AGRICULTURAL AND FOOD SCIENCE

Vol. 15 (2006): 402–413.

Review article

Quality characteristics of edible linseed oil

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In this review the quality properties of linseed oil for food uses are discussed as well as factors affecting this quality. Linseed oil has a favourable fatty acid composition with a high linolenic acid content. Linseed oil contains nearly 60% α-linolenic acid, compared with 25% for plant oils generally. The content of linolenic acid and omega-3 fatty acids is reported to be high in linseed grown in northern latitudes. The composition of fatty acids, especially unsaturated fatty acids, reported in different studies varies considerably for linseed oil. This variation depends mainly on differences in the examined varieties and industrial processing treatments. The fatty acid composition leads also to some problems, rancidity probably being the most challenging. Some information has been published concerning oxidation and taste, whereas only a few studies have focused on colour or microbiological quality. Rancidity negatively affects the taste and odour of the oil. There are available a few studies on effects of storage on composition of linseed oil. In general, storage and heat promote auto-oxidation of fats, as well as decrease the amounts of tocopherols and vitamin E in linseed oil. Several methods are available to promote the quality of the oil, including agronomic methods and methods of breeding as well as chemical, biotechnological and microbiological methods. Time of harvesting and weather conditions affect the quality and yield of the oil.

Key-words: linseed, *Linum usitatissimum*, oil, quality, edible, methods

Introduction

Flax (*Linum usitatissimum* L.) is an annual plant belonging to the genus *Linum* and the family *Linaceae* (Sultana 1992). Different varieties of *Linum* have been developed for production of fibre and oilseed. Varieties of *Linum* bred for fibre use are called flax, whereas the oilseed varieties are called linseed, oilseed flax or just flax. In the present study the term linseed is used.

The main production areas of linseed are the Far East, where 1 309 000 ha was cultivated in 2005, and Canada with 811 000 ha. In Europe, approximately 380 000 ha of linseed and 377 000 ha in the USA was cultivated in 2005 (FAOSTAT

Manuscript received December 2005

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2006). The growing area of linseed was a little less than 2 000 ha in 2005 in Finland (Anneli Partala, Information Centre of the Ministry of Agriculture and Forestry, personal communication). There are some advantages to growing linseed in the northern latitudes, as the content of linolenic acid and omega-3 fatty acids in the oil are higher in linseed grown in cool temperatures typical for northern countries compared to southern countries (Dybing and Zimmerman 1966). However, the effect of northern production of linseed on other quality properties has not been published. In recent times there has been demand for domestic linseed, leading to need for increasing the growing area of linseed in Finland (Kortesmaa et al. 2005). In addition the fractions of the stem could be exploited (Kymäläinen 2004).

Linseed contains 26–45% oil (Diedrichsen 2001). Approximately 22% of the oil is located in the seed coat and 4% in the embryo. The oil is present mainly as triacylglycerols in oil bodies having an average diameter of 1.3 μm (Daun et al. 2003). Approximately 70% of all the linseed oil produced worldwide is destined for technical applications and 30% is for food production (Järvenpää 2000). Linseed oil is used in a wide variety of applications, including additives in PVC plastics, anti-rust agents, laquers and paints (Kanta-Oksa 1992, Chimielarz et al. 1995, Rüsch gen Klaas and Warwel 1999), aroma substances for the food industry (Bonnarme et al. 1997) or volatile compounds for obtaining a fresh green odour to offset the decreased odour caused by the processing of vegetables (Noodermeer et al. 2002). Special technical applications have also been suggested, for example as an agglomerating agent for coal (Gryglewicz et al. 2000). In addition to these technical uses, linseed oil is used as an edible oil (Sridhar et al. 1991, Morris and Vaisey-Genser 2003, Sikorska et al. 2005). Edible linseed oil is usually produced by cold-pressing the oil from the seeds (Morris and Vaisey-Genser 2003). The Codex Alimentarius (1999) does not set specific requirements for linseed oil, but it must meet the general quality requirements for food oils, especially regarding hygiene and safety. In addition, the colour should be characteristic of the designated product and the odour and taste should be characteristic of the designated product and free from foreign and rancid odour and taste (Codex Alimentarius 1999). Standards ISO 150 intended for technical linseed oils and ASTM D234-82 include particular requirements for raw linseed oil and some of these values are reported in this text.

