Camelina oil in human nutrition

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ABSTRACT: Nutritionally deficient food is one of the factors contributing to the increasing occurrence of life-style diseases among the population in industrialized countries. Ordinary food is particularly deficient in n-3 fatty acids. A conventional source of these fatty acids (FA) is fish oil, but vegetable oils with a high content of n-3 FA are also available. A rich source of the covetous n-3 FA is camelina oil (CO). The oil originates from seed of Camelina sativa (L.) Crantz. The nutritional qualities of the oil were assessed. The oil was analyzed for the content of FA and tocopherols. The mean content of essential linoleic acid 18:2n-6 (LA) was 12.4-15.3 percent and α-linolenic acid 18:3n-3 (ALA) was 36.8-40.8 percent. The mean total content of tocopherols in natural CO ranged from 806 - 1,008 μg/g. The content of the predominant γ–tocopherol was 742 - 935 μg/g. The effects of heating on FA, tocopherols and on the nutritional quality of the oil were evaluated. The culinary exploitation and dietary application of CO were investigated. Products, such as dressings and ice cream, enriched with ALA from CO were developed. Mixed fat with CO as an ingredient was produced in pilot plant. A special diet enriched with ALA from CO was modified and was tested. A cholesterol reducing effect of CO was confirmed in a trial with volunteers. The health promoting potential of CO was elucidated by reviewing relevant scientific documentation.

KEYWORDS: Camelina oil, α-linolenic acid, tocopherols, dietary supplement, healthy food.

INTRODUCTION

Relationship between nutritionally deficient food and life-stile diseases has been known for long time. The food, consumed by the population in industrialized countries, is particularly deficient in n-3 FA. The n-6/n-3 FA ratio in ordinary diet is 20 (20:1) while the optimum ratio is close to 1 (1:1), as found in the traditional Greek diet (1).
The common dietary source of n-3 polyunsaturated fatty acids (PUFA) is fish meat. The fat in fish meat is characterized by the content of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The dietary supply of these PUFA via fish meat diet, however, is small. An elevated consumption of fish meat in various parts of the world is associated with a risk of ingesting environmental poisons (2). Thus, the desirable enrichment of food with n-3 FA and the improvement of n-6/n-3 FA ratio, depends mainly on the supplementation of n-3 ALA from vegetable sources. Among cultivated plants, the largest content of ALA was found in oil from flax seed. The oil consists of 50-60 percent ALA. Anyhow, due to susceptibility to oxidation and a distinctive taste, flax oil is not widely used in human nutrition. Another rich source of ALA is CO. The content of ALA in CO is about 38 percent. When compared with flax oil, CO possesses numerous benefits (3). The present report is focusing on the nutritional qualities of CO and the applicability of the oil in human nutrition.

RESULTS AND DISCUSSION

Selected results from proper research, carried out during the period 1985-1998, are presented and discussed. From abundant documentation (intern reports), only representative results are shown. Analyses for FA and tocopherols were carried out by authorized laboratories (3). The methods for exploitation of CO in different food products are described in separate sections.

Content of essential fatty acids in camelina oil

The profile of FA in CO depends on several factors, such as pedoclimatic conditions under which the crop was grown, weather conditions during the growth season, genetic variation among varieties, etc. (4). Large differences were found among the oil samples from winter (W) and summer (S) varieties. The qualitative differences were particularly large in the content of the nutritionally most important LA and ALA (Table 1). Noticeably smaller variation was found in the other FA (4).

Fatty acid	Varieties	
	Winter	Summer
Linoleic	12.4 ± 0.1	15.3 ± 0.4
α-linolenic	40.8 ± 0.2	36.8 ± 0.8
Total (n=18)	53.2	52.1

Table 1. Content of essential fatty acids in camelina oil (percent of total FA).

The analyses disclosed the mean content of LA (n-6 FA) ranging from 12.4 to 15.3 percent. The content of ALA (n-3 FA) was 36.8 to 40.8 percent (Table 1.). This was considerably less than in flax oil with 50-60 percent ALA, but CO can be still classified as a rich source of n-3 FA.

