application, or on taste, personal preference or cost. The most important message for consumers to understand is that all oils, regardless of whether they contain 'good' or 'bad' fats, are almost 100% fat and that the oils themselves, as well as products manufactured from them, should only ever be included in the diet in moderate quantities.

Keywords: vegetable oil, rapeseed, sunflower, monosaturates, polyunsaturates, olive

1 Introduction

Getting the quantity and quality of fat in the diet right can be confusing enough for health professionals, let alone for the general public. As time has passed, the balance of fatty acids in the UK diet has shifted slightly, and, although at a population level we are meeting the recommendations for total fat, saturates are making up proportionally too much of the energy in our diets, and we are not consuming sufficient amounts of some of the unsaturates, which are believed to be relatively good for our health.

This Briefing Paper has been written to provide a concise introduction to the nutritional and health aspects of the main plant-based oils in the UK diet (namely sunflower, rapeseed, olive, soybean, palm, peanut, sesame, corn, flaxseed, coconut and walnut oils). On some occasions throughout this paper, other oils that are important on a global scale have been included for comparison; however, their health effects have not been assessed. Although all oils are 99% fat and so very energy dense, there are subtle differences in the nutrient composition of the oils, and these are often considered when recommending which culinary oils to use. In this paper, the term *culinary oil* refers to edible vegetable oils, such as those used in food preparation and production. NB: animal fats (*e.g.* tallow and lard) are also used for culinary purposes but are not considered in this paper.

To put the oils commonly consumed in the UK diet into a more global context, this paper first briefly considers the worldwide production of vegetable oils, the production process from plant materials and vegetable products and the nutritional value of the finished products. The contribution that vegetable oils and their products make to our diet and nutrient intake in the UK is then briefly discussed. Section 6 explores each oil in turn, in relation to its nutritional composition and usage and pulls together the key facts to determine whether one oil should be recommended over another. Finally, the paper considers the role that vegetable oils and the products derived from them play in a healthy, balanced diet and lists some consumer-friendly tips for selecting oils for everyday use in the home.

2 Worldwide production, processing and consumption

Most plants contain some oil, but only the oil from certain major oil crops (along with several minor oil crops) is widely used and traded. The worldwide production of the major oilseeds is shown in Table 1. Globally, soybeans represent roughly half of the total

Table 1 Worldwide production of major oilseeds (2005)*

Oilseed	Production (million tonnes)
Soybean	219.6
USA	84.0
Brazil	55.0
Argentina	40.3
China	17.4
Others	22.9
Rapeseed	48.3
EU-25	15.4
China	12.4
Canada	9.6
India	6.7
Others	4.2
Cottonseed	42.5
China	10.0
USA	7.4
India	8.2
Pakistan	4.2
Others	12.7
Sunflower seed	29.7
CIS	11.5
EU-25	3.7
Argentina	3.8
Eastern Europe	2.5
Others	8.2
Groundnut	23.7
China	10.0
India	4.4
USA	1.6
Nigeria	1.3
Others	6.4
Palm kernel†	9.4
Malaysia	4.2
Indonesia	3.6
Nigeria	0.4
Others	1.2
Copra (coconut)	5.2
Philippines	2.1
Indonesia	1.4
India	0.6
Mexico	0.2
Others	2.3
Sesame seed	3.2
India	0.6
China	0.6
Myanmar	0.5
Sudan	0.3
Others	1.2
Flaxseed	2.9
Canada	1.1
China	0.4
USA	0.5
India	0.2
Others	0.7

Source: FEDIOL (2008).

*Olive oil and rice bran oil are major tradable commodities but are not derived from an oilseed, so data on their production are not included in this table.

†Palm oil is extracted directly from the palm fruit and is processed immediately, so it is not included in this table.

CIS, Commonwealth of Independent States; EU, European Union.

production of major oilseeds, with rapeseed, cottonseed, sunflower and groundnuts making up a further third.

After harvest, these crops are used to produce a number of different vegetable oils. Vegetable oils and fats are used in the manufacturing of many foodstuffs: from salad dressings to dairy and confectionery products. However, these oils and fats are not only used in food applications, they are also used for cosmetics (especially soap), detergents, paints, plastics, candles, pharmaceuticals and biofuels, among many other technical applications.

The production of vegetable oils is on a worldwide scale, and therefore it is difficult to extract information on the proportions of the different oils that are used for different purposes. However, data on the quantity of oils produced have been collated by the European Union Oil and Proteinmeal Industry (FEDIOL) (Table 2).

As Table 2 illustrates, four main types of vegetable oil dominate the world market in terms of the quantities produced. These are palm oil, soybean oil, rapeseed oil and sunflower oil. Roughly one-third of all the vegetable oil produced in the world is palm oil, produced mainly in Malaysia and Indonesia. The oil produced in the second largest amount is soybean oil from North and South America. Sunflower oil is the third most commonly produced oil, originating from Southern and Eastern Europe, South America and South Africa, followed by rapeseed oil produced in Europe, China, India and Canada (FEDIOL 2008).

The production of most types of vegetable oil has increased over the past 30 years, but soybean and palm oil production have expanded the most. The continued growth in world demand for oilseeds is linked to the increased demand in India and China, recent developments in growing crops for biofuels and extreme weather conditions that have affected harvests. There are indications that about half of the increased demand for grains and vegetable oils over the past two years was because of biofuels (OECD-FAO 2008). It is also forecasted that, over the next decade, the use of vegetable oils for biofuels will increase and will account for more than a third of the expected growth in need (OECD-FAO 2008).

All these effects have had knock-on consequences for the price of vegetable oils, although it has been suggested that the increased demand for biodiesel has had the greatest impact on oil prices (Fig. 1). Over the past decade, the price of crude oil rose to over US$100 a barrel. This sudden increase made it attractive to use vegetable-based oils as an alternative to other types of fuel, even though extra costs are incurred to make the vegetable oil suitable for use. As crude oil prices have

Table 2 Worldwide production of edible vegetable oils (2005)

Vegetable oil	Production (million tonnes)
Palm oil	33.6
Malaysia	14.9
Indonesia	13.9
Nigeria	0.8
Thailand	0.7
Others	3.3
Soybean oil	33.5
USA	8.8
Brazil	5.7
China	5.5
Argentina	5.4
Others	8.1
Rapeseed oil	16.0
EU-25	5.6
China	4.6
India	1.8
Canada	1.3
Others	2.7
Sunflower oil	9.7
Russia	2.0
EU-25	1.7
Argentina	1.5
Ukraine	1.3
Others	3.2
Cottonseed oil	5.0
China	1.5
India	0.7
Pakistan	0.5
CIS	0.4
Others	1.9
Groundnut oil	4.5
China	2.0
India	1.1
Nigeria	0.3
Others	1.1
Palm kernel oil	3.9
Malaysia	1.8
Indonesia	1.4
Nigeria	0.2
Others	0.5
Coconut oil	3.2
Philippines	1.3
Indonesia	0.8
India	0.4
Mexico	0.1
Others	0.7
Olive oil*	3.0
Europe	2.5
Asia	0.3
Africa	0.3
Others	0.1
Corn oil	2.1
USA	1.1
EU-25	0.2
China	0.1
Others	0.7
Sesame oil	0.8
China	0.2
India	0.1
Myanmar	0.1
Others	0.4
Flaxseed oil	0.6
EU-25	0.2
China	0.1
USA	0.1
Others	0.2

Source: FEDIOL (2008).
*Data on olive oil production is not compiled by FEDIOL, but for completeness, the most recent available data have been included in this table. Source: FAOSTAT/FBS (2006).
EU, European Union; CIS, Commonwealth of Independent States.

recently fallen back to around US$60 a barrel, it is no longer economical to sell vegetable oil-based products as fuel, and it will be interesting to see the effect that this has on the cost of the oils, as well as the levels of production.

However, concerns surrounding future food security, among other things, initiated a review into the effects of biofuels. This review concluded that there was a need to take a more precautionary approach to UK and European Union (EU) targets for biofuel production (see DEFRA 2008).

In response to this heightened demand for oilseeds and cereal crops, the European Commission (EC) has withdrawn the 10% set-aside policy previously introduced to control the amount of food produced while protecting a farmer's income. However, the oilseed market is vulnerable to influences that cannot be anticipated, such as unpredictable weather conditions and natural disasters, and therefore it is likely that supply and demand could change again in the next 12 months, let alone the next 10 years.

In terms of the actual consumption of these oils on a global scale, useful data have been collected by the United States Department of Agriculture (USDA) Foreign Agriculture Service (Fig. 2). The most recent report suggests that soybean and palm oils together contribute over half of all the vegetable oil consumed across the world. Rapeseed and sunflower oils together contribute roughly a quarter. When viewed at this global scale, it is clear that oils such as olive oil and speciality nut oils, which often receive high prominence in the media, actually make a very small contribution to overall consumption.

2.1 UK situation

In the UK, the only oilseed crops harvested are rapeseed, hempseed and linseed/flaxseed (amounting to roughly 2 million tonnes each year). However, there are substantial imports of groundnuts, soybeans, sunflowers and palm kernels that are processed in the UK by one of three companies specialising in oil crushing, resulting in the production of a variety of different oils in the UK. These oils are used in a number of different applications. Table 3 shows how the consumption of these oils has changed over time.

Such figures will of course reflect the substantial quantities of oils used in food manufacturing and so are not necessarily representative of the selection of oils lined up in the store cupboard. Today, the variety of vegetable oils available for domestic cooking in the UK has grown as consumers have become more interested in health issues, taste and quality of food ingredients

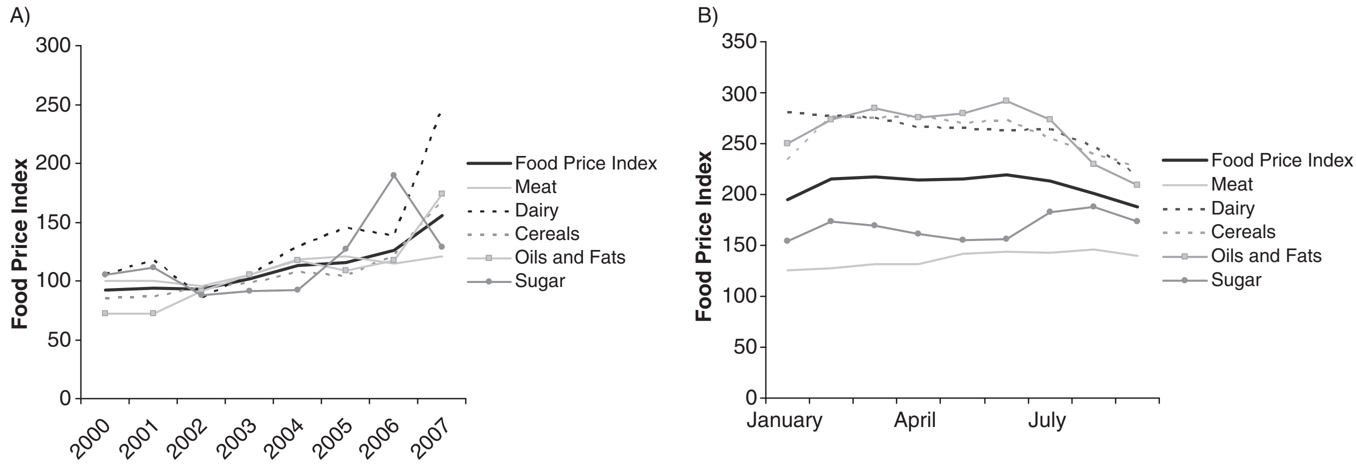

Figure 1 Changing food price index for six main commodities from A) 2000 to 2007 to B) 2008. Food price index = consists of the average of six commodity group price indices weighted with the average export shares of each of the groups for 1998–2000: in total, 55 commodity quotations, considered by the Food and Agriculture Organization of the United Nations Commodity Specialists as representing the international prices of the food commodities noted, are included in the overall index. Source: FAO (2008).

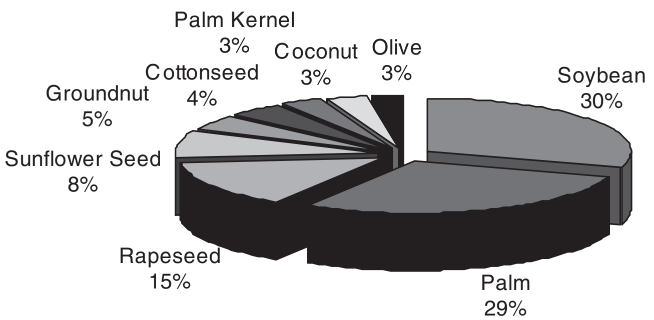

Figure 2 World consumption of vegetable oils 2005. Source: USDA-FAS (2008).

(Mintel 2007). Indeed, when questioned, two-thirds of consumers reported purchasing two or more different types of oils in the past 12 months.

The UK liquid oil market comprises three main segments: standard seed oils, olive oils and speciality oils. Over the past few years, consumers have increased their purchases of premium olive oils and speciality oils possibly because of their perceived health benefits (Table 4). Furthermore, over the last decade, the proliferation in cookery programmes on television and celebrity status of chefs has made consumers more interested in cooking and in the quality and variety of ingredients they use. In particular, many foods from around the world are being recreated using ingredients, including oils, which are specific to a dish.

Mintel has predicted that there will be further growth within the speciality oils segment of the market as 'health-boosting superoils', fortified with vitamins and minerals, become popular. However, olive oil (including all refined, virgin and extra virgin oils) continues to be the most popular culinary oil among consumers across the UK, based on product purchases (Fig. 3), closely followed by 'vegetable' (usually rapeseed) and sunflower oils.

Key points: worldwide production, processing and consumption

- Over the past 30 years there has been a growth in the production of oilseeds and it is well recognised that the drive to produce healthier oils and, more recently, the interest in biofuels and the changing world market are partly responsible. However, the data available make it difficult to identify the changes in the proportions of different crops that are used for foodstuffs.
- The four main types of vegetable oil that dominate the world market in terms of the quantities produced are palm oil, soybean oil, rapeseed oil and sunflower oil.
- Within the UK market, speciality oils are becoming more popular with consumers.

3 Production, storage and processing

3.1 Production and processing

Vegetable oils and fats are obtained from plants and plant materials (Table 5). Vegetable oils either originate from oilseeds (*e.g.* rapeseed, sunflower seed); nuts (*e.g.*

Table 3 UK consumption of vegetable oils and fats (tonnes)

	1990	1995	2000	2001	2002	2003
Coconut oil	3	29 673	0	0	13 013	12 361
Cottonseed oil	816	453	172	668	333	333
Peanut oil	11 481	4 417	2 437	2 346	5 149	7 461
Maize germ oil	15 118	18 945	11 987	12 214	11 258	22 222
Olive oil	6 804	15 311	41 463	32 245	26 802	46 658
Palm oil	97 396	118 619	114 948	115 576	108 527	75 603
Palm kernel oil	4 539	0	0	0	0	0
Rapeseed oil	320 150	470 162	576 022	587 997	520 726	380 942
Sesame oil	420	46	809	2 011	2 516	2 392
Soya bean oil	192 810	131 675	136 774	174 915	184 609	251 695
Sunflower oil	141 184	114 365	173 744	134 084	99 733	71 384
Oil crops oil, others	30 937	37 282	17 586	19 646	27 338	23 790
Total vegetable oils	**821 664**	**940 951**	**1 075 944**	**1 081 704**	**1 000 006**	**894 844**

Source: FAOSTAT/FBS (2006).

Table 4 UK retail sales of specialty oil, 2005–2007

Specialty oil	2005 (£m)	2007 (£m)	% change 2005–2007
Nut-/seed-based*	9.2	19.8	115.2
Flavoured†	1.7	3.2	88.2
Total	10.9	23	111

Source: Mintel (2007).
*Those that fall outside the traditional nut and seed oils market, for example, sesame, groundnut, walnut, flaxseed/linseed, safflower and specialist rapeseed.
†Oils flavoured with garlic, lemon and black truffles, for example.

almond, walnut); legumes (*e.g.* peanut, soybean); or from the fruit of the plant (*e.g.* olive, palm).

3.1.1 Harvesting and storage

Most crops are harvested annually, which in the northern hemisphere is late in the calendar year (early in the year in the southern hemisphere). Some equatorial crops can be harvested throughout the year, such as coconut and palm. Rapeseed typically has two harvests in the UK (the 'winter sown' varieties in late July and the 'spring sown' varieties in late August).

After harvesting, the seed/legume/fruit/nut may be cleaned, and, if the weather has been wet during the run up to the harvest, it is likely that the harvested material will also need to be dried. To prevent spoilage and maintain mechanical stability, the seeds need to be stored in specific conditions, relating to humidity and moisture (Macrae *et al.* 1993).

3.1.2 Crushing and heating

In order to extract the oil, the vegetable material is often pressed, using a hydraulic or screw press. The pressure exerted in the process squeezes out the oil. Most plant materials especially those with a relatively low oil content, are thermally treated, or toasted, before they are mechanically crushed. However, sometimes the raw material is pressed without heating; such oils are known as cold-pressed oils. As cold pressing does not extract all the oil, it is practised only in the production of a few special edible oils, such as olive oil and some rapeseed oils. The resulting pressed crude oil can be consumed as such or be further refined.

In the case of the oils obtained from the palm plant, the material is separated into the palm fruit (mesocarp) and palm kernel. The palm fruit is cooked before it is crushed, and no solvents are used.

3.1.3 Solvent extraction

Alternatively, solvent extraction is often used to separate the oil from the toasted seeds/beans. In this instance, a volatile liquid, in which the oil is freely soluble, is used to repeatedly extract the oil from the seeds. The most common solvent used by crushers is hexane. The oil is then separated from the solvent by distillation. The solvent is recycled into the extraction process.

The crude oils obtained by pressing and/or extraction are sometimes used directly for food and feed purposes. However, in most cases, the crude oils are degummed and refined in a multi-stage process culminating in deodorisation, which is a steam distillation process carried out

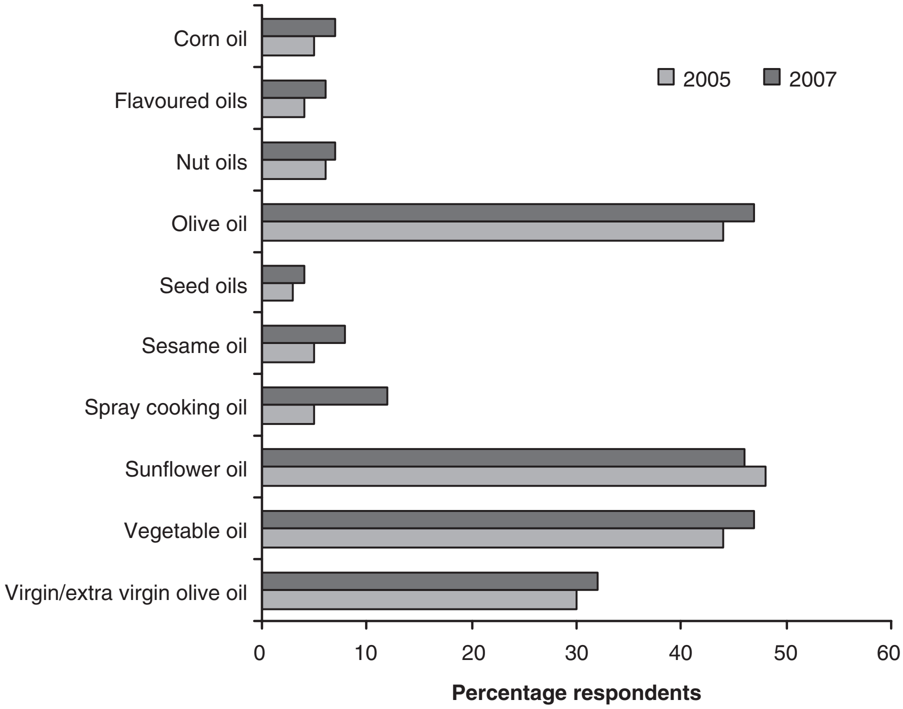

Figure 3 Type of culinary oil purchased by a sample population (UK) in 2005 and 2007. Shoppers aged over 16 years were asked 'which, if any, of these cooking oils have you purchased in the last 12 months?' Classification derived by source: Mintel (2007). NB: Vegetable oil usually refers to rapeseed oil.

