Some Compositional Properties of Camelina (*Camelina sativa* L. Crantz) Seeds and Oils

John T. Budin[a], William M. Breene[a,]* and Daniel H. Putnam[b,1]

[a]Departments of Food Science and Nutrition and [b]Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minnesota 55108

ABSTRACT: Fatty acid profiles (FAP), tocopherol (T), and tocotrienol (T3) contents, total lipid contents, and trypsin inhibitor activity were quantitated from thirteen accessions of camelina (*Camelina sativa* L. Crantz), a little-known oilseed. Camelina seeds of ten accessions were also assayed for ß-glucans. FAP (%) of camelina oils were: oleic (14.1 to 19.5), linoleic (18.8 to 24.0), linolenic (27.0 to 34.7), eicosenoic (12.0 to 14.9), erucic (0.0 to 4.0), all others (11.8 to 17.4). Camelina oil T and T3 contents (mg/100 g) were: αT (0.66 to 2.38), ßT (0.38 to 1.45), γT/ßT3 (4.37 to 18.68), δT (0.00 to 0.48), αT3 (0.00 to 0.79), γT3 (0.00), γT3 (0.00). Total tocols were higher in camelina than in canola, crambe, flax, soybean, and sunflower, with γT/ßT3 constituting 82% of total tocols. The oil content of camelina seeds ranged from 29.9 to 38.3%. Camelina seeds did not contain ß-glucans. Trypsin units inhibited ranged from 12 to 28 compared to 111 for raw soybean.
JAOCS 72, 309–315 (1995).

KEY WORDS: Camelina, false flax, fatty acid, ß-glucan, tocopherol, tocotrienol, trypsin inhibitor.

Camelina sativa (L. Crantz) is an ancient crop that originated in Germany about 600 B.C. (1). Cultivation spread to central Europe as camelina was probably grown for oil (2). The crop became unimportant in the Middle Ages, and production declined for reasons unknown, but it continued to evolve as a weed with flax; hence, camelina is also known as false flax. Camelina is a member of the Cruciferae (Brassicaceae) family, which includes mustards, rapes, canola, crambe, radish, turnip, broccoli, cabbage, rutabaga, tyfon, collards, kales, cauliflower, brussels sprouts, kohlrabi, and many weeds (2).

Camelina, also known as "Gold of Pleasure," has several unique and positive agronomic attributes. It is a low-input crop that grows well in semiarid regions and in low-fertility or saline soils, which is unusual for an oil crop (3). Other oil crops, such as canola, soybean, and sunflower, have high nutrient requirements. Soybeans, furthermore, are not well adapted to the more northerly regions of North America, Europe, and Asia. Camelina competes favorably with other plants and appears to be tolerant to insects and weeds (2,3). Remarkably, it can be broadcast at low seeding rates onto frozen ground in Minnesota in late November and early December and can survive frost and freeze–thaw cycles after emergence during late winter and spring. It is also unusual for a nontraditional crop to have an oil content as high as 28 to 40% (2).

Camelina oil contains high concentrations of linolenic (27.9%), linoleic (18.7%), oleic (17.5%), and eicosenoic acid (16.4%) (2). This level of unsaturation would probably make the unhydrogenated oil unsuitable for food applications because it would likely be highly prone to autoxidation. In addition, the physiological effects of eicosenoic acid are not understood. Erucic acid was present in camelina oil at a concentration of 3.5% (2). Published information on oil extracted from camelina is limited. The extent of variation of both oil and fatty acid contents due to environment and accession or variety is not known. The oil has not been characterized in terms of quantifying other lipid fractions such as vitamin E isomers, the tocopherols (T) and tocotrienols (T3).

The objectives of this research were to analyze a fairly broad range of Minnesota-grown camelina seed lots, which represent thirteen accessions with promising agronomic traits, for their crude fat content, fatty acid, and vitamin E (tocol) profiles, ß-glucan content, and trypsin inhibitor activity (TIA). For comparison and to validate methodology, fatty acid, and tocol profiles as well as ß-glucans were also determined in some other more common oilseed crops. Further knowledge of the contents of these constituents and the extent of their variation among accessions should provide insight as to possible utilization potential of the crop as well as a focal point for plant breeders who may wish to genetically modify its composition.