Content of tocopherols in camelina oil

Tocopherols have important function in fats as antioxidants. Also in human nutrition, tocopherols play the role of antioxidants. From the nutritional point of view, tocopherols are commonly designated as vitamin E. In CO was found the total content of tocopherols amounting to the mean of 806 μg/g in S and 1,008 μg/g in W (Table 2.). The total content of tocopherols in CO was higher than in the common vegetable oils, such as rape oil, sunflower oil and flax oil (3).
Remarkable differences in the distribution of tocopherols were found between W and S (Table 2.). The mean content of the predominant γ-tocopherol was 742 - 935 μg/g. The other tocopherols were represented by α, δ and P-8 (plastochromanol-8). The minor β-tocopherol and tocotrienols with the content below 10 μg/g were omitted in Table 2.

Tocopherol	Varieties	
	Winter	Summer
α	23.5 ± 0.1	28.1 ± 6.2
γ	935 ± 72	742 ± 39
δ	25.0 ± 1.3	20.5 ± 2.3
P-8	24.3 ± 4.5	14.9 ± 3.7
Total (n=15)	1,008	806

Table 2. Content of tocopherols in camelina oil (µg/g).

Effect of heating on fatty acids in camelina oil

The effect of heating on the nutritional quality of CO was examined by using a simple test, resembling the habitual preparation of food by frying. Samples of 50 mL CO in open aluminium beakers were heated electrically up to 200°C in a thermostat controlled box. Before and after heat treatment, the oil was analysed for the content of FA.

The exposure of CO to high temperature evoked certain shifts in the FA profile. Heating for 30 min did not affect the content of LA, but caused a small decrease in the content of ALA by 1.9 percent. Heating for 60 min evoked proportional increases of oleic, gondoic and erucic acids. The content of LA remained almost unaffected, while the content of ALA was reduced by 6.9 percent (Table 3.).

	Natural oil		
FA / Min >	0	30	60
16:0	5.2	5.3	5.5
18:0	2.5	2.5	2.6
18:1n-9	14.1	14.1	15.0
18:2n-6	14.6	14.6	14.5
18:3n-3	36.5	35.8	34.0
20:1n-9	15.8	16.0	16.6
22:1n-9	3.3	3.4	3.6
	Deodorized oil		
FA / Min >	0	30	60
16:0	5.4	5.4	5.5
18:0	2.5	2.5	2.6
18:1n-9	14.1	12.9	13.6
18:2n-6	15.3	15.3	15.3
18:3n-3	36.2	36.8	35.6
20:1n-9	15.3	15.5	15.8
22:1n-9	3.0	2.9	3.1

The oil was exposed to 200 °C for 30 and 60 min.

Table 3. Effect of heating on fatty acids in camelina oil (percent of total FA).

In deodorized oil the heating for 30 min did not change the content of LA, but caused a proportional increase of ALA by 1.7 percent. The heating for 60 min had no effect on the content of LA, but caused a reduction of ALA by 1.8 percent. Small proportional increases in the content of oleic, gondoic and erucic acids were recorded (Table 3.).

The investigation disclosed a moderate suppressing effect of heating on the content of ALA and negligible effects on the content of LA and the other FA in both the natural and deodorized oils.

Effect of heating on tocopherols in camelina oil

Laboratory test was carried out to examine the effect of high temperature on tocopherols. The oil was obtained from the seed of S. Samples of natural and deodorized CO (50 mL) in open aluminium beakers were exposed to heating. The oil was analysed before and after the treatment.

The heating of natural CO for 30 min reduced the total tocopherols by 12.0 percent. Heating for 60 min suppressed the total content of tocopherols by 33.8 percent. Large reduction by 52.4 percent was observed in α-tocopherol. The content of the predominant γ-tocopherol was reduced by 33.9 percent (Table 4).

