Structural and Compositional Characteristics of Canaryseed (*Phalaris canariensis* L.)

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Canaryseed (*Phalaris canariensis* L.) has small elliptical grains with hulls, which are covered with very fine silicious spicules that are severe skin irritants and potentially carcinogenic. Because chemical treatments and a glabrous genotype are now available for eliminating the spicules, the chemical composition of the dehulled groat was determined to evaluate its potential food and industrial applications. Canaryseed groats contained 61.0% starch, which comprised small polygonal granules with diameters of 1.5−3.5 μm. The groats averaged 18.7% protein compared to 15.0% in wheat, and the proportions of prolamin and glutelin in the protein averaged 77.7%, exceeding that in the control wheat protein of 73.5%. Canaryseed proteins were more deficient in lysine and threonine than wheat proteins but were very rich in cystine, tryptophan, and phenylalanine. For a cereal, canaryseed groats were very high in crude fat, 8.7%, and purified total lipid, 11.0%, containing 55% linoleic, 29% oleic, 11% palmitic, and 2.5% linolenic acids. The groat and roller-milled flours were low in dietary fiber, soluble sugars, and total ash. The composition of small granule starch and gluten-like proteins, rich in tryptophan, suggests unique functional and nutritional properties for canaryseed groats.

Keywords: *Canaryseed; seed morphology; composition; amino acids; protein fractions; fatty acids; sugars*

INTRODUCTION

Canaryseed or annual canarygrass (*Phalaris canariensis* L.) is an important cereal crop in western Canada, where production has increased from 90 600 ha in 1986 to 212 500 ha in 1996. Canaryseed is also grown in Argentina, Australia, Hungary, North Africa, the Middle East, and the United States. The current use for canaryseed is principally as a feed for small songbirds. Canaryseed is not safe for food consumption because the attached hulls are covered by small silicious hairs or spicules that can contaminate the groat during dehulling. The hairs are opaline silica emerging from the abaxial epidermal cells, being approximately 500 μm long and tapering from a diameter of 15 μm at the base to a tip diameter of 0.6 μm (Newman and Mackay, 1983). The hairs are potential carcinogens and have been linked to cancer of the esophagus when they were present as a contaminant in wheat flour used in baking bread (O'Neill et al., 1980). The hairs are also severe skin irritants to operators during harvesting and transportation of the grain.

Little information is available on the structure and composition of canaryseed and its potential as a food crop. Recently, Putnam et al. (1996) reviewed the historical, botanical, agronomic, genetic, nutritional, and marketing aspects of canaryseed. In addition, Robinson (1978) reported that annual canarygrass caryopses has potential as a food crop on the basis of its chemical composition. He also concluded that there was no toxicity problem with the grain since generations of caged birds have survived on canaryseed as a major part of their diet. However, the birds dehull the seeds prior to consumption of the groats. Therefore, further studies are required on the toxicological effects of canaryseed spicules, their removal by genetic or processing techniques, and the safety of spicule-free canaryseed.

Canaryseed contains relatively higher levels of protein and oil compared with other cereal grains (Putnam et al., 1996; Holt, 1988; Robinson, 1978). Canaryseed oil is highly unsaturated, containing mainly linoleic, oleic, and palmitic acids (Malik and Williams, 1966). However, the crude oil showed excellent antioxidant activity, sterol and triterpene alcohol esters of caffeic acid being the major effective antioxidant components in the crude oil (Takagi and Iida, 1980). There is also little information in the literature on the carbohydrates in canaryseed, but Goering and Schuh (1967) found that canaryseed starch consisted of small polygonal granules with diameters of 2.5−5.0 μm and high pasting temperatures.

The objectives of the present research were to evaluate the characteristics and composition of canaryseed grain and its components and their potential in food and nonfood applications. Wheat was grown beside canaryseed plots, and the harvested grains were used in this study for comparative purposes. Because of the problems associated with the existence of canaryseed hairs, their morphological characteristics were also investigated in whole grain and groat of hairy and glabrous cultivars. Seed of a recently developed glabrous cultivar was obtained from a plant breeder's plot at Saskatoon, but the supply was only sufficient for morphological evaluation.