EXPERIMENTAL PROCEDURES

Camelina and other oilseeds. Camelina seed from Bulgaria, Germany, the former Soviet Union, and Minnesota was planted in two separate trials at the Rosemount, Minnesota, Experiment Station. Certain agronomic factors (e.g., yield) were considered and reported elsewhere (3). In Trial I, a total of ten accessions were seeded at a rate of 18 kg/ha in late

*To whom correspondence should be addressed at University of Minnesota, 1334 Eckles Ave., St. Paul, MN 55108.

[1]Present address: Department of Agronomy and Range Science, University of California-Davis, Davis, CA 95616-8515.

April in 76-cm rows. Mechanical and hand cultivation were applied as needed; plants were not thinned. In Trial II, eight accessions were seeded at a rate of 9 kg/ha in 25.4-cm rows with four replicate 1.2 × 76.2 m plots. For both trials, 90 kg N/ha was applied as ammonium nitrate; phosphorus and potassium were applied as indicated by soil test. The crop was harvested manually in late July. Analyses were performed on a number of accessions randomly selected from Trial I and on all eight accessions in Trial II. Not all Trial I accessions were subjected to all analysis because quantities of seed were limited.

Other seeds processed commercially for their oils were obtained for comparison. These included canola, crambe, flax, soybean, a traditional sunflower high in linoleic acid (HLA), and a new sunflower cultivar high in oleic acid (HOA). All were grown at the Rosemount, Minnesota, Experiment Station with the exception of the HOA sunflower, which was obtained from North Dakota State University (Fargo, ND).

Crude fat analysis. Seeds of camelina were ground for 30 s in a MicroMill model 502 (TechniLab Instruments, Inc., Pequannock, NJ) and were analyzed in triplicate for crude fat by AOAC Method 27.006 (4).

Fatty acid profiles. The Soxhlet fat extracts of all seeds were analyzed in duplicate for fatty acid profiles. Residual petroleum ether, boiling range 30 to 60°C, was removed by gentle boiling immediately after extraction and then in a rotary evaporator with a water bath temperature of 37°C. Methyl ester derivatives were prepared according to Einig and Ackman (5), with the exception of using 200 mg of extracted oil instead of the specified 20 mg. The fatty acid derivatives were stored at 4°C in amber crimp vials wrapped in aluminum foil and were analyzed within a week. Standards of methyl ester derivatives were obtained from Nu-Chek-Prep (Waterville, MN).

The fatty acid derivatives were analyzed with a Hewlett-Packard 5890 gas chromatograph with flame-ionization detector and Hewlett-Packard 7673A automatic injector (Palo Alto, CA). The carrier gas was helium, and the samples were injected in split mode with a split ratio of 20:1. The column head pressure was 12 psig. The column was a DB 23 (J&W Scientific, Folsom, CA) with dimensions of 30 m × 0.32 mm and 25 μm film thickness. The initial column temperature of 40°C was increased at a rate of 15°C/min to 160°C, where the rate was changed to 5°C/min to a final temperature of 220°C. The length of each run was 27 min.

Tocol analysis. The T and T3 were extracted in duplicate from all seeds in minimal light or complete darkness. One gram of seed was homogenized for one min in 20 mL of reagent-grade methanol with a polytron (model 10/35; Brinkman Instruments, Rexdale, Ontario, Canada) on the #4 setting. The samples were then centrifuged (IEC model K; International Equipment Co., Needham Heights, MA) at 5,400 × *g*. The supernatant was removed and placed in a 25-mL glass vial and evaporated under nitrogen. The pellet was resuspended in 15 mL of reagent-grade methanol, and the homogenization and centrifugation steps were repeated. The supernatant was removed and added to the first extract and dried under nitrogen. The dried extract was dissolved in 2 mL of high-pressure liquid chromatography (HPLC)-grade hexane, mixed briefly in a vortex mixer (model S8220; Scientific Products, McGraw Park, IL), placed in a 2-mL amber crimp vial and immediately analyzed. Acetone was compared to methanol as an extracting solvent, and they were found to be similar. Methanol was chosen because it would extract less total lipid material than acetone or hexane and is more effective in extracting T3 than other solvents (Barry Tan, personal communication, 1991).