Different food applications have been developed, including salad dressings, and food additives, as well as the use of whole and crushed seeds in healthfood products. According to Morris and Vaisey-Genser (2003), high-lignan linseed oil is produced by adding a lignan-containing flax particulate to a standard oil product, and low-lignan oils and blended oils are also available. According to Tarpila et al. (2005), flaxseed lignans and fatty acids have been investigated in several cohort studies for their effects on breast cancer risk and there is an association between elevated serum enterolactone and decreased incidence of breast cancer. Flaxseed lignan precursors are converted to enterodiol and further enterolactone after consumption. In a study by Hall and Schwarz (2002), partial substitution of milk fat by 10% linseed oil in an ice cream formulation produced a texture similar to a control containing 12% milk fat. Linseed oil substitution increased alpha linolenic acid content of the ice cream. Goh et al. (2006) also found that incorporation of linseed oil in a 12% (w/w) ice cream is possible at 2% (w/w) without drastically affecting the ice cream overall functionality. However, the tendency for oxidation of linseed oil, as well as its colour are problematic. Solutions to solve this problem include the micro encapsulation OmegaDry® process, which utilizes γ-cyclodextrin (Oomah 2003). Owing to its valuable nutritional properties, linseed oil also has applications in the production of medicines (Tarpila et al. 2005).

In Finland there has been interest in using linseed oil in a wider range of food applications and production of oil and food applications and product development has been intensive. Several Finnish linseed companies intensified their cooperation during the Agro fibre network project during the years 2002–2005 (Kortesmaa et al. 2005). Examples of cooperation include studies of the cadmium

content (Kymäläinen and Sjöberg 2006a) and fatty acid composition of linseed (Kymäläinen and Sjöberg 2006b), as well as networking between companies, farmers and universities (Kortesmaa et al. 2005). During the project, the companies were interested in overcoming the quality problems of linseed oil. A first step towards this was to review the literature concerning the quality properties of edible linseed oil and its food uses concentrating particularly on the need for product development and experimental research.

Characteristics of linseed oil

Oomah (2001) has published a review concerning flax as a functional food source, presenting a collection of studies concerning the medical health benefits of linseed oil, whole flaxseed and its fractions. According to that review, most of the known biological activities of flaxseed have been assigned to α-linolenic acid.

Chemical characterization

The iodine value of linseed oil is 175–177 according to the standards ISO 150 and ASTM D234-82. This is high compared with those of other food oils, such as olive oil (81), turnip rape oil (98) or sunflower oil (125) (Lide 1996, the British Pharmacopoeia 1998) and indicates the highly unsaturated nature of linseed oil. Acid and peroxide values are used to measure the deterioration in the sensory properties of oil. The acid value measures free fatty acids, which indicates the extent of hydrolytic rancidity. According to the standards ISO 150 and ASTM D234 (1998) and the British Pharmacopoeia (1998) linseed oil has an acid value of less than 4.0. The peroxide value of linseed oil, an empirical measure of oxidation products (Frankel 1998), is approximately 2 (Rudnik et al. 2001). The TBA (thiobarbituric acid) test is based on a reaction between thiobarbituric acid and also measures oxidation products (Frankel 1998). It is particularly sensitive with polyunsaturated fats containing three or more double bonds, but is not so sensitive for the oxidation products of oleic and linoleic acid (Frankel 1998). The greater the TBA value, the more the oil contains oxidation products (Shahidi and Wanasundara 1998). Saponification value is a measure of the average molecular weight (chain length of the fatty acids. The saponification value of linseed oil (188–195 according to the standard ISO 150) is similar to that of many other food oils (Lide 1996, the British Pharmacopoeia 1998).