Table 5 Plant origin of vegetable oils

Plant product	Common vegetable oils
Seeds	Maize (corn), rapeseed, sunflower, safflower, flaxseed, sesame, coconut
Legumes	Peanut, soybean
Fruits	Olive, palm*
Nuts	Walnut, almond

*Palm olein or palm super olein are the main forms used. The stearin is used for non-food uses.

at temperatures in excess of 200°C. Crude oils might contain substances and trace components that are undesirable with respect to taste, stability, appearance or odour, or may interfere with further processing. These substances and trace components include seed particles, impurities, phosphatides, carbohydrates, proteins and traces of metals, pigments, waxes, oxidation products of fatty acids, polycyclic aromatic hydrocarbons and pesticide residues (Allman-Farinelli & Macan 2000). The extent of refining will depend on the desired properties or function of the oil. High quality oils will require more refining; hence, the methods used to do this are important. For example, one of the characteristics of virgin olive oil is that solvents cannot be used to treat the oil, as defined by EC regulations. Traditionally, the term 'extra virgin' has been used to describe olive oil, and Commission Regulation (EC) No. 1019/2002 on marketing standards for olive oil outlines all the specific analytical and labelling requirements. There are no regulations to control the use of the term 'virgin' for other oils.

3.1.4 Modifying the properties of oils and oil-based products

In their crude state, the physical, nutritional and chemical properties of oils mean that they are not suitable for use in food manufacturing processes. However, over the last century, lipid technologists have developed procedures to overcome some of the issues specific to vegetable-based oils (see Table 6). Some of these are discussed in the following section.

Hydrogenation The process of hydrogenation is used to convert liquid oils into semi-solid or solid fats suitable for food manufacturing applications. During the process of hydrogenation, hydrogen gas is passed into a pressurised vessel that contains the vegetable oil and a suitable catalyst (nickel) to cause the hydrogen atoms to adsorb onto/desorb from the catalyst and link to the double bonds of the fatty acids. At the chosen endpoint, the reaction is completed by stopping the flow of hydrogen, cooling the oil rapidly and removing the catalyst. In some cases, oils may be lightly or partially hydrogenated; it is in this instance that *trans* fatty

Table 6 Methods used to modify the properties of oils

Technological solutions	
	Blending
	Distillation
	Fractionation
	Hydrogenation
	Interesterification with chemical catalysts
	Interesterification with specific lipases
	Enzymatic enhancement
Biological solutions	
	Domestication of wild crops
	Oils modified by conventional seed breeding
	Oils modified by genetic engineering
	Lipid from other sources (e.g. microalgae)

acids are formed. As noted later, these have been linked with adverse effects to health (see SACN 2007).

Until recently, partially hydrogenated vegetable oils were widely used in food manufacturing and catering in the UK, in particular, in the manufacture of both hard and soft margarines, bakery products, fried foods and other processed foods (see Aisbitt & Buttriss 2006). However, action and innovation by leading food manufacturers to move away from the use of partially hydrogenated fats have resulted in a considerable reduction in *trans* fatty acid intake. After thorough collection of data on current intakes in the UK, the Food Standards Agency (FSA) Board has recommended to UK health ministers that voluntary measures to reduce sources of *trans* fatty acids in food have resulted in such low consumer intakes that mandatory restrictions (such as those imposed in the USA and Denmark), are not necessary (see FSA 2007a).

In addition, consumer awareness of *trans* fatty acids and their adverse effects on health seems to be relatively high. Some consumers have become vigilant in looking at the ingredients list; unfortunately, loose media reporting around this topic has caused confusion, and many people do not realise that they should be looking to avoid partially hydrogenated fat, rather than fully hydrogenated fat which, by definition, contains only very low levels of *trans* fatty acids (less than 1%). (Complete hydrogenation of a fatty acid yields a saturate as all the double bonds between the carbon atoms become saturated with hydrogen.) What makes this issue more confusing is that current food labelling regulations require vegetable oil that has been hydrogenated to be labelled as 'hydrogenated vegetable oil' in the ingredients list regardless of whether this is partial or full hydrogenation (Food Labelling Regulations 1996). The refiners would prefer to be able to differentiate between partially hydrogenated oils (containing nutritionally significant levels of *trans* fatty acids) and fully hydrogenated oils (containing virtually no *trans* fatty acids), but this is not yet permitted. The EC is currently considering whether there is still a need for hydrogenation to be declared when a full nutrition profile, including the *trans* fatty acid content, is given on-pack for all products.

Interesterification Today, interesterification is used to modify the physical properties of oils and/or fats, thus altering the functional and nutritional properties. Interesterification is a process whereby the positions of the three fatty acids within a triacylglyceride (TAG) molecule are rearranged by the use of either the enzyme lipase or a chemical catalyst, both within and between molecules, which changes the properties of the fat.

Interesterification is used as an alternative process to hydrogenation to make dietary fats more functional (*i.e.* to provide modified melting and crystallisation properties). In order to make products such as cakes and biscuits, fats must be in a solid form to provide sufficient structure, but must melt quickly to allow flavour release. Most predominantly unsaturated fats occur as liquids, so these must be converted to more solid forms before use. Traditionally, manufacturers have used hydrogenation to achieve this. However, as already discussed *trans* fatty acids, produced as a result of the partial hydrogenation of vegetable oils, are now known to bring about adverse health effects, and many manufacturers have chosen to cease using hydrogenated oils altogether.

Over the years, interesterification has been shown to be a safe process, although few studies have specifically investigated the health aspects of interesterified fats. However, a small number of recent studies have raised some interesting questions on the potentially adverse effect that these fats might have on lipoprotein metabolism and blood sugar control (*e.g.* Meijer & Weststrate 1997; Sundram *et al.* 2007). The studies have typically been small scale and have not necessarily been designed well enough to investigate the specific effect of the interesterified fat. Nevertheless, they do pose some interesting questions, and it is likely that more research will be carried out to ensure that these fats pose no harm to human health.

Fractionation Fractionation involves the removal of solids by controlled crystallisation, and separation techniques may involve the use of solvents or dry processing. Dry fractionation is the most widely practiced form. It relies upon the differences in melting points and solubility of components in the oils to separate the oil fractions. Pressing is also sometimes used to separate liquid oils from solid fat. This process presses the liquid oil from the solid fraction by hydraulic pressure or vacuum filtration and is used commercially to produce hard butters and specialty fats from oils such as palm and palm kernel. Alternatively, solvent fractionation is used to crystallise a desired fraction from a mixture of fatty acids dissolved in a suitable solvent. Fractions may be selectively crystallised at different temperatures, after which the fractions are separated and the solvent is removed. Solvent fractionation is practiced commercially to produce hard butters, specialty oils and some salad oils from a wide array of edible oils.

3.2 Storing oils in the home

All oils are sensitive to heat, light and exposure to oxygen, so it is important that they are stored correctly to prevent them from going 'rancid' and off-flavours developing. Ideally, oils should be kept in a dark, cool, dry place. Sunlight can destroy the vitamin E in the oil, and storing oil at very cool temperatures, such as in a refrigerator, can cause the oil to become cloudy and thicken slightly as the fatty acids with higher melting points precipitate. When left at room temperature, the crystals will melt, and the oil will return to a clear liquid. To delay the development of rancid flavours, often a layer of inert gas such as nitrogen is pumped over the surface of the oil immediately after processing and the cap should be replaced tightly on the container after use. Typically, oils should be consumed within 12 months of purchase.

Key points: production, storage and processing

- Vegetable oils and fats are obtained from plants and plant materials, including seeds, beans, fruits and nuts.
- Vegetable oils tend to be extracted through pressing, with or without the use of solvents. The oil then goes through a series of refining processes to remove unwanted residues.
- The properties of the oil can be modified through technical processes including hydrogenation, interesterification and fractionation.
- The processes used to modify the oil properties have become a widely debated topic. The process of hydrogenation is rarely used now in the UK, as partial hydrogenation results in the formation of *trans* fatty acids. Some food manufacturers have been using interestification as an alternative, to ensure the oil has the functional properties required for an acceptable shelf life and the desired organoleptic qualities.

4 Culinary oils, nutrition and health

4.1 Nutrient composition of oils and spreads

Vegetable oils are mainly composed of triacylglycerides (TAGs, sometimes known as triglycerides) (*i.e.* three fatty acids on a glycerol backbone), so the main nutrient they provide is fat. The only other nutrient that is present in appreciable amounts is vitamin E, although fat spreads are fortified with vitamins A and D in the UK. The minor components include mono- and diglycerides, free fatty acids, phosphatides, sterols, fatty alcohols and other substances, including a range of phytochemicals (or bioactive compounds).

4.1.1 Fatty acid composition

In common with all sources of fat, plant oils contain a range of different fatty acids (both saturated and unsaturated), and their fatty acid composition varies widely, but typically, one type of fatty acid will predominate. For example, the major fatty acid found in olive oil is the monounsaturate oleic acid, and therefore it is classified as a 'monounsaturated oil', whereas the predominant fatty acid in sunflower oil is linoleic acid (LA), and therefore it is often referred to as a 'polyunsaturated oil'.

Most culinary oils used in the home tend to be predominantly unsaturated and high in either monounsaturates (*e.g.* rapeseed oil, olive oil, peanut oil) or polyunsaturates (*e.g.* sunflower oil, corn oil, walnut oil). However, there are some vegetable oils that are high in saturates, particularly coconut oil (86% saturates) and palm kernel oil (82% saturates). The fatty acid composition of different culinary oils is shown in Table 7.

Margarines and spreads are produced from a range of vegetable oils and fats and are used in the manufacture of a variety of food products. Margarine was invented in 1869 as a substitute for butter. Today, margarine is defined by EU legislation (along with different criteria for other spreadable fats), as: *a product obtained from vegetable and/or animal fats with a fat content of not less than 80%, but less than 90%, and with a milk fat content of not more than 3%* (EU 2991/94).

Spreads have a similar composition to margarine but are usually lower in fat. For example, some spreads, especially the low fat spreads (defined as a spread with less than 40 g fat/100 g), cannot be called margarine as they do not meet the minimum fat level requirement. Water is used to bulk out these spreads. The different methods used to produce these different spreads results in the fatty acid composition of margarines and fat spreads varying widely (see Table 8). However, the overall percentage of fat is controlled by strict guidelines (EU 2991/94; available at http://eur-lex.europa.eu).

In the UK, the most commonly used culinary oils for the manufacture of margarines and spreads are rapeseed, sunflower, soybean, palm and palm kernel. Oils are refined to purity and blended. Vitamins, A, D and sometimes E, flavours, salt and milk and/or whey are then added, and the final mixture is emulsified, pasteurised and chilled before being packed. Each stage of production is subject to rigorous quality control.

Over the years, a variety of technological innovations have taken place, resulting in products suitable for a number of uses. Examples include margarines sold in tub packaging, and products which can be spread straight from the fridge. There are also a number of health products on the market that can help to reduce dietary intake of fat or saturates and products that are based on particular types of fat, for example, polyunsaturates or monounsaturates. Recently a number of 'functional' spreads with additional health benefits have been made available. These include spreads with plant sterols and stanols that bring about cholesterol reduction in individuals with high cholesterol (see BNF 2008) along with spreads with added long-chain *n*-3 polyunsaturates. There are also a number of premium taste products, which offer a 'buttery' taste with many of the advantages of a vegetable-based spread, such as being low in saturates.

Table 7 Fatty acid composition of different culinary oils

	Total fat (g/100 g)	SFAs (g/100 g)	MUFAs (g/100 g)	PUFAs (g/100 g)		
				Total	*n*-6	*n*-3
Sunflower oil	99.9	12.0	20.5	63.3	63.2	0.1
Rapeseed oil	99.9	6.6	59.3	29.3	19.7	9.6
Corn oil	99.9	14.4	29.9	51.3	50.4	0.9
Soybean oil	99.9	15.6	21.3	58.8	51.5	7.3
Olive oil	99.9	14.3	73.0	8.2	7.5	0.7
Flaxseed oil*	99.9	9.4	20.2	66.0	12.7	53.0
Peanut oil	99.9	20.0	44.4	31.0	31.0	0
Walnut oil	99.9	9.1	16.4	69.9	58.4	11.5
Sesame oil	99.7	14.6	37.5	43.4	43.1	0.3
Safflower oil	99.9	9.7	12.0	74.0	73.9	0.1
Coconut oil	99.9	86.5	6.0	1.5	1.5	0
Palm oil	99.9	47.8	37.1	10.4	10.1	0.3
Palm kernel oil*	99.9	81.5	11.4	1.6	1.6	0

Source: FSA (2002) and MAFF (1998).
*Data obtained from USDA (2008).
SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

A note on trans fatty acids Recognising the adverse health effects of *trans* fatty acids, many food manufacturers and retailers have voluntarily chosen to systematically remove them from their products in recent years. For example, they have been absent from major brands of fat spreads for some time, which are now made using a different technique. Also, many companies now have guidelines in place that have resulted in reformulation and the reduction or elimination of *trans* fatty acids from

Table 8 Fatty acid composition of cooking fats and fat spreads

	Total fat (g/100 g)	SFAs (g/100 g)	MUFAs (g/100 g)	PUFAs (g/100 g)		
				Total	*n*-6	*n*-3
Baking fat 'for pastry' (75% vegetable fat)	75.0	25.7	33.7	14.8	n/a	n/a
Baking fat 'for cakes' (59% vegetable fat)	59.0	14.8	29.7	14.0	n/a	n/a
Blended 70% fat spread with vegetable oils	70.0	15.6	19.9	34.0	28.0	6.0
59% vegetable fat spread with sunflower oil	59.0	12.0	17.0	29.5	26.0	3.5
38% vegetable fat spread with sunflower oil	38.0	9.3	9.3	19.0	16.0	3.0
38% vegetable fat spread with 2.7% fish oil	38.0	9.5	9.0	19.0	15.0	3.0 (of which 0.8 g EPA/DHA)
18% vegetable fat spread with sunflower oil	18.0	5.1	4.1	8.8	7.2	1.6
59% vegetable fat spread with olive oil	59.0	14.0	30.0	14.5	n/a	n/a
38% vegetable fat spread with olive oil	28.0	9.5	22.0	6.3	n/a	n/a
Cholesterol-lowering spread (35% fat spread with sterols/stanols)	35.0	9.0	8.0	17.5	14.5	3.0
Cholesterol-lowering spread – olive (35% vegetable fat spread with olive oil and sterols/stanols)	35.0	9.5	11.0	14.0	12.0	2.0

Source: Manufacturers' information.
SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids; n/a, data not available; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid.

products where they have been found in the past, such as snack products, fried foods and baked goods.

The FSA has collated data on the current levels of *trans* fatty acids in processed food categories from up to date information provided by the food industry (FSA 2007a). As part of the FSA's review of the evidence of the health effects of *trans* fatty acids, a new estimate of *trans* fatty acid intake was made in November 2007 using this new data along with the food consumption data from the 2000/01 National Diet and Nutrition Survey (NDNS) of adults (Henderson *et al.* 2002). A new value for mean *trans* fatty acid intake for all adults aged 19–64 years was estimated at 1.0% of food energy. This is lower than the original NDNS estimate of mean intake of *trans* fatty acids in this age group (1.2% food energy). Furthermore, it was not possible to take account of all the reductions in *trans* fatty acid levels in foods that have taken place, so this figure is likely to be an overestimation of the actual intake, particularly now, one year on, as reductions have continued.

4.1.2 Essential fatty acids

Most fatty acids can be synthesised in the body, but there are two fatty acids required for normal physiological function that are known as essential fatty acids (EFAs) because they cannot be made in the body. These are the omega-6 (ω-6 or *n*-6) fatty acid, LA (18 : 2 *n*-6) and the omega-3 (ω-3 or *n*-3) fatty acid, alpha-linolenic acid (ALA, 18 : 3 *n*-3).

These are both polyunsaturated, and it is from these two EFAs that the *n*-3 and *n*-6 fatty acid 'families' are derived. LA is metabolised to the long-chain *n*-6 polyunsaturate arachidonic acid (AA), and ALA can be metabolised to the long-chain *n*-3 polyunsaturates eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Fig. 4). However, the conversion of ALA to its longer-chain derivatives is not considered to be very efficient. It has been estimated that less than 8% of ALA is metabolised to EPA, and the capacity to synthesise DHA appears to be particularly limited (see Lunn & Theobald 2006). As well as being inefficient, the conversion of ALA to EPA is also very slow and can be further reduced by the presence of other types of fatty acids in the diet, which can compete for the same enzymes in the metabolic pathway.

Plant oils are a good source of EFAs. For example, sunflower oil, safflower oil, corn oil, soybean oil, peanut oil and sesame oil are all rich sources of LA. Flaxseed oil is a rich source of ALA, with rapeseed oil, walnut oil and soybean oil also providing significant amounts (see Table 7).

***n*-6 Family**	***n*-3 Family**
Linoleic acid (LA) 18:2 *n*-6	Alpha-linolenic acid (ALA) 18:3 *n*-3
↓	↓
18:3 *n*-6	18:4 *n*-3
↓	↓
20:3 *n*-6	20:4 *n*-3
↓	↓
Arachidonic acid (AA) 20:4 *n*-6	Eicosapentaenoic acid (EPA) 20:5 *n*-3
↓	↓
22:4 *n*-6	22:5 *n*-3
↓	↓
22:5 *n*-6	Docosahexaenoic acid (DHA) 22:6 *n*-3

Figure 4 The *n*-6 and *n*-3 polyunsaturate pathways.

Margarines and spreading fats (particularly those made from polyunsaturate-rich oils) also provide EFAs, predominantly in the form of LA (Table 8). Some manufacturers have increased the amounts of *n*-3 fatty acids present, in the form of ALA, for example, from flaxseed oil. However, increasing the amount of ALA at the expense of LA leads to an increased likelihood of oxidation (as more double bonds are present). Antioxidant compounds (*e.g.* vitamin E) are often added to counteract this problem (see Lunn & Theobald 2006). It is also possible to add the longer-chain *n*-3 fatty acids to spreads by the addition of fish oils to products. Such products do have a slightly reduced shelf life (12 weeks) because of the instability of the long-chain, highly unsaturated fatty acids; however, sensory testing panels have revealed that there are no discernable differences in the taste of the products.

4.2 Fatty acids and their impact on health improvement and disease prevention

Today, we have a good understanding of the nutrients required for normal physiological function; consequently, nutrition research is now focusing on the amounts and types of nutrients required for optimum health and reduced risk of disease. The World Health Organization reviewed the evidence relating dietary fat to the risk of developing a number of chronic diseases in 2003 (see Table 9), and another review began in 2008.

4.2.1 Recommendations on fat in the diet for cardiovascular health

The most convincing associations are between diets high in saturates and increased risk of cardiovascular disease

Table 9 Strength of evidence linking dietary fat and risk of chronic disease

	Decreased risk	No relationship	Increased risk
CVD			
Convincing	EPA/DHA; LA		C14 and C16 saturates
Probable	ALA; oleic acid	Stearic acid	
Possible			C12 saturates
Type 2 diabetes			
Probable			C18 saturates
Possible	*n*-3 PUFAs		Total fat
Cancer			
Possible	*n*-3 PUFAs		Animal fat

Source: WHO/FAO (2003).

CVD, cardiovascular disease; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; LA, linoleic acid; ALA, alpha-linolenic acid; PUFAs, polyunsaturated fatty acids.

Table 10 Adult UK Dietary Reference Values for fat expressed as a percentage of daily total energy intake (food energy in brackets)

	Individual minimum	Population average	Individual maximum
SFAs		10 (11)	
PUFAs		6 (6.5)	10
n-3	0.2		
n-6	1.0		
MUFAs		12 (13)	
Trans fatty acids		2 (2)	
Total fat		33 (35)	

Source: DH (1991).

SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids.

(CVD), and the objectives of current dietary advice are to adjust the balance of fatty acids in the diet in order to elicit a more favourable balance of blood concentrations of lipoproteins that transport cholesterol around the body (see Frayn & Stanner 2005; Lunn 2007). High levels of low density lipoproteins (LDLs) in the bloodstream are a risk factor for coronary heart disease (CHD). Conversely, high density lipoproteins (HDLs) transport cholesterol from peripheral tissues back to the liver for removal from the system and hence are associated with a reduced risk of CHD.

For several decades now, there have been recommendations on fat intake in the UK, originally set by an expert committee [Committee on Medical Aspects of Food and Nutrition Policy (COMA)] and adopted by the government (Table 10) (DH 1991).