The HPLC system (Gilson Medical Electronics, Middleton, WI) consisted of a pump (model 302), a manometric module (model 802B), a diluter (model 401), a fluorometer (model 121), and a fraction collector (model 201). Excitation and emission wavelengths were 280 and 240–410 nm, respectively, rather than 290 and 330 nm, respectively, as suggested by Pocklington and Dieffenbacher (6). The wavelengths employed were based on the reported optimum values (6) and availability of filters for the fluorometer. The column was a LiChrosorb Si 60 (Anspec, Ann Arbor, MI), 250 mm long × 4.6 mm i.d. and 5 μm particle size. The column was washed and conditioned for about 10 min with HPLC-grade methanol (Sigma Chemical Co., St. Louis, MO), then 10 min with dichloromethane (Sigma Chemical Co.) followed by hexane (Fischer Scientific Co., Chicago, IL) at a flow rate of about 1 mL/min. After all analyses were completed, the column was stored in HPLC-grade methanol.

The method used for HPLC analysis of tocols (6) was an isocratic system with a mobile phase of 99.5% hexane and 0.5% isopropanol (Sigma Chemical Co.) at a flow rate of 1.0 mL/min. A typical run would last 35 min.

T standards were purchased from E.M. Science (Gibbstown, NJ), and α-tocotrienol was a gift from Hoffman-La Roche (Nutley, NJ). The pure tocol standards were obtained in sealed ampules in approximate quantities of 50 mg each. The ampules were opened and quantitatively rinsed with 2 mL ethanol. The solutions were stored in 10-mL screw-cap vials, sealed under nitrogen, wrapped with parafilm and aluminum foil and stored at –55°C. Our experience suggests that storage in this manner limits tocol degradation for more than one year. Standard solutions for analysis were made by taking a 20- to 50-μL sample of each isomer from its stock solution, drying it with nitrogen, dissolving it in spectral grade methanol and determining the concentration from the ultraviolet spectrometric (Bausch and Lomb Spectronic 21; Bausch and Lomb, Rochester, NY) result and the published concentration divisor factor (6). After the concentration of each tocol (α-, ß-, γ-, δ-T and α-T3) was determined, the five isomers were quantitatively combined, dried under nitrogen and dissolved in hexane. Serial dilutions were made to create a working standard curve. A typical chromatogram is given in Figure 1.

Because pure standards of ß-, γ- and δ-T3 are not commercially available, qualitative analysis was performed by obtaining a preparative HPLC extract of crude palm oil that was rich

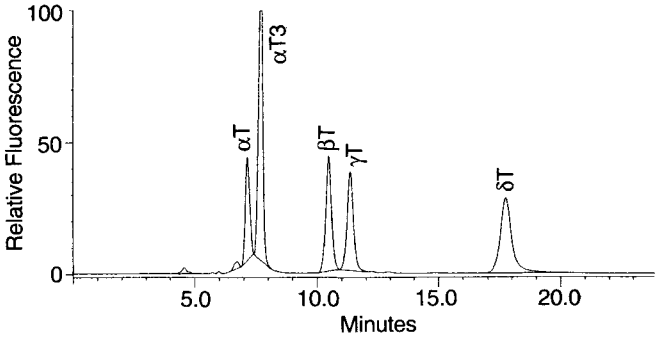

FIG. 1. A typical chromatogram of αT, αT3, ßT, γT and δT standards.

in γ- and δ-T3 (USDA Cereal Research Laboratory, Madison, WI). Crude palm oil, which is inherently rich in α-, γ- and δ-T3 (7), was also obtained from the Embassy of Malaysia (Washington, DC). HPLC fractions for each isomer were collected and dried; the trimethylsilyl ether (TMS) derivatives were prepared, and the structure of each was confirmed by gas chromatography–mass spectrometry (GC-MS) (8). The GC and MS units were model 5890 (Hewlett-Packard) and model 25 (Kratos, Ramsey, NJ), respectively. Quantitative analyses of γ- and δ-T3 were performed by using the standard curve of the respective corresponding T because the fluorescent intensities are the same (9).