	Natural oil		
Tocopherols / Min >	0	30	60
α	21	17	10
γ	575	507	380
δ	10	10	10
Total	606	534	401
% of total	100	88	66
	Deodorized oil		
Tocopherols / Min >	0	30	60
α	9	6	5
γ	628	519	386
δ	10	11	8
Total	647	536	399
% of total	100	83	62

The oil was exposed to 200 °C for 30 and 60 min.

Table 4. Effect of heating on tocopherols in camelina oil (µg/g).

The heating of deodorized CO for 30 min diminished the total content of tocopherols by 17.2 percent. Heating for 60 min caused a reduction of the total tocopherols by 38.3 percent. As in natural CO, also in deodorized oil, the largest loss was recorded in α-tocopherol. The content of γ-tocopherol in deodorized oil was reduced by 38.5 percent. The content of δ-tocopherol in both oils remained almost unaffected (Table 4). It can be concluded that heating caused significant losses of tocopherols and thereby reduced the nutritional quality of the oil considerably.

Effect of heating on the nutritional quality of camelina oil

Under culinary exploitation, vegetable oils are exposed to temperatures of up to 230°C. Free access of air at elevated temperatures stimulate thermo-chemical reactions leading to polymerization and oxidation products (5). To quantify the effects of heating, qualitative parameters such as free fatty acids (FFA), peroxide value (Pv) and anisidine value (Av) were chosen. Sensory testing was used as an auxiliary estimate of quality. Oil samples (50 mL) of natural CO and commercial cold pressed rape oil for comparison, were tested simultaneously.

Heating for 30 min caused a small increase of FFA content in both tested oils. Heating for up to 60 min evoked a larger increase of FFA content in CO than in rape oil (Table 5). The effect of heating on Pv was proportionally larger in CO than in rape oil. In rape oil the heating for 30 and 60 min caused rather inconsistent changes of Pv (Table 5). Secondary oxidation products (aldehydes) were expressed as Av. Heat treatment for 30 min caused a small increase of Av in CO and a large increase in rape oil. Heating for 60 min evoked a very large increase of Av in CO and a large increase in rape oil (Table 5).

Sample	Min	FFA %	Pv	Av
Camelina oil	I0	0.20	4.5	0.5
	30	0.22	13.9	3.2
	60	0.28	15.3	163
Rape oil	0	0.10	13.7	2.4
	30	0.12	17.1	40
	60	0.14	14.7	87

The oil was exposed to 200 °C for 30 and 60 min.

Table 5. Effect of heating on the nutritional quality of natural camelina oil and rape oil.

Sensory testing after heat treatment for 30 min disclosed rancidity. In CO, the original cauliflower resembling taste turned to fishy flavour. In rape oil, the original taste was described as resembling the vegetable marrow. The rancidity was pronounced by bitter harsh taste. During prolonged heating in both oils the rancidity increased proportionally with time. Prolonged heating affected the nutritional quality of both oils negatively.

Generally in all fats, oxidation products are considered as hazardous to health. In practice, the health hazard can be diminished by using lenient temperatures and by limiting the time of the thermal treatment. Nevertheless, the application of CO in cold dishes without heating appears preferable to the use of heated oil.

Experience with human consumption of camelina oil

Camelina oil was traditionally used as edible oil (6-9). After Great War, expanding margarine industry in Europe was interested mainly in rape oil that was suitable for hydrogenation. CO with the iodine value of about 160, was not attractive raw material for the production of margarine. The specific nutritional qualities of CO were evidently underestimated. The cultivation of CS in European countries ceased during 1950s and CO disappeared from the market. In the Southeastern Europe, however, sporadic cultivation of CS was maintained and CO is still produced for human consumption. The oil is used as a dietary supplement and a remedy in folk medicine (8). The medicinal properties of CO are deriving primarily from LA , ALA and antioxidants (10, 11).

