Canola Oil:

Physical and Chemical Properties

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Canola oil produced in Canada is obtained from the seeds of *Brassica napus* and *Brassica rapa*. These cultivars, low in erucic acid and glucosinolates, are very different from high erucic acid rapeseed oil in chemical, physical and nutritional properties.

PHYSICAL PROPERTIES

Selected physical properties for canola oil are shown in Table 1.

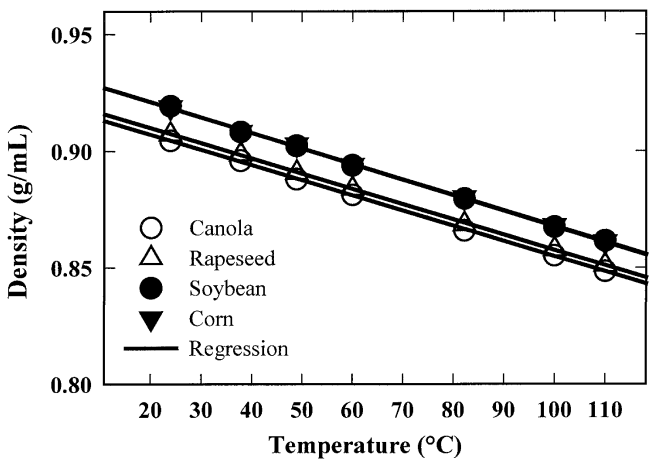
Table 1. Physical Properties of Canola Oil

Parameter	Value
Relative Density (g/cm3; 20˚C/water at 20˚C)	0.914 - 0.917
Refractive Index (nD 40˚C)	1.465 - 1.467
Crismer Value	67 - 70
Viscosity (Kinematic at 20˚C, mm2/sec)	78.2
Cold Test (15 Hrs at 4˚C)	Passed
Smoke Point (˚C)	220 - 230
Flash Point, Open cup (˚C)	275 - 290
Specific Heat (J/g at 20˚C)	1.910 - 1.916
Thermal Conductivity (W/m˚K)	0.179 - 0.188

Relative Density

The relative density of canola oil was first reported by Ackman and Eaton in 1977 and later confirmed by Vadke et al. (1988) and Lang et al. (1992). Noureddini et al. (1992) reported a density for high erucic acid rapeseed oil of 0.9073 g/cm^3 while Appelqvist & Ohlson (1972) reported a range from 0.906 g/cm^3 to 0.914 g/cm^3. Ackman and Eaton (1977) indicated that a different proportion of eicosenoic (C20:1) and C18 polyunsaturated acids could be a major factor for the increase in relative density of canola oil. The higher specific gravity of 0.9193 g/cm^3 observed for soybean oil can be attributed to the higher content of linoleic acid (Ackman and Eaton, 1977). As for other liquids, the density of vegetable oils is temperature dependent and decreases in value when temperature increases (Figure 1).

Figure 1: Effect of Temperature on Density of Selected Oils. Adapted from Lang, et al (1992) and Noureddini, et al (1992)



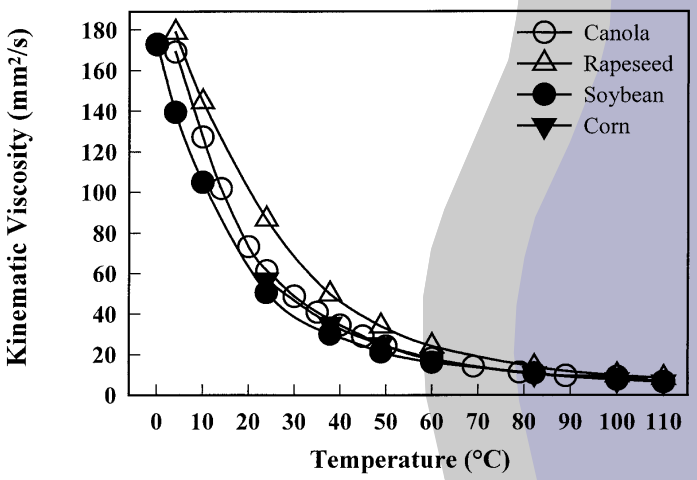
Crismer Value

The Crismer Value measures the miscibility of an oil in a standard solvent mixture, composed of *t*-amyl alcohol, ethyl alcohol and water in the volume proportion 5:5:0.27. Crismer value (CV) is one of the specification criteria used for international trade, mostly in Europe. Characteristic values are usually within a narrow limit (AOCS, 1992). The miscibility of an oil is related to the solubility of glycerides, and is affected mainly by the unsaturation and chain length of the constituent fatty acids. Little data is available describing the solubility characteristics of canola oil. Sahasrabudhe (1977) found that the Crismer value decreased from 82.0 to 76.8 with the reduction of erucic acid content from 54 to 0.1%.

Viscosity

Viscosity values estimate an oil's relative thickness or resistance to flow. Viscosity of refined, bleached and deodorized (RBD) canola is higher than soybean oil (Figure 2).