Because wheat bran contains α- and ß-T and α- and ß-T3 (7), samples obtained from local retail sources were analyzed to confirm peak retention times. These isomers appeared where expected on HPLC chromatographs of a methanol extract of wheat bran, but ß-T3 did not appear on the GC–MS. It was concluded that the concentration of the TMS derivative of ß-T3 was below the sensitivity of the GC–MS and that preparative HPLC would be needed to create a concentrated source of ß-T3 to confirm this peak. However, since wheat bran contains α- and ß-T and α- and ß-T3 but not their γ- and δ-counterparts, qualitative speculations could be made about the retention time of ß-T3, which had the same retention time as γ-T with this method. Because ß-T3 and γ-T coeluted, the peak was quantitated as γ-T. Results are reported as µg tocol/100 g of seed. Recovery from this extraction procedure was verified at 95.0% by the addition of γ-T to three separate samples of camelina seed. Typical recoveries range from 93 to 95% (10,11).

ß-Glucan measurement. A few grams each of ten accessions of camelina seeds were dried overnight in a convection oven at 80°C and then stored in a desiccator. The seeds (three millings per sample) were ground in a Retsch mill (model ZM-1; Brinkman Instruments) with a 0.5-mm sieve, combined and mixed well to assure homogeneity. A barley check sample, containing 3.1% ß-glucans, was included as a reference standard to confirm accuracy.

The milled samples were analyzed in duplicate the next day for ß-glucan contents by AACC Method 32-22 (12). All water used was distilled. The glucose test kit (5X98808) and lichenase/ß-glucosidase ß-glucan assay kit (5X98805) were purchased from Quest Biocon™ (Sarasota, FL) The centrifuge was a Heraeus Sepatech Biofuge 15 (Osterode, Germany). Sample absorbance was read in a Bausch and Lomb Spectronic 20 spectrophotometer at 505 nm with results reported as % ß-glucan on a dry basis.

TIA. Seed samples from thirteen accessions of camelina were each ground to a fine powder for 1 min in a MicroMill model 502. In triplicate, 0.5 g of each was suspended in 50 mL distilled water and shaken for 30 min in a G10 gyratory mechanical shaker (New Brunswick Scientific, New Brunswick, NJ) at 200 rpm. The assay for trypsin inhibitor activity by Liu and Markakis (13) was used. Benzoyl-DL-arginine-*p*-nitroanilide hydrochloride (BAPA), Tris buffer (preset crystals) and porcine trypsin were obtained from Sigma Chemical Co. Soybeans purchased from a local health food store were used as a reference standard.

Sample absorbance was read in a Bausch and Lomb Spectronic 20 spectrophotometer at 410 nm. TIA is defined as an A_{410} increase of 0.01 under conditions of the assay. TIA is expressed as trypsin units inhibited (TUI) per mg of dry sample.

Statistical analysis. Analysis of variance was performed with the Statistix program (version 3.5; Analytical Software, St. Paul, MN) and the General Linear Models procedure. The significance of species was determined separately for Trials I and II because they represented two plant population levels. Tukey's Honestly Significant Differences (HSD) test ($P \leq 0.05$) was used to compare treatment means.

RESULTS AND DISCUSSION

Crude fat. Camelina is high enough in extractable lipids to be classified as an oilseed. The crude fat content of five accessions in Trial I (Table 1) ranged from 30.0 to 33.4%, dry basis (db). Accession C021 was significantly higher in fat ($P \leq 0.05$) than the other four accessions, which did not differ from one another. In the lower plant population trial (Trial II, Table 1), crude fat content was somewhat higher (34.3 to 36.5%,

TABLE 1
Crude Fat Content, Dry Basis, of Camelina Seed from Trials I and II[a]

Trial I			Trial II		
Accession	Crude fat (%, db)[b]	SD[c]	Accession	Crude fat (%, db)	SD
C008	30.9	0.3	C028	35.8	1.7
C018	30.0	0.8	C037	34.3	1.6
C021	33.4	0.6	C046	36.5	1.0
C031	31.6	0.4	C053	35.4	1.2
C049	31.0	0.7	C054	35.7	0.6
			C082	36.2	0.2
			C088	35.5	0.7
			MN1	34.6	0.6
Overall means	31.4	0.6		35.5	1.0
HSD[d] ($P \leq 0.05$)	1.1			NSD[e]	

[a]Means of triplicate determinations.
[b]db = Dry basis.
[c]SD = Standard deviation.
[d]HSD = Honestly significant difference.
[e]NSD = Not significantly different.

db) with no significant differences among the eight accessions. These values fall within the range of 28 to 40% reported by Robinson (2). An inverse relationship may exist between planting density and crude fat content. However, the observed trend toward higher fat content in Trial II might simply have reflected genetic differences.