These recommendations have been updated from time to time. For example, in 1994, the guidelines on intakes of polyunsaturates were revised to take into account the cardioprotective effects afforded by the long-chain *n*-3 polyunsaturates. The COMA report on CVD advised that there should be no further increase in intakes of *n*-6 polyunsaturates, as the population target had been achieved, and that the intake of long-chain *n*-3 polyunsaturates should increase from 0.1 g to 0.2 g/day (DH 1994). The most recent government recommendations relating to the consumption of fatty acids were issued in 2004 (SACN/COT 2004). A committee consisting of representatives from both the Scientific Advisory Committee on Nutrition (SACN) and the Committee on Toxicology (COT) assessed the health impacts of increasing intakes of the long-chain *n*-3 polyunsaturates, taking into account the potential toxicological hazards of consuming the recommended levels from oil-rich fish, known to be the richest source of these fatty acids. They endorsed the population recommendation to eat at least two portions of fish per week, of which one should be oil-rich, and agreed that this recommendation should also apply to pregnant women (see SACN/COT 2004). However, in light of issues regarding the sustainability of some types of fish, the FSA is currently reviewing the advice on eating fish. The review reflects the growing concern about the sustainability of fish stocks and the wider environmental impact of fishing and fish farming. A consultation process is currently underway, and revised advice is expected in early 2009.

In recent years, there has been further research into the specific health effects of individual fatty acids, and the consensus is possibly moving away from the concept that all saturates are bad – indeed, several of the medium-chain saturates in the diet have been shown to have neutral effects on blood lipid levels (see Frayn & Stanner 2005). However, as is the case with all fatty acids, foods containing fat provide a mixture of fatty acids, and total saturates will consist of the blood lipid neutral fatty acids, as well as those with adverse health effects. It has been observed that many vegetable oils, notably palm oil, have saturates in the first and third positions (so called sn-1 and sn-3) along the TAG molecule. This may affect their nutritional properties as saturates in the second position (sn-2) may have a greater cholesterol-raising effect (Berry & Sanders 2005). Nevertheless, public health recommendations are still to increase intake of unsaturates and reduce intakes of saturates.

4.2.2 Guideline daily amounts

The recommended population average intakes of fat (expressed as percentage energy) are useful for health

Table 11 Guideline daily amounts for adults and children

	Women	Men	Children aged 7–10 years
Calories	2000 kcal	2500 kcal	1800 kcal
Fat	70 g	95 g	70 g
SFAs	20 g	30 g	20 g

Source: IGD (1998).
SFAs, saturated fatty acids.

professionals but of limited use for consumers. To help consumers, guideline daily amounts (GDAs) have been developed. GDAs represent a single figure that can be used to help understand the amounts of different nutrients that should be incorporated into the diet. These values are based on the recommendations made by COMA (see Table 11) (DH 1991). However, individual nutritional requirements will vary depending on age, weight and variation in activity levels. GDAs are not targets, they are guides, providing a benchmark suitable for the majority of people.

4.2.3 Specific health effects of the n-3 polyunsaturates

Studies have provided convincing evidence that diets high in EPA and DHA, the long-chain *n*-3 fatty acids found in fish oils, protect against fatal heart disease by influencing other markers of CVD risk. These include effects on blood lipid levels, blood pressure, inflammatory response, arrhythmia and endothelial function, along with many other effects (see Lunn & Theobald 2006). There may also be beneficial effects of plant-derived ALA of the *n*-3 family, although further evidence is required to determine whether such associations exist as it may be the case that any health benefits are brought about because of the displacement of other fatty acids rather than the effects of ALA *per se*.

Interestingly, for individuals with diabetes, *n*-3 polyunsaturates bring about improvements in their blood lipid profile, resulting in a decrease in the concentration of TAGs in the blood. However, a diet low in saturates may be particularly important for individuals with type 2 diabetes, as this can affect insulin sensitivity, possibly by reducing the amount of glucose that is taken up from the bloodstream when the concentration of insulin is raised. Initial research among individuals with type 2 diabetes indicated that diets high in monounsaturates may improve glycaemic control (*e.g.* Luscombe *et al.* 1999). Similar findings were found among healthy subjects (Perez-Jimenez *et al.* 1999), although more recent findings from both the RISCK multicentre study (RISCK; Reading University, Imperial College London, Surrey University, MRC Human Nutrition Research Cambridge and Kings College London) and the pan-European *Lipgene* study have indicated that the proportion of saturates and monounsaturates does not have a major effect on insulin sensitivity in subjects at increased risk for the metabolic syndrome (Jebb *et al.* 2007; Lipgene 2008).

The long-chain *n*-3 polyunsaturates are also important for brain development. The brain is a lipid-rich organ, in which approximately two-thirds of its dry weight is made up of fats, particularly long-chain polyunsaturates. These fatty acids are mainly incorporated in the cell membranes and are considered to be the building blocks of good brain development. Their main roles include keeping cell membranes fluid and enabling brain cells to send signals efficiently.

The consumption of oil-rich fish during pregnancy is very important for the developing embryo. Several studies have reported a link between brain development and EFA intake during pregnancy and early life of the baby (see SACN/COT 2004). The baby can continue to obtain these fatty acids during the breastfeeding period, as they are passed on to the infant through breastmilk.

The favourable effects of long-chain *n*-3 fatty acids are also evident in older children. For example, Hibbeln *et al.* (2007) linked EFA consumption during pregnancy with mothers having children with higher IQ scores and better communication and social skills at age 7. Specifically, the consumption during pregnancy of less than 340 g of fish and seafood per week was associated with a 48% increased risk of children being in the lowest group for verbal intelligence. It was also associated with poorer behaviour and lower motor, communication and social development scores. In other words, the lower the consumption of fish by pregnant women, the higher the risk of poorer scores on neurodevelopmental tests in their offspring.

Epidemiological evidence suggests that dietary consumption of EPA and DHA, commonly found in fish or fish oil, may also modify the risk for certain degenerative or neuropsychiatric disorders. For example, decreased blood concentrations of long-chain *n*-3 fatty acids have been associated with several neuropsychiatric conditions, including Alzheimer's disease, schizophrenia and depression in several cross-sectional studies (see Rogers 2001). Supplementation studies, using individual or combinations of *n*-3 polyunsaturates, suggest the possibility of decreased symptoms associated with some of these conditions in those with higher intakes of *n*-3 polyunsaturates. Thus far, however, the benefits of supplementation, in terms of decreasing disease risk and/or aiding in symptom management, are not clear, and more research is needed (Young & Conquer 2005).

4.2.4 *The ratio of n-3 and n-6 polyunsaturates in the diet*

It has been suggested that the ratio of *n*-6 : *n*-3 fatty acids in the diet may be an important risk factor for CHD. This hypothesis is mainly derived from ecological data that suggest that as intakes of *n*-6 polyunsaturates have increased and intakes of *n*-3 polyunsaturates have decreased over the last 150 years, there has been a parallel increase in the incidence of CHD in the developed world (see Simopoulos 1999; Kris-Etherton *et al.* 2000). Both *n*-6 and *n*-3 polyunsaturates compete for the same enzymes involved in fatty acid desaturation and elongation, so it is thought that an increase in dietary *n*-6 polyunsaturates may lead to an increase in the production of prothrombotic rather than antithrombotic metabolites, increasing the risk of CHD (Chan *et al.* 1993; Freese *et al.* 1994; James *et al.* 2000). Furthermore, if intakes of LA are high, there may be a reduced capacity for ALA conversion to the cardioprotective fatty acids EPA and DHA.

However, few studies have investigated the influence of the relationship between *n*-3 and *n*-6 fatty acids on the risk of CHD and, as yet, the ratio of *n*-6 : *n*-3 fatty acids associated with a reduced risk of CHD has not been determined. Indeed, some question whether the ratio is physiologically relevant. Mozaffarian and colleagues have recently reported no influence of EPA and DHA intakes relative to *n*-6 polyunsaturates on risk of CHD in men (Mozaffarian *et al.* 2005). Similarly, another recent large cohort study has reported no significant increase in CVD deaths in men with the highest *n*-6 : *n*-3 ratio when compared with those men with the lowest (Laaksonen *et al.* 2005). What is becoming increasingly clear is that both *n*-3 and *n*-6 polyunsaturates have independent health effects on the body, and as intakes of the *n*-6 polyunsaturates are within the guidelines for a healthy diet, concerns about the *n*-6 : *n*-3 ratio are driven by low intakes of *n*-3 rather than high intakes of *n*-6. In fact, it may not be that useful to talk in terms of a ratio, as this might bring about a reduction in intakes of *n*-6 polyunsaturates that would be unnecessary and even undesirable. If the population was to meet the guideline intakes for the *n*-6 and *n*-3 unsaturates, the *n*-6 : *n*-3 ratio would automatically be 5 : 1, so perhaps it would be more useful to talk in terms of absolute amounts, rather than in terms of a ratio, which is very difficult to interpret.

4.2.5 *Fatty acids and cancer risk*

The most authoritative and up-to-date information on associations between aspects of diet and cancer is the recent World Cancer Research Fund review, which concluded that there was only 'limited suggestive evidence' that total fat may be associated with lung and postmenopausal breast cancer and there was insufficient evidence to suggest a protective effect of any type of fatty acids (WCRF/AICR 2007).

4.3 Minor components of oils

4.3.1 *Bioactive compounds*

Bioactive compounds are non-nutritive constituents in food plants with anticipated health effects (both positive and negative). Thousands of plant bioactives have been identified (see Buttriss 2003), many of which are involved in plants' metabolic processes and in the interaction of the plant with its surrounding environment. The specific functions of plant bioactives are diverse and include attracting pollinating insects and other seed dispersing insects; protecting plants from being attacked by insects or being eaten by herbivores; protecting plants from microbial infection; and protecting plants from UV light.

Plant bioactives with proposed health benefits can be classified into several different groups (see Crozier 2003):

- flavonoids and other phenolic compounds;
- carotenoids;
- plant stanols/sterols;
- glucosinolates;
- other sulphur-containing compounds.

Plant stanols and sterols are of particular relevance to the topic of culinary oils (Frayn & Stanner 2005).

Plant stanols and sterols

Plant stanols and sterols are lipids derived from plants. Sterols are essential components of cell membranes that play a role in controlling membrane fluidity and permeability. Over 250 different sterols have been isolated from plants. Stanols are saturated sterols.

These naturally occurring compounds have a similar structure to cholesterol. When they are present in foods, they can inhibit the absorption of cholesterol resulting in a reduction in LDL. This improves the cholesterol profile and can help to reduce the risk of developing CHD. An intake of 2 g of plant sterols per day is associated with a 10% reduction in LDL (Plat & Mensink 2005). However, the concentrations of sterols in foods are generally quite low, and therefore unrealistically large quantities of a food (*e.g.* 425 tomatoes!) would need to be consumed to have any clinical effect. With this in mind, the vegetable oils are the principal natural source of plant sterols in the diet, with β-sitosterol, stigmasterol and campesterol being the most common (Table 12) (see Wahle *et al*. 2001). However, oil refining does lead to a sterol loss of 10–70%, depending on the oil and the processing conditions employed, with further loss as processing time and temperature increase, so one could never consume enough plant sterols from oils alone to bring about any health effects.

'Functional' products, with added plant sterols, are available to help reduce/control cholesterol levels in those diagnosed with hypercholesterolaemia. To improve their solubility when added to foods, plant stanols are often combined with a fatty acid and are present in the form of plant stanol esters. For more information, see BNF (2008).

Additionally, beta-sitosterol has been found *in vitro* to have anti-cancer properties and thus it has been speculated to protect against colon, breast and prostate cancer (Moon *et al*. 2008). However, no studies conducted in humans have demonstrated such anti-cancer effects.

4.3.2 Vitamin E

Vitamin E acts as an antioxidant and is required to protect cells against oxidative damage by free radicals. There are eight naturally occurring forms of vitamin E (four tocopherols and four tocotrienols) found in plants. They all share a common structure, but the biological activity of each form varies considerably. As a result, the amount of vitamin E present is often expressed as alpha-tocopherol equivalents (as alpha-tocopherol is the most active form). Vegetable oils are the richest sources of vitamin E (Table 13).

It is predicted that vitamin E requirements increase if the intake of polyunsaturates is high; a ratio of 0.4 mg alpha-tocopherol/g polyunsaturates is recommended. However, the natural association between vegetable oils and vitamin E means this is not too difficult to achieve, and the increased consumption of vegetable oils in recent decades has resulted in a concomitant increase in vitamin E intakes (DEFRA 2008).

However, the tocopherol content of oils is often reduced in processing, primarily because of the high temperatures used in deodorisation (a process that removes odours and flavours caused by impurities). There has been an emphasis on preserving the natural antioxidants (tocopherols) present in rapeseed oil during processing, and it has been found that as much as 80% of the original tocopherol content can be retained in deodorised oil (Przybylski & Mag 2002).

Table 12 The sterol composition of some commonly consumed seed oils (mg/kg)

Sterol	Corn oil	Olive oil	Rapeseed oil	Sunflower oil
Campesterol	2691	28	1530	313
Stigmasterol	702	14	–	313
Beta-sitosterol	7722	1310	3549	2352
Delta 5-avenasterol	648	29	122	156
Delta 7-stigmastenol	117	58	306	588
Delta 7-avenasterol	–	–	–	156
Brassicasterol	–	–	612	–
Others	–	–	–	39

Source: Gunstone *et al*. (1994).
Figures are quoted for refined oils.

4.3.3 Vitamin K

Vitamin K promotes the synthesis of a special amino acid that is an essential component of four important coagulation factors required to make blood clot. It is also required to help build strong bones. Vitamin K is present in green leafy vegetables, and a form of the vitamin is synthesised by the resident bacteria in the large intestine and then absorbed from the caecum. Some vegetable oils are also good sources of this important vitamin, although the content of the different oils varies quite considerably (see Table 13).

4.3.4 Phospholipids

Phospholipids are the primary component of cell membranes and play an important role in all cell functions. Vegetable oils typically contain between 0.1% and 3% phospholipids, which are removed during refining.

Table 13 Vitamin E and K in selected vegetable oils

	Vitamin E (mg/100 ml)	Vitamin K (μg/100 ml)
Sunflower oil	41.1	5.4
Rapeseed oil	17.5	71.3
Corn oil	14.3	1.9
Soybean oil	8.2	189.9
Olive oil	14.4	60.2
Flaxseed oil	17.5	NR
Peanut oil	15.7	0.7
Walnut oil	0.4	15.0
Sesame oil	1.4	13.6
Safflower oil	34.1	7.1
Coconut oil	0.1	0.5
Palm oil	15.9	8.0
Palm kernel oil	3.8	24.7

Source: USDA (2008).
NR – not reported.

Phospholipids, such as lecithins, act as surfactants, stabilising emulsions, and they are often used as a food ingredient.

4.4 A note about allergens

In recent years, concern about food allergies has increased. An allergy involves an abnormal reaction of the immune system to a substance, for example a pollen grain or food constituent, that would have no harmful effect in the majority of people. Genetic predisposition and a susceptible immune system are the key determinants of allergic disease. Exposure to environmental factors, including particular foods, is secondary to these.

The prevalence of food allergy in the UK at present is estimated to be 1.4% of the population (Thompson *et al*. 2008). This figure has been confirmed by double-blind, placebo-controlled food challenges. However, the perceived incidence among adults is over 20%. The prevalence is at its highest in young children, at 5–7% (5–7 children out of 100), although 80–90% of sufferers have outgrown their sensitivity by the age of 3 years.

Many foods have the potential to cause an allergic reaction, but just a few foods are responsible for 90% of allergic reactions to food in the EU. These are: celery; cereals containing gluten (including wheat, rye, barley and oats); crustaceans (including crabs and prawns); eggs; fish; lupin; milk; molluscs (such as mussels and oysters); mustard; nuts (including Brazil nuts, hazelnuts, almonds and walnuts); peanuts (groundnuts or monkey nuts); sesame seeds; and soya. These, together with sulphur dioxide and sulphites, are the EC's list of ingredients that must be listed on the labels of pre-packed foods (Regulation 2000/13/EC).

In relation to culinary oils, nut, peanut, sesame seed and soya allergic individuals must pay particular attention. Refined oils are unlikely to be a problem for people with food allergy because almost all the proteins that have the potential to cause allergic reactions are likely to be removed during the manufacturing process. However, refined oil made from nuts, seeds and legumes is still covered by the food labelling rules, and so the source of the oils will be listed as an allergen when used in pre-packed foods. Cold-pressed or unrefined/unprocessed (crude) oils are likely to contain proteins which can cause a reaction in people who are sensitive, so these should be avoided.

Key points: culinary oils, nutrition and health

- Vegetable oils are mainly comprised of TAGs. The main nutrient they provide is fat. The only other nutrient that is present in appreciable amounts is vitamin E (as tocopherols and tocotrienols).
- The fatty acid composition of plant oils varies. Most culinary oils tend to be high in either monounsaturates or polyunsaturates, with the exception of palm and coconut oils, which are high in saturates.
- Vegetable oils contain the EFAs LA (18 : 2 *n*-6) and ALA (18 : 3 *n*-3).
- The fatty acid composition of margarines and fat spreads varies widely, although the overall percentage of fat is controlled by strict guidelines.
- Associations between fat intake and health have been identified, and healthy eating recommendations have been developed to improve heart health.
- Categorising fats into 'saturated fats', 'monounsaturated fats' and 'polyunsaturated fats' may be helpful for consumer understanding. However, it does over-simplify the situation. All fats are a mixture of different fatty acids and each fatty acid has a unique effect on the different markers of CVD risk.
- Vegetable oils are the main source of natural plant sterols in the diet. Plant sterols can inhibit the absorption of cholesterol, resulting in an improvement in the cholesterol profile and can help to reduce the risk of developing CVD. The concentrations of sterols naturally present in foods is low, but products fortified with plant sterol or stanols are now readily available.

5 Contribution of culinary oils to nutrient intakes in the UK diet

The UK has a programme of national surveys to gather information on the dietary habits and nutritional status of the population. These surveys provide information on the intakes of vegetable oils and fat spreads in the UK population and their contribution to nutrient intakes.

The National Food Survey (NFS) has been carried out since the 1940s and provides data on household food purchases, providing invaluable information on trends in estimated food, energy and nutrient intake for the British population (DEFRA 2007). The NFS was replaced by the Expenditure and Food Survey (EFS) in 2000, and this now provides information on out-of-home purchases. Around 6000 households take part in the survey each year.

Vegetable oils and products derived from them (particularly fat spreads) make a significant contribution to fat intakes in the UK and to the overall fatty acid profile of the UK diet. The proportion of dietary energy coming from fat, as estimated from household purchases, has shifted since records began in the 1940s. In the 1960s and 1970s, the energy from fat in the British diet increased, reaching a peak of 42% of energy (120 g) in 1969. However, there has been a substantial downward trend in the total amount of fat in the diet since the late 1980s, and the intake of fat as a percentage of energy has fallen to close to the population target intake of 35% of food energy (see Section 4) (DEFRA 2007). The fatty acid profile of the diet has also changed considerably since the 1970s. The UK population is now consuming less saturates and obtaining proportionally more energy from unsaturates. This is mainly attributable to the replacement of whole milk, butter, margarine and lard with skimmed and semi-skimmed milks, vegetable oils and low- or reduced-fat spreads, as well as the availability of lean meats, lower-fat meat products and improvements in the fatty acid profile of meats (see Williamson *et al*. 2005; Foster & Lunn 2007). However, as a nation, we are still consuming more saturates than recommended (Henderson *et al*. 2003a) (see Section 4).

Table 14 shows changes in the consumption of oils and fat spreads since 1975, as estimated from household food purchases in the NFS/EFS. The data show that there has been a significant decline in the consumption of both butter and margarine since the mid-1970s, which has been accompanied by a gradual increase in the consumption of reduced- and low-fat spreads (although intake of reduced- and low-fat spreads has recently declined slightly, having peaked in 1995/2000). Furthermore, there has been a gradual increase in the consumption of olive oil and other vegetable and salad oils for the last three decades (DEFRA 2007). These changing trends in the consumption of fat spreads and the increase in consumption of vegetable oils are reflected in the changing fatty acid profile of the UK diet.

Another useful source of information is the NDNS. The NDNS provides data on food and nutrient intakes in the UK population. Information is collected from a national sample of 2000 adults aged 19–64 years living in private households in Britain (Henderson *et al*. 2002). The most recent NDNS was carried out in 2000 and 2001 (published in 2002/2003).

Table 15 shows the percentage of NDNS respondents (men and women) consuming different oils and spreads, and the mean amounts consumed per week (by those consuming the food item). Butter was found to be the most commonly consumed spreading fat, consumed by 40% of men and 42% of women, followed by reduced fat spread (non-polyunsaturated), consumed by 37% of men and 33% of women. However, reduced-fat spread (non-polyunsaturated) was consumed in the greatest quantity per week, with men consuming 85 g/week and women

Table 14 Changes in consumption of oils and fat spreads since 1975 (averages per person per week), estimated from household food purchases

	1975	1980	1985	1990	1995	2000	2005–2006
Margarine (g)	78	115	113	96	43	22	20
Reduced-fat spreads (g)	0	4	0	20	48	50	39
Low-fat spreads (g)	1	6	14	27	27	22	16
Olive oil (ml)	4	6	6	9	10	10	12
Other vegetable and salad oils (ml)	15	26	25	37	42	40	46

Source: DEFRA (2007).