Figure 2: Effect of Temperature on Viscosity of Canola and Selected Oils. Adapted from Lang et al. (1992), Vadke et al. (1988) and Noureddini et al. (1992)



Lang et al. (1992) and Noureddini et al. (1992a) found that the viscosity of canola and other vegetable oils, like other liquids, was affected by temperature and proposed an equation to calculate viscosity in the temperature range from 4 to 100˚C. Figure 2 shows the relation between temperature and viscosity for canola and selected vegetable oils. Rapeseed oil exhibited a higher viscosity than canola, corn and soybean oils. This can be directly related to the contribution of saturated fatty acids (Noureddini et al., 1992a).

Smoke Point

Smoke point is the temperature at which a fat or oil produces a continuous wisp of smoke when heated. This provides a useful characterization of its suitability for frying. The Canadian Government specifications define that frying oil should have a smoke point above 200˚C. Table 1 indicates that canola oil fulfills this requirement. A similar smoke point was observed for rapeseed oil (Appelqvist & Ohlson, 1972).

The heating technique used in the standard method for smoke point determination is well-defined (AOCS Method Cc 9a-48). Arens et al. (1977) reported that, when measured by different laboratories, the smoke point for the same oil can differ by 10%, causing ±20˚C deviation. Therefore, caution should be exercised when comparing smoke points reported from different laboratories. These variations are related to the subjective determination by an observer as to when "a continuous stream of smoke" occurs, and is not matched with a reference.

Flash Point

Flash point defines the temperature at which the decomposition products formed from frying oils can be ignited (AOCS Method Cc 9b-55). This temperature ranges from 275˚C to 330˚C for different oils and fats. Canola oil falls within this range (Table 1).

Cold Test

The cold test measures the resistance of an oil to formation of a sediment at 0˚C or 4˚C (AOCS Method Cc 6-25), and is generally used to measure the effectiveness of the winterization process. Compounds with high melting temperatures, mainly waxes and triglycerides with saturated fatty acids, usually cause sediment formation (Przybylski et al., 1993). The cold test reveals whether an oil remains free of clouding when held at 4˚C or 0˚C for 15 hours. The formation of haze in canola oil is not a common occurrence, but may happen on occasion (Mag, 1990). It has been observed that oil produced from seeds grown in dry conditions will develop sediment more quickly. This may be related to the higher content of saturated fatty acids formed as a response to dry stress conditions (Przybylski et al., 1993).

Melting Characteristics, Polymorphism and Crystal Properties

Canola oil has a homogeneous fatty acid composition with 95% 18 carbon fatty acids (Ackman, 1990). Canola oil is hydrogenated to produce shortenings and margarines, as the *trans* isomers formed have higher melting points than *cis* fatty acids, as is shown in Table 2 (D'Souza et al., 1991).

Table 2: Melting Characteristic of Octadecanoic Fatty Acid Family[a]

Fatty Acid	Melting Point (˚C)
Linolenic (*cis* 9, 12, 15)	-11.2
Linoleic (*cis* 9, 12)	-5.1
Oleic (*cis* 9)	13.2
Octadecenoic (*cis* 6)	28.6
Elaidic (*trans* 9-octadecenoic)	43.7
Stearic	69.6

[a] - Adapted from Mag (1990)

Polymorphism is a well-known phenomenon associated with the crystallization behaviour of long chain compounds. Fats can crystallize into a number of sub-crystalline forms such as α, β, and β', each differing in size and stability of the crystals (D'Souza et al., 1991). The ability of a fat to exist in a number of different crystalline forms depends on how the molecules arrange themselves in the solid state. It has been established that hydrogenated canola oil has a tendency to crystallize in the β-form, which forms large crystals ranging in size from 5 - 25 μm. The formation of these large crystals causes an increase in graininess, which is directly responsible for gritty and crumbly products (Yap et al., 1989). In the manufacturing of margarine the β' crystal form is desired, as it has smaller crystals (less than 1μm in size), thereby giving the formulated product desirable textural characteristics. However, the β' form is less stable, requiring higher amounts of energy for crystals to pack than in the β-form. Therefore, it has a tendency to transform into the lower energy state β form (Sato, 1988). *Trans* isomers of fatty acids were found to have a tendency to produce products with higher β' stability than *cis* acids. This was attributed to the sterical effect of these isomers, which hinders the transformation to β form (D'Souza et al., 1991).

To stabilize the β' form, a blend of three hydrogenated canola oils is used to increase the heterogeneity of the triglycerides. This prompts the margarine to crystallise in small, needle-shaped crystals, giving the final product a smooth, pleasing mouth feel and good spreadability (Mag, 1990). A more effective approach in avoiding β crystal formation is to use 10 - 15% palm oil or 20 - 25% cottonseed oil to supply triglycerides containing palmitic acid (Mag, 1990). Yap et al. (1989) found that the addition of 10 % palm oil before hydrogenation had a better effect on β' stability than blending it with hydrogenated canola oil prior to product formulation. Increased crystalline stability is directly related to the presence of palmitic acid as it has a tendency to crystallize in β' form (Postmus et al., 1989). The type of hydrogenation was also shown to affect the β' stability. Naguib-Mustafa and deMan (1985) found that selectively hydrogenated canola oil with an iodine value of 70 was more stable in this crystalline form than any oil hydrogenated under nonselective conditions. Addition of crystallization inhibitors such as sorbitan tristearate, in the amount of 0.3% of the oil phase, also prevented β crystal formation. Interesterification of canola oil with palmitic acid containing edible product can also produce stocks with high β' crystallization tendencies (Mag, 1990). Manufacturers often use this process to replace hydrogenation.