MATERIALS AND METHODS

Grains. The hairy canaryseed (*P. canariensis* L.), cultivar Keet, was grown in three-replicate randomized complete block experiments at three locations (Saskatoon, Kernen, and Elrose) in central Saskatchewan in 1993. The hard red spring (HRS) common wheat (*Triticum aestivum* subsp. *vulgare* [Vill. Host]

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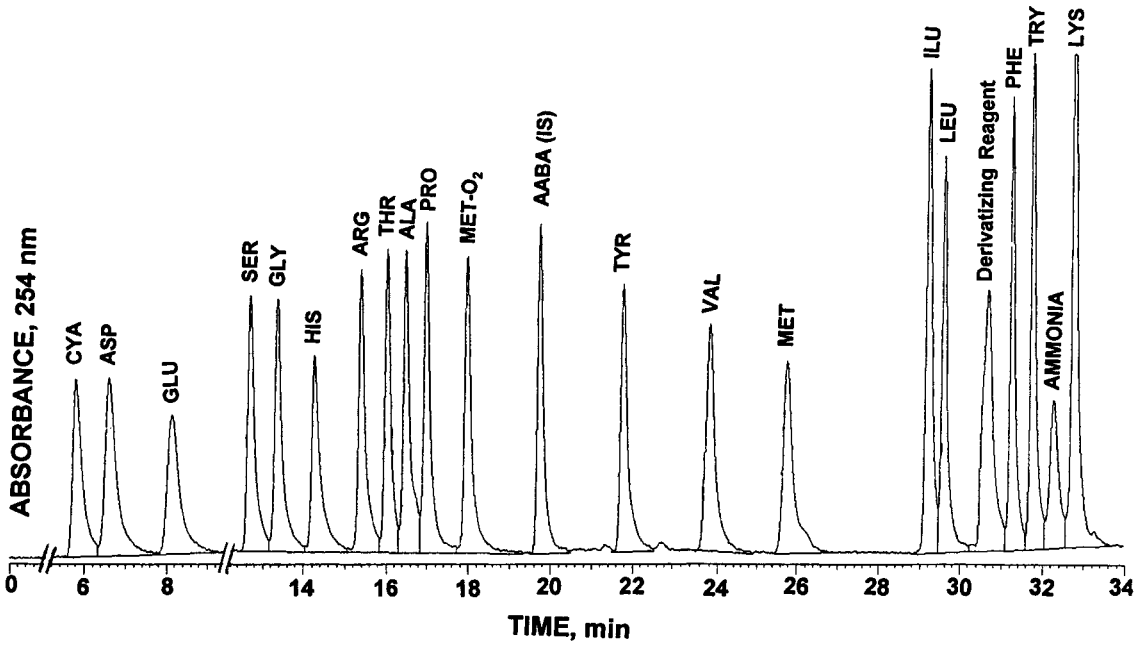

Figure 1. Calibration standard chromatogram of phenylthiocarbamylamino acids separated by reversed phase HPLC.

Mackey), cultivar Katepwa, was grown in replicated plots adjacent to the canaryseed field trials. Two replicates from each trial were analyzed separately, and the analytical results are expressed as means of two replicates for each location. Wheat grains from the three sites were used in proximate composition analysis, and only the grains from the Saskatoon site were used for further analysis.

The canaryseed grains were dehulled on an abrasive dehuller and air-aspirated to remove the hulls. The hull-free grains, called groats, were then ground to pass through a 1 mm screen on a Udy Cyclone sample mill (Udy Co., Fort Collins, CO) prior to analysis. Canaryseed flour was obtained by tempering the groats from the Saskatoon location for 16−18 h to 14% moisture and milling on a Brabender Quadrumat Jr. flour mill (Brabender Co., South Hackensack, NJ).