Table 15 Percentage of respondents (men and women) consuming oils and fat spreads and total quantities consumed per week (g/week)

	Men		Women	
	Percentage of consumers (%)	Amount consumed (g/week)	Percentage of consumers (%)	Amount consumed (g/week)
Soft margarine, non-PUFA	32	31	23	24
PUFA margarine	3	*	2	*
Reduced-fat spread, PUFA	23	81	19	50
Other reduced-fat spread	37	85	33	58
Low-fat spread, PUFA	13	82	12	53
Other low-fat spread	8	71	10	46
PUFA oils	4	10	4	7
Other oils and cooking fats, non-PUFA	15	14	14	11

Source: National Diet and Nutrition Survey: adults aged 19–64 years (Henderson *et al*. 2002).
*Number of consumers <30 (too few to calculate mean intake reliably).
PUFA, polyunsaturated fatty acid.

Table 16 Percentage contribution of different types of fat spreads to energy and nutrient intake (% total intake)

	All fat spreads	Margarines	Reduced-fat spreads, PUFA (60–80% fat)	Other reduced-fat spreads (60–80% fat)	Low-fat spreads (40% fat or less)
Total fat	12	1	n/a	5	1
SFAs	11	1	1	2	1
MUFAs	11	2	1	4	1
n-3 PUFAs	7	2	0	3	1
n-6 PUFAs	14	1	6	3	2
Vitamin A	10	1	1	2	1
Vitamin D	17	3	n/a	8	5
Vitamin E	18	n/a	8	3	3

Source: Henderson *et al.* (2003a, 2003b).

SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFA, polyunsaturated fatty acid; n/a, information not available.

58 g/week, closely followed by low-fat polyunsaturated spread and reduced-fat polyunsaturated spread.

In the NDNS, vegetable oils have been subdivided into two groups: 'PUFA oils' and 'other oils and cooking fats, non-PUFA'; therefore it is not possible to determine information on consumption of individual oils from the published NDNS data. As shown in Table 15, the NDNS found that 4% of men and women consumed polyunsaturated oils and 15% of men and 14% of women consumed other oils and cooking fats (non-polyunsaturated). These data may be misleading about the proportion of the population that use different varieties of oil because it represents food intake for only 5 days of the week, and oil may be used relatively infrequently, compared with butter or a spread for example. Also, the way the information is collected may influence the results of the survey. For example, a fried egg is probably recorded as an egg, rather than an egg and some oil. Thus, the consumption of the oil may have been overlooked.

Table 16 shows the percentage contribution of different types of fat spreads (including butter) to nutrient intake. The NDNS data show that fat spreads contribute 12% of total fat intake and 11% of saturates intake (Henderson *et al.* 2003a). Most notably, fat spreads make a significant contribution to intakes of fat-soluble vitamins; for example, they are the main contributor to vitamin E intake in the adult population. Overall, they contributed 10% of vitamin A intake, 17% of vitamin D intake and 18% of vitamin E intake (Henderson *et al.* 2003b). This reflects the fact that fat spreads are fortified with vitamins A and D in the UK, to a level comparable with butter (see Section 4). Similar data are not available in the published reports for individual vegetable oils in this survey because they are grouped together (as mentioned earlier).

Key points: contribution to nutrient intakes in the UK diet

- Vegetable oils and products derived from them (particularly fat spreads) make a significant contribution to fat intakes in the UK.
- There has been a downward trend in the total amount of fat in the diet since the late 1980s, and currently the proportion of dietary energy coming from fat is close to the population target intake of 35%, according to the NDNS.
- There has been a decline in butter and margarine consumption and an increase in the consumption of reduced- and low-fat spreads and vegetable oils since the 1970s. These trends are reflected in the changing fatty acid profile of the UK diet. The UK population is now consuming less saturates and obtaining proportionately more energy from unsaturates.
- The most recent food consumption data for individual adults (as opposed to purchased data for households) found butter was the most commonly consumed spreading fat, followed by reduced-fat spread (non-polyunsaturated). However, reduced-fat spread (non-polyunsaturated) was consumed in the greatest quantity per week.
- In the NDNS, data on vegetable oil intake are broken down into polyunsaturated and non-polyunsaturated oils only, so may not accurately reflect the variety of oils consumed.

6 The culinary oils

Although all vegetable oils are very similar, in that they are mainly composed of TAGs, there are subtle, yet significantly important differences, in:

Box 1 Factors affecting the choice of oils

Oxidation

Oxidation may occur when oils are heated or stored for a long time. Oxidation changes the chemical structure of the fatty acids present, resulting in the release of a range of volatile carbonyls, hydroxy acids, keto acids and epoxy acids, which cause unpleasant flavours and darkening of the oil. Oxidation also results in the loss of nutritional value as the fat-soluble vitamins in the oil are destroyed. Tocopherols and tocotrienols act as antioxidants in the oil and can help minimise the proportion of unsaturates that become oxidised. However, over time, the tocopherols are used up, and therefore sufficient levels need to be present in order to prolong the shelf life of the oil and protect it against rancidity.

Frying oils/cooking with hot oil

When food is placed in hot oil (typically 180–190°C), the surface temperature rises rapidly, and water is vapourised as steam. As the food product forms a crust, the water and water vapour are replaced by hot oil. The oil is used as the heat transfer medium, although during heating some changes may occur in the structure of the oil, which will in turn affect the food being cooked. The extent of the changes depends 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 over time, oxidation can reduce the concentration of polyunsaturates (Stauffer 1996). Heating any type of unsaturated oil at high temperatures will result in the breakdown of double bonds present in the fat, which leads to the formation of compounds such as short-chain aldehydes. These have been shown to have unfavourable effects in the body, such as interfering with endothelial function and accelerating the atherosclerosis process (Uchida 2007). Unsaturates, particularly polyunsaturates, tend to be less stable and therefore some commercial frying has, in the past, used lightly hydrogenated oils, or palm oil*. This is less of a concern when frying at home, provided the fat is used only once. When frying at home, the quantity of fat absorbed is an important factor, as this will significantly affect the nutritional content of the food. This can be heavily influenced by the presence or absence of a coating on foods, as breadcrumbs, batter or flour will readily soak up fat. The frying temperature is also important. If the temperature is too low, the cooking time is extended, which allows more time for the fat to penetrate into the product.

*In the UK, companies involved in the manufacture of snack products are now moving towards high-oleic sunflower oils for frying to reduce the saturates content of the finished products.

- functionality;
- taste;
- distribution of the fatty acids in the triglyceride molecule;
- fatty acid profile and content of minor components.

For most people, the type of oil purchased is likely to be based on cost or preferred taste and awareness of any health implications associated with the oil (*e.g.* olive oil). The oils used by food manufacturers will be primarily influenced by the functional characteristics, such as the oxidative stability, which is determined by the fatty acid profile of the oil and the antioxidants present (see Box 1).

This section considers each oil in turn, looking at production and processing, nutrient composition and evidence to support any association between the oil and markers of health (primarily heart health). A number of literature searches have been conducted to identify relevant and up to date studies reporting associations between oil intake and markers of health in humans. Only those studies that investigated specific oils have been considered, rather than those studies that have used oil as a proxy measure of fatty acid intake. This is for two main reasons: firstly, dietary oils are not just nutrients but foods that contains different components that may work in synergy; secondly, there are already a number of good quality reviews drawing associations between fatty acid intakes and health, as referred to in Section 4.

6.1 Rapeseed oil

Most of the generic 'vegetable oil' in supermarkets in the UK is rapeseed oil, as this is the cheapest of the readily available vegetable oils. It is frequently used in cooking and is also used to make spreads.

6.1.1 Production and processing

Rapeseed oil is third on the list in terms of worldwide production of oils and fats. The main producing countries are those in Europe, along with Canada and China. The biggest importer is the USA (FEDIOL 2008). About a third of the rapeseed oil produced in the UK is used as biodiesel.

The oilseed rape species used to produce rapeseed oil (and meal) are from the *Brassica* genus of the Cruciferae family (broccoli, cabbage and cauliflower are from the same genus.) Large-scale cultivation of rapeseed in Europe has been reported as far back as the 13th century. However, early cultivars produced high levels of erucic acid in the oil and high levels of glucosinolates in the meal (used as animal feed), which were not considered to be good for health. Animal studies have demonstrated that high levels of erucic acid produce fatty deposits in the heart and skeletal muscle; evidence from human studies is less clear cut but suggests that this fatty acid is less of a threat to humans (Przybylski & Mag 2002). Nevertheless, it was still considered undesirable to produce an oil containing too much erucic acid. Similarly, the levels of glucosinolates originally found in rapeseed meal were considered to be detrimental, as the hydrolysed products interfere with the uptake of iodine by the thyroid gland in animals. The level of glucosinolates in rapeseed meal has also now been reduced. Recently, scientists have become more interested in glucosinolates as they appear to have anti-cancer effects when tested *in vitro*; studies are now underway to assess whether the glucosinolates in broccoli, cabbage and cauliflower have similar effects (see Denny & Buttriss 2007).

Plant breeding programmes in Canada led to the development of the first low-erucic acid rapeseed (LEAR) cultivar in 1968; this was carried out via chain shortening from the longer chain erucic acid (22 : 1 *n*-9) to shorter chain oleic acid (18 : 1 *n*-9). By 1974, over 95% of the rapeseed grown in Canada was LEAR and, around this time, the name 'canola' was adopted in Canada to refer to cultivars containing less than 5% erucic acid in the oil and low glucosinolates in the meal. During the 1970s and 1980s, the levels of glucosinolates and erucic acid in rapeseed for culinary use were reduced all over the world. Today, levels of erucic acid in foods are strictly controlled. The Erucic Acid in Food Regulations 1977 limit the erucic acid content of foods to no more than 5% of total fatty acids in products with more than 5% fat (the latter restriction does not apply to foods aimed at infants or young children). Double low rapeseed oil is defined by European Community standards as having less than 35 μmol of total glucosinolates and less than 1% erucic acid (HGCA 2005). Single low rapeseed oil has higher levels of glucosinolates and less than 1% erucic acid. These terms are only used for rapeseed oils as they refer to the glucosinolate and erucic acid content of the oil.

High erucic acid varieties are now used in a range of technical non-food applications, for example, biodegradable lubricating oil.

6.1.2 Nutrient composition

Rapeseed oil typically has a favourable nutritional profile in terms of its fatty acid composition. It is lower in saturates (6.6 g/100 g) than all other vegetable oils, high in monounsaturates (59.3 g/100 g) and has a high ALA (9.6 g/100 g) and lower LA (19.7 g/100 g) content, compared with other vegetable oils. It therefore provides a good balance of *n*-3 to *n*-6 polyunsaturates. Although, the high ALA content causes this oil to have a reduced oxidative stability, making it unsuitable for use in products that have a long shelf life. However, the low total polyunsaturation of rapeseed oil, together with the high monounsaturates content, allow for good flavour stability, despite the high ALA content.

A number of varieties of rapeseed oil with differing fatty acid compositions have been developed. For example, rapeseed oil with a reduced ALA content has been developed and shows improved oxidative stability (so that light hydrogenation is not necessary). However, up to 2% ALA is required to form positive characteristic flavour in fried foods because of the formation of oxidation products from ALA, which are important factors in the flavour formation (Warner & Mounts 1993). This type of oil is used in Canada and the USA predominantly for deep-frying.

Minor components of rapeseed oil The main tocopherols found in rapeseed oil are alpha-tocopherol and gamma-tocopherol. Alpha-tocopherol is recognised to have the highest vitamin E activity in humans (FNB 2000), and rapeseed has almost twice the amount of alpha-tocopherol as soybean oil.

Rapeseed oil contains both free sterols and esterified sterols in similar amounts. Brassicasterol is a major sterol in rapeseed oil.

6.1.3 Rapeseed oil and health

A recent study using rapeseed oil intake as a proxy of ALA intake (rapeseed oil has the second highest quantity of ALA compared with other vegetable oils) has investigated trends in CHD mortality in Eastern Europe in association with increased consumption of ALA. Using data from the Food and Agriculture Organization (FAO) of the United Nations statistics website, Zatonski *et al.* (2008) calculated the ALA intake (using vegetable oil consumption as a proxy, primarily rapeseed or sunflower oil) and correlated this with CHD mortality. The authors reported that the decrease in CHD incidence in Eastern Europe was strongly correlated with the increase in ALA consumption over a 10-year period (1991–2001). Interestingly, other sources of ALA were not incorporated into the analysis, and no mention was made of the impact of the *n*-6 polyunsaturates. Associations between food and health can sometimes be predicted through ecological studies such as this, although it is important to be aware of the limitations of such studies. In particular, in this case, the study period was also subject to other fundamental changes, including economic and market transformation that may have influenced lifestyle practices that affect risk of CVD. Also, diets containing more vegetable oils will probably contain lower amounts of saturates, which are a known contributor to heart disease risk.

A small number of intervention studies have taken place to compare the effects of different oils on markers of CVD risk (see Table 17).

As outlined earlier, there is clear evidence linking diets high in monounsaturates and polyunsaturates with decreased risk of CHD. The evidence from intervention studies relating specifically to rapeseed oil varieties reaffirms this, although the small size of the studies needs to be taken into consideration. The two studies highlighting the potential benefits of the minor components of rapeseed, such as sterols and antioxidants, should also be noted as dietary oils are not just suppliers of nutrients, but they also contain a variety of other plant-derived substances with potential bioactive effects, and these may work in synergy. Furthermore, the study by Zatonski *et al.* (2008) added an interesting angle to the evidence base and justified the need for larger intervention studies taking account of intakes of rapeseed oil, as has occurred with research into olive oil and heart health. In particular, studies noting the benefits of olive oil have been carried out in older men, and therefore it may be useful for future studies into the health benefits of rapeseed oil to take account of specific population groups who may already be at higher risk.

6.1.4 Food uses

Rapeseed oil is commonly used as a cooking oil and in pan frying. In Europe, rapeseed oil is commercially used in large quantities in salad oils, salad dressings, mayonnaise, spreading fats and baking margarine. The use of rapeseed oil is favoured in Europe because of its low content of saturates and high oleic acid and ALA content.

Key points: rapeseed oil

- Most of the generic 'vegetable oil' in supermarkets in the UK is rapeseed oil, as this is the cheapest of the readily available vegetable oils.
- Conventional plant breeding has led to the introduction of new varieties with different fatty acid profiles.
- Traditional rapeseed oil is high in monounsaturates and, unusually, high in ALA.
- There are a number of small-scale studies that suggest that rapeseed oil has a beneficial effect on heart health.

6.2 Sunflower oil

Sunflower seeds have a high oil content. Sunflower oil is very high in polyunsaturates and low in saturates. The oil is used in spread manufacture, in cooking and for dressing salads. The seeds can also be eaten as a snack.

6.2.1 Production and processing

Sunflower oil is one of the four major vegetable oils produced worldwide. It is produced mainly in the Russian Federation, Europe and Argentina (FEDIOL 2008).

Early plant breeding studies in Russia produced sunflower varieties with improved oil yield and insect resistance. High oil-yielding varieties were then introduced into Canada and the USA in 1960. A variety containing more oleic acid (referred to as 'TriSun') was then developed and introduced into the USA in the 1980s. High-oleic sunflower oil was first commercially produced in the USA in 1998.

Demand for sunflower oil increased significantly in the mid-1980s, when margarine high in polyunsaturates became popular for health reasons, but demand has since fallen and there has been a significant decline in production since 1999/2000. Sunflower plants can only be grown in limited geographical locations because of the soil and climatic conditions required (Gupta 2002).

6.2.2 Nutrient composition

Traditional sunflower oil has a high polyunsaturate content, and most of this is in the form of LA (typically 65–70% LA). However, there are also high-oleic (>80%

Table 17 Studies comparing the effects of different oils on markers of cardiovascular disease risk

Investigation	Study results	Study details
Nielsen *et al.* (2002) *British Journal of Nutrition*		
Comparison of sunflower, rapeseed, olive oil on postprandial lipid and lipoprotein concentrations and lipoprotein oxidation.	Diets containing olive oil gave rise to significantly higher postprandial plasma and lipoprotein TAG and cholesterol levels compared with sunflower and rapeseed oil diets.	Intervention study 18 males, aged 20–28 years. BMI range from 18–27 Crossover design, three periods of 3 weeks with strict dietary control, tested at the end of the 3-week period.
	Diets rich in rapeseed oil and olive oil lowered the susceptibility to oxidation of lipoproteins, compared with diets rich in sunflower oil.	Diets had a total fat content of 30% energy, 19% energy from the oil.
Wardlaw *et al.* (1991) *The American Journal of Clinical Nutrition*		
Serum lipid and apolipoprotein concentration after diets containing rapeseed or safflower oil.	Both canola oil and safflower oil diets significantly reduced LDL (10–20%) and apolipoprotein B-100, even with high-fat diet.	Intervention study 16 men Diet containing 39% energy from fat. Baseline diet (3 weeks) was high in SFA. SFA intake was reduced for an 8-week trial diet during which MUFA and PUFA provided the majority of energy from fat.
Lichtenstein *et al.* (1993) *Arteriosclerosis, Thrombosis and Vascular Biology*		
Comparison of rapeseed, olive and corn oil on blood lipoprotein profile, compared with baseline diet.	None of the three oils used had a significant advantage in terms of altering the overall lipoprotein profile, although all reduced LDL and apolipoprotein B levels compared with baseline diet higher in SFA.	Intervention study
	Consumption of each of the vegetable oil-rich diets resulted in a characteristic plasma fatty acid profile related to the fatty acid content of the diet.	15 subjects, aged 50–60 years. Slightly high BMI. For 32 days, subjects were given either olive, rapeseed or corn oil.
Sodergren *et al.* (2001) *European Journal of Clinical Nutrition*		
Lipid peroxidation on diets containing rapeseed compared with a diet rich in SFA.	PUFA-rich LDL particles are more susceptible to lipid peroxidation *in vitro*; however, findings suggest no significant differences in the biomarkers of lipid peroxidation *in vitro*. This suggests that rapeseed oil-rich diet does not seem to increase the degree of lipid peroxidation in the body. This could be explained by a sufficient content of antioxidants in rapeseed oil to protect the unsaturated acids from oxidation.	Intervention study 19 healthy, moderately hyperlipidaemic subjects; two consecutive 4-week diet periods, separated with 4-week washout. Rapeseed oil-based diet + control diet (high in SFA).
Ellegard *et al.* (2005) *European Journal of Clinical Nutrition*		
Cholesterol absorption after rapeseed oil and olive oil diets.	Rapeseed oil decreased cholesterol absorption, increased excretion of cholesterol and bile acids, increased serum marker of bile acid synthesis and decreased serum levels of cholesterol compared with olive oil.	Intervention study 9 volunteers with ileostomies.
	Results were attributed to the plant sterol content.	Two 3-day diet periods, controlled diet included 75 g of rapeseed oil or olive oil.

TAG, triacylglyceride; BMI, body mass index; LDL, low density lipoprotein; SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid.

Table 18 Fatty acid composition (typical) of three different types of sunflower oil (g/100 g)

	SFAs	MUFAs (oleic acid)	PUFAs Linoleic acid	PUFAs Alpha-linolenic acid
Traditional sunflower oil	11–13	20–30	60–70	<1
High-oleic sunflower oil	9–10	80–90	5–9	<1
Mid-oleic sunflower oil	<10	55–75	15–35	<1

Adapted from Gupta (2002).

SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acid; n/a, information not available.

oleic acid) and mid-oleic (55–75% oleic acid and 15–35% LA) varieties. The typical fatty acid composition of these three different kinds of sunflower oils is shown in Table 18.

Sunflower oil also contains a number of other compounds including tocopherols, plant sterol and stanol esters, phospholipids, carotenoids and trace elements. However, some of these are removed during processing, including the carotenoids and trace metals. Sunflower oil is high in alpha-tocopherol, which makes it resistant to photo-oxidation, but it is low in gamma-tocopherol, which is required to provide stability against oxidation.

6.2.3 *Sunflower oil and health*

Much of the work on the health effects of sunflower oil was carried out in the 1970s and 1980s and was integral to our understanding of the specific effects of different fatty acids on heart health (see BNF 1992). As mentioned previously, sunflower oil is high in the *n*-6 EFA LA and as a result, it is associated with an improved blood lipid profile and thus a reduced risk of CVD.