When melted fat is cooled, the high-melting glycerides (HMG) crystallize first and dictate the polymorphic form in which the solids will crystallize, as well as their future behaviour during storage. It has been established that HMG consist of saturated and monounsaturated fatty acids. The saturates are mainly palmitic and stearic acid, while the unsaturates consist mostly of *trans* isomers (D'Souza et al., 1991). The rate and extent of β' to β transformation depends on the molecular composition and configurations of the fat, crystallization conditions, temperature, and the duration of storage.

Solid Fat Index (SFI) and Dilatation Curve

The solid fat index (SFI) and dilatation curve for hydrogenated fat describe the amount of solid fat remaining at defined temperatures. Individual triglycerides differ in physical properties according to their fatty acid composition. Thus, when a fat is kept at a particular temperature those triglycerides containing unsaturated fatty acids melt first, while those containing the more saturated and *trans* isomers of fatty acids melt last. An expansion of the solid fat component occurs as temperature increases, reaching a maximum when it melts completely. The expansion of the fat or dilatation can be monitored by measuring the increase in specific volume with temperature and establishing a dilatometric curve. This enables calculation of the percent solid fat at any specific temperature.

The spreadability of a margarine or spread can also be predicted from the SFI. To achieve the desired body and melting properties with stick margarines, selectively hydrogenated canola oils (SH) are used, along with nonhydrogenated oils. The most desirable approach is to use SH and SH1 canola oils together with a certain amount of liquid canola oil

(Table 4). The solid fat indices of the oil phase blend must be in the range of 25 - 30 at 10˚C, 14 -18 at 21.1˚C, and 2 -3.5 at 33.3˚C (Moustafa, 1992). The low solid fat index at 10˚C in soft margarines appeared to be responsible for their spreadability at refrigeration temperatures (Table 4). Formulation of these margarines requires the use of 70 -85% of slightly hydrogenated and/or liquid oils, with a minimum of about 11 -15% of highly hydrogenated stock (usually nonselective) (Table 4). Using this stock, the formulated product is characterized by good spreadability at refrigeration temperatures and good emulsion stability so there are no oiling-out problems (Mag, 1990). Typical solid fat indices of soft margarines are 8 - 14 at 10˚C, 5 - 8 at 21.1˚C, and 0.5 -2.5 at 33.3˚C (Moustafa, 1992).

In margarines with good mouth-melt characteristics the oil phase in the product melts sharply at body temperature which results in the total breakdown of the emulsion in the mouth with the release of the flavour-laden water phase (Moustafa, 1992). If the crystalline structure does not melt rapidly the margarine feels waxy or thick in the mouth.

Table 3. Solid Fat Indices of Hydrogenated Canola Stocks and Margarines[a]

Sample	Solid Fat Index			Fatty acids			
	10.0˚C	21.1˚C	33.3˚C	PUFA	MUFA	SAT.[e]	TRANS
Hydrogenated[b]							
SH[c]	10.8	1.4	0.1	10.6	78.1	9.1	34.0
SH1	41.3	22.5	15.9	3.5	76.7	17.7	51.9
NS[d]	6.2	1.8	1.2	14.4	67.5	14.9	24.6
NS1	24.5	13.4	8.2	7.7	67.0	23.1	31.7
Margarines							
Stick Regular	25 - 30	14 - 18	2 - 4	3 - 10	50 - 70	16 - 25	
Stick Hi - Li[f]	16 - 24	10 - 15	1.5 - 4.0	20 - 40	20 - 50	13 - 23	
Soft (70% Liq.)	8 - 14	5 - 8	0.5 - 2.5	30 - 60	15 - 42	10 - 20	

a - Adapted from Mag (1990) and Moustafa (1992)
b - Hydrogenated stocks
c - Selective hydrogenation
d - Nonselective hydrogenation
e - Saturated fatty acids
f - Margarine with high content of liquid oil

CHEMICAL CHARACTERISTICS

Nature of Edible Oils and Fats

Edible oils and fats are composed primarily of triglycerides, which are the ester of one molecule of glycerol and three molecules of fatty acids. Canola oil analyses show that the triglycerides constitute 94.4 to 99.1% of the total lipid (Mag, 1990). The typical composition of canola, rapeseed and soybean oils is presented in Table 4.