Fatty acid composition

The fatty acid composition of linseed oil makes it of interest for food use. Generally plant oils contain less than 25% of α-linolenic acid. However, linseed oil has an exceptionally high content of α-linolenic acid (Hiltunen and Holm 2000). As can be seen in Tables 1 and 2, the composition of fatty acids, especially unsaturated fatty acids, reported in different studies varies considerably for linseed oil. This variation is due to differences in the examined varieties and methods of analysis. For example the content of α-linolenic acid varied between 34.1 and 64.6% in the natural oils (Table 1). Modification of oils has in most cases aimed at decreasing the amount of linolenic acid, and as a result the content of α-linolenic acid was between 1.6 and 39.1% in the modified oils (Table 2). The relationship between omega-3- and omega-6- fatty acids is approximately 4:1 in linseed oil (Hiltunen and Holm 2000). In addition to varieties, food processing treatments and experimental setups for linseed and linseed oil often differ widely from each other. For example in a study by Shimada et al. (1996), 45–50% of the fatty acids of linseed oil were converted to caprylic acid by a *Rhizopus delemar* lipase.

Varieties with almost no linolenic acid have also been developed (Green and Marshall 1984, Green 1986). This, and other variations in fatty acid composition, affect the physico-chemical properties of the oil. For example the melting point of solin oil containing a high level of palmitic acid

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Table 1. Fatty acids of natural linseed oil (mass-%).

Definition of samples	Fatty acid					Reference
	Saturated		Mono-unsaturated	Poly-unsaturated		
	Palmitic acid (16:0)	Stearic acid (18:0)	Oleic acid (18:1)	Linoleic acid (18:2)	α-linolenic acid (18:3)	
Varieties K_2, local and NP, cultivated in India	7.2–11.7	3.8–6.2	24.4–27.6	14.2–19.0	40.2–43.0	Bhatia and Sukhija 1970
Australian cultivar Glenelg	8.8	3.0	24.6	17.8	45.8	Green and Marshall 1984
Australian cultivar Glenelg	8.5	4.8	37.9	14.7	34.1	Green 1986
Variety FP1001, cultivated in Manitoba, Canada	5.5	4.0	19.1	12.6	58.8	White et al. 1999
Varieties NorLin and McGregor, cultivated in Manitoba, Canada	5.5–5.9	3.5–5.0	18.6–24.1	12.6–17.2	53.3–54.3	White et al. 1999
Flax from the collection of Plant Gene Resources of Canada and other world genebanks, cultivated in Saskatoon, Canada	3.7–7.0	2.4–8.7	15.1–33.8	7.6–19.2	42.4–61.2	Diedrichsen 2001
Varieties Opal and Hungarian Gold, cultivated in Crakow, Poland	5.8–9.2*	2.9–5.2*	18.5–27.9*	12.3–16.0*	44.6–59.7*	Gambus et al. 2003
Linseed was processed in Saskatoon, Canada	7.0	2.9	16.1	14.7	58.5	Hosseinian et al. 2004
Variety Helmi, cultivated in Finland	4.3*	2.7*	19.0*	16.1*	57.3*	Kymäläinen & Sjöberg 2006
Variety Laser, cultivated in Finland	4.1*	3.1*	17.0*	15.6*	59.6*	Kymäläinen & Sjöberg 2006
Variety Bor line, cultivated in Finland	4.1*	3.0*	20.0*	17.4*	54.9*	Kymäläinen & Sjöberg 2006
Oil obtained by cold pressing seed, and purified with alumina	6.1	3.2	12.9	13.2	64.6	Tautorus and McCurdy 1990
Commercial linseed oil	7.8	4.8	21.9	17.7	46.6	Bonnarme et al. 1997
Commercial linseed oil	5.4	4.0	21.3	14.5	55.0	Hénon et al. 1999
Commercial linseed oil	4.2	3.2	27.4	16.1	46.8	Gryglewicz et al. 2000
Commercial linseed oil	5.3	3.3	17.6	15.6	57.6	van Ruth et al. 2001
Not mentioned	9.2	2.3	14.7	31.0	43.6	Cherian et al. 1996
Not mentioned	5.7	2.7	11.5	16.1	63.4	Li et al. 1996

* determined from the seed

(−13.3ºC) is high compared with that of normal solin oil (−15.1ºC) and linseed oil (−20.0ºC) (Hosseinian et al. 2004). In Canada, the term solin is used for varieties with less than 5% linolenic acid (Saeidi and Rowland 1997). The density and viscosity of solins and traditional linseed varieties are also different (Hosseinian et al. 2004).