However, there have been two more recent, small-scale studies ($n = 18$ and 32) focusing on sunflower oil, which both considered the health effects of a diet containing sunflower oil, olive oil or rapeseed oil. These studies have reported some interesting findings. The olive oil led to a significantly higher postprandial lipid and lipoprotein response compared with the sunflower and rapeseed oil diets, although there was a higher susceptibility to *in vitro* lipoprotein oxidation after the sunflower oil diet (Nielsen *et al.* 2002). Overall, the take-home message from these studies is really that no one oil has health benefits related to CVD over and above any other of the vegetable-based oils investigated. Furthermore, the nature of the population group consuming the oil is an important factor; for example, the second study was conducted within a population with hypercholesterolaemia. The study used the mid-oleic sunflower oil available in the USA (NuSun), and compared this to a diet including olive oil and to the average American diet. The 32 subjects consumed each diet for 4 weeks, with a 2-week wash-out, before crossing over to another diet. The study reported a decrease in total cholesterol of 4.7% and LDL by 5.8% on the NuSun sunflower oil *vs.* the average American diet. No adverse effects on LDL oxidation were reported (Binkoski *et al.* 2005). Given the release of this product onto the market, it would be interesting to investigate if there are any beneficial effects on markers for CVD risk among healthy individuals.

6.2.4 *Food uses*

Traditional sunflower oil is commonly used for cooking and making salad dressings. It is also used commercially to make fat spreads. However, it cannot be used for making shelf-stable fried foods because of its poor oxidative stability, unless manufacturers are very careful with the use of the oil and take precautions against its inherent oxidative instability. High-oleic sunflower oil, on the other hand, can be used for industrial frying, and therefore is commonly used today for some products, such as crisps. However, high-oleic sunflower oil is relatively expensive, and this has limited its use to date.

More recently, mid-oleic varieties have been developed by the USDA and seed companies and have been promoted as an alternative. Production of mid-oleic sunflower oil varieties (*e.g.* NuSun in the USA) has grown steadily in recent years. NuSun has been found to be a very good oil for use in margarines and in restaurant and industrial frying, such as in the production of crisps.

Key points: sunflower oil

- Sunflower oil is fourth in terms of worldwide production of oils.
- As with rapeseed, a number of new varieties have been introduced through plant breeding, including high- and mid-oleic sunflower oil.
- Traditionally, sunflower oil has a high polyunsaturate (LA) content, which makes it unsuitable for making shelf-stable foods.
- The high proportion of the *n*-6 polyunsaturate LA in sunflower oil means it is associated with an improved blood lipid profile and thus a reduced risk of CVD.

6.3 Soybean oil

The soya bean has been grown as a staple food for years; soya beans produce a protein-rich bean curd which is used in some food products. The oil, which is high in polyunsaturates and low in saturates, is used to produce margarine and spread. However, there are issues with the sustainability of the production of soybean oil as the process has a negative impact on the environment.

6.3.1 Production and processing

Soybean oil is the most widely used oil in the world; this is in part because of the fact that soybeans are a commonly produced agricultural crop. Soybeans are mainly grown for the production of soymeal, which is used for animal feed, and soybean oil is a useful by-product. Recently, soybean oil has become increasingly utilised for the production of biodiesel.

Soybeans are well known for their health benefits and, in particular, their phytoestrogen content, which may have a role to play in the prevention of certain cancers and CHD (see BNF 2002). Soy protein has also been shown to have a beneficial role in the control of blood lipids.

The major countries producing soybean oil include the USA, Brazil, Argentina and China (produced mainly from imported soya beans), with Argentina being the biggest exporter (FEDIOL 2008).

6.3.2 Nutrient composition

Fatty acid composition Soybean oil is comprised approximately 60% polyunsaturates, 20% monounsaturates and 15% saturates. It is not only high in LA but also contains some ALA. Soybean and rapeseed oils are the only two of the more common plant oils that contain a significant amount of ALA. While this is an EFA in the human diet, the presence of double bonds in its structure also results in a degree of oxidative instability of the oil. Plant breeding studies and genetic modification (GM) technology have been used to modify the fatty acid composition in order to improve its oxidative properties, and much of the world crop is now genetically modified.

Minor components Soybean oil contains tocopherols, mainly in the form of gamma-tocopherol. alpha-tocopherol content is lower than in sunflower and rapeseed oils and similar to corn oil.

Phytosterols are also found in very low concentrations in soybean oil, and this is further reduced during refining. However, soybean germ oil (recovered from the raw material after oil extraction) is a rich source of phytosterols and may therefore have cholesterol-lowering benefits (Sato *et al.* 2004). The effects of this oil have been tested in a small-scale intervention study that found a significant cholesterol-lowering effect (10%) among those who had high cholesterol at the beginning of the 12-week study (Sato *et al.* 2004). However, it should be noted that this was just a small sample of the study population. Interestingly, an earlier study of 49 active males also found that 22 g of soybean germ oil reduced serum total cholesterol and LDL, compared with the control group using safflower oil. Further evidence will be needed to backup health claims for such a product, should it be sold in the EU.

6.3.3 Food uses

Agricultural statistics from the USA indicate that 95% of the soybean oil produced worldwide is used in food applications. These include margarine, shortening and salad/cooking oils (12%, 31% and 41% of domestic consumption, respectively) (USDA-NASS 2005).

Fully refined soybean oil can be used directly as a salad oil or as a cooking oil. Soybean oils that are lower in saturates have also been developed for the US market (*e.g.* LoSatSoy). More recently, diacylglycerol oil has been developed from soybean oil, which is thought to be metabolised quite differently from other oils – its fatty acids are not stored as body fat but used immediately as a source of energy. There have been some human trials suggesting that this type of oil may be effective in helping to prevent obesity (Wang 2002).

Soybean oil is also used extensively to produce margarines and shortening. Most fat spreads in the USA are formulated using soybean oil (whereas palm oil is commonly used in Europe). Margarines and spreads are usually produced by blending unmodified liquid oils, naturally hard fats, fractionated oils and/or interesterified fats to give them the desired firmness and texture. A high stearic, low ALA soybean oil has been developed via traditional breeding to serve as a substitute for partially hydrogenated soybean oils used in food manufacturing (see DiRienzo *et al.* 2008).

Finally, soybean oil is a major ingredient in commercially produced mayonnaise and salad dressings. For example, in the USA, most mayonnaise contains 75–82% vegetable oil, which is usually in the form of soybean oil. However, the type of oil used to produce mayonnaise and salad dressings is likely to vary depending on the availability of different vegetable oils in specific regions or countries.

Key points: soybean oil

- Since the mid-1980s, soybean oil production has rocketed.

Table 19 Food uses of some palm oil products

	Palm oil	Palm olein	Palm stearin (soft)	Palm stearin (hard)	Hardened palm oil	Palm kernel oil
Shortenings	+++	+++	+++	++	+++	+
Margarines	++	+++	+++	+	+++	+++
Frying fats	+++	+++	++		++	
Cooking oils		++				
Fats and coating			+++		++	+++
Ice cream	+++				++	+++
Biscuits	+++		++	+	++	++
Cookies	+++		++	+	+	
Crackers	+++		++	+	+	+++
Cake mix	+++		++	+	+	
Icings	++		+		+++	
Instant noodles	+++	+++	++		+	

Adapted from Ong and Goh (2002).

- Soybean oil comprises 60% polyunsaturates, primarily LA, and also relatively high amounts of ALA. It also contains significant quantities of minor components, such as gamma-tocopherol. However, the alpha-tocopherol content is lower than in sunflower and rapeseed oil.
- A lack of evidence makes it difficult to identify any particular health benefits of soybean oil, although given the quantities of minor bioactive components and increasing levels of consumption, more research in this area would be worthwhile.

6.4 Palm oil and derivatives

Palm oil is the cheapest of all the major edible oils and fats. It is a versatile oil that can be fractionated to produce a wide range of fats with varied functional and nutritional profiles. However, issues regarding its production have brought the oil to the attention of environmental interest groups worldwide. All UK refiners, food manufacturers and retailers are members of the Round Table on Sustainable Palm Oil (see http://www.rspo.org for more information).

6.4.1 Production and processing

Palm oil is currently the oil produced in the greatest quantity worldwide; Malaysia and Indonesia are the main producing and exporting countries. As well as Europe, the major importers of palm oil are India, China and Pakistan (FEDIOL 2008).

The crop provides the highest oil yield per planted hectare (Ong & Goh 2002). There are two types of oil obtained from the fruit: oil from the flesh of the fruit and oil from the kernel inside the nut (palm kernel oil). The latter is primarily used for the oleochemical industry, although it does have some food applications. The oil from the flesh of the fruit can be separated into liquid and solid fractions (olein and stearin, respectively). From these, the refining industry produces various types of palm oil for different applications. The main ones are listed in Table 19, along with examples of their uses in the food industry.

Palm oil and palm oil products are commonly used in the food manufacturing industry for two main reasons. Firstly, the oil has a high oxidative stability (due to its fatty acid composition and the carotenoids and tocotrienols present), thus it can be used at high temperatures and supports a prolonged shelf life of products. Furthermore, being naturally semi-solid, it does not require hydrogenation in the majority of applications. Secondly, because of the high oil yield per hectare, it remains a relatively economical choice and is readily available.

In those countries where palm oil is produced and manufactured, it is commonly used in the home and in commercial food outlets for frying. Palm oil is an effective frying oil as less free acids are formed during heating and it has a low polymer content. Because of this, it is frequently blended with other oils. Palm oil products are also commonly blended with other oils for use in domestic, industrial, bakery and pastry margarines.

6.4.2 Nutrient composition

Palm oil has equal proportions of saturates and unsaturates. Palmitic acid is present in significant amounts, and as outlined earlier, has an adverse effect on blood cholesterol. On the other hand, oleic acid that is also present has a positive effect on risk factors for CHD.

The fatty acid composition of palm oil products varies substantially and is partly responsible for the characteristics of each product. For example, palm stearin is the saturated fraction of palm oil and can be solid, although the melting and crystallisation behaviour varies greatly. The minor components of palm oil also vary depending on the conditions of refining. Crude palm oil is rich in carotenes, tocopherols, tocotrienols, sterols and squalene, although the presence of these compounds diminishes, the more refined a product becomes. However, the carotenes can be recovered during the refining process, and several companies market a beta-carotene-rich palm oil (*e.g.* Carotino). In parts of West Africa and Brazil, unrefined palm oil is a traditional food recognised for its reputed health benefits, but it is not available as a commercial product elsewhere (see Ong & Goh 2002).

6.4.3 Palm oil and health

Two intervention studies have looked at palm oil (or palm olein oil) and its effects on CVD risk. Interestingly, intervention studies by Choudhury *et al*. (1995) and Tony *et al*. (1991) reported no effect of palm oil on blood markers of CVD risk (see Table 20 for details of the studies).

A review by Ong and Goh (2002) has also concluded that palm oil has no adverse health consequences. The authors suggested that palm oil should not be classified as a 'saturated fat', because it behaves like an 'unsaturated oil' with respect to blood lipid parameters, as the majority of the saturates present, namely palmitic and stearic acids, have been shown to have a relatively neutral effect on blood cholesterol elevation.

However, studies that have compared the effects of palm oil with other oils have reported adverse effects on heart health of both palm oil and hydrogenated oils (Mutalib *et al*. 1999; Vega-Lopez *et al*. 2006). For example, a large case-control study in Costa Rica looked for associations between the type of fat consumed and incidence of myocardial infarction (MI) (Kabagambe *et al*. 2005). Results indicated that, compared with users of soybean oil (containing 5% *trans* fatty acids), people who regularly consume palm oil (containing 1.5% *trans* fatty acids) were more likely to have an MI. However, there was no significant risk associated with consuming palm oil compared with soybean oil or 'other' oil types. Unlike similar studies that have relied on diet diaries and food frequency questionnaires to assess the participants' consumption of oils, this study also took adipose tissue biopsies from the 4222 participants to validate their reported intake.

In light of these studies, further research to identify the health implications of this widely used oil would be useful.

6.4.4 Food uses

Almost 90% of the palm oil produced in the world is used in edible products (sometimes in combination with other products), such as commercial cooking or frying oils, margarines, shortening, specialty fats and spray-dried products. As mentioned earlier, it is a particularly useful oil for the food industry as it is relatively stable to oxidation and has a semi-solid nature. Therefore it does not require the application of hydrogenation.

Table 20 Intervention studies investigating the effect of palm oil on markers of cardiovascular disease risk

Study results	Study details
Tony *et al*. (1991) *American Journal of Clinical Nutrition*	
Serum total cholesterol concentrations were reduced by 9% (significant) after the palm olein and by 29% (significant) after the corn oil periods. Serum TAGs were unaffected during the palm olein period but were significantly reduced during the corn oil period (–0.20 mmol/l). LDL : HDL ratio was slightly reduced by palm olein (–8%) and dropped markedly when corn oil was fed.	Intervention study 83 normocholesterolemic volunteers (aged 21–34 years) were provided with all meals containing palm, corn or coconut oils only. Other opportunities to reduce fat intake were sought, for example, skimmed milk, lean meat. 5-week trial period for each oil
Choudhury *et al*. (1995) *American Journal of Clinical Nutrition*	
The high levels of alpha-tocopherol in the palm oil were evident in plasma, but tocotrienols were not detected. No difference in effect on serum lipids and lipoproteins were found between the two oils.	Intervention study 21 normocholesterolemic subjects (aged 19–21 years). Crossover feeding trial for 30 days. Participants were given 50% of their usual fat intake in the form of palm olein or olive oil, and dietary fats from other sources were minimised.

TAGs, triacylglycerides; LDL, low density lipoprotein; HDL, high density lipoprotein.

Key points: palm oil

- More palm oil is produced than any other vegetable oil. Undoubtedly, this is because of its broad functionality and high yield.
- Palm oil contains equal proportions of saturates and unsaturates and therefore would be expected to have negative effects on markers of heart health. However, results from short-term studies using palm oil are inconsistent. In light of this, further research to identify the health implications of this widely used oil would be useful.

6.5 Olive oil

Produced mainly in Italy, but also grown in Turkey, Tunisia, Greece and increasingly in Spain, olive oil is high in monounsaturates. The production and processing of olive oil is highly regulated by the Olive Oil Council and EC. The terms used to describe the various different types of olive oil are subject to strict EC regulations. Olive oil can be used for cooking or as a salad dressing, and the olive itself can be eaten cooked or uncooked. Olive oil is now also used in spreads.

6.5.1 Production and processing

Olive oil is mainly produced and consumed in the Mediterranean countries of Europe and has traditionally been a major component of the Mediterranean diet. However, in recent years, it has also become more popular in other regions, particularly Northern Europe, the USA and Canada (Gunstone 2001). This increase in popularity is attributable to studies showing that the consumption of a Mediterranean-style diet, including olive oil, is beneficial in the prevention of chronic diseases, particularly CVD (see later).

Olive oil extraction Virgin olive oil is obtained from the fruits (olives) of the olive tree (*Olea europaea*). There are a number of important factors in the production of good quality olive oil, including the harvesting period, maturity of the fruit, the form of harvesting (*e.g.* hand picking, use of nets or other method), the storage of the olives before processing, the way in which the olives are crushed and the system of extraction (Boskou 2007).

The oil is first released by crushing either using a stone mill (pressure system) or metal crushers (continuous centrifugation plants). This produces an olive paste, which is mixed for about 30 minutes (known as malaxation). Separation of the paste (which comprises olive oil, kernel, water and cellular debris) is then carried out by pressure, centrifugation or filtration processes. The use of processing aids also helps to improve the oil yield and quality. However, these are not permitted in the production of virgin olive oil, which must be extracted using only mechanical or other physical means (Boskou 2007).

Olive-residue oil (pomace oil) extraction The processing of olive oil leaves two residual products – husks (pomace) and water. The pomace contains some residual oil, the amount varying depending on the method of extraction (*e.g.* 3–5% if separated using a three-phase centrifugation). The residual oil is obtained from the pomace using solvent extraction (with hexane). This usually takes place at another plant, which involves transportation of the residual product, and this can be costly because of its high moisture content (25–58%). The olive-residue oil has to be neutralised, bleached and deodorised to make it edible. Some minor constituents remain (*e.g.* waxes, sterols) at higher levels than would be found in olive oil, because of the use of solvent extraction.

6.5.2 Nutrient composition

Fatty acid composition The fatty acid composition of olive oil may vary depending on factors such as the area of production, latitude, climate, variety and the extent of maturity of the fruit. For example, olive oil from Italy, Spain and Greece tends to have a high proportion of oleic acid and to be low in LA and palmitic acids. In contrast, olive oil from Tunisia tends to be higher in LA and palmitic acids and lower in oleic acid (Boskou 1999). The beneficial properties of olive oil are mainly attributable to the high content of monounsaturates (predominantly oleic acid). The fatty acid composition of the oil is around 14% saturates, 73% monounsaturates and 8% polyunsaturates (mainly in the form of LA); however, this may vary (see Table 21).

Minor components As with the fatty acid composition, the tocopherol (vitamin E) content of olive oil is highly variable and may range from 5–300 mg/kg. The main tocopherol present is alpha-tocopherol, which contributes around 95% of the total tocopherol content. The other 5% comprises beta- and gamma-tocopherols. In countries where there is a high consumption of olive oil, it can contribute significantly to vitamin E intake. However, processing methods such as refining, bleaching or deodorising can significantly reduce the tocopherol content (Boskou 2002).

Table 21 Variation in the fatty acid composition of olive oil (amounts shown in percentages)

Fatty acid		Percentage (%)
SFAs	Palmitic acid	7.5–20
	Stearic acid	0.5–5
MUFAs	Oleic acid	55–85
	Palmitoleic acid	0.3–3.5
PUFAs	Linoleic acid	7.5–20
	Alpha-linolenic acid	0–1.5

Source: Boskou (2002).
SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids.

Carotenoids have a role as antioxidants and protect the oil from photo-oxidation. However, their role in the maintenance of the oxidative stability of olive oil has not yet been fully determined; it is likely that they act in conjunction with alpha-tocopherol and other phenolic compounds (see below). The main carotenoids present in olive oil are beta-carotene and lutein, although there are very small quantities of other carotenoids present. The carotenoid content can vary from 1–20 mg/kg. In an analysis of a series of samples of olive oil from Greece, a beta-carotene content of 0.4–5.1 mg/kg and a lutein content of 0.2–3.4 mg/kg were reported (Psomiadou & Tsimidou 2001). The carotenoid content can be affected by the method of extraction and is greater in oils extracted using centrifugation.

Polyphenols Virgin olive oil contains some minor constituents that make it unique among all the vegetable oils. These include phenolic compounds, usually characterised as polyphenols, that are associated with the beneficial properties of olive oil in human health. The polyphenols are an important class of minor constituents that are associated with both the flavour of olive oil and its shelf life. Many different polyphenol compounds have been found in olive oil, including phenolic acids (such as gallic acid), flavanoids (such as luteolin) and lignans. The major polyphenols are reported to be tyrosol and hydroxytyrosol in their various forms (Boskou 2002).

The polyphenol content varies (usually ranges from 100 to 300 mg/kg) and depends on the cultivar, system of extraction and processing conditions. For example, pressure extraction and two-phase decanter extraction give rise to oil with a higher polyphenol content. Polyphenols are important for both the flavour and stability of olive oil and can give a bitter taste to the oil when present in large amounts. However, a high polyphenol content improves the shelf life of olive oil, which may be attributable to the anti-oxidant properties of the polyphenols present.

6.5.3 *Olive oil and health*

Olive oil has been associated with health-promoting properties for many years and many have extolled the virtues of this Mediterranean staple. Despite a wealth of anecdotal evidence, the scientific knowledge that links a diet containing plentiful amounts of olive oil and good health is still developing, and, as yet, there are no formal food-based guidelines on the inclusion of olive oil specifically to reduce disease risk. Nevertheless, the antioxidant effects of the phenolic components of the oil have generated much research interest, and there is a growing body of evidence offering new insights into the mechanisms by which olive oil could reduce the risk of CVD (see Visioli *et al.* 2006). Other researchers are investigating the effects of olive oil on blood lipid profiles, haemostatic factors, immune function and glycaemic control, demonstrating the health-promoting effects that this oil could have on the progression of many chronic diseases.