Table 4: Constituents of Canola, Rapeseed and Soybean Oils[a]

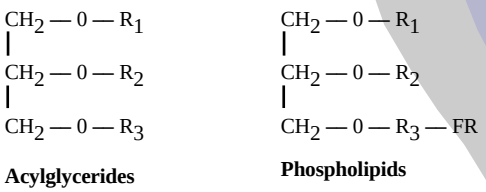
Component	Canola	Rapeseed	Soybean
Triglycerides (%)	94.4 - 99.1	91.8 - 99.0	93.0 - 99.2
Phospholipids (%)			
Crude Oil	up to 2.5	up to 3.5	up to 4.0
Water-degummed	up to 0.6	up to 0.8	up to 0.4
Acid-degummed	up to 0.1	-	up to 0.2
Free Fatty Acids (%)	0.4 - 1.2	0.5 - 1.8	0.3 - 1.0
Unsaponifiables (%)	0.5 - 1.2	0.5 - 1.2	0.5 - 1.6
Tocopherols (ppm)	700 - 1200	700 - 1000	1700 - 2200
Chlorophylls (ppm)	5 - 35	5 - 35	Trace
Sulfur (ppm)	3 - 15	5 - 25	Nil

a - Adapted from Mag (1990) and Ying, et al (1989)

Triglycerides

Triacylglycerols (TAG) are the most abundant lipid class found in canola oil. The combination of fatty acids on the glycerol moiety is complex, with n^3 amount of potential molecular species where n is the number of different fatty acids present in the oil (Figure 3).

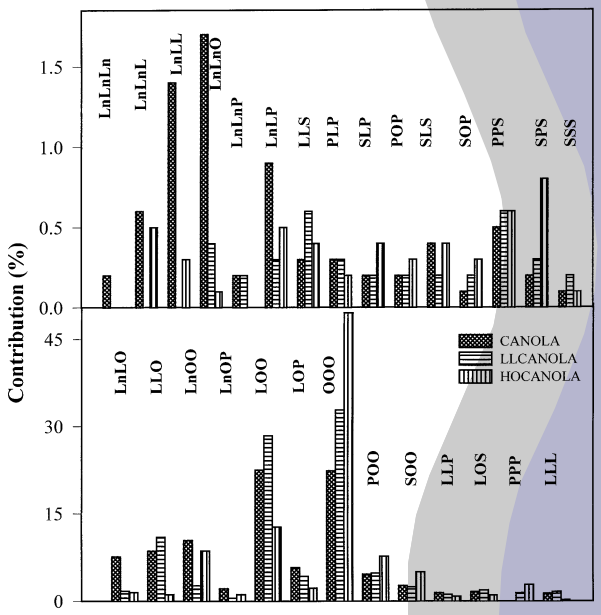
Figure 3: Structure of Acylglycerides and Phospholipids. FR - Functional Residue such as Nitrogenous or Polyol $R_{1, 2, 3}$ - Residue of Fatty Acid



Acylglycerides **Phospholipids**

The TAG molecular species profile represents a key to understanding the physical characteristics of an oil and also is a unique means of identification (Rezanka and Mares, 1991). The position of fatty acids on the glycerol molecule was originally examined in rapeseed oil. Long chain (C20:0-C24:0) and saturated fatty acids occurred mostly in the 1- and 3-positions, while the octadecanoic (C18) fatty acids, especially linoleic and linolenic, are integrated in the 2-position (Kallio and Currie, 1993; Ackman, 1983). Paterson (1981) examined the triglyceride composition of canola oil and found 25% of the total TAG's to be triolein. The triglyceride compositions of modified canola oils are presented in Figure 4. Triglyceride composition is governed by the type and amount of fatty acids present in an oil. As can be predicted, in high oleic acid canola oil the main triglyceride was triolein (Figure 4). In regular canola oil four triglycerides, namely: olein-dilinolein, linolenin-dilinolein, triolein and linolein-diolein were detected in almost equal amounts.

Figure 4: Composition of Triglycerides in Canola Oils. Abbreviations: Ln - Linolenic; L - Linoleic; O - Oleic; P - Palmitic; S - Stearic; LL Canola - Low Linolenic Canola; HOCanola - High Oleic Canola. Adapted from Neff et al (1994)



Jáky and Kurnik (1981) investigated the concentration of linoleic acid in the 1, 3- and 2-positions. They found that in high erucic acid rapeseed oil (HEAR) at least 95% of the linoleic acid was concentrated in the *sn*-2 position, whereas in canola oil only 54% was in this position. The increased amount of linoleic acid in canola oil was placed by the plant's enzymatic system into *sn* -1,3 position to replace erucic acid. Ohlson et al. (1975) indicated that linoleic acid replaced erucic acid in the *sn*-1 position, and while only present in canola oil at low levels, gadoleic and erucic acids were preferentially esterified in the *sn*-3 position. The investigators also found that linolenic acid was similarly distributed to linoleic acid. Kallio and Currie (1993) found that triglycerides with 54 carbons and two double bonds consisted of glycerides where stearic acid was

present predominately at the *sn*-2 position. Glycerides with saturated fatty acids in this position usually have higher a melting point and poor solubility, (Rezanka, 1989). Additionally high melting glycerides can directly effect the clarity of an oil and stimulate sediment formation (Liu et al., 1993).