Camelina oil is a rich source of α-linolenic acid and antioxidants with health promoting potential

During the last decade the production of CO for human consumption was started in several European countries (Germany, United Kingdom, Ireland, Finland, Denmark). The historical experience with exploitation of CO in human nutrition proves that the oil is not a "novel food" (Regulation (EC) No 258/97 of the European Parliament and of the Council of 27 January 1997 concerning novel foods and novel ingredients).

Culinary exploitation of camelina oil

Besides the major exploitation as dietary supplement in salads and in various cold dishes, CO can be also used for cooking, baking and frying. An official test confirmed that CO is suitable for frying beef, fish, eggs and vegetables (12). During frying for up to 15 min at the temperature of 180°C, no rancidity was detected. However, prolonged heating accelerated the release of volatiles and the formation of polymerization and oxidation products.

Culinary exploitation of CO in practice revealed certain disadvantages. When the oil was used for frying, polymerization products were formed. A brown - yellow sticky layer of polymers gradually accumulated at the surfaces of frying pans and utensils. When the oil was used for cooking and baking, no polymerization was observed. Nevertheless, it is obvious that the application of CO in cold dishes is preferable to the exploitation requiring heating.

Camelina oil in dressings

Laboratory investigation confirmed the applicability of natural CO as ingredient in dressings. The method for laboratory production of dressings was adapted from the ordinary industrial procedure. The basis for the product was UHT treated homogenised milk with the fat content of 3.5 percent. The milk was fermented by a lactic culture at 25°C for about 12 h until pH 4.6 was achieved. The fermented milk (about 65 percent v/v) and natural CO (30 percent v/v) were emulsified in a food processor at the temperature of 20°C.

Prior to mixing, minor ingredients such as minced onion, garlic and other vegetables, taste regulating additives, salt and natriumbenzoate (E 211) were added. A stabilizer Keltol GB - xantham gum (E 415) was in advance diluted in oil at 20°C. Vinegar was added during processing to adjust pH to 3.8. The dressings, stored in sealed bottles in darkness at 5°C, had a shelf life of up to 12 months. To avoid oxidation by light, the dressings with CO must be distributed in dark bottles. The dressings with CO represent a nutritionally attractive source of n-3 FA.

Camelina oil in ice cream

Laboratory experiments were carried out to verify the applicability of deodorized CO as ingredient in ice cream. The ice cream was produced according to modified procedure from instruction book for Ice Cream Maker, Phillips HR 2300. The basis for the product was UHT treated homogenized fresh milk with the fat content of 3.5 percent. An emulsion, consisting of ca. 75 percent v/v milk and 20 percent v/v CO with diluted stabilizer xantham gum (E 415), was prepared in a food processor at 20°C.

Various ingredients such as sugar, eggs, jam, syrup, taste regulating additives, etc., were added to the major ingredients before mixing. The emulsion was made to ice cream in Ice Cream Maker at a temperature of -18°C during 45 min. The nutritionally enriched ice cream with n-3 FA from CO is particularly suitable for consumption by children.

Camelina oil in mixed fat product

A procedure for nutritional enrichment of milk fat with ALA from deodorized CO was tested in a pilot production run (13). The major ingredients for the mixed fat product were milk cream with fat content of 38 percent and deodorized CO.

The milk cream (70 percent v/v) and CO (25 percent v/v) together with lactic culture (ca. 5 percent v/v) were emulsified at 40-42°C in food processor. The emulsion was fermented during 10-20 h at 15-20°C until pH 4.5-4.8 was achieved.
Subsequently, water content of the emulsion was reduced to 15 percent in chilling vacuum centrifuge Damon / IEC M 25 with 5,000 RPM for 13 min. The concentrated emulsion was finally exposed to crystallization in a perfector at the process temperature of -25°C and 5°C at outlet. The produced mixed fat had smooth consistency and was spreadable at refrigeration temperature. The product was stored in darkness at 5°C and was sensory tested monthly. The shelf life of the product was 6 months. An independent investigation shows that spread with CO, stored at 4°C and 8°C, maintained adequate sensory quality for 4 months (14).