Fatty acid profiles. The fatty acid profiles of camelina oil, extracted from seeds produced in Trial I (Table 2), showed significant variation ($P \leq 0.05$) among accessions in the contents of palmitic, oleic, linoleic, and erucic acids, but not those of stearic, linolenic, and 11-eicosenoic acids. Although statistically significant, the differences were relatively small in absolute terms. A similar pattern is seen for camelina oil from seeds produced by plants seeded at the lower population density (Trial II, Table 3), where significant variation occurred in the contents of all except 11-eicosenoic acid. It is unclear whether the trend toward higher concentrations of palmitic, linoleic, and linolenic acids and toward lower concentrations of stearic, oleic, 11-eicosenoic, and erucic acids in Trial I than in Trial II reflects genetic differences or the effect of plant density.

Overall means across accessions for both trials show camelina oil to be highest in linolenic acid, followed in descending order by linoleic, oleic, 11-eicosenoic, and palmitic acids, with small but approximately equal concentrations of stearic and erucic acids. These values agree favorably with those reported by Robinson (2), i.e., linolenic, 27.9%; linoleic, 18.7%; oleic, 17.5%; eicosenoic, 16.4%; and erucic, 3.5%. Mean saturated/unsaturated (S/U) ratios were 0.11 in both trials, indicating a relatively high degree of unsaturation. The absence of erucic acid in accession C009 provides some potential for eliminating it through plant breeding. Erucic acid is known to inhibit growth and to induce changes in various organs when included in diets of experimental animals (14).

In Table 4, the overall mean fatty acid profile for the thirteen accessions analyzed in Trials I and II is compared with those of the oils extracted from seeds of six other oilseeds, namely canola, crambe, flax, soybean, traditional sunflower, and HOA sunflower. Camelina oil differed from the others in several respects. It was the only oil that contained 11-eicosenoic acid, and in relatively high concentrations (13.6%). It was somewhat higher in erucic acid than flax (linseed) oil but much lower than crambe oil. In terms of saturation, it was more highly saturated overall than crambe, canola, and HOA sunflower oils, comparable to linseed and tradi-

TABLE 2
Fatty Acid Profiles and Saturated/Unsaturated (S/U) Ratios of Oils Extracted from Camelina Seeds in Trial I[a]

	Fatty acid (%)								
Accession	Palmitic 16:0	Stearic 18:0	Oleic 18:1	Linoleic 18:2	Linolenic 18:3	11-Eicosenoic 20:1	Erucic 22:1	All others	S/U ratio[b]
C004	6.7	2.6	14.7	20.0	34.7	12.5	3.1	5.7	0.11
C009	8.4	1.4	17.1	24.0	34.5	12.6	0.0	2.0	0.11
C016	7.5	3.0	15.2	21.4	33.6	12.6	1.4	5.3	0.13
C024	6.1	2.7	14.1	21.2	32.1	13.1	3.6	7.1	0.11
C049	6.5	2.7	15.7	20.8	30.9	12.3	3.0	8.1	0.11
Overall mean	7.0	2.5	15.4	21.5	33.2	12.6	2.2	5.6	0.11
HSD ($P \leq 0.05$)	2.0	NSD[c]	2.7	2.0	NSD	NSD	NSD	—	—

[a]Means of duplicate determinations. See Table 1 for other abbreviations.
[b]S/U ratio = (16:0 + 18:0)/(18:1 + 18:2 + 18:3 + 20:1 + 22:1).
[c]NSD = Not significantly different.

TABLE 3
Fatty Acid Profiles and S/U Ratios of Oils Extracted from Camelina Seeds in Trial II[a]

	Fatty acid (%)								
Accession	Palmitic 16:0	Stearic 18:0	Oleic 18:1	Linoleic 18:2	Linolenic 18:3	11-Eicosenoic 20:1	Erucic 22:1	All others	S/U ratio[b]
C028	6.1	2.9	14.8	20.8	31.1	13.8	3.4	7.1	0.11
C037	6.2	3.1	16.2	20.4	27.9	14.7	4.0	7.5	0.11
C046	5.7	2.6	15.8	20.5	29.7	14.6	3.8	7.3	0.10
C053	5.8	3.2	15.5	20.3	30.4	14.1	3.5	7.2	0.11
C054	5.9	2.8	14.2	21.0	30.7	14.0	3.8	7.6	0.10
C082	6.3	3.1	17.9	19.0	28.7	14.5	3.5	7.0	0.11
C088	5.7	3.5	19.4	19.5	27.9	14.2	3.2	6.6	0.11
MN1	6.6	3.3	16.5	22.3	27.1	13.6	3.3	7.3	0.12
Overall mean	6.0	3.1	16.3	20.5	29.2	14.2	3.6	7.2	0.11
HSD ($P \leq 0.05$)	0.5	0.3	0.8	1.0	1.1	NSD	0.6	—	—
Overall mean (13 accessions)	6.4	2.8	15.9	20.9	30.7	13.6	3.0	6.6	