Effects of varieties and agronomic factors

There is somewhat contradictory evidence for the health benefits of linolenic acid, because α-linolenic acid is susceptible to rancidity. Many attempts have been made to decrease the contents of linolenic acid. One example of such a variety is

Table 2. Fatty acids of modified linseed oil (mass-%)

Aim of modification	Definition of samples	Fatty acid					Reference
		Saturated		Mono-unsaturated	Poly-unsaturated		
		Palmitic acid (16:0)	Stearic acid (18:0)	Oleic acid (18:1)	linoleic acid (18:2)	α-linolenic acid (18:3)	
Lower level of linolenic acid	Australian cultivar Glenelg, exposed to either γ radiation or the chemical mutagen ethyl methane-sulphonate	8.5	2.9–3.4	24.1–24.9	25.0–26.7	37.1–39.1	Green and Marshall 1984
Lower level of linolenic acid	Australian cultivar Glenelg, exposed to either γ radiation or the chemical mutagen ethyl methane-sulphonate	7.6–8.4	5.4–6.2	35.1–37.8	27.6–28.9	21.4–21.6	Green 1986
Lower level of linolenic acid	Australian cultivar Glenelg, double-mutant homozygous genotype	9.2	4.7	36.3	48.2	1.6	Green 1986
Lower level of linolenic acid	Solin, cultivated in Saskatoon, Canada	6.3	3.6	14.6	72.9	2.4	Hosseinian et al. 2004
Lower level of linolenic acid and higher level of linoleic acid	Linola, cultivated in Manitoba, Canada	6.6	4.7–5.1	17.7–19.8	66.8–69.1	1.7–1.9	White et al. 1999
Production of eicosapentaenoic acid-containing oil	*Mortierella* fungi incubated with linseed oil	6.1*	3.3*	9.2*	9.4*	27.8*	Shimizu et al. 1989b
Higher level of palmitic acid	High-palmitic acid solin, cultivated in Saskatoon, Canada	16.6	2.5	11.3	63.7	3.4	Hosseinian et al. 2004

* also γ-linolenic acid 2.1 %, dihomo-γ-linolenic acid 3.0 %, arachidonic acid 33.8 %, eicosapentaenoic acid 5.1 %
** determined from the seed

solin. Increase in the linoleic acid content gives the potential to produce conjugated linoleic acid (CLA), which has several health benefits (Oomah 2001). An example of such a fatty acid modification is variety Linola, which has a linolenic acid content below 2%, and a high linoleic acid content, 72% (Haumann 1990). According to Wajkira et al. (2004), genetic engineering and exotic varieties should be taken into consideration when breeding genotypes with a low content of linolenic acid.

In addition to the improvement of fatty acid composition of new varieties, one main method for the improvement of linseed oil is breeding of varieties with improved disease resistance, earlier maturation and resistance to lodging. Diseases can cause losses in yield and they can affect the oil content, fatty acid composition and protein content of the seed. All registered flax and solin varieties commercially cultivated in Canada are resistant to rust and moderatedly resistant to fusarium wilt (Daun et al. 2003).

Weather conditions that are favourable for large seed size are also favourable for high oil content and high iodine value (Comstock 1960). According to Adugna and Labuschagne (2003) if the oil yield is high, the amount of polyunsaturated fatty acids, namely linoleic and linolenic acids, is also high. In their study there was a negative cor-

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relation of the oil yield with saturated fatty acids (palmitic and stearic acids) and a weak positive correlation with monounsaturated oleic acid.

Bhatia and Sukhija (1970) studied the changes of fatty acid composition and oil content during maturation of seeds. In their study the oil content increased for 30 days from flowering. The greatest change in the composition of fatty acids and total oil content was 10–20 days after flowering, when the oil content increased 3.4% per day. The relative amount of linolenic acid increased and that of palmitic acid decreased during maturing. However, differences among varieties were found in this trait.