Analytical Tests. Groat samples were ground and analyzed according to standard AACC procedures (American Association of Cereal Chemists, 1995) for moisture (Method 44-15A), crude protein (Method 46-11A), crude fat (Method 30-20), and total ash (Method 08-03). For crude protein, a nitrogen-to-protein conversion factor of 5.7 was used. Starch was measured as glucose on the YSI Model 27 industrial analyzer (Yellow Springs Instrument Co., Yellow Springs, OH) after hydrolysis with α-amylase and amyloglucosidase. Insoluble and soluble dietary fibers were quantified by the enzymatic gravimetric procedure of the AmericaN Association of Cereal Chemists (1995), Method 32-21. Total and purified lipids were determined according to the procedure of Fölch et al. (1957). Canaryseed proteins were fractionated into four classes (albumin, globulin, prolamin, and glutelin) based on their solubilities in water, 0.5 M NaCl, 70% ethanol, and 0.1 M NaOH, respectively, by the successive extraction method of Osborne, with some modifications (Sosulski and Bakal, 1969).

Amino acid composition of canaryseed protein was determined by reversed-phase HPLC following hydrolysis with 6 N HCl at 110 °C under nitrogen for 24 h and derivatization with phenyl isothiocyanate. Sulfur-containing amino acids were converted into cysteic acid and methionine sulfone by preoxidation with performic acid prior to hydrolysis and derivatization. A Supelcosil LC-18-DB, 25 cm × 4.6 mm, column (Supelco Co., Mississauga, ON) and Bio-Rad UV detector at 254 nm (Bio-Rad Co., Mississauga, ON) were used with the following elution solvents: (A) 970 mL of 0.16 M sodium acetate trihydrate containing 0.75 mL/L of triethylamine, which was titrated to pH 6.4 with glacial acetic acid and 30 mL of acetonitrile, and (B) acetonitrile and nanopure water (80:20, v/v). Amino acid standard H from Pierce (Rockford, IL) was used for calibration, and α-amino *n*-butyric acid was used as the internal standard. A typical calibration standard chromatogram of phenylthiocarbamylamino acids is presented in Figure 1. Tryptophan was quantified on an alkaline extract of grain proteins according to the spectrophotometric method of Concon (1975). Amino acid score was calculated as the ratio of the first limiting amino acid in the grain to that of the FAO/WHO/UNU (1985) amino acid requirement for a preschool child (2−5 years). *In vitro* protein digestibility was measured according to the multienzyme technique of Pedersen and Eggum (1983) using trypsin, chymotrypsin, and peptidase.

The fatty acids in crude fat and total and purified lipids were converted to fatty acid methyl esters by direct methanolysis and then analyzed by gas−liquid chromatography on a Hewlett-Packard Model 5880A gas chromatograph equipped with flame ionization detector connected to a HP 3396 Series II integrator. A capillary column of fused silica (30 m × 0.25 mm) coated with Durabond-Wax was used. The initial column temperature of 180 °C was held for 2 min, after which time the temperature was programmed to 240 °C at 8 °C/min. The injector and detector temperatures were 250 and 300 °C, respectively.

Sugar analyses were conducted on 80% methanol extracts, following purification and derivatization with STOX reagent (oxime internal standard, Pierce Co., Rockford, IL) to form oxime derivatives of sugars prior to silylation with hexamethyldisilazane (Sigma Chemical Co., St. Louis, MO). The sugar derivatives were analyzed on a Hewlett-Packard Model 5880A gas chromatograph equipped with flame ionization detector connected to a HP 3396 Series II integrator. A WCOT DB-5 capillary column of fused silica (10 m × 0.2 mm) was used. The initial column temperature of 180 °C was held for 6 min and then was programmed to 320 °C at 15 °C/min. The injector and detector temperatures were both at 300 °C. A standard mixture of arabinose, fructose, glucose, and sucrose was prepared and used for calibration.

Microscopy. For the morphological study of hairs, intact hulled canaryseed grains were ignited at 550 °C for 3−4 h and the remaining ash was microscopically examined. Samples of hulled canaryseed, groats, ash, ground ash, flour, bran, and starch were mounted on circular aluminum stubs with double-sticky tape and then coated with approximately 20 nm of gold under a 5 mTorr vacuum. The specimens were examined and photographed with a scanning electron microscope (Phillips SEM 505) at an accelerating potential of 20 kV.