Camelina oil is a healthy dietary supplement

Health promoting application of camelina oil

A special diet for prevention of diseases such as allergy, asthma, hearth disorders, diabetes, cancer, etc., was known since 1950s. Originally, the diet was composed of cottage cheese and flax oil (15). The preventive and curative effects were ascribed primarily to a reinforced immunity of human organism. The immunity was apparently deriving from biochemical processes in which LA, ALA , tocopherols and phytosterols were involved (16, 17). Both the LA and ALA are precursors for PUFA and are the substrates for important hormones with various functions in the human organism (18, 19).
Motivated by unique nutritional quality and beneficial properties of CO (3), flax oil in the diet was replaced with CO. The major ingredients (ca. 80 percent v/v fermented milk and 20 percent v/v CO) were mixed to obtain emulsion. The fermented milk was a source of essential amino acids and microorganisms e.g. Lactobacillus acidophilus, with well known positive dietary effects. The oil provided LA, ALA, tocopherols, phenols, phytosterols, etc.
During testing with adults, 8 table spoons of fermented milk and 2 table spoons of CO were used per serving. To improve the nutritional value and taste, oats flakes and seasonally available small fruits, minced fruits or vegetables, dry fruits, grape raisins, jam, sugar, etc., were mixed with the emulsion. The complex mixture was consumed with 2-3 slices of toast (Figure 1). The most convenient was the consumption of the diet at breakfast.

Cholesterol reducing effect of camelina oil

A mixed fat product consisting of butter fat and CO (1:1), was tested by mildly hypercholesterolemic subjects. The volunteers aged 25-75 years (14 males and 31 females) during 4 weeks consumed 50-60 g /d of the mixed fat. Their habitual diet was maintained, only fats (butter, margarine, oil) were substituted with the tested product. Blood analyses were performed during morning hours in the intervals of 2 weeks by using Reflotron Boehringer, Manheim. The initial mean content of total cholesterol in blood serum of the subjects was 6.3 ± 0.25 mmol/L. After 2 weeks on the diet, the volunteers experienced a decreasing cholesterol level. At the end of the trial, their cholesterol in blood serum was reduced to 5.8 ± 0.23 mmol/L.
The cholesterol reducing effect was ascribed to CO.
A similar cholesterol reducing effect of CO was achieved in a test with mildly and moderately hypercholesterolemic subjects. The volunteers consumed 33 mL CO per day during 6 weeks. Their total cholesterol in blood serum was reduced from 5.9 to 5.6 mmol/L and LDL (low density lipoprotein) decreased by 12.2 percent (20). In another trial, volunteers during 4 weeks consumed 12 g/d ALA in the form of ground flax seed (50 g/d) or flax oil (20 g/d). The content of long chain n-3 FA and erythrocyte lipids in blood serum of the subjects increased significantly. Simultaneously was lowered serum total cholesterol by 9 percent and LDL cholesterol by 18 percent (11). A provision of functional oil with flax oil reduced the total cholesterol by 12.5 percent and LDL by 13.9 percent (17).
Meanwhile, unusually high content of cholesterol in CO, amounting to 188 μg/g, was reported (21). Experimental evidence, however, proves that CO possesses a cholesterol reducing property. Besides the effects of ALA and tocopherols also phytosterols were found effective in lowering cholesterol (22). Preliminary unpublished experimental results indicate that the amount of cholesterol in blood serum is not proportional to the dietary intake. The major determinants of cholesterol level in blood serum are saturated FA (C12:0 - C16:0). The development of atherosclerosis actually is deriving from the oxidation of LDL (23).