For many oilseed plants, low temperature during the maturation of the seeds increases the amount of polyunsaturated fatty acids in oil. Green (1986) examined the effect of temperature on the fatty acid composition of three normal and three genetically modified varieties of linseed. Low temperature during maturation of the seeds did lead to a decline in the amount of palmitic, stearic and oleic acids and an increase in the content of linoleic and linolenic acids in all four the varieties examined. Day length during the growing season also affects the quality of linseed. In a study by Dybing and Zimmerman (1966), the content of linolenic acid was 49% in mature seeds grown at 15ºC but only 31% in seeds grown at 30ºC. The content of palmitic acid was 7% at 15ºC and 37% at 30ºC, the content of oleic acid 28% and 47%, and that of linoleic acid 15% and 11%, respectively. The oil contents were 38% (15ºC) and 31% (30ºC), and iodine values 176 and 140, respectively.

Effect of storage, chemical composition and microbiological contamination

In a study of White et al. (1999) the composition of linseed and solin oil changed only slightly during storage over 6 months. Only the increase in the amount of palmitic acid was statistically significant, e.g. from 5.9% to 6.1% in variety McGregor and from 6.6% to 7.0% in variety Linola™ 947. Free fatty acids increased during storage when moisture level, temperature and duration of the storage increased. For example, the amount of free fatty acids increased slightly from an initial value 1.69% to 1.72% at 8.0% moisture content and 10ºC, but increased to 9.00% at 11.0% moisture content and 30ºC. El-Gharbawi et al. (1974) showed that acid values, peroxide value and TBA value increased as a result of increasing temperature and storage time. In that study, acid value increased from an initial value of 1.20 to 3.65 after 14 weeks at 28ºC and to 5.21 in 14 weeks at temperature 58ºC. Concomitantly, peroxide value increased from 2.1 to 26.7 in 14 weeks at temperature 28ºC and to 53.4 in 14 weeks at temperature 58ºC, TBA value increased from 13 to 37 in 14 weeks at temperature 28ºC and to 73 in 14 weeks at temperature 58ºC. Storage time and temperature had no significant effect on iodine value. In addition to linseed oil, El-Gharbawi et al. (1974) studied linseed oil contaminated with oil from typical weeds growing in linseed fields, and probably due to their high contents of tocopherols with function as antioxidant found it to be chemically and physically more stable than pure linseed oil.

Unless precautions are taken, linseed may become mouldy during storage. In a study by White et al. (1998), seed with a moisture content as low as 9.5% became mouldy during six months of storage. In a study by Mondal and Nandi (1984) lipases of the fungi broke down the structure of the oil and the amount of free fatty acids increased as the oil content decreased as a consequence of treatment with fungi of the genus *Aspergillus*, decreasing its suitability for food and technical purposes. Dubey et al. (1985) examined the effects of six typical storage fungi and found that four species, namely *Aspergillus flavus, Aspergillus repens, Alternaria alternate* and *Torula allii*, decreased the oil content of the seeds between 5% and 71% depending on the fungal species. *Fusarium culmorum* had no significant effect and *Cladosporium herbarum* increased the oil content. All the examined fungal species significantly increased the amount of free fatty acids and increased the saponification number. Three fungal species (*A. alternata, T. allii* and *A. flavus*) decreased and two (*C. herbarum* and *F. culmorum*) increased the io-

dine value, whereas the effect of one fungal species (A. *repens*) was negligible. In addition to decreasing oil content, fungi can produce mycotoxins (Rustom 1997) that present a risk to human health.

Linseed oil contains natural tocopherols (Li et al. 1996, van Ruth et al. 2001). Tocopherols are the most important source of vitamin E and are known for their antioxidant properties, as well as their essential role in neurological function and prevention of several diseases (Meydani 1995). The profiles of sterols and tocopherol of solin and traditional linseed varieties are similar (Hosseinian et al. 2004).