[a]Means of duplicate determinations. See Tables 1 and 2 for other abbreviations.
[b]S/U ratio = (16:0 + 18:0)/(18:1 + 18:2 + 18:3 + 20:1 + 22:1).

TABLE 4
Overall Mean Fatty Acid Profile and S/U and PU/MU Ratios of 13 Accessions of Camelina Compared with Those of Six Other Oilseeds[a]

	Fatty acid (%)									
Crop	Palmitic 16:0	Stearic 18:0	Oleic 18:1	Linoleic 18:2	Linolenic 18:3	11-Eicosenoic 20:1	Erucic 22:1	All other	S/U ratio[b]	PU/MU ratio[c]
Camelina	6.4	2.8	15.9	20.9	30.7	13.6	3.0	6.6	0.11	1.59
Canola	6.2	0.0	61.3	21.6	6.6	0.0	0.0	4.3	0.07	0.46
Crambe	2.4	0.4	18.4	10.7	5.1	0.0	54.0	9.0	0.03	0.22
Flax	5.1	4.6	24.3	16.3	45.1	0.0	0.9	3.7	0.11	2.44
Soybean	10.4	4.0	27.2	45.5	7.2	0.0	0.0	5.7	0.18	1.94
Sunflower	6.1	3.8	17.4	69.3	0.0	0.0	0.0	3.4	0.11	3.98
Sunflower HOA	3.3	3.9	69.7	21.7	0.1	0.0	0.0	1.3	0.08	0.31

[a]Means of duplicate determinations. HOA, high oleic acid. See Table 2 for other abbreviation.
[b]S/U ratio = (16:0 + 18:0)/(18:1 + 18:2 + 18:3 + 20:1 + 22:1).
[c]PU/MU ratio = Polyunsaturated/monounsaturated = (18:2 + 18:3)/(18:1 + 20:1 + 22:1).

tional sunflower oils and more unsaturated than soybean oil. If one compares the polyunsaturated to monounsaturated ratios among the unsaturated fatty acids (PU/MU), camelina oil was similar to soybean oil, more polyunsaturated than canola, crambe, and HOA sunflower oils and less polyunsaturated than linseed and traditional sunflower oils. Because monounsaturated fatty acids are much more stable to autoxidation than polyunsaturated ones, the PU/MU ratio may be a better predictor of oxidative stability of an oil than the overall S/U ratio.

Vitamin E. The vitamin E profiles of camelina seeds from Trial I (Table 5) show significant differences ($P \leq 0.05$) among accessions in αT, αT3, ßT, ßT3/γT, and total tocols. The γT3 and δT3 isomers were not detected in any of the accessions. However, only one accession (C009) contained any αT3, and then only in small quantity. All five accessions contained δT in small but similar concentrations. Accession C014 was unique in that it contained the lowest concentrations of total as well as individual tocols.

A similar pattern is seen for the vitamin E profiles of camelina seeds from Trial II (Table 5). None of the accessions contained detectable quantities of γT3 or δT3, and αT3 was present in small concentrations in only two accessions (C053, C054). There were significant differences ($P \leq 0.05$) among accessions only in ßT3/γT and total tocols. In each of the trials, the ßT3/γT peak accounted for 82% of the total tocols, based on the overall means. No data could be found in the literature on the vitamin E content of camelina seed.