Dietary supplementation of ALA

Dietary supplementation of ALA in European countries, USA and Canada was estimated to be between 0.8 and 2.2 g/d per person (24). The dietary provision of ALA was a subject of numerous investigations. Recommendations for dietary intake of ALA, however, are somewhat inconsistent. A supplementation of ca. 2 g ALA (20 g rape oil) and 7 - 10 g LA for the daily intake by healthy persons was suggested. The conversion of ALA to EPA was found to be about 10 percent (25).
Other studies show that intake of 3.5 g/d ALA increased the proportion of EPA but not DHA in plasma phospholipids (26).

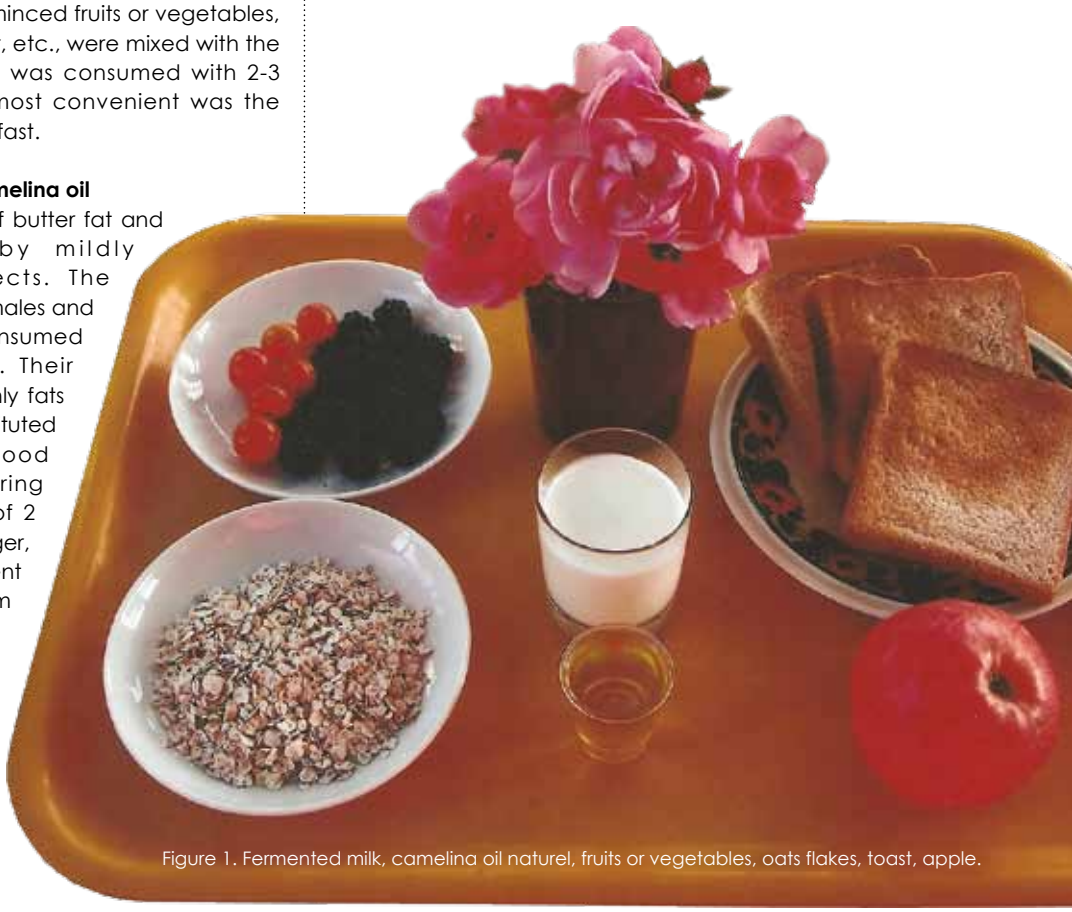

Figure 1. Fermented milk, camelina oil naturel, fruits or vegetables, oats flakes, toast, apple.

A supplementation of 4.5 and 9.5 g/d ALA was used experimentally (27). On the basis of studies with volunteers was proposed an intake of 12 g ALA, corresponding to 20 g flax oil per day (11). Approximately 33 percent of the administered ALA was recovered as CO_2 on breath over the first 24 h after intake (24).