Effect of oxidation and other factors on taste, odour and colour

Effect of oxidation on taste and odour

The high level of polyunsaturated fatty acids in linseed oils makes it susceptible to oxidation and the oxidation products may be associated with the development of cancer and atherosclerosis (Kubow 1990). The monounsaturated fatty acid, oleic acid, has no such unfavourable effects. Lipase can increase the content of oleic acid from 23.1 to 55.7% and decrease the content of linolenic acid from 52.8 to 30.4 % and that of linoleic acid from 11.9 to 8.1% (Sridhar et al. 1991). This makes the oil less susceptible for oxidation, because linoleic and linolenic acids are typical polyunsaturated fatty acids present in linseed oil. Finding the optimal fatty acid composition is a challenge for plant breeders and technologists. Prozorovskaja et al. (2003) developed a pressing method for the seed of linseed, with which the acid and peroxide values can be diminished and thus the quality of oil improved.

Oxidation of linoleic acid and α-linolenic acid also leads to a rancid taste (Green and Marshall 1984, Hiltunen and Holm 2000, Rudnik et al. 2001). Hydrogenation can be used to improve the stability of oils containing α-linolenic acid. However, because of the high α-linolenic content of linseed oil compared to many other oils, a better method of improving the taste of linseed oil is the elimination of linolenic acid from the oil e.g. by breeding. The effect of linolenic acid on aroma stability has been studied with soybean oil. Cowan et al. (1970) reported that when the content of linolenic acid was reduced to less than 3%, the stability of the taste properties increased, and that in order to obtain good stability the content of linolenic acid should be below 1%. In the study by Wiesenborn et al. (2004) sensory analysis of clarified and stored (7 days in the dark) oil from screw-pressed linseed indicated that sensory scores for nutty, paint-like, and bitter flavours and overall acceptability of the oil were not related to its free fatty acid content and peroxide value. According to the study by Hadley (1996), linseed oil can be used in stir-frying without the development of objectionable taste. However, stir-frying with linseed oil conducted at 177°C and 191°C generated odours indicative of the presence of significant levels of oxidation products. Sensory analysis indicated preference for oils heated at low temperature below 150°C stir-frying.

Factors affecting colour

The colour of technical linseed oils is normally yellowish, a greenish colour is considered undesirable in food use. According to the standards ISO 150 and ASTM D234-82 raw linseed oil should be clear and transparent, with no sediment at 65ºC. According to these standards the colour of raw linseed oil should have a maximum value of 13 on the Gardner colour scale ranging from 1 (lightest) to 18 (darkest). The colour 13 refers to a mixture of 16.6 ml of iron(III) chloride solution, 10.0 ml of cobalt(III) chloride solution and 73.4 ml of hydrochloride solution, defined in detail in the standard ISO 4630. Solin contains less chlorophyll and has a lighter colour than normal linseed oil (Hosseinian et al. 2004). Daun et al. (2003) reported a chlo-

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rophyll content below 1 mg kg^{-1} in top-quality Canadian linseed. Microbiological quality also affects the colour of the oil, according to e.g. Mondal and Nandi (1984) fungi of the genus *Aspergillus* affect the colour changes of oil plants. All fungal treatments increased the amount of red and yellow pigments formed during storage. The colour of oil can be improved by deodorization, which decreases the yellow and red pigments in the oil (Johnson 1998). However, the instability of linseed oil decreases the usefulness of bleaching but the method may be suitable for linseed varieties with a more stable composition of fatty acids.

Quality enhancement

Hydrogenation and antioxidants

Hydrogenation can be used to stabilise polyunsaturated fatty acids, by converting them to more saturated fatty acids. However, it is not suitable for increasing the stability of linseed oil containing high levels of α-linolenic acid because it is an expensive and non-specific method. There is also the possibility that hydrogenation leads to the formation of undesirable iso-linoleic acid that tastes unpleasant (Green 1986).

A high content of palmitic acid is an important feature e.g. for production of margarine and shortening for baking (Saeidi and Rowland 1997). The minimum content of linoleic acid for production of polyunsaturated margarines is 62% (Green 1986). As can be seen in Table 2, for example solin contains polyunsaturated fatty acids over 62%. There have, however, been a public concern about the health risks of *trans*- fatty acids, although the evidence for these are contentious (FDA 2003, Hunter 2005). The study by Nestel el al. (1997) reveals that dietary n-3 fatty acids in linseed oil confer a novel approach to improving arterial function. In that study, purified deodorized linseed oil was the basic oil of the margarine used in the diet (percent fatty acid composition of the margarine: palmitic 8.7, stearic 3.7, oleic 15, linoleic 10.5, α-linolenic 36.7 and *trans* 7.4). This indicates the possibility of producing margarine with linseed oil despite the presence of *trans*- fatty acids.