In Table 6, the overall mean vitamin E profile for the thirteen accessions analyzed in Trials I and II is compared with those for seeds of the six oilseeds used for comparison of fatty acid profiles, namely canola, crambe, flax, soybean, traditional sunflower, and HOA sunflower. The δT3 isomer was not detected in any of the seven oilseeds. Perhaps the most

TABLE 5
Vitamin E Profiles of Camelina Seeds from Trials I and II[a]

	Tocol (mg/100 g seed; WB[b])					
Trial I (accession)	αT	αT3	ßT	ßT3/γT	δT	Total
C004	2.07	0.00	1.27	16.75	0.34	20.43
C009	1.52	0.26	1.28	18.94	0.49	22.49
C014	1.30	0.00	0.40	6.60	0.29	8.60
C016	2.42	0.00	1.48	17.53	0.40	21.83
C024	1.29	0.00	1.38	17.64	0.42	20.72
Trial I Mean	1.72	0.05	1.16	15.49	0.39	18.81
Trial I HSD ($P \leq 0.05$)	0.55	0.18	0.60	4.92	NSD	5.25
Trial II (accession)						
C028	1.71	0.00	0.66	15.97	0.24	18.57
C037	1.50	0.00	0.88	12.19	0.32	14.88
C046	1.56	0.00	0.93	11.03	0.25	13.76
C053	1.70	0.09	0.77	12.88	0.25	15.69
C054	1.71	0.19	0.85	11.37	0.28	14.40
C082	1.83	0.00	0.92	12.20	0.32	15.28
C088	2.30	0.00	1.13	17.35	0.46	21.25
MN1	1.79	0.00	0.93	15.19	0.39	18.30
Trial II mean	1.76	0.04	0.88	13.52	0.31	16.52
Trial II HSD ($P \leq 0.05$)	NSD	NSD	NSD	4.03	NSD	9.99
Overall mean (13 accessions)	1.75	0.04	0.99	14.28	0.34	17.40

[a]Means of duplicate determinations. See Table 1 for other abbreviations.
[b]WB = Wet basis.

TABLE 6
Overall Vitamin E Profile of 13 Accessions of Camelina Compared with Those of Other Oilseeds[a]

	Tocol (mg/100 g seed; WB)						
Crop	αT	αT3	ßT	ßT3/γT	γT3	δT	Total
Camelina	1.75	0.04	0.99	14.28	0.00	0.34	17.40
Canola	1.56	0.00	0.56	6.88	0.09	0.18	9.27
Crambe	0.65	0.04	0.23	2.82	0.00	0.13	3.87
Flax	0.88	0.00	2.42	9.20	0.00	0.24	12.74
Soybean	1.71	0.00	0.38	5.97	0.00	2.93	10.99
Sunflower	12.89	0.00	0.90	0.28	0.00	0.03	13.29
Sunflower HOA	8.62	0.09	0.21	0.20	0.00	0.03	9.15

[a]Means of duplicate determinations. See Tables 4 and 5 for abbreviations.

TABLE 7
Trypsin Inhibitor Activity (dry basis) in Camelina Seed from Trials I and II[a]

Trial I			Trial II		
Accession	TUI (%, db)	SD	Accession	TUI (%, db)	SD
C014	18.9	0.5	C028	11.8	1.8
C018	19.9	0.7	C037	13.1	0.5
C021	25.5	0.7	C046	14.9	1.1
C031	23.5	0.3	C053	12.5	1.5
C049	18.6	0.6	C054	17.1	0.5
			C082	26.6	1.0
			C088	16.3	0.9
			MN1	15.5	0.3
Overall means	21.3	0.6		16.0	1.0
HSD ($P \leq 0.05$)	1.7	2.5			
Overall mean (13 accessions)		18.0			
Raw soybean reference		110.7			

[a]Means of duplicate determinations. TUI, trypsin units inhibited; db, dry basis. See Table 1 for other abbreviations.

notable difference was the high content of ßT3/γT compared to the other oilseeds. Camelina was comparable to the other oilseeds in αT content except for the two sunflower types, which contained considerably higher concentrations. All seven oilseeds were essentially devoid of αT3, γT3 and δT3, and only soybean contained an appreciable quantity of δT. The total tocol content was about 30% higher in camelina than in the second ranking oilseed, traditional sunflower, apparently because of the high ßT3/γT content.

ß-Glucan content. Maximum mean ß-glucan contents in seeds of ten camelina accessions and seven other crop seeds (lupin, canola, crambe, flax, and traditional and HOA sunflower) were 0.4 and 0.3%, respectively, compared to 3.0% for the barley reference check sample, which had a predetermined value of 3.1%. Hence, neither camelina nor any of the other crop seeds are major sources of ß-glucans.