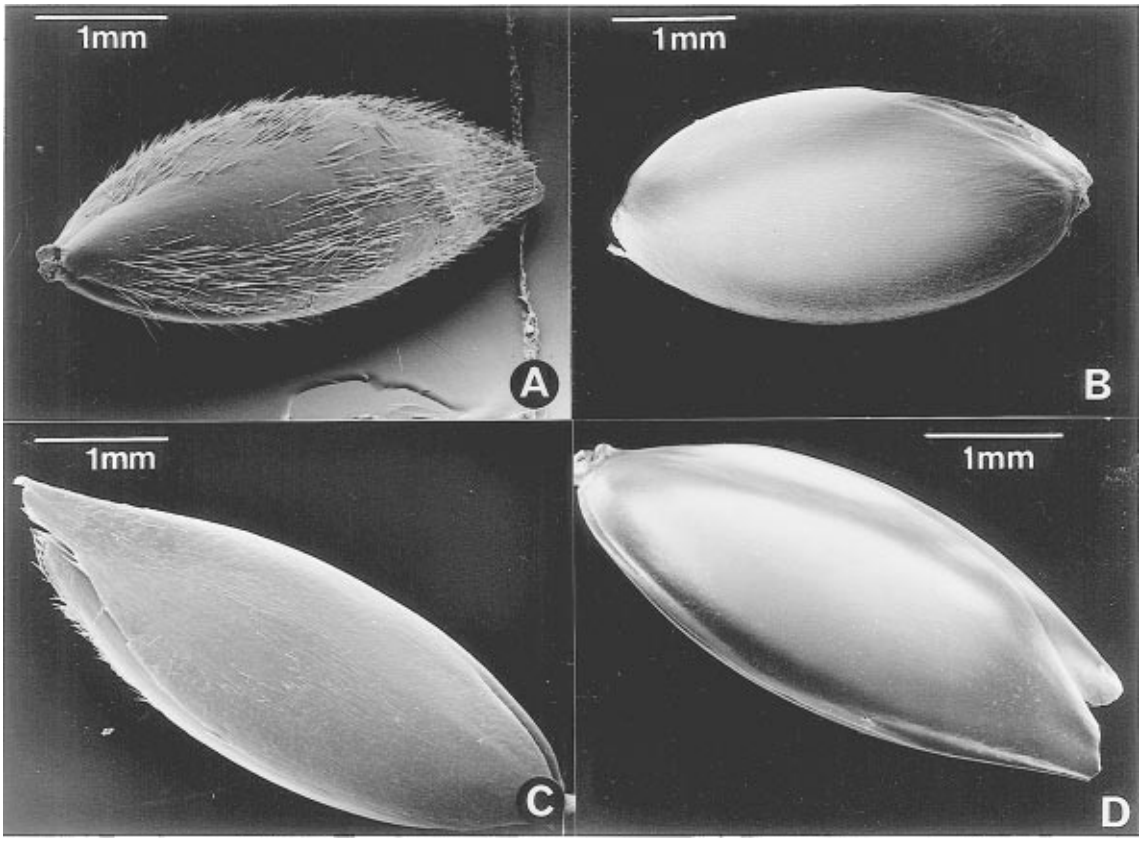

Figure 2. SEM photomicrographs of canaryseed grains: (A) hairy hulled grain; (B) hairy dehulled groat; (C) processed hairy hulled grain; and (D) hairless hulled cultivar developed by mutagenesis.

RESULTS AND DISCUSSION

Morphology of Canaryseed and Hairs. The morphological characteristics of canaryseed grain and groat are illustrated in Figure 2. The grains are very small, elliptical in shape, being approximately 4 mm in length and 1.5−2 mm in width. The average kernel weight was 7 mg, and the test weight averaged 63 kg/hL (Hucl et al., 1995). The canaryseed grain has an attached hull (lemma and palea), which is covered with numerous fine hairs (Figure 2A). The grains are readily dehulled, and the groats show no evidence of silicious hairs on the surface (Figure 2B), but the groat sample would be contaminated with hairs. The proportion of hulls in canaryseed grain was approximately 35%. The embryo appears on the dorsal side of the groat, having a narrow longitudinal shape.