Synthetic and natural antioxidants are widely used to increase the stability of food oils. Many phenolic compounds found in plants are important for improving the oxidation stability of plant oils. In a study by van Ruth et al. (2001), a soybean extract added to linseed oil decreased the amount of primary oxidation products, conjugated diene-hydroperoxides, by 30%, and that of secondary, volatile and odour-affecting compounds by 99%, thus improving the oxidative stability of linseed oil significantly. The main tocopherol in the seed of linseed is γ-tocopherol present at 85–395 mg kg^{-1}. The content of other tocopherols together is between 121 mg kg^{-1} and 186 mg kg^{-1} (Daun et al. 2003). In a study by van Ruth et al. (2001) the tocopherol content of fresh, commercial linseed oil was 70.3 mg kg^{-1}, whereas in the study by Li et al. (1996) it was approximately 890 mg kg^{-1}. The cause for this difference is unclear, as in both studies the oil was food grade and had not been heat-treated. In a study by Rudnik et al. (2001), butylated hydroxyanisol (BHA) and an antioxidant blend (α-tocopherol, ascorbyl palmitate, citric acid, ascorbinic acid and ethoxylated ethylene) both increased the oxidative stability of linseed oil, with the blend being more effective. The peroxide value of untreated oil was 2.0 before the treatment and 12.3 after the nine-month test period. Similarly, the peroxide values of the oil containing 0.2% of oxidant blend were 2.0 and 3.2, respectively.

Storage and heat decrease the amounts of tocopherols and vitamin E in linseed oil, and promote the auto-oxidation of fats. This must be taken into consideration when selecting the cooking temperature and storage conditions. Heating e.g. at 110ºC for 22 h decreased the tocopherol content of linseed oil from 896 to 665 mg kg^{-1} in a study by Li et al. (1996). Tautorus and McCurdy (1990) found that linseed oil stored at 55ºC contained more oxidation products than oil stored at 28ºC. Addition of enzymes or chemical substances to linseed oil did not significantly improve its oxidative stability. Packaging can also prevent oxidation, and linseed oil is generally packaged in dark containers. Some

companies even infuse garlic and pepper to improve the taste and concurrently inhibiting oxidation.

Deodorization

Deodorization is the final step in refinement of fats and oils, and it is designed to improve the sensory properties by removing compounds such as free fatty acids, aldehydes, ketones and alcohols. The peroxide value of recently deodorized oil is zero and the amount of free fatty acids is below 0.03%. Deodorization is based on steam distillation that is carried out in anaerobic conditions with high temperature and a vacuum. Residues of pesticides and hexane are also removed in the process, and the taste and odour of the oil is improved (Janssen 1997, Johnson 1998).

Microbiological methods of enhancement

A derivative of α-linolenic acid, eicosapentaenoic acid (EPA), is a polyunsaturated fatty acid with potential pharmaceutical value (Shimizu et al. 1989b). EPA has been shown to be of major importance in the prevention human diseases (Bajpai and Bajpai 1993). Shimizu et al. (1989a) found that oil containing EPA can be produced from linseed oil with the fungus *Mortierella alpina* at a low temperature. α-linolenic acid was converted to EPA when *Mortierella* fungus was grown on linseed oil. The best yield of EPA was obtained at a temperature of around 12°C. Compared with other food oils, linseed oil was the most suitable for production of EPA. Approximately 4% of the α-linolenic acid presented to the *Mortierella* strain was converted to EPA (Shimizu et al. 1989b).