The hydrogenation of unsaturated fatty acids proceeds more rapidly in the *sn*-1 and 3 positions than in the *sn*-2 position (Kaimal and Lakshinarayana, 1979). Therefore, the distribution of fatty acids in canola oil is a factor affecting the selectivity of hydrogenation.

Fatty Acids

Fatty acids are composed of a carboxyl group and a hydrocarbon chain. Individual fatty acids are distinguished from one another by the nature of the hydrocarbon chain (Figure 5). This chain can vary in length from 4 to 24 carbon atoms and can be saturated, monounsaturated (one double bond, MUFA) or polyunsaturated (two or more double bonds, PUFA). The most common fatty acids in edible oils and fats are those containing 18 carbons. These include: stearic acid (a saturated fatty acid), oleic acid (a monounsaturated fatty acid), and linoleic and linolenic acids (polyunsaturated fatty acids containing two and three double bonds, respectively) (Figure 5).

Figure 5: Configuration of Octadecanoic Fatty Acids

Formula	Common Name	Abbreviation
COOH	Stearic	18:0
COOH	Oleic	18:1 n-9 *cis*
COOH	Linoleic	18:2 n-6 *cis*
COOH	Linolenic	18:3 n-3 *cis*
COOH	Elaidic	18:1 n-9 *trans*

Fatty acid abbreviations are made according to the number of carbon atoms in the molecule and the number of *cis* ethylenic double bonds. The general assumption is that all multiple double bonds are methylene-interrupted. The chemical nomenclature requires that carbon atoms be counted from the carboxyl end of the fatty acid. However, for biological activity carbon atoms are numbered from the terminal methyl group to the first carbon of the ethylenic bond. Such a classification is designated by the symbol ϖ-x, ϖx, or n-x, nx, where x denotes the position of the double bond closest to the terminal methyl group. For example, linoleic acid with two double bonds, where one is located on the sixth carbon atom counted from the methyl group, will be abbreviated as C18:2n-6.

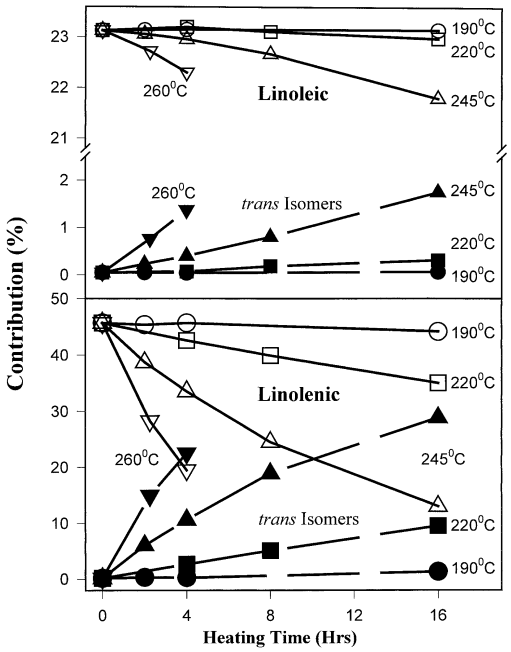
Geometric Isomerism

In the case of unsaturated fatty acids, the carbon chain is bent into a fixed position at the double bond, resulting in several possible geometric isomers. When the portions of the chain are bent towards each other they are called *cis*; and when bent away from each other, *trans* (Figure 5). The natural configuration of fatty acids is *cis*, as shown for oleic acid. The corresponding *trans* configuration, elaidic acid, results in a straight chain (Fig. 5).

From a nutritional point of view the *cis* isomer is more desirable. However, fatty acids with *trans* configuration affect the texture and melting properties of fat or oil. Isomerization from *cis* to *trans* occurs mainly during the hydrogenation of an oil. Formation of *trans* isomers of linolenic and linoleic acids may also occur when harsh conditions are applied during refining. During processing of canola oil formation of *trans* isomers of linolenic and linoleic acids are observed. Oleic acid is less prone to isomerization, *trans* isomers were detected only when extreme parameters were applied. (Ferrari, 1996).

Due to elevated temperatures, deodorization is the stage of processing where isomerization predominantly occurs. The effect of time and temperature on isomerization of linoleic and linolenic acids is presented in Figure 6 (Wolff, 1993). After heating for two hours at 260˚C about 22% of the linolenic acid was transformed into *trans* isomers (Figure 6). Measurement of the amount of isomers can be used as an assessment of the deodorization process, where a lack of vacuum is often "replaced" by an increase in temperature to obtain odourless oil. Properly optimized deodorization will produce oil that contains zero or very low amount of *trans* isomers of linolenic acid.

Figure 6: Thermal Isomerization of Linoleic and Linolenic Acids. Adapted from Wolff (1993)



Fatty Acid Composition of Canola Oil

The reduction of erucic acid (C22:1) in rapeseed oil resulted in a marked increase in octadecanoic acids. In fact, 18 carbon fatty acids account for about 95% of canola's total fatty acids (Table 6).