In the development of canaryseed as a new food crop, two approaches were undertaken to eliminate the hairs. The first was to remove the hairs by a chemical/mechanical process, based on a hydrogen peroxide treatment (unpublished data). A chemically treated hairy hulled canaryseed is presented in Figure 2C, showing nearly complete digestion of the hairs. The second approach was to develop a glabrous cultivar through classical metagenesis with the mutagen sodium azide. A grain of the glabrous cultivar is presented in Figure 2D, showing absolutely no hairs on the lemma. Safety assessments of both the glabrous genotype and chemical treatment are being conducted, and the results will be submitted to Health Canada for approval of canaryseed as a food crop.

In regard to hair morphology, the intact grains were ashed to isolate the hairs that remained attached to the ashy residue of the hull. The resulting ash was examined and photographed by SEM (Figure 3). The hairs were needle-shaped, about 340 μm long and tapering from a diameter of 8−10 μm at the base to 1−2 μm at the tip (Figure 3A,B). These measurements were similar to those published by Newman and Mackay (1983). A natural fracture in the ashy residue of the hull was also examined and photographed by SEM (Figure 3C). It can be seen from this photomicrograph that the hull consisted of several cell layers and that the hairs emerged from the outer surface layer. The hair surface appeared very smooth. The hairs remained intact despite grinding of the ashy residue of the hull (Figure 3D).

Proximate Composition. The average protein concentration in Keet canaryseed groats grown at the three locations was 18.7% (N × 5.7) or 20.5% (N × 6.25), which exceeded that of HRS wheat by 25% (Table 1). The crude fat levels of 8.4−8.9% were very high for a cereal grain, being almost 4 times that of wheat. Starch was the major constituent of canaryseed groat, averaging 61.0% of the dry matter, quite comparable to wheat. Canaryseed groat contained slightly more ash but substantially less sugar, soluble and insoluble dietary fiber relative to wheat. Soluble and insoluble dietary fiber concentrations in canaryseed groats were approximately half of those in wheat. Total constituents of both grains averaged about 97%, indicating that other components were present such as polar lipids and phytate. Previously, Robinson (1978) reported that canarygrass caryopses were much higher in nitrogen, ash, oil, phosphorus, and potassium, but lower in fiber, than other grain crops. Location had only minor effects on the chemical composition of canaryseed groats except for protein, which was significantly lower in Elrose grains as compared to grains from the other locations.