Trypsin inhibitor activity. Significant differences ($P \leq 0.05$) existed in TIA among camelina accessions in both Trial I and Trial II. The overall mean TIA values were 21.3 and 16.0 TUI/mg, dry basis, for camelina seed in Trials I and II, respectively (Table 7). Among the thirteen accessions tested, TUI/mg ranged from 11.8 in C028 to 26.6 in C082 and averaged 18.0 overall. Although TIA in camelina appears high enough to warrant some concern, the data suggest that sufficient variation exists to enable it to be minimized as a problem *via* plant breeding.

At 30 to 36% crude fat, camelina qualifies to be classed as an oilseed. The seed is unique among oilseeds examined in its relatively high content (*ca.* 14%) of 11-eicosenoic acid. Although erucic acid averaged 3.0% among the accessions tested, its complete absence in one accession signals the possibility of eliminating it from the oilseed by breeding and selection. In terms of overall S/U, camelina oil is comparable to linseed and traditional (HLA) sunflower oils. However, its ratio of monounsaturated to polyunsaturated fatty acids puts it in the same class as soybean oil. Camelina oil was substantially higher in total tocol content than canola, crambe, linseed, soybean, and sunflower, oils. The ßT3/γT fraction accounted for 82% of total tocols.

The ß-glucan content of camelina seed was similar to that of the other oilseeds at about one-tenth that of barley. TIA appears high enough (12 to 27 TUI/mg) to warrant some concern, but the extent of variation among accessions indicates the potential to reduce it by breeding and selection. Camelina has promise as a specialty oilseed crop, particularly in northern latitudes where soil fertility and rainfall are marginal.

Much more research is needed to more fully characterize the oil chemically and physically and to determine its possible uses in foods and nonfood industrial products.

ACKNOWLEDGMENTS

This paper is published as Paper No. 21,405 of the contribution series of the Minnesota Agricultural Experiment Station on research conducted under project 18-043 and was supported by Hatch funds with additional support from the Northern Regional Agricultural Utilization Consortium. Special thanks to Dr. Tom Krick and Dr. Dan Gallaher for their technical assistance, to Dr. Frank Martin of the UM Department of Applied Statistics for his help in experimental design and data analysis.

REFERENCES

1. Knorzer, K.H., *Berichte der Deutschen Gesellschaft. 91*:187 (1978).
2. Robinson, R.G., Minnesota Agricultural Experiment Station Bulletin 579-1987, (AD-SB-3275), St. Paul, 1987, pp 1–12.
3. Putnam, D.H., J.T. Budin, L.A. Field and W.M. Breene, in *New Crops*, edited by J. Janick, and J. Simon, John Wiley and Sons, New York, 1993, pp. 314–322.
4. *Official Methods of Analysis of the Association of Official Analytical Chemists*, 14th edn., Association of Official Analytical Chemists, Arlington, 1984.
5. Einig, R.G., and R.G. Ackman, *J. Am. Oil Chem. Soc. 64*:499 (1987).
6. Pocklington, W.D., and A. Dieffenbacher, *Pure and Appl. Chem. 60*:877 (1987).
7. Bauernfeind, J., in *Vitamin E: A Comprehensive Treatise*, Marcel Dekker, New York, 1980, pp. 99–167.
8. Rao, M.K.G., and E.G. Perkins, *J. Agric. Food Chem. 20*:240 (1972).
9. Thompson, J.N., and G. Hatina, *J. Liq. Chrom. 2*:327 (1979).
10. Hakkarainen, R.V.J., J.T. Tyopponen and S.G. Bengtsson, *J. Sci. Food Agric. 34*:1029 (1983).
11. Speek, A.J., J. Schrijver and W.H.P. Schreurs, *J. Food Sci. 50*:121 (1985).
12. *Approved Methods of The American Association of Cereal Chemists*, The American Association of Cereal Chemists, St. Paul, 1983.
13. Liu, K., and P. Markakis, *Cereal Chem. 66*:415 (1989).
14. Kramer, J.K.G., and F.D. Sauer, in *High- and Low-Erucic Rapeseed Oils*, edited by J.K.G. Kramer, F.D. Sauer and W.J. Pigden, Academic Press, Toronto, 1983, pp. 413–474.

[Received August 12, 1994; accepted December 12, 1994]