In 2004, the Food and Drug Administration (FDA) of the USA approved a qualified health claim for olive oil based on studies showing that eating about two tablespoons of olive oil a day may reduce the risk of heart disease. The precise wording of the claim stipulates that:

> "Limited and not conclusive scientific evidence suggests that eating about 2 tablespoons (23 grams) of olive oil daily may reduce the risk of coronary heart disease due to the monounsaturated fat in olive oil. To achieve this possible benefit, olive oil is to replace a similar amount of saturated fat and not increase the total number of calories you eat in a day. One serving of this product [Name of food] contains [x] grams of olive oil". (FDA 2004)

The body of literature describing the health effects of olive oil is too large to describe in this short Briefing Paper, so we refer readers to a comprehensive text describing the scientific evidence for more information (see Quiles *et al.* 2006).

6.5.4 *Food uses*

Olive oil is most commonly used as a dressing for salads and for frying foods in the home. It can also be used repeatedly for domestic deep-frying. The presence of natural antioxidants may increase the oil's stability to thermal oxidation, which would otherwise rapidly deteriorate the oil at high temperatures.

Key points: olive oil

- Olive oil contains a high proportion of monounsaturates and is a good source of vitamin E and phenolic compounds.
- The production and processing of olive oil is highly regulated by the Olive Oil Council and EC.
- There is some evidence to suggest that the components in olive oil have beneficial properties over and above cholesterol lowering that may bring about a reduction in CVD risk.
- Olive oil is a popular oil to use in the home because of its thermal stability and pleasant taste.

6.6 Peanut oil

Extracted from peanuts, groundnut oil, or peanut oil, has a pale colour and a light consistency. It has a subtle, pleasant flavour and can be heated to a high temperature without oxidative effects.

6.6.1 Production and processing

Worldwide, around a third of peanuts produced are used as a food commodity. Peanut oil is produced and used mainly in China and India; there is little trade in this type of oil outside these countries (FEDIOL 2008).

The peanut is a legume that is native to South America and has been cultivated for many centuries. However, the economic importance of peanuts and peanut oil has increased significantly over the past 100 years. Peanuts contain 40–50% oil, which is expressed from the seeds of the plant *Arachis hypogaea* L. (also known as groundnut, or earth nut, as the seeds develop beneath the ground). Peanut oil generally requires limited refining, and hydrogenation is not usually required for the majority of peanut oil uses (Sanders 1982).

One of the problems with peanuts and peanut oil production is the potential for contamination with aflatoxin. This is a potentially carcinogenic compound produced by *Aspergillus* and *Aspergillus parasiticus*, which can contaminate peanuts as well as corn and other food commodities. The concentrations are usually quite low in peanuts produced in developed countries, where control and testing programmes are in place. However, this is not always the case in many developing countries where peanut oil is also produced and consumed. Aflatoxin is usually found in the protein component of peanuts and therefore not usually found in refined oil.

6.6.2 Nutrient composition

Fatty acid composition Peanut oil contains a high proportion of unsaturates, mainly in the form of oleic and LAs. The fatty acid composition of the oil is around 20% saturates, 50% monounsaturates and 30% polyunsaturates (in the form of LA), although this can vary widely depending on the origin (Worthington *et al.* 1972). The level of unsaturation in peanut oil is affected by climate, temperature and irrigation, as well as maturity. For example, cooler climates produce oils with more unsaturation and a lower oleic acid to LA ratio. More mature seeds produce oil with a higher ratio of oleic acid to LA. The oxidative stability of peanut oil is closely correlated with the oleic acid to LA ratio, with oil from more mature seeds being more stable and having a longer shelf life. Peanut varieties with a high oleic acid trait have also been identified and incorporated into commercially produced varieties. These have been found to have much greater oxidative stability (Sanders 1982).

Vitamin E The tocopherol content of peanuts varies depending on the origin. For example, peanuts produced in the USA have been found to have a higher tocopherol content than those from China and Argentina. The tocopherol content is a key factor in determining the stability of the oil – it has been estimated that 87% of the stability can be correlated with the ratio of total tocopherol to percentage LA (Sanders 1982).

Plant sterols Peanuts contain a number of different types of plant sterols, of which beta-sitosterol is the major component; when unrefined, peanut oil contains approximately 200 mg sitosterol per 100 g (which is comparable to soybean oil, at 220 mg/100 g) (Awad & Fink 2000).

6.6.3 Peanut oil and health

CVD Consistent data from a large number of epidemiological studies have shown a 30–50% reduction in CVD risk in people eating nuts (including peanuts) 4–5 times per week. Clinical studies have also shown consistent reduction in total cholesterol and LDL in subjects who consume peanuts and peanut oil (Sanders 1982). Kris-Etherton *et al.* (2001) compared a number of different diets and found that a diet including peanuts and peanut butter, peanut oil or olive oil (all low in saturates) lowered total cholesterol, LDL and TAG levels, without lowering HDL. Similar findings were reported after a short crossover trial in a sample population aged 40–60 years, which compared a basic diet to a low-fat diet and a peanut oil diet. The strongest association was found among those on the peanut oil diet: total cholesterol level and LDL decreased by 3.32% and 8.52%, respectively, while HDL levels increased by 4.62% (Xu *et al.* 2004).

Peanut allergy Several peanut allergens have been identified, which are all proteins. In refined peanut oil, all the protein is removed, so this oil is not allergenic. However, some oils may contain residual quantities of the peanut protein and therefore have the potential to cause allergic reactions in sensitive individuals. Cold-pressed oils are more likely to contain peanut proteins than hot-pressed oils (Sanders 1982). Peanut oil must be labelled as an allergen, whether it is fully refined or not.

6.6.4 Food uses

Peanut oil is most commonly used for frying and cooking, as well as in salad dressings. It is suitable for deep-fat frying as it has a high smoke point (229.4°C), which allows the food to cook quickly and develop a crisp coating without absorbing too much oil. Peanut oil is particularly popular in Chinese cookery because of its subtle flavour.

The raw crude oil has a nutty aroma, but this is lost in refining so that the oil becomes odourless. Highly aromatic peanut oil and peanut extracts are used in products such as baked goods, desserts, sauces, breakfast cereals, frozen dairy products and flavourings, because of the strong nut flavour and aroma.

Key points: peanut oil

- Production of peanut oil is the fifth highest of all the plant oils worldwide. It contains predominately monounsaturates and also contains low levels of sterols and high levels of tocophercols, which contribute to its stability.
- There is good evidence to support associations between a reduction in risk of CVD and the consumption of peanuts. There is less evidence available to support the beneficial effects of peanut oil; however, one study has suggested that incorporating peanut oil into the diet can have positive effects on markers of CVD risk, compared with a lower-fat diet with no peanut oil.

6.7 Sesame oil

Sesame seed is one of the oldest oilseed crops and has been a popular food ingredient for thousands of years. The seed has a high oil content (42–56%) and, over the centuries, has acquired a reputation for having a number of health benefits.

6.7.1 Production and processing

The production and consumption of sesame oil mainly takes place in China, India and Burma (FEDIOL 2008). The dark colour and characteristic nutty odour is developed by roasting the seeds before extracting the oil.

6.7.2 Nutrient composition

Sesame oil contains approximately 15% saturates, but primarily consists of polyunsaturates (45%) (43% LA and 0.3% ALA) and monounsaturates (40%). The composition of the oil will vary if the sesame seeds are roasted at high temperatures (above 220°C). However, roasting at lower temperatures has been found to be effective at protecting and, in some cases, increasing the anti-oxidant activity of sesame oil. It is particularly high in the anti-oxidant *sesamolin*, which has been shown to be effective in the physiological suppression of lipid peroxidation (see Kochhar 2001).

6.7.3 Sesame oil and health

In the UK, sesame oil is primarily used as a speciality oil for its flavour, rather than its health effects. Indeed, few studies have been published on the health effects of this oil. Only one study was identified in a literature search. This was a small-scale study of 40 patients with type 2 diabetes that compared the effects of sesame oil with coconut oil. The study lasted for two months, and reported that fasting blood glucose levels were significantly lower and the blood lipid profile was significantly improved after the diet containing sesame oil (Mitra 2007). However, there were no significant effects on the blood parameters measured when compared with baseline values. Furthermore, no information about the compliance of the 40 subjects is available, which may be important in the interpretation of the results.

6.7.4 Food uses

Compared with other oils, sesame oil is highly resistant to oxidative deterioration (Fukuda & Namiki 1988). The stability of the oil, which does depend on the quality of the extracted oil and how it has been processed, means it is suitable for frying foods and supports a prolonged shelf life of fried snack foods. It is also used in salad dressings and provides a characteristic roasted sesame flavour for Eastern cuisine. The seed itself is used mainly for human consumption in bread, biscuits, breakfast cereals and crackers.

Key points: sesame oil

- Within the UK, sesame oil tends not to be used as the main household oil but is used in salads and oriental dishes for its flavour.
- Sesame oil has a positive fatty acid profile, containing equal amounts of monounsaturates and polyunsaturates (predominately LA and small quantities of ALA) and approximately 15% saturates.
- The stability of the oil means it is suitable for fried snack foods when a prolonged shelf life is desirable.

6.8 Corn oil

Corn oil is also known as maize oil. The oil is high in polyunsaturates and is a good all-round cooking oil, although some believe it to have a rather bland taste.

6.8.1 Production and processing

Corn oil is mainly produced and consumed in the USA, which is also the major exporter. However, there is a smaller European market for corn oil (FEDIOL 2008). The oil is extracted from the corn germ, which comprises approximately 30% oil. Other parts of the corn kernel are used for animal feed. Most corn plants grown in the USA are genetically modified to yield more hardy crops.

6.8.2 Nutrient composition

Corn oil contains approximately 15% saturates and 25% monounsaturates. It is high in polyunsaturates, containing approximately 60% LA and low levels of ALA (<1%).

Corn oil is a rich source of tocopherols (see Section 4). Although corn kernels contain high levels of carotenoids, the germ contains only 2–4%; furthermore, they are removed during the bleaching process of production.

6.8.3 Corn oil and health

Corn oil was used in many studies during the 1950s when the association between the fatty acid composition of a food and its effects on blood cholesterol was first being investigated. Only two studies came to light as a result of our search for recent studies (since 1990). Tony *et al.* (1991) compared the effects of a diet containing corn oil to palm or coconut oil in 83 healthy subjects aged between 21 and 31 years and reported a significant 29% reduction in serum total cholesterol after the corn oil periods. Serum TAGs were also significantly reduced during the corn-oil period (–0.20 mmol/l) and the LDL : HDL ratio dropped by 25% when corn oil was fed. The oils were incorporated into their meals, along with snacks and drinks, all of which were provided for subjects. A more recent study modified the types of snacks subjects were consuming, by providing snack chips fried in corn oil, high-fat snacks and low-fat snacks to modify the base diet. The profile of each diet became either a high polyunsaturate diet (37.9% energy from fat), a low-fat diet (30% of energy from fat, of which <10% of energy from saturates) or a high-fat diet (36.3% energy from fat). The high polyunsaturate diet resulted in the best overall CVD risk profile, although it was higher in total fat. All three diets lowered total cholesterol and LDL, but only the high polyunsaturate diet reduced TAG concentrations. Changes in total cholesterol and LDL were significantly greater with the high polyunsaturate diet than with the low-fat diet. Also, the pattern of LDL particle size was significantly more favourable with the high polyunsaturate diet than the low-fat diet. Limitations of the study included the small sample size ($n = 33$), although this is similar to the majority of intervention trials that have tested the health effects of different oils. The relatively short trial period of 25 days (three-way crossover with 4- to 8-week washout) was also of concern to the authors (St-Onge *et al.* 2007).

6.8.4 Food uses

Within the USA, a quarter of the corn oil consumed is used for margarines and spreads, while half is used for cooking and salad oils. It is a popular cooking oil because of its mild flavour and oxidative stability. For example, a frying study comparing rapeseed, soybean and corn oil found that corn oil retained the most tocopherols during 5 days of continuous exposure to high frying temperatures (Moreau 2005).

Key points: corn oil

- Corn oil contains approximately 60% polyunsaturates, 25% monounsaturates, 15% saturates and substantial quantities of tocopherols.
- It is considered to be a stable oil and is popular in cooking and commonly used in the manufacture of

margarines. Of the studies available that have focused on oil type, results support existing evidence of the benefits of a high polyunsaturate diet on blood lipids.

6.9 Flaxseed oil

The oil extracted from the flaxseed is often called linseed oil and has been widely used for non-culinary purposes. However, flaxseed oil has become a popular dietary supplement because of its reputed health-promoting properties.

6.9.1 Production and processing

The names linseed and flaxseed are used interchangeably, as both seeds are cultivars of *Linum usitatissimum*. The production of linseed oil has actually changed little over the past 20 years, and the main producers are Europe, China and the USA (FEDIOL 2008). It is used mainly as an industrial oil, but its consumption as a food oil is increasing; there is significant trade in the seeds as well as the oil.

6.9.2 Nutrient composition

The fatty acid profile of flaxseed oil is largely comprised of polyunsaturates (66%), primarily the *n*-3 fatty acid ALA (over 50%), and it is this that makes the oil oxidise rapidly. The oil also contains 440–588 mg/100 g of tocopherols.

6.9.3 Flaxseed oil and health

The assumed health benefits of flaxseed oil stem from studies reporting the benefits of the *n*-3 polyunsaturate ALA on markers of CVD risk (Brouwer *et al.* 2004). Two small-scale studies have been published comparing the effects of flaxseed oil with one other oil. For example, Layne *et al.* (1996) compared the effects of flaxseed and fish oils on serum TAG or cholesterol levels, but found little effect of either oil or other CVD risk markers. A statistically significant reduction in platelet aggregation was recorded with 40 g of flaxseed per day, compared with approximately 40 g of sunflower seed oil (Allman *et al.* 1995).

Associations between the consumption of flaxseed oil and an improvement in autoimmune disorders/function have also been noted, although of the three published studies, only one (with a sample size of 8) reported results of clinical significance (Nordstrom *et al.* 1995; Clark *et al.* 2001; Wallace *et al.* 2003).

6.9.4 Food uses

Edible flaxseed oil must be stored under cold, oxygen-free, light-free conditions and protected by a suitable anti-oxidant formulation; otherwise, the fatty acids in the oil will undergo spontaneous reactions to produce undesirable *trans* fatty acids. For this reason, most refiners do not process or supply flaxseed oil as a pure oil. Ground or whole flaxseeds are sometimes used in bakery products to enhance the nutritional value. Notably, in the USA, plant breeding schemes and GM technology have produced an edible, stable, flaxseed oil, by changing the fatty acid composition from 50% ALA to only 2%, thus increasing the oxidative stability of the oil. The oil produced from this new crop, linola, has a fatty acid composition similar to that of sunflower, safflower or corn oil, that is, it has much lower levels of the *n*-3 polyunsaturate ALA. The oil was approved for use by the FDA in 1998.

After oil extraction, flax cake or meal is sold for animal feed. In particular, there has been a recent trend in feeding it to poultry in order to produce eggs and meat higher in omega-3 fatty acids. The oil itself is also now used to boost the levels of the short-chain *n*-3 fatty acids in fat spreads, to reduce the predominance of the *n*-6 fatty acids in spreads based on sunflower or corn oils.

Key points: flaxseed oil

- Traditional flaxseed is dominated by polyunsaturates, primarily ALA, and contains approximately 440 mg/100 g of tocopherols.
- The oil has a low oxidative stability, so it has little use in food preparation; however, modified versions with improved functionality have been developed through plant breeding schemes.
- Flaxseed oil is now used to boost the levels of short-chain omega-3 fatty acids in yellow fat spreads, to reduce the predominance of omega-6 in, for example, sunflower oil spreads.

6.10 Other less commonly used oils

6.10.1 Coconut oil

The production of coconut oil mainly takes place in the Philippines, Indonesia and India, while the major importing countries are Europe and the USA (FEDIOL 2008). However, production levels can be quite variable because of climatic and political instability in the countries where it is produced (Gunstone 2001).

The oil is derived from copra, the dried kernel of coconuts, which is 34% oil. The fatty acid profile of coconut oil varies widely. The main fatty acid found in coconut oil is lauric acid, a medium-length chain saturate, which accounts for between 45% and 48% of the fatty acid mass. Coconut oil is oxidatively very stable because of its high saturates content.

Coconut oil contains only trace amounts of tocols and larger quantities of sterols (836.4 mg/kg), although the presence and quantities in which they may be found varies significantly.

Because of its high saturates content, UK health professionals recommend that coconut oil and products containing it (*e.g.* coconut cream and milk) should be consumed in moderation only. Although in the past, coconut oil has not been consumed widely in the UK, it has recently become more popular as our culinary repertoire has expanded to include foods from the different ethnic group now resident in the country. In countries where coconuts are grown, it is commonly used for culinary purposes, although the majority of coconut oil is used for oleochemical purposes.

Is coconut oil a superfood? In early 2008, there was a flurry of media activity about a Hollywood star's sudden inclusion of coconut oil in her diet because of its purported benefits in aiding weight loss (Atkins 2008). Even though coconut oil is energy dense, some enthusiasts maintain that because of the medium-chain-length TAGs present, the body burns off the calories more quickly than it would calories from other fat sources. One study seemed to confirm this, reporting that coconut oil could help overweight men to burn more calories and lose weight (St-Onge & Jones 2003). However, this study was of only 24 people and carried out over a 4-week period, so the results are not highly significant. Ultimately, it is the overall energy balance of the diet that determines weight loss or gain. As weight loss relies upon 'energy in' to be less than 'energy out', reducing (rather than increasing) the consumption of high energy-dense foods, such as coconut oil, is one of the simplest ways to achieve this.

6.10.2 Walnut oil

China and the USA are the major producers of walnut oil, although other countries such as India, France, Hungary, Italy and Spain also produce some walnuts for oil extraction.

Compared with other nut oils, it has small quantities of saturates (9.1 g/100 g), and primarily consists of polyunsaturates (predominantly LA). Compared with other oils, it also contains relatively large quantities of ALA (see Section 4). It contains 'average' amounts of sterols (*e.g.* 1511 mg/kg β-sitosterol), although the composition varies depending on the country of origin (Crews *et al.* 2005).

Walnut oil tends to be used as an ingredient in cold dishes, possibly because of its low oxidative stability.

6.11 Comparison of the culinary oils

Despite a small number of interesting studies comparing the effects of various different culinary oils on health outcomes, there is insufficient evidence to indicate that any one particular oil should be promoted over any other oil. Instead, it should be recommended that the public look to consume moderate amounts of unsaturated vegetable-based oils in place of the common sources of saturates in the diet (see Section 8). In this way, heart health benefits can be gained from consuming oils with a favourable fatty acid profile (see further discussion), along with any potential additional health benefits from the vitamins and bioactive compounds also present in varying quantities in the different oils.

The most interesting differences between the major culinary oils can be seen when the fatty acid profiles of the oils are compared (see Fig. 5). The relative amounts of saturates, mono- and polyunsaturates present affect the impact that the oil has on blood lipid profiles. The saturates myristic and palmitic acids increase blood cholesterol levels, whereas other saturates, such as lauric acid and stearic acid, have relatively little effect on cholesterol levels. Conversely, the polyunsaturates decrease total cholesterol. The response of the human body to dietary fats is so consistent that equations can be developed to predict the change in blood cholesterol level based on an oil's fatty acid profile (Hegsted *et al.* 1965, 1993; Mensink & Katan 1992; Mensink *et al.* 2003). Figure 6 summarises the relative effect on total blood cholesterol of several common vegetable oils when included as 10% of total calories. The constituent fatty acids also determine an oil's suitability for use as a cooking or frying oil, both in the home and on an industrial scale (Table 22).

Key points: the culinary oils

- All oils predominately comprise fat in the form of TAGs; the main difference among them is their fatty acid profile. The constituent fatty acids are primarily responsible for the functionality of the oil. The minor components also contribute to functionality, but are also responsible for the flavour.
- Studies looking for associations between health and choice of culinary oil are small-scale intervention

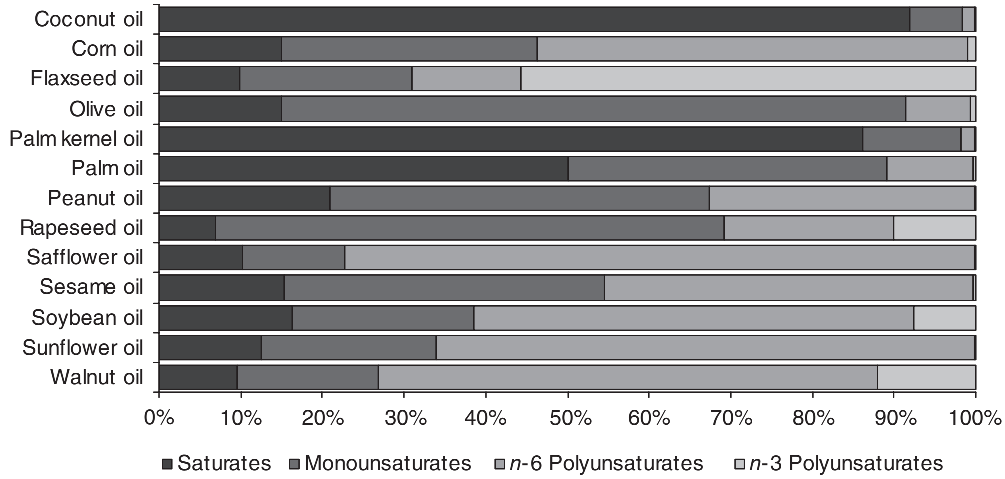

Figure 5 Comparison of the fatty acid profile of the main culinary oils. Source: MAFF (1998); USDA (2008).