Table 6: Comparison of Major Fatty Acids in Some Vegetable Oils (w/w%)[a]

Fatty Acid	Canola	HEAR	LLCAN[b]	HOCAN[b]	LTCAN[e]	LLFlax[b]	Soybean	Sunflower	Corn
C10:0	-	-	-	-	0.1	-	-	-	-
C12:0	-	-	-	-	38.8	-	-	-	-
C14:0	0.1	-	0.1	0.1	4.1	0.1	0.1	-	-
C16:0	3.5	4.0	3.9	3.4	2.7	6.3	10.8	6.2	11.4
C18:0	1.5	1.0	1.2	2.5	1.6	4.1	4.0	4.7	1.9
C20:0	0.6	1.0	0.6	0.9	0.4	0.1	-	-	-
C22:0	0.3	0.8	0.4	0.5	0.2	0.1	-	-	-
Total Saturated	6.0	6.9	6.2	7.4	47.9	10.4	14.9	10.9	13.3
C16:1	0.2	0.3	0.2	0.2	0.2	0.1	0.2	0.2	0.1
C18:1	60.1	15.0	61.1	76.8	32.8	16.5	23.8	20.4	25.3
C20:1	1.4	10.0	1.5	1.6	0.8	0.1	0.2	-	-
C22:1	0.2	45.1	0.1	0.1	0.5	-	-	-	-
Total MUFA[c]	61.9	70.1	62.9	78.7	34.3	16.7	24.2	20.6	25.4
C18:2n-6	20.1	14.1	27.1	7.8	11.2	69.5	53.3	68.8	60.7
C18:3n-3	9.6	9.1	2.1	2.6	6.3	1.8	7.1	-	-
Total PUFA[d]	29.7	23.2	29.2	10.4	17.5	71.4	60.4	68.8	60.7

a - Adapted from Ackman (1990)
b - Adapted from Przybylski, unpublished; LLCAN - Low linolenic acid canola oil; HOCAN - High oleic acid canola oil; LLFlax - Flaxseed oil with reduced content of linolenic acid.
c - Monounsaturated fatty acids
d - Polyunsaturated fatty acids
e - LTCAN - Canola oil with high content of lauric acid (Adapted from Del Vecchio, 1996)

Plant breeders developed canola oil with the linolenic acid content reduced to 2.1% (Scarth et al., 1988) (Table 6). Storage stability of this oil was shown to be better than regular canola oil (Przybylski et al., 1993a). Low linolenic canola oil also exhibited improved frying performance and better storage stability of fried products such as french fries and potato chips (Petukhov et al., 1999; Warner and Mounts, 1993). Canola has been further developed to produce an oil with an oleic acid content raised from 60% to 85% (Wong et al, 1991). The fatty acid composition of high oleic canola is presented in Figure 6. This oil showed improved frying stability and produced better quality fried potato chips (Petukhov et al, 1999). From the health and flavour formation point of view, both low linolenic and high oleic canola oils should provide good quality frying products without the presence of *trans* isomers (Ackman, 1990). Warner and Mounts (1993) found that some amount of linolenic acid is required for good flavour formation in fried foods. This is due to the formation of oxidation products, which are important flavour compounds. Thus elimination of linolenic acid from oil can cause negative changes in fried product flavour formation.

Recently canola oil with an elevated content of lauric acid was developed (Table 6). This oil is being used in confectionery coatings, coffee whiteners, whipped toppings and center filling fats (Del Vecchio, 1996). Calgene has also succeeded in the development of a canola plant that produces oil containing 40% stearic acid. This oil could be used as a replacement for hydrogenated fats in bread and bakery applications (INFORM, 1999).

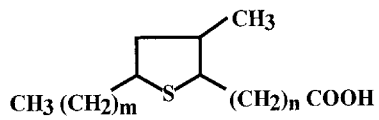
Minor Fatty Acids

Minor fatty acids present often differ from their acid family members by the location of the double bond (Table 6). Most of these acids are present in the 0.01 - 0.1% range, except for C16:1n-7 which is around 0.3%. Most of the minor fatty acids in canola oil are from the n-7 series, but n-9 isomers are also present in varying amounts. (Ackman, 1990).

A similar series of minor fatty acids was found in the *B. rapa* variety Candle (Sebedio and Ackman, 1981). Conjugated C18:2 fatty acids have also been found in canola oils. Some of these compounds are artefacts of refining, although some were observed as natural components in some oil seeds. The refining process itself is a source of artefact fatty acids due to the isomerization of one or more of the double bonds of *cis* linolenic acid. These *trans* isomers can be found after refining in any linolenic acid-containing oil, accounting for 1% or more of the parent acid (Ackman, 1990).

Canola oil is the only known edible oil that contains one or more fatty acid with sulfur as the integral part of the molecule (Figure 7). The structure of the proposed molecule of this fatty acid suggests the formation or presence of many isomers (Wijesundera and Ackman, 1988).