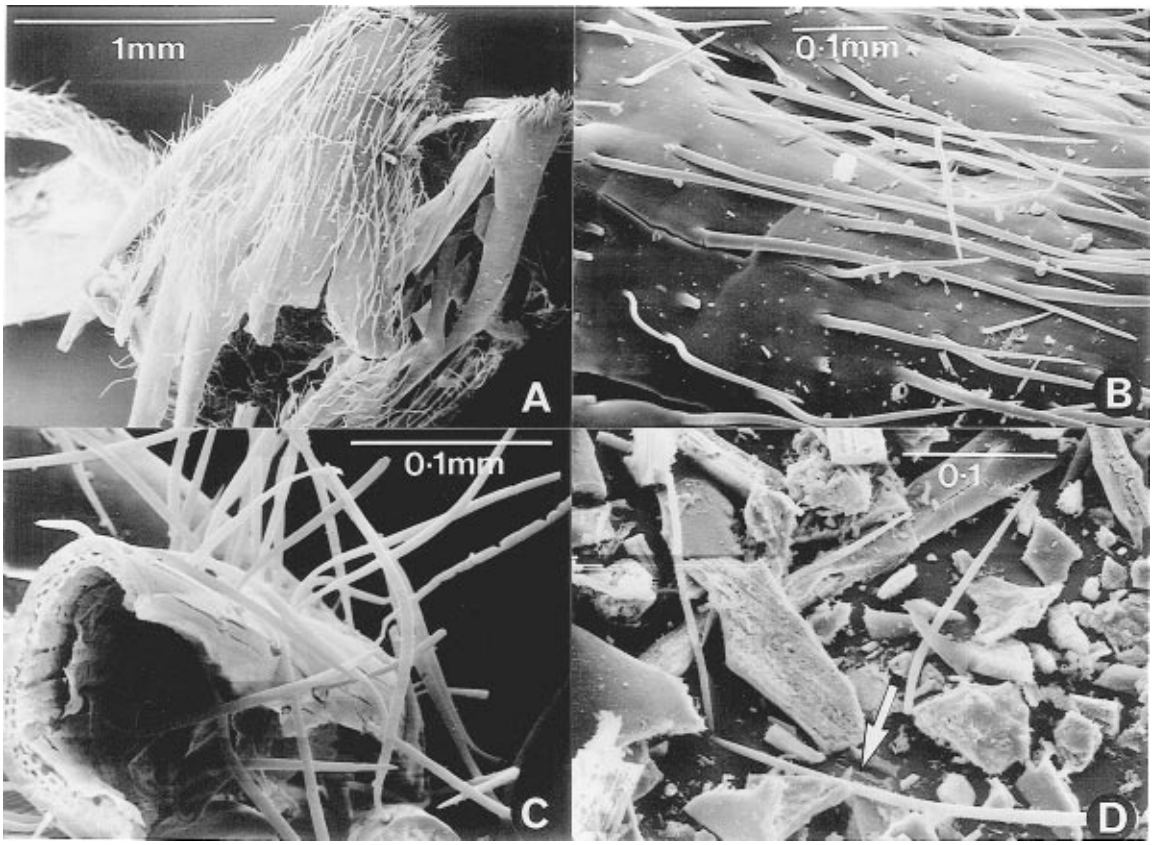

Figure 3. SEM photomicrographs of canaryseed hairs prepared by ashing of intact grains: (A) magnification 38×; (B) magnification 150×; (C) natural fracture; and (D) ground ash. (This figure is reproduced here at 67% of the original.)

Table 1. Chemical Composition of Canaryseed Groat and Wheat Grown at Three Sites in Central Saskatchewan (Percent Dry Basis)

location	crude protein (N × 5.7)	crude fat	total ash	soluble sugars	starch	soluble fiber	insoluble fiber	total constituents
				Canaryseed Groat				
Saskatoon	20.3	8.4	2.0	1.8	58.6	1.0	4.9	97.0
Kernen	20.1	8.9	2.1	1.8	59.9	0.9	5.6	99.3
Elrose	15.6	8.9	2.1	1.6	64.4	0.8	4.7	98.0
mean	18.7	8.7	2.1	1.7	61.0	0.9	5.1	98.1
SD ($n = 6$)	2.7	0.3	0.1	0.1	3.0	0.1	0.5	1.2
				Wheat Grain				
Saskatoon	16.8	2.3	1.7	3.2	61.1	2.1	10.4	97.6
Kernen	15.2	2.4	1.8	2.6	61.5	2.0	10.7	96.2
Elrose	12.9	2.3	1.7	2.6	63.3	2.1	10.5	95.4
mean	15.0	2.3	1.7	2.8	62.0	2.1	10.5	96.4
SD ($n = 6$)	2.0	0.1	0.1	0.3	1.2	0.1	0.2	1.1

Canaryseed groats from the Saskatoon test were roller milled into flour and bran. The microstructures of canaryseed flour and bran are presented in Figure 4, parts A and B, respectively. Canaryseed flour appeared as aggregates of starch granules embedded in a protein matrix that were clearly dissimilar to the structure of wheat flour (Evers and Bechtel, 1988). The particle sizes of the aggregates ranged from 25 to 35 μm. Canaryseed bran consisted of thin flakes about 0.3−1.0 mm in their longest diameter. Hairs were not present on the bran.