The exploitation of ALA as a substrate for EPA depends on the n-6/n-3 FA ratio. The conversion of ALA to EPA can be inhibited by the excess of LA. An appropriate supplementation of ALA is needed to ensure the conversion of ALA to EPA (19, 28). An enrichment of food with ALA appears extraordinary important for infants and children. Dietary ALA promotes a healthy growth as well as optimal neurological development (29). The incorporation of CO in diet for children appears to be promising health promoting measure.

Camelina oil is applicable for nutritional enrichment of different food products

Health promoting potential of camelina oil

The high contents of ALA, tocopherols and other antioxidants make CO nutritionally very attractive. Besides being a substrate in human metabolism, ALA is capable of improving the n-6/n-3 FA ratio in food. Experimental documentation shows that LA and ALA are in human metabolism convertible to PUFA through desaturation and chain elongation metabolic pathway (1). ALA is a precursor for prostaglandins and other eicosanoids and hormones involved in wide range of body functions including the immune system (18). Additional health effects may be ascribed to antioxidants and phytosterols in CO. Specific studies disclosed that phytosterols, incorporated in functional fat with flax oil, had beneficial effects on lipids and cholesterol in blood serum (17).

A dietary intake of 13.7 g/d ALA from flax oil significantly increased the content of ALA in blood serum. The concentration of ALA increased approximately eightfold in the serum lipid fractions (phospholipids, cholesteryl esters and triglycerides) and 50 percent in the neutrophil phospholipids. The concentration of EPA in plasma phospholipids increased 2.5 fold. A supplementation of ALA from vegetable oils can elevate EPA in tissues to concentrations comparable to those achieved with fish oil (30). Another investigation shows a conversion of LA to n-6 metabolites ranging from 1.0 to 2.2 percent. The conversion of ALA to n-3 metabolites was 11.0 - 18.5 percent and to DHA it was 3.8 percent (19). A significant increase of ALA, EPA and DHA in blood serum in a trial with volunteers was reported. At the same time, the saturated FA (C14:0, C15:0, and C16:0) decreased (20). The trial demonstrated that a supplementation of CO had about the same effects as flax oil.

CONCLUSIONS

Camelina oil is a rich source of essential LA and ALA. The content of the predominant ALA (18:3n-3) in CO is approximately 2.5 fold higher than LA (18:2n-6). The oil is capable of improving the n-6/n-3 FA ratio in food. ALA serves as a substrate for EPA, DHA and hormones with important functions in human organism, particularly in the maintenance of immunity. A cholesterol reducing effect of CO was confirmed in trials with volunteers. The reduction of cholesterol in blood serum was ascribed to the synergistic effects of ALA and antioxidants.

Heating of CO up to 200°C caused small reduction in the content of ALA while the effect on the other FA was negligible. Heat treatment, however, caused considerable damage to tocopherols. Due to heating, the content of total tocopherols in both the natural and deodorized CO was reduced significantly. The largest detrimental effect of heating was recorded in α-tocopherol, but the content of the predominant γ-tocopherol was also reduced considerably.

The oil is primarily applicable as food supplement. The application of natural CO in cold dishes appears preferable to the culinary exploitation with heating. Natural CO can be used as an ingredient in dressings and similar products. A very suitable exploitation of natural CO was found in a special health promoting diet. Deodorized CO is applicable for nutritional enrichment of ice cream and mixed fat products. Nutritionally improved food with CO can play decisive role in preventing life-style diseases.

Fatty acids: Saturated - mainly myristic (14:0), palmitic (16:0), stearic (18:0). Monounsaturated - mainly oleic (18:1n-9). Doubleunstaurated - mainly linoleic (18:2n-6). Polyunsaturated - mainly a-linolenic (18:3n-3), eicosapentaenoic (20:5-n3, docosahexaenoic (22:6-n3).

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