Figure 7: Isomers of a Sulfur-Bearing Cyclic Fatty Acid Found in Canola Oil Adapted from Wijesundera et al. (1988)



Isomers	m	n
1	5	7
2	6	6
3	7	5

In the sediment from industrial winterization, additional minor fatty acids and alcohols with 26 to 32 carbon atoms have been found in waxes and triglycerides (Przybylski et al., 1993). Most of these compounds are extracted from the seed coat/hull and can initiate sedimentation in canola oil (Hu et al., 1994).

Polar Lipids

Sosulski et al. (1981) examined the polar lipids (PL) in several rapeseed cultivars, including a low erucic acid (LEAR) winter cultivar grown in Poland, and found that phospholipids formed the major component (3.6 %) of the total polar lipids, while glycolipids contributed only 0.9%. A more recent study by Przybylski and Eskin (1991) reported changes in phospholipids during the early stages of canola oil processing (Table 7).

Table 7: Composition of Phospholipids in Canola Oil During Processing (%)

Oil Sample	Phosphorus (ppm)	PC[a]	PE[a]	PI[a]	PA[a]	PS[a]
Solvent	529.0	31.2	18.8	19.8	21.6	3.1
Expeller	242.3	34.3	16.1	18.7	20.3	4.5
Degummed	12.2	2.8	10.8	28.9	38.4	14.6

[a] Phospholipids: PC - Phosphatidyl Choline; PE - Phosphatidyl Ethanolamine; PI - Phosphatidyl Inositol; PA - Phosphatidic Acid; PS - Phosphatidyl Serine.

Significant amounts of PA were formed during processing, which indicates hydrolysis of other phospholipids due to the hydro-thermal treatment during the conditioning of flaked seeds. Cmolik et al. (1987) observed an increase in the amount of phospholipids from 0.5% to 15% during conditioning of seed flakes. This increase was explained as the result of lipoprotein decomposition in seeds by hydro-thermal treatment. It was reported that hydratable phospholipids such as PC and PE stimulate removal of nonhydratable phospholipids. PI and PA are considered nonhydratable phospholipids and are difficult to remove during degumming.

Smiles et al. (1989) examined the effectiveness of different chemical treatments for degumming canola and soybean oils. Phosphoric acid was found to be the most effective degumming agent in terms of reducing the levels of nonhydratable phospholipid (Table 8). Other nonhydratable phospholipids were more effectively removed by water. Water and phosphoric acid were not different in terms of their ability to remove PE. These researchers found that lecithins obtained from these oils by water degumming formed the most stable oil-in-water emulsion.

Table 8: Relative Phospholipid Composition of Acetone Insoluble Mixture from Degumming of Canola and Soybean Oils

Oil	PC	PE	PI	LPC[b]	PA	PG+DPG[b]
Canola WDG[c]	32.5	21.1	15.2	4.6	3.2	23.4
Canola PDG[d]	39.2	17.9	12.6	11.8	1.1	17.5
Soybean WDG	32.5	33.3	17.3	4.2	3.5	9.2
Soybean PDG	29.1	32.9	16.4	14.3	1.8	5.6

[a] Adapted from Smiles et al. (1989)
[b] LPC - Lysophosphatidyl choline; PG - Phosphatidyl glycerol; DPG - Diphosphatidyl glycerol
[c] WDG - Water degummed oil
[d] PDG - Phosphoric acid degummed oil

Sosulski et al. (1981) examined the fatty acid composition of the individual phospholipids in the LEAR varieties from winter rapeseed cultivars (Table 9). Smiles et al. (1988) found a similar fatty acid composition in phospholipids from canola oil, with the exception of slightly higher levels of linolenic acid (Table 9). Phosphatidyl choline contained the highest amount of unsaturated fatty acids, mostly oleic and linoleic acids. The other two phospholipids were rich in palmitic, linoleic and linolenic acids. The presence of highly unsaturated fatty acids in phospholipids is important as they can initiate oxidation of other fatty acids causing accelerated deterioration of the oil. It was reported that phospholipids have a tendency to complex heavy metals and in this form they are a rather stable catalyst which can initiate and stimulate oxidation (Pokorny, 1987).

Table 9: Fatty Acid Composition of Phospholipids (w/w%)[a]

Phospholipid	16:0	16:1	18:0	18:1	18:2	18:3	20:1
Phosphatidyl Choline	8.7	0.8	1.2	55.8	30.9	1.9	0.5
Phosphatidyl Inositol	21.8	0.8	1.9	33.6	38.1	3.6	-
Phosphatidyl Ethanolamine	17.7	1.8	2.0	47.7	27.3	2.7	0.5

[a] Adapted from Sosulski et al. (1981) and Smiles et al. (1988)

Trace Elements

The existing Codex standard for canola provides the maximum permitted levels for iron, copper, lead and arsenic. While these metals are found in other edible oils and are present naturally in the seed, they can be introduced during handling and processing. Diosady et al. (1983) and Elson et al. (1979) examined the effect of processing on trace elements in canola oils. Their results are summarized in Table 10. These oils were all of high quality with respect to cadmium and copper levels. It is clear from the data in Table 10 that processing reduces the amount of toxic and damaging trace elements, particularly lead, iron and sulfur. Iron in the oil acts as a catalyst which can initiate free radical oxidation of unsaturated fatty acids.