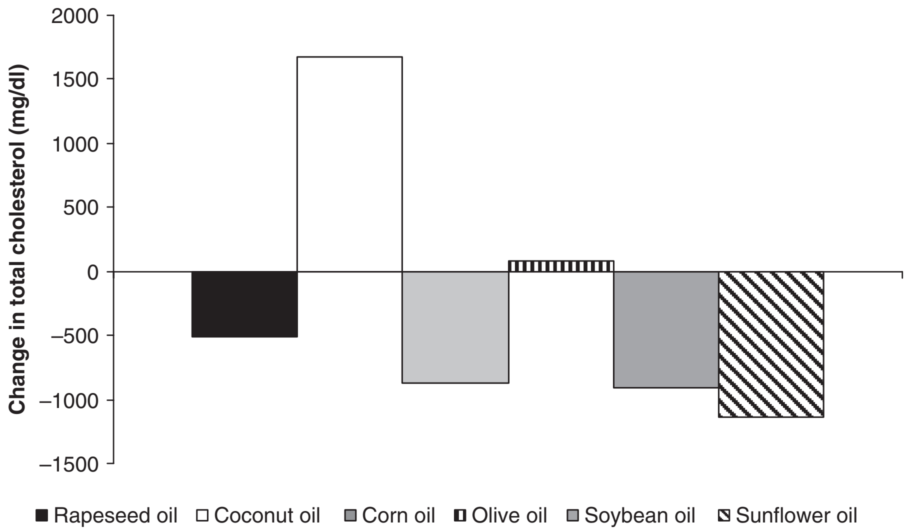

Figure 6 Culinary oils and their effects on total blood cholesterol.

studies and therefore need to be interpreted with caution.

• The lack of evidence to support or refute the health benefits of the various different culinary oils makes it inappropriate to conclude at present that any one oil has greater health benefits over any other.

7 Developments in culinary oils

7.1 Plant breeding and modifications to traditional oilseeds

As a result of hundreds of years of plant breeding, there are now many varieties of oilseeds grown today. Each has slightly different features, differing from other varieties by, for example, seed yield, seed quality (including oil content), crop standing ability, crop height or earliness of flowering. Seed companies responsible for developing new varieties of seed are continually researching and developing new strains and are increasingly working with food manufacturing companies and retailers, who are looking for new oils to minimise the saturates and *trans* fatty acid content of foods. In some cases, the new oilseed variety and subsequent oil is used solely by one food manufacturer/retailer after a substantial financial investment in the development and trial of the oil.

Successful modification of the fatty acid profile of fats, without diminishing the functional characteristics, has come at an important time. During the 1990s,

Table 22 Common uses of oils

	Uses at home	By industry
Coconut oil	Unsuitable for use in frying	Used commercially to make baked goods
Corn oil	Salad dressings and a good frying and baking oil	Little use in commercial salad dressings and the manufacture of margarines and spreads because of its high price
Flaxseed oil	Rarely used, although may be available from health food stores and as capsules	Primarily used for non-edible purposes (linseed oil). Crushed or whole seeds are used in bakery products. Added to yellow fat spreads to boost the short-chain omega-3 content
Olive oil	Used in the home for salad dressings, shallow and deep-fat frying	Small quantities may be added to fat spreads
Palm oil	Widely used for frying and cooking in less economically developed countries	Commercial cooking/frying, margarines, shortening, vanaspati, specialty fats and spray-dried products
Peanut oil	Used for deep-frying, cooking and salad dressings	Used to make margarine, shortening and mayonnaise, as well as salad dressings
Rapeseed oil	Cooking oil (not suitable for deep-frying because of its moderately high PUFA content), salad dressing	Used in salad dressings, margarine formulations and in shortenings. Rapeseed oil is also used by the food industry for frying and in margarine and shortenings
Sesame oil	Salad dressings	Used for frying snack foods and commercially produced salad dressings
Soybean oil	Tends not to be used in the home in the UK, extensively used in the USA	Margarine, shortening and salad dressings (mayonnaise in the USA) and cooking oils. Commonly used as salad oil
Sunflower oil	Good for cooking and making salad dressings	Used commercially to make fat spreads
Walnut oil	Salad dressings	

PUFA, polyunsaturated fatty acid.

efforts to minimise the *trans* fatty acid content of foods resulted in some manufacturers switching to oils higher in saturates, such as palm olein, which is stable, cheap and low in *trans* fatty acids; thus, consumers were likely to inadvertently increase their saturates intake, which was already then above recommended levels (see Section 4). The use of alternative oils, such as high oleic sunflower or rapeseed oil can significantly decrease intakes of saturates. Analyses by Minihane and Harland (2007) suggested that if just 50% of the snack food and fast food we eat was made with high oleic rapeseed oil in place of oils currently used, there would be a decrease in saturates intake of 3.1%, taking account of current intakes of these foods among adults, and a 6.1% reduction in saturates intake in children. Many changes have occurred to the oils used in food manufacturing since this analysis was undertaken, and it is likely that the percentage reductions reported may be a slight overestimation today (as the oils used in food processing now contain a greater proportion of unsaturates than they did five years ago and the *trans* fatty acid content of the oils is now virtually zero).

In 2007, a new zero-*trans* canola oil was released in the USA. *Nutra-Clear* is made from naturally bred Nexera canola seeds and is said to have low amount of saturates and high amounts of monounsaturates. The FDA has approved a qualified health claim for canola oil, to the effect that a daily intake of $1^1/_2$ tablespoons (19 g) may reduce the risk of CHD, because of its unsaturate content, provided this replaces an equivalent amount of 'saturated fat' and without increasing total energy intake (FDA 2006). Other health claims have also been approved for use in the USA, linking the consumption of olive oil (FDA 2004) and corn oil (FDA 2007) with a reduction in CVD risk.

Legislation governing claims made on foods has now come into force across the EU. Written into the Regulation is a requirement for foods bearing claims to meet specific compositional criteria. This is to avoid nutrient or health claims being used to mask the overall nutrient content of a product, for example, a high saturates content. The European Food Safety Authority is working with the EC to identify detailed compositional criteria (nutrient profiling work) and evidence-based health claims; the nutrient profiling model currently under discussion requires vegetable oils and spreads to have a saturates content of less than 30% in order to make any sort of nutrition or health claim (EC 2008). For more information, see Aisbitt (2007).

7.2 Future developments in plant breeding

In the past, many developments in oilseed crop research have focused on increasing the oil content of the seed by conventional breeding techniques. Most rapeseed used to yield a seed that produced 40% oil, which has now increased to 45%. Further increases are likely as this is a highly desirable trait – a high oil content increases the value of the seed, as it is more efficient to crush.

In the future, we would expect to see further developments in plant breeding techniques using both conventional methods and emerging technologies. This area of research is set to expand further, driven by the strong demand from the food industry for frying oils that have all the functional characteristics required for successful application in food products, along with a desirable fatty acid profile. A high oleic/low linolenic variety of rapeseed currently makes up an estimated 3% of the market and this market share is expected to grow. However, it takes several years to modify oil fatty acid profiles through conventional breeding practices and, in order to produce oils for a fast-moving food industry, researchers are looking at other agro-food technologies to drive future developments.

One piece of work that is using GM technology to produce oils with a more desirable fatty acid profile is the EU-funded *Lipgene* project (see Nugent 2005; Lipgene 2008). The ultimate goal of the plant biotechnology group of *Lipgene* is to establish a sustainable source of long-chain *n*-3 polyunsaturates for human consumption. While oil-rich fish provides a valuable source of these compounds in the diet, consumption of fish is low in many parts of the EU, and there are concerns over long-term sustainability. Therefore scientists in this arm of the *Lipgene* project aim to investigate the potential of genetic engineering to create transgenic plants that contain a substantial proportion of long-chain *n*-3 polyunsaturates. Producing long-chain *n*-3 polyunsaturates in seed oil has many advantages over fish oil, including a lower odour, less environmental contamination, and the fact that plants are a sustainable and cheap source of fatty acids.

Using genes that regulate the production of EPA and DHA in marine algae, it was demonstrated that the *n*-6 polyunsaturate (AA) and the *n*-3 polyunsaturate EPA could be produced in flaxseed. However, at only 5%, the concentration of these long-chain polyunsaturates in the seed oil was too low for commercial use. Further, the ratio of *n*-6 and *n*-3 in these seeds needed to be optimised (in a healthy, balanced diet, *n*-6 and *n*-3 polyunsaturates should be present in a ratio of 5 : 1 – based on population recommendations). Scientists working in this area have identified genes within rapeseed that are responsible for this 'bottleneck' in the synthesis of long-chain polyunsaturates, and new genes associated with the biosynthesis of long-chain *n*-3 polyunsaturates have also been identified. This has enabled the production of a strain of rapeseed oil with a fatty acid composition optimised towards *n*-3 fatty acids and also allowed an increased yield of *n*-3. As well as producing these modified oils for human consumption, the possibility of using these oils in animal feed has also been discussed, with a view to enhancing the fatty acid profile of meat products by using a sustainable source of *n*-3-rich oils.

However, such developments in plant biotechnology will not reap the potential health benefits if consumers are not thoroughly convinced on the safety and worth of the resultant oils. In the past, consumer opinion, especially in Europe, has been very sceptical of this new technology, and some food manufacturers are going out of their way to ensure that they can claim that their products are 'GM free'. The American public has not been so averse to GM technologies, and many products derived from GM ingredients are available in supermarkets in the USA. As there is currently a lot of resistance to genetic engineering among the public, it may be some time before the use of this technology is accepted and the potential benefits realised. Nevertheless, research carried out within *Lipgene* among consumers across Europe has indicated that a more liberal view is emerging with regard to the use of GM technology, especially when there are potential health gains (Stewart-Knox *et al*. 2008).

Key points: developments in culinary oils

- Many varieties of oilseeds are grown today; some have been developed by conventional breeding methods and others have been developed using new agro-food technologies.
- Seed companies are continually developing new strains of seeds and have been working with food manufacturing companies and retailers, who are looking for new oils to minimise the saturates and *trans* fatty acid content of foods.
- It takes several years to modify oil fatty acid profiles through conventional breeding practices, and, in order to produce oils for a fast-moving food industry, researchers are looking at other agro-food technologies such as genetic engineering to drive future developments.

8 Culinary oils in a healthy, balanced diet

A small amount of fat is an essential part of a healthy, well-balanced diet. Apart from providing us with the fat-soluble vitamins A, D and E, and essential fats that our bodies cannot make, fat in some foods can help to improve the taste and texture of a dish.

Table 23 The contribution that fatty acids make to the energy content of the UK diet

	% food energy			
	Men	Women	Boys	Girls
Total fat	35.8	34.9	35.4	35.9
SFAs	13.4	13.2	14.2	14.3
Trans fatty acids	1.2	1.2	1.4	1.3
MUFAs	12.1	11.5	11.7	11.8
n-3 PUFAs	1.0	1.0	0.8	0.8
n-6 PUFAs	5.4	5.3	5.1	5.3

Source: Henderson *et al.* (2003a); Gregory and Lowe (2000).
SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids.

The model that health professionals use to describe a healthy, well-balanced diet in the UK is the FSA's *eatwell* plate (FSA 2007b). The *eatwell* plate shows how much of the food eaten each day, including snacks, should come from each food group.

The culinary oils and products derived from them, such as margarine, other spreading fats and low-fat spreads, oil-based salad dressings, fried foods, crisps, biscuits, pastries, cakes, puddings and ice-cream, are all in the 'foods and drinks high in fat and/or sugar' group. People should be eating just small amounts of these foods.

Many healthy eating tips exist to help the public select a daily diet that is well balanced to make sure that all nutrient requirements are met. The key issues at present, in relation to fat, are not the total amount – at a population level, average intake of fat is in line with government recommendations (contributing to 35% food energy). However, the average intake of saturates in both men and women is approximately 13% of food energy, which is higher than the recommended target of 11%, and further reductions are required (see Table 23). Intakes of saturates are also too high in children. The recommendation for total polyunsaturates is also being met, on average (Gregory & Lowe 2000; Henderson *et al.* 2003a).

Improving the fatty acid make-up of the UK diet requires a shift in the proportions of fatty acids present in the diet, alongside a slight decrease in total fat consumption. Given the known health benefits of unsaturates, monounsaturates and both *n*-6 and *n*-3 polyunsaturates should be *substitutes* for saturates in our diets, rather than consumed in addition. Regardless of the nature of the 'good fats' used to substitute saturates in the diet, it is important that they are not promoted in such a way that people end up *increasing* their total fat intakes, while believing that they are making positive dietary changes for their future health – it is important to 'get the balance right'.

The FSA's Saturated Fat and Energy Intake Campaign

The FSA is working with health experts and the food industry to tackle high intakes of saturated fat and excess energy intakes (FSA 2008). Eating a diet that is high in saturated fat and/or a diet providing excess energy, compared with the energy burnt off through activity, can contribute to the development of a range of diet-related illnesses including obesity, CVD, diabetes and some cancers.

The FSA has announced the first steps of its programme to help people in the UK reduce the amount of saturated fat they eat and to achieve a better balance between energy intake and energy output (*e.g.* physical activity).

Key aspects of the programme include encouraging further voluntary reformulation of specific food groups to reduce the amount of saturated fat (and sugar) they contain, along with exploring routes for the most effective consumer awareness activities to raise the profile of saturated fats in the diet. One route that will be used will highlight tips and suggestions for the types of oils and fats used in cooking (see Box 2).

Box 2 Suggested shopping and food preparation tips to reduce intake of saturates when choosing oils

- Check food labels so you know how much saturated fat is in the foods you are consuming.
- Choose polyunsaturated or monounsaturated spreads where possible.
- Use unsaturated oils such as olive, sunflower or rapeseed oils in cooking.

Key points: culinary oils in a healthy, balanced diet

- A small amount of fat is an essential part of a healthy, well-balanced diet. Apart from providing us with the fat-soluble vitamins A, D and E, and essential fats that our bodies cannot make, fat in some foods can help to improve the taste and texture of a dish.
- However, the culinary oils and products derived from them should be eaten in small amounts.
- Given the known health benefits of unsaturates, monounsaturates and both *n*-6 and *n*-3 polyunsaturates

should be substitutes for saturates in our diets, rather than consumed in addition.

• Regardless of the nature of the 'good fats' used to substitute saturates in the diet, it is important that they are not promoted in such a way that people may actually increase their total fat intakes, while believing that they are making positive dietary changes for their future health. It is important to 'get the balance right'.

Conclusions

Culinary oils and the products made from them, such as fat 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. They are also rich sources of EFAs.

Although most of the vegetable-based culinary oils contain primarily unsaturates, the oils do differ in the proportions of the different fatty acids present. Some of the oils, for example, rapeseed oil, provide a good balance of the monounsaturates and *n*-3 and *n*-6 polyunsaturates, when compared with some of the other oils that have less well-balanced fatty acid profiles. While there seems to be an important role in health for polyunsaturates (*e.g.* they can have a positive effect on decreasing LDL), particularly in replacing saturates in the diet, it may be especially important to increase the *n*-3 family of polyunsaturates. The long-chain *n*-3 polyunsaturates (for which most of the health benefits have been found) occur in oil-rich 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 polyunsaturates, EPA and DHA.

It is likely that, in the future, both conventional plant breeding programmes, as well as emerging agro-food technologies, including the application of GM, will result in a wider variety of more functional oils being produced. Such oils may have enriched concentrations of specific fatty acids, or may even contain the long-chain *n*-3 fatty acids currently only found in fish oils, which could have a significant impact on the fatty acid profile of the diet. However, whether oils derived from plant breeding programmes utilising GM technology will become acceptable to a GM-wary population in the future, remains to be seen.

There is currently little evidence to suggest that one vegetable oil should be promoted over any other oil on the basis of additional health effects, as there are few good quality trials that have adequately compared the health outcomes of individuals consuming specific oils. Indeed, because of the use of a variety of different vegetable-based oils in food manufacturing processes, most people are already consuming a wide variety of different oils each day. Instead, the choice of culinary oil often depends on the functionality of the oil for a particular food application, or on taste, personal preference or cost. The most important message for consumers is that all oils, regardless of whether they contain 'good' or 'bad' fats, are almost 100% fat and therefore the oils themselves, as well as products manufactured from them, should only be included in the diet in moderate quantities.

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References

Aisbitt B (2007) *Nutrition and Health Claims: The Facts on Your Food*. EuroFIR Synthesis Report No. 5. EuroFIR/British Nutrition Foundation: London.

Aisbitt B & Buttriss J (2006) *Trans* fats – should we be worried? *Nutrition Bulletin* **31**: 273–366.

Allman MA, Pena MM & Pang D (1995) Supplementation with flaxseed oil versus sunflower seed oil in healthy young men consuming a low fat diet: effects on platelet composition and function. *European Journal of Clinical Nutrition* **49**: 169–78.

Allman-Farinelli M & Macan L (2000) Fats and oils. In: *Essentials of Human Nutrition*, (J Mann, AS Truswell eds), pp. 367–369. Oxford University Press: Oxford.

Atkins L (2008) Coco loco. *Guardian*, Tuesday, January 15. Available at: http://www.guardian.co.uk/lifeandstyle/2008/jan/15/healthandwellbeing.foodanddrink (accessed December 2008).

Awad AB & Fink CS (2000) Phytosterols as anticancer dietary components: evidence and mechanisms of action. *Journal of Nutrition* **130**: 2127–30.

Berry SE & Sanders TAB (2005) Influence of triacylglycerol structure of stearic acid-rich fats on postprandial lipaemia. *Proceedings of the Nutrition Society*. **64**: 205–212.

Binkoski AE, Kris-Etherton PM, Wilson TA *et al.* (2005) Balance of unsaturated fatty acids is important to a cholesterol-lowering diet: comparison of mid-oleic sunflower oil and olive oil on cardiovascular disease risk factors. *Journal of the American Dietetic Association* **105**: 1080–6.

BNF (British Nutrition Foundation) (1992) *Taskforce Report. Unsaturated Fatty Acids: Nutritional and Physiological Significance*. British Nutrition Foundation: London.

BNF (British Nutrition Foundation) (2002) *Soya and health*. British Nutrition Foundation: London.

BNF (British Nutrition Foundation) (2008) *The Evidence for the Cholesterol Lowering Effects of Plant Stanol Esters*. British Nutrition Foundation: London. Available at: http://www.nutrition.org.uk/PSE (accessed December 2008).

Boskou D (1999) Non-nutrient antioxidants and stability of frying oils. In: *Frying of Food*, (D Boskou and I Elmadfa eds), pp 183–204. Technomic Publishing Company: Lancaster.

Boskou D (2007) Olive oil. *World Review of Nutrition and Dietetics* **97**: 180–210.

Brouwer IA, Katan MB & Zock PL (2004) Dietary alpha-linolenic acid is associated with reduced risk of fatal coronary heart disease, but increased prostate cancer risk: a meta-analysis. *Journal of Nutrition* **134**: 919–22.

Buttriss J (2003) Introduction: Plant foods and health. In: *Plants: Diet and Health. The Report of the British Nutrition Foundation Task Force*, (G Goldberg ed.), pp. 1–26. Blackwell Publishing: Oxford.

Chan JK, McDonald BE, Gerrard JM *et al.* (1993) Effect of dietary alpha-linolenic acid and its ratio to linoleic acid on platelet and plasma fatty acids and thrombogenesis. *Lipids* **28**: 811–7.

Choudhury N, Liling T & Truswell AS (1995) Comparison of palm olein and olive oil: effects on plasma lipids and vitamin E in young adults. *American Journal of Clinical Nutrition* **61**: 1043–51.

Clark WF, Kortas C, Heidenheim AP *et al.* (2001) Flaxseed in lupus nephritis: a two-year nonplacebo-controlled crossover study. *Journal of the American College of Nutrition* **20**: 143–8.