By fractionation of the groat into bran and flour components, with yields of 25% and 75%, respectively, starch was concentrated into the flour but the level of 67% was only a 10% increase over the concentration in the groat (Table 2). The protein distribution in the groats appeared to be relatively uniform since bran and flour were similar in protein concentration, over 20%. In addition to 35% starch content, bran contained a major proportion of the crude fat, and essentially all of the groat ash and soluble and insoluble fiber. Canaryseed flour contained 69% total carbohydrate that was essentially starch (96.4%); thus, the small polygonal granules would largely determine the principal food and industrial applications of the flour. With over 20% protein in flour, this component would also have a major influence on nutritional and functional properties. With 5.6% crude fat, the stability and functionality of flour would be dependent on the lipid and fatty acid compositions of this fraction. Canaryseed starch was isolated by wet milling and purified by washing with an alkaline solution. A photomicrograph of canaryseed starch is presented in Figure 4C. The starch granules were small and distinctly polygonal in shape, the granule diameters ranging from 1.5 to 3.5 μm.

Amino Acid Composition. The total amino acids in canaryseed groat, wheat grain, and casein proteins and non-protein nitrogenous constituents were determined after acid hydrolysis, and the concentrations are reported in grams per 100 g of protein (N × 5.7) in

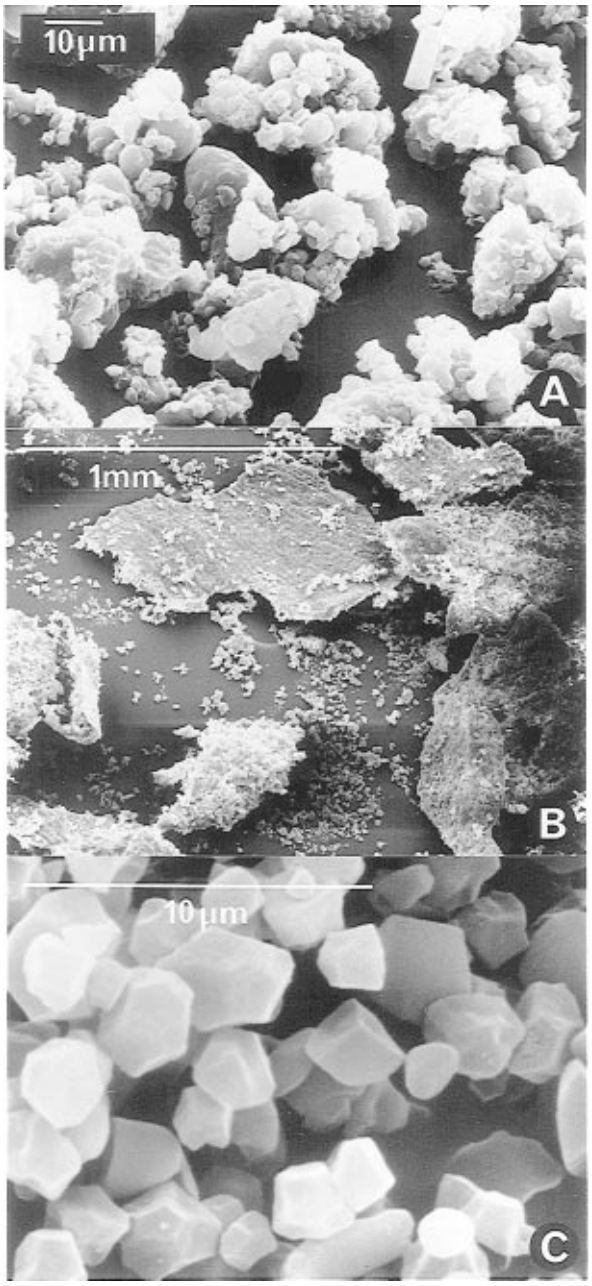

Figure 4. SEM photomicrographs of canaryseed groat products: (A) flour; (B) bran; and (C) starch.