Table 10: Mineral Element Content in Canola Oils[a] (ppm)

Oil Sample	Phosphorus	Iron	Calcium	Sulfur	Zinc	Lead
Crude Oil	1190.0	3.52	296.0	6.5	2.4	0.24
Degummed with						
Water(WDG)	222.0	1.32	169.0	1.2	2.1	-
Phosphoric Acid(PDG)	117.2	0.63	34.8	1.5	-	-
Bleached						
WDG	0.21	0.23	5.6	-	-	-
PDG	0.19	0.59	4.1	0.87	-	-
Deodorized						
WDG	0.25	-	-	0.25	-	0.07
PDG	0.22	-	-	0.38		

[a] Adapted from Diosady et al. (1983) and Garrido et al. (1994).

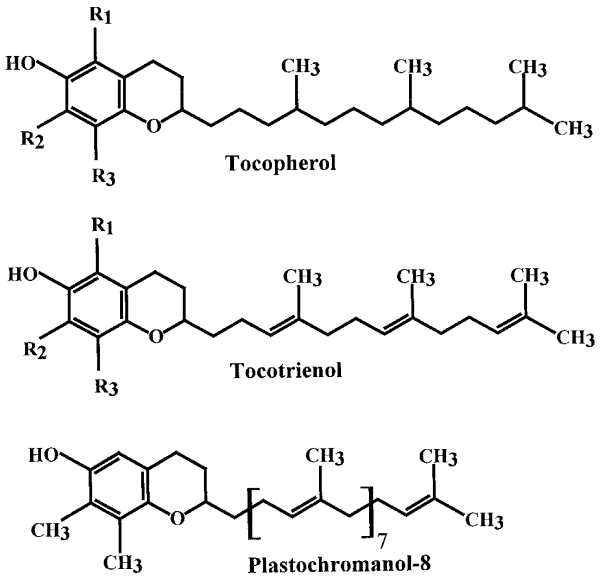
As shown in Table 10, the levels of phosphorus and calcium are greatly reduced during processing.

Sulfur in canola oil is in the form of organic compounds as the decomposition products of glucosinolates. Although these sulfur components occur in trace quantities, they are known to inhibit catalysts used for hydrogenation as well as impart characteristic odours to the oils. Recent developments in analytical methods for sulfur content evaluation revealed that soybean, sunflower, and even coconut oils all contain sulfur at a level of 2 - 10 ppm. In crude and RBD (refined, bleached and deodorized) canola oils the amounts of sulfur detected were 25 ppm and 9.4 ppm, respectively (Wijesundera et al. 1988; Ying and deMan, 1989). Sulfur components may negatively affect canola oil quality, but they also may improve the stability of the oil. Some sulfur components can act as antioxidants and protect the oil from autoxidation by complexing hydroperoxy radicals with the sulfur to form stable compounds. The other positive action of these compounds is inactivating catalysts involved in the oxidation process (Barnard et al., 1958).

Tocopherols

The main nonsaponifiable components in vegetable oils are tocopherols and sterols, which are present in varying amounts depending on the oil. Tocopherols are natural antioxidants and their amount in the plant is probably governed by the content of unsaturated fatty acids. Tocopherols are present in different isomeric forms (Figure 8).

Figure 8: Structure of Plastochromanol-8 and Isomers of Tocopherol and Tocotrienol



Tocopherol and Tocotrienol Isomers

Isomers	R_1	R_2	R_3
α	CH_3	CH_3	CH_3
β	CH_3	H	CH_3
γ	H	CH_3	CH_3
δ	H	H	CH_3

Plastochromanol-8 is a derivative of γ- tocotrienol which has a longer side chain. This compound has been detected in canola and flax oils (Zambiazi, 1997).The tocopherol content in canola and some common vegetable oils is summarized in Table 11. Canola oil contains mostly two isomers of tocopherols, alpha and gamma, and the gamma isomer is normally present in higher amounts.

Table 11: Tocopherol Contents in Selected Vegetable Oils (ppm)[a]

Oil	α	β	γ	δ	P-8
HEAR	268.0	-	426.0	-	96.8
Canola	272.1	0.1	423.2	-	74.8
LLCanola	149.8	-	313.6	7.1	46.5
HOCanola	226.3	-	201.6	2.7	42.2
HOLLCanola	285.8	-	607.2	8.2	82.5
Soybean	116.0	34.0	737.0	275.0	-
Sunflower	613.0	17.0	18.9	-	-
Corn	134.0	18.0	412.0	39.0	-
LLFlax	25.8	-	212.6	9.2	129.3

[a] Adapted from Zambiazi (1997) and Normand (1998). Abbreviations: HEAR - high erucic acid rapeseed; LLCanola - canola oil with low content of linolenic acid; HOCanola - canola oil with high content of oleic acid; HOLLCanola – canola oil with low linolenic acid and high oleic acid; LLFlax - flax oil with low content of linolenic acid; P-8 - Plastochromanol-8.

The content of tocopherols in RBD oils is affected by processing, mainly by the extraction procedure and deodorization (Figure 9).