Removal of phospholipids

Plant oils contain phosphatides or phospholipids (Nilsson-Johansson et al. 1988). The amounts vary from 1–23 g kg^{-1} of linseed (Daun et al. 2003). Phospholipids may be associated with humid harvesting conditions and delayed harvesting. At high concentrations phospholipids cause problems in production systems, causing stickiness and irreversible opacity (Froment et al. 1999). In that study, the content of all phospholipids varied between 43 ppm and 1436 ppm, and the content of hydratable phospholipids between 43 ppm and 1429 ppm, depending on site and variety of linseed. Some phospholipids can be removed by water, but many seed oils contain also non-hydratable phospholipids (Nilsson-Johansson et al. 1988). Their amount varied but was less than 10.6 ppm in the study by Froment et al. (1999). A traditional compound for removing the phospholipids of linseed is phosphoric acid (Nilsson-Johansson et al. 1988). The costs caused by removal of phospholipids can be decreased if the phospholipids are identified early in the processing, ideally at the crushing stage (Froment et al. 1999). Paronjan et al. (2004) patented a method for removal of phospholipids and waxes.

Conclusions

The fatty acid composition, especially the high linolenic acid content of linseed oil makes it a valuable raw material for food and medicinal purposes. The content of certain fatty acids that are beneficial to human health is reported to be high in linseed grown in the north of Finland. However, this fatty acid composition also gives rise to some problems, in particular with rancidity leading to an unpleasant taste and odour. This review also presents some of the various means that exist for enhancing the quality of the oil. However, many of the enhancement treatments increase the cost of the oil. Contrary to the wish of the industry, no single method with positive wide-scale effect on quality of linseed oil was reported. The quality of fats is a question of balance between useful and harmful properties in the product, as well as of economic considerations. The methods of enhancing quality found in literature may be helpful in some cases, but there is still a need for specific product de-

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velopment in the Nordic industry. One possibility to balance the economy of linseed is the total exploitation of the plant, including use of the fractions of the stem, so that both food and non-food fractions of the linseed plant are used.

Acknowledgements. We are grateful to the Agro Fibre Network project in the EMOTR/ALMA program for financial support.

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SELOSTUS

Elintarvikkeeksi käytettävän pellavaöljyn laatu

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Suomessa kasvatetusta öljypellavasta valmistetulle öljylle on kysyntää, ja öljypellavan viljelyala voi täten kasvaa. Öljypellavan tuottajat ovat olleet kiinnostuneita öljypellavan laadun hallinnasta, ja yksi kiinnostuksen kohteista on ollut öljyn käyttö elintarvikkeissa ja lääketuotteissa. Tässä kirjallisuuskatsauksessa tarkastellaan elintarvikekäyttöön tarkoitetun öljypellavaöljyn laatuominaisuuksia ja niihin vaikuttavia tekijöitä.

Rasvahappokoostumus, erityisesti korkea linoleenihappopitoisuus, tekee pellavaöljystä arvokkaan elintarvikkeiden ja lääkevalmisteiden raaka-aineen. Rasvahappokoostumus vaihtelee kuitenkin paljon eri tutkimuksissa lajikkeiden ja tutkimusmenetelmien mukaan. Rasvahappokoostumus aiheuttaa myös ongelmia erityisesti rasvahappojen hapettumisherkkyyden vuoksi. Syötäväksi tarkoitetun pellavaöljyn tutkimuksissa on keskitytty erityisesti rasvahappokoostumukseen, hapettumiseen ja makuun. Vain harvoissa tutkimuksissa on selvitetty öljyn tuoksun ja mikrobiologisen laadun parantamista. Yleisesti ottaen varastointi ja kuumentaminen lisäävät rasvojen hapettumista sekä vähentävät tokoferolien ja E-vitamiinin määrää pellavaöljyssä. Hapettuminen heikentää öljyn makua. Pellavaöljyn laatua voidaan parantaa useilla menetelmillä, mm. lajikejalostuksella, viljelytekniikalla sekä kemiallisilla, bioteknologisilla ja mikrobiologisilla menetelmillä. Yhtä selkeää ja yleisvaikutteista menetelmää ei kuitenkaan löytynyt, vaan laatua on tarkasteltava tuotekohtaisesti suhteessa sen käyttötarkoitukseen. Korkea siemensato, sadon öljypitoisuus ja korjuuaika vaikuttavat öljyn laatuun. Myös sääolot vaikuttavat öljyn laatuun, mutta ne ovat vaikeasti hallittavissa.