Crews C, Hough P, Godward J *et al.* (2005) Study of the main constituents of some authentic walnut oils. *Journal of Agriculture and Food Chemistry* **53**: 4853–60.

Crozier A (2003) Classification and biosynthesis of plants and secondary products: an overview. In: *Plants: Diet and Health. The Report of the British Nutrition Foundation Task Force*, (G Goldberg ed.), pp. 27–48. Blackwell Publishing: Oxford.

DEFRA (Department for Environment, Food and Rural Affairs) (2007) *Family Food 2005–06. A Report on the Expenditure & Food Survey*. TSO: London.

DEFRA (Department for Environment, Food and Rural Affairs) (2008) *Bioenergy*. Available at: http://www.defra.gov.uk/FARM/crops/industrial/energy/energy2.htm (accessed December 2008).

Denny AR & Buttriss JL (2007) *Plant Foods and Health: Focus on. Plant Bioactives*. EuroFIR Synthesis Report No. 4. EuroFIR/British Nutrition Foundation: London.

DH (Department of Health) (1991) *Dietary Reference Values for Food Energy and Nutrients for the United Kingdom*. HMSO: London, UK.

DH (Department of Health) (1994) *Nutritional Aspects of Cardiovascular Disease*. HMSO: London.

DiRienzo MA, Lemke SL, Petersen BJ *et al.* (2008) Effect of substitution of high stearic low linolenic acid soybean oil for hydrogenated soybean oil on fatty acid intake. *Lipids* **43**: 451–6.

EC (European Commission) (2008) Working Document on the Setting of Nutrient Profiles. Available at: http://www.food.gov.uk/multimedia/pdfs/consultation/ecsettingnp.pdf (accessed December 2008).

Ellegard L, Andersson H & Bosaeus I (2005) Rapeseed oil, olive oil, plant sterols, and cholesterol metabolism: an ileostomy study. *European Journal of Clinical Nutrition* **59**: 1374–8.

FAO (Food and Agriculture Organization of the United Nations) (2008) Food Outlook Global Market Analysis. November 2008. Available at: http://www.fao.org/giews/english/fo/index.htm (accessed December 2008).

FAOSTAT/FBS (Food and Agriculture Organization of the United Nations Statistics/Food Balance Sheets) (2006) Summary of World Food and Agricultural Statistics 2005. Available at: http://faostat.fao.org/site/372/default.aspx (accessed December 2008).

FDA (Food and Drug Administration) (2004) FDA Allows Qualified Health Claim to Decrease Risk of Coronary Heart Disease. Available at: http://www.fda.gov/bbs/topics/news/2004/NEW01129.html (accessed December 2008).

FDA (Food and Drug Administration) (2006) Qualified Health Claims: Letter of Enforcement Discretion – Unsaturated Fatty Acids from Canola Oil and Reduced Risk of Coronary Heart Disease. Available at: http://www.cfsan.fda.gov/~DMS/qhccanol.html (accessed December 2008).

FDA (Food and Drug Administration) (2007) Qualified Health Claims: Letter of Enforcement Discretion – Corn Oil and Corn Oil-Containing Products and a Reduced Risk of Heart Disease. Available at: http://www.cfsan.fda.gov/~dms/qhccorno.html (accessed December 2008).

FEDIOL (European Union Oil and Proteinmeal Industry) (2008) FEDIOL Statistics on EU Production, Imports, Exports and Consumption 1980–2006. Available at: http://www.fediol.be/6/index.php (accessed December 2008).

FNB (Food and Nutrition Board) (2000) *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. The National Academies Press: Washington DC.

Food Labelling Regulations (1996) Regulation 14(4) Generic Names in List of Ingredients. Available at: http://www.opsi.gov.uk/si/si1996/Uksi_19961499_en_9.htm (accessed December 2008).

Foster RK & Lunn J (2007) 40th Anniversary Briefing Paper: food availability and our changing diet. *Nutrition Bulletin* **32**: 187–249.

Frayn K & Stanner S (2005) The aetiology and epidemiology of cardiovascular disease. In: *Cardiovascular Disease: Diet, Nutrition and Emerging Risk Factors. The Report of the British Nutrition Foundation Task Force*, (S Stanner ed.), pp. 1–21. Blackwell Publishing: Oxford.

Freese R, Mutanen M, Valsta LM *et al.* (1994) Comparison of the effects of two diets rich in monounsaturated fatty acids differing in their linoleic/alpha-linolenic acid ratio on platelet aggregation. *Thrombosis and Haemostasis* **71**: 73–7.

FSA (Food Standards Agency) (2002) *McCance and Widdowson's The Composition of Foods*. Sixth summary edition. Royal Society of Chemistry: Cambridge.

FSA (Food Standards Agency) (2007a) Re-estimate of trans fat intake in adults. Available at: http://www.food.gov.uk/multimedia/pdfs/reestimatetransfats.pdf (accessed December 2008).

FSA (Food Standards Agency) (2007b) The eatwell plate. Available at: http://www.food.gov.uk/healthiereating/eatwellplate/ (accessed December 2008).

FSA (Food Standards Agency) (2008) Saturated Fat and Energy Intake. Available at: http://www.food.gov.uk/healthiereating/satfatenergy/ (accessed December 2008).

Fukuda Y & Namiki M (1988) Recent studies on sesame seed oil. *Journal of the Japanese Society of Food Science and Technology* **35**: 552–62.

Gregory J & Lowe S (2000) *National Diet and Nutrition Survey: Young People Aged 4 to 18 Years. Volume 1: Report of the Diet and Nutrition Survey*. TSO: London.

Gunstone FD, Harwood JL & Padley FB (1994) *The Lipid Handbook* 2nd edition. Chapman & Hall: London.

Gunstone FD (2001) Oilseed crops with modified fatty acid composition. *Journal of Oleo Science* **50**: 269–79.

Gupta MK (2002) Sunflower oil. Vegetable oils in food technology. In: *Vegetable Oils in Food Technology Composition, Properties and Uses*, (FD Gunstone ed.), pp. 128–156. Blackwell Publishing: Oxford.

Hegsted DM, McGandy RB, Myers ML *et al.* (1965) Quantitative effects of dietary fat on serum cholesterol in man. *American Journal of Clinical Nutrition* **17**: 281–95.

Hegsted DM, Ausman LM, Johnson JA *et al.* (1993) Dietary fat and serum lipids: an evaluation of the experimental data. *American Journal of Clinical Nutrition* **57**: 875–83.

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

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

HGCA (Home Grown Cereals Authority) (2005) Oilseed Rape – A Grower's Guide. London, UK. Available at: http://www.unitedoilseeds.co.uk/Images/pdf_downloads/hgca_guide.pdf (accessed December 2008).

Hibbeln JR, Davis JM, Steer C *et al.* (2007) Maternal seafood consumption in pregnancy and neurodevelopmental outcomes in childhood (ALSPAC study): an observational cohort study. *Lancet* **369**: 578–85.

IGD (Institute of Grocery Distribution) (1998) *Voluntary Nutrition Labelling Guidelines to Benefit the Consumer*. IGD: Watford, UK.

James MJ, Gibson RA & Cleland LG (2000) Dietary polyunsaturated fatty acids and inflammatory mediator production. *American Journal Clinical Nutrition* **71**: 343S–8S.

Jebb SA, Frost G, Griffin B *et al.* (2007) The RISCK study: testing the impact of the amount and type of dietary fat and carbohydrate on metabolic risk. *Nutrition Bulletin* **32**: 154–6.

Kabagambe EK, Baylin A, Ascherio A *et al.* (2005) the type of oil used for cooking is associated with the risk of nonfatal acute myocardial infarction in Costa Rica. *Journal of Nutrition* **135**: 2674–9.

Kochhar SP (2001) Analysis of commercial sesame seeds from various origins and commercially produced rice bran oil samples, unpublished data.

Kris-Etherton PM, Taylor DS, Yu-Poth S *et al.* (2000) Polyunsaturated fatty acids in the food chain in the United States. *American Journal of Clinical Nutrition* **71**: 179S–88S.

Kris-Etherton PM, Zhao G, Binkoski AE *et al.* (2001) The effects of nuts on coronary heart disease risk. *Nutrition Reviews* **59**: 103–11.

Laaksonen DE, Nyyssonen K, Niskanen L *et al.* (2005) Prediction of cardiovascular mortality in middle-aged men by dietary and serum linoleic and polyunsaturated fatty acids. *Archives of International Medicine* **165**: 193–9.

Layne KS, Goh YK, Jumpsen JA *et al.* (1996) Normal subjects consuming physiological levels of 18 : 3 (n-3) and 20 : 5 (n-3) from flaxseed or fish oils have characteristic differences in plasma lipid and lipoprotein fatty acid levels. *Journal of Nutrition* **126**: 2130–40.

Lichtenstein AH, Ausman LM, Carrasco W *et al.* (1993) Effects of canola, corn, and olive oils on fasting and postprandial plasma lipoproteins in humans as part of a National Cholesterol Education Program Step 2. *Arteriosclerosis, Thrombosis and Vascular Biology* **13**: 1533–42.

Lipgene (2008) *Lipgene – Diet, Genomics, and the Metabolic Syndrome: an Integrated Nutrition, Agro-food, Social and Economic Analysis*. British Nutrition Foundation: London. Available at: http://www.ucd.ie/lipgene (accessed December 2008).

Lunn J (2007) Monounsaturates in the diet. *Nutrition Bulletin* **31**: 378–91.

Lunn J & Theobald H (2006) The health effects of dietary unsaturated fatty acids. *Nutrition Bulletin* **31**: 178–224.

Luscombe N, Noakes M & Clifton P (1999) Diets high and low in glycemic index versus high monounsaturated fat diets: effects on glucose and lipid metabolism in NIDDM. *European Journal of Clinical Nutrition* **53**: 473–8.

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

MAFF (Ministry of Agriculture, Fisheries and Food) (1998) *Fatty Acids – Supplement to McCance and Widdowson's the Composition of Foods*. Royal Society of Chemistry: Cambridge.

Meijer GW & Weststrate JA (1997) Interesterification of fats in margarine: effect on blood lipids, blood enzymes, and hemostasis parameters. *European Journal of Clinical Nutrition* **51**: 527–34.

Mensink R, Zock P, Kester A *et al.* (2003) Effects of dietary fatty acids and carbohydrates on the ratio of serum total to HDL cholesterol and on serum lipids and apolipoproteins: a meta-analysis of 60 controlled trials. *American Journal of Clinical Nutrition* **77**: 1146–55.

Mensink RP & Katan MB (1992) Effect of dietary fatty acids on serum lipids and lipoproteins: a meta-analysis of 27 trials. *Arteriosclersis and Thrombosis* **12**: 911–9.

Minihane AM & Harland JI (2007) Impact of oil used by the frying industry on population fat intake. *Critical Reviews in Food Science & Nutrition* **47**: 287–97.

Mintel (2007) *Edible Oils – UK*. Mintel International Group Limited: London.

Mitra A (2007) Study on the benefits of sesame oil over coconut oil in patients of insulin resistance syndrome, notably type 2 diabetes and dyslipidaemia. *Journal of Human Ecology* **22**: 61–6.

Moon DO, Kim MO, Choi YH *et al.* (2008) Beta-sitosterol induces G2/M arrest, endoreduplication, and apoptosis through the Bcl-2 and PI3K/Akt signaling pathways. *Cancer Letters* **264**: 181–91.

Moreau RA (2005) Corn oil. In: *Bailey's Industrial Oil and Fat Products*, (F Shahidi ed), pp 146–169. Wiley-Blackwell: Oxford.

Mozaffarian D, Bryson CL, Lemaitre RN *et al.* (2005) Fish intake and risk of incident heart failure. *Journal of the American College Cardiology* **45**: 2015–21.

Mutalib MSA, Wahle KWJ, Duthie GG *et al.* (1999) The effect of dietary palm oil, hydrogenated rape and soya oil on indices of coronary heart disease in healthy Scottish volunteers. *Nutrition Research* **19**: 335–48.

Nielsen NS, Pedersen A, Sandström B *et al.* (2002) Different effects of diets rich in olive oil, rapeseed oil and sunflower-seed oil on postprandial lipid and lipoprotein concentrations and on lipoprotein oxidation susceptibility. *British Journal of Nutrition* **87**: 489–99.

Nordstrom DCE, Honkanen EA, Nasu Y *et al.* (1995) Alpha-linolenic acid in the treatment of rheumatoid arthritis. A double-blind, placebo-controlled and randomized study: flaxseed vs. safflower seed. *Rheumatology International* **14**: 231–4.

Nugent AP (2005) LIPGENE: an EU project to tackle the metabolic syndrome. *Biochimie* **87**: 129–32.

OECD-FAO (Organization for Economic Cooperation and Development and the Food and Agriculture Organization of the United Nations) (2008) Agricultural Outlook 2008-17. Available at: www.agri-outlook.org/dataoecd/54/15/40715381.pdf (accessed December 2008).

Ong AS & Goh SH (2002) Palm oil: a healthful and cost-effective dietary component. *Food and Nutrition Bulletin* **23**: 11–22.

Perez-Jimenez F, Castro P, Lopez-Miranda J *et al.* (1999) Circulating levels of endothelial function are modulated by dietary monounsaturated fat. *Atherosclerosis*. **145**: 351–8.

Plat J & Mensink R (2005) Plant stanol and sterol esters in the control of blood cholesterol levels: mechanism and safety aspects. *American Journal of Cardiology* **96**: 15–22.

Przybylski R & Mag T (2002) Canola/rapeseed oil. In: *Vegetable Oils in Food Technology*, (F Gunstone ed.), pp. 98–127. Blackwell Publishing: Oxford.

Psomiadou E & Tsimidou M (2001) Pigments in Greek virgin olive oils: occurrence and levels. *Journal of the Science of Food and Agriculture* **81**: 640–7.

Quiles JL, Ramirez-Tortosa MC & Yaqoob P (2006) *Olive Oil and Health*. CABI Publishing: Wallingford, UK.

Rogers P (2001) A healthy body, a healthy mind: long-term impact of diet on mood and cognitive function. *Proceedings of the Nutrition Society* **60**: 135–43.

SACN (Scientific Advisory Committee on Nutrition) (2007) *Update on* Trans *Fatty Acids and Health*. TSO: London. Available at: http://www.sacn.gov.uk/pdfs/sacn_trans_fatty_acids_report.pdf (accessed December 2008).

SACN/COT (Scientific Advisory Committee on Nutrition/ Committee on Toxicity) (2004) *Advice on Fish Consumption: Benefits and Risks*. HMSO: London.

Sanders TH (1982) Peanut triacylglycerols: effect of season and production location. *Journal of the American Oil Chemists' Society* **59**: 346–351.

Sato H, Ito K, Sakai K *et al.* (2004) Effects of soybean-germ oil on reducing serum cholesterol levels in a double-blind controlled trial in healthy humans. *Journal of Oleo Science* **53**: 9–16.

Simopoulos AP (1999) Essential fatty acids in health and chronic disease. *American Journal of Clinical Nutrition* **70**: 560S–9S.

Sodergren E, Gustafsson I-B, Basu S *et al.* (2001) A diet containing rapeseed oil-based fats does not increase lipid peroxidation in humans when compared to a diet rich in saturated fatty acids. *European Journal of Clinical Nutrition* **55**: 922–31.

Stauffer CE (1996) *Practical Guides for the Food Industry: Fats and Oils*. American Association of Cereal Chemists: St. Paul, MN.

St-Onge MP & Jones PJ (2003) Greater rise in fat oxidation with medium-chain triglyceride consumption relative to long-chain triglyceride is associated with lower initial body weight and greater loss of subcutaneous adipose tissue. *International Journal of Obesity and Related Metabolic Disorders* **27**: 1565–71.

St-Onge MP, Aban I, Bosarge A *et al.* (2007) Snack chips fried in corn oil alleviate cardiovascular disease risk factors when substituted for low-fat or high-fat snacks. *American Journal of Clinical Nutrition* **85**: 1503–10.

Stewart-Knox BJ, Bunting BP, Gilpin S *et al.* (2008) Attitudes toward genetic testing and personalised nutrition in a representative sample of European consumers. *British Journal of Nutrition*. **Sep 8**: 1–8. [Epub ahead of print]

Sundram K, Karupaiah T & Hayes KC (2007) Stearic acid-rich interesterified fat and trans-rich fat raise the LDL/HDL ratio and plasma glucose relative to palm olein in humans. *Nutrition and Metabolism* **4**: 3.

Thompson R, Miles L, Lunn J *et al.* (2008) Systematic review of literature on early life patterns of exposure to, and avoidance of, food allergens and later development of sensitisation and clinical food allergy, with particular reference to peanut allergy. Final Technical Report of FSA research project T07052. Available at: http://www.foodbase.org.uk (accessed December 2008).

Tony KW, Hassan K, Lim JB *et al.* (1991) Nonhypercholesterolemic effects of a palm-oil diet in Malaysian volunteers. *American Journal of Clinical Nutrition* **53**: 1015s–20s.

Uchida K (2007) Lipid peroxidation and redox-sensitive signaling pathways. *Current Atherosclerosis Reports* **9**: 216–21.

USDA (United States Department of Agriculture) (2008) USDA National Nutrient Database for Standard Reference, Release 20. Nutrient Data Laboratory. Available at: http://www.ars.usda.gov/nutrientdata (accessed December 2008).

USDA-FAS (United States Department of Agriculture Foreign Agriculture Service) (2008) Oilseeds: world markets and trade monthly circular. Available at: http://www.fas.usda.gov/oilseeds/circular/Current.asp (accessed December 2008).

USDA-NASS (United States Department of Agriculture – National Agricultural Statistics Service) (2005). Acreage 2005 (June report). United States Department of Agriculture National Agricultural Statistics Service, Washington DC.

Vega-Lopez S, Ausman LM, Jalbert SM *et al.* (2006) Palm and partially hydrogenated soybean oils adversely alter lipoprotein profiles compared with soybean and canola oils in moderately hyperlipidemic subjects. *American Journal of Clinical Nutrition* **84**: 54–62.

Visioli F, Grande S, Bogani P *et al.* (2006) Antioxidant properties of olive oil phenolics. In: *Olive Oil and Health*, (JL Quiles, ML Ramirez-Tortosa, P Yaqoob eds), pp. 109–118. Cabi Publishing: Wallingford, UK.

Wahle KWJ, Heys SD, Majumder B *et al.* (2001) *Conjugated Linoleic Acids Modulate Apoptotic and Anti-signal Mechanisms in Breast and Prostate Cells*. 1st International Conference on CLA, Aleslund, Norway, 11.

Wallace FA, Miles EA & Calder PC (2003) Comparison of the effects of linseed oil and different doses of fish oil on mononuclear cell function in healthy human subjects. *British Journal of Nutrition* **89**: 679–89.

Wang T (2002) Soybean oil. In: *Vegetable Oils in Food Technology Composition, Properties and Uses*, (FD Gunstone ed.), pp. 18–58. Blackwell Publishing: Oxford.

Wardlaw GM, Snook JT, Lin M-C *et al.* (1991) Serum lipid and apolipoprotein concentrations in healthy men on diets rich in either canola or safflower oil. *American Journal of Clinical Nutrition* **54**: 104–10.

Warner K & Mounts TL (1993) Frying stability of soybean and canola oils with modified fatty acid compositions. *Journal of the American Oil Chemical Society* **60**: 983–8.

WCRF/AICR (World Cancer Research Fund/American Institute for Cancer Research) (2007) *Food, Nutrition, Physical Activity, and the Prevention of Cancer: a Global Perspective*. AICR: Washington DC.

WHO/FAO (World Health Organization/Food and Agriculture Organization) (2003) *Global Report on Diet, Nutrition and Prevention of Chronic Diseases*. Technical Report 916. WHO: Geneva.

Williamson C, Foster R, Stanner S *et al.* (2005) Red meat in the diet. *Nutrition Bulletin* **30**: 323–55.

Worthington RE, Hammons RO & Allison JR (1972) Varietal differences and seasonal effects of fatty acid composition and stability of oil form 282 peanut genotype. *Journal of Agriculture and Food Chemistry* **20**: 727–30.

Xu G, Guo H, Zhu F *et al.* (2004) The protective effect of peanut oil on risk of cardiovascular disease. *Acta Nutrimenta Sinica* **26**: 249–52.

Young G & Conquer J (2005) Omega-3 fatty acids and neuropsychiatric disorders. *Reproduction Nutrition Development* **45**: 1–28.

Zatonski W, Campos H & Willet W (2008) Rapid declines in coronary heart disease mortality in Eastern Europe are associated with increased consumption of oils rich in alpha-linolenic acid. *European Journal of Epidemiology* **23**: 3–10.