Table 2. Chemical Composition of Canaryseed Bran and Flour (Percent Dry Basis)

constituent	bran	flour
yield (%)	25	75
starch	35.1 ± 0.9[a]	66.8 ± 1.5
protein (N × 5.7)	21.4 ± 0.6	20.2 ± 0.5
crude fat	12.7 ± 0.6	5.6 ± 0.2
ash	6.3 ± 0.3	0.7 ± 0.1
soluble sugars	1.8 ± 0.1	1.5 ± 0.1
soluble fiber	2.1 ± 0.1	0.1 ± 0.0
insoluble fiber	16.7 ± 0.4	0.9 ± 0.1
total digestible carbohydrate	36.9	68.3
total carbohydrate	55.7	69.3
total constituents	96.1	95.8

[a] Mean ± standard deviation ($n = 4$).

comparison with the FAO/WHO/UNU (1985) pattern (Table 3). Among the essential amino acids, wheat proteins are seriously deficient in lysine and moderately deficient in threonine relative to human and animal requirements. Canaryseed proteins contained only two-thirds of the lysine in wheat protein but were comparable to wheat in threonine level.

The methionine concentrations in canaryseed proteins were also comparable to that of wheat, which were only half of the levels in casein and the FAO standard (Table 3). The deficiency in this sulfur-containing amino acid is ameliorated by the presence of high concentrations of cystine, which is methionine-sparing during protein synthesis. The levels of cystine in canaryseed proteins averaged 3.3 g/100 g of protein, compared to 2.3 and 0.5 g/100 g, respectively, in wheat protein and casein.

Tryptophan is another essential amino acid that is commonly deficient in dietary protein sources, and the level in canaryseed protein was exceptionally high (Table 3). At 2.8 g/100 g of protein, canaryseed would be an excellent supplement or blending protein for other cereal (wheat at 1.2 g/100 g) or animal (casein at 1.0 g/100 g) protein sources that barely meet the FAO pattern of 1.1 g/100 g of protein. Tryptophan is labile to acid condition, and most investigators fail to conduct separate analyses for this important essential amino acid. Of the limited data available on tryptophan concentrations in canaryseed, Robinson (1978) reported 3.3 g/100 g of protein and Holt (1988) obtained 2.0 g/100 g of protein.

The total essential amino acids in canaryseed were in excess of that in wheat protein but well below the casein control (Table 3). The amino acid score was, unfortunately, very low since it is based on the concentration of the first limiting amino acid, lysine. The protein digestibility was 84.0%, on average, similar to that of wheat protein. Because amino acids are expressed in grams per 100 g of protein, there were few differences among the three locations in amino acid composition and their nutritive indices.

The high concentrations of cystine, tryptophan, phenylalanine, and arginine combined with low levels of lysine and proline suggest a unique protein structure and functionality for canaryseed proteins. The low concentration of lysine and high concentration of arginine provide a low lysine/arginine ratio that was found to be hypocholesterolemic in soybean protein (Kritchevsky, 1979). The ratio was 0.9 in soybean protein, and the value for canaryseed protein was 0.2 in the present study.

Protein Fractions. The proportions of canaryseed and wheat protein fractions, based on their solubility in water, salt, alcohol and alkali, are reported in Table 4. The albumin and globulin fractions occurred in low concentrations in canaryseed, well below the levels in wheat protein. This may reflect low levels of enzymes and antinutrients in canaryseed groats. Prolamins were the major storage proteins in canaryseed, averaging 45.5% of total protein, compared to 37.1% for wheat protein. The total prolamin and glutelin constituted 78% of the total canaryseed protein. The prolamin to glutelin ratios in canaryseed of 1.4 were higher than that of wheat (1.0), indicating that, in total, canaryseed flour has the potential to produce high-viscosity dough. The high prolamin contents in canaryseed groat proteins would not be predicted from its low proline contents, and further studies are needed on this fraction. There were marked differences in proportions of the protein fractions among locations, especially in prolamin and glutelin proteins.

Fatty Acid Composition. The total lipids and other materials extracted with chloroform/methanol (2:1 v/v) were 15.9% of canaryseed groat but only 4.4% of wheat

Table 3. Amino Acid (AA) Composition (Grams of AA/100 g of Protein) and Chemical Nutritive Indices of Canaryseed Groat Grown at Three Sites in Central Saskatchewan in Comparison with Wheat and Casein

	canaryseed groat						
AA	Saskatoon	Kernen	Elrose	mean ± SD	wheat	casein	FAO pattern[a]
lysine	1.1	1.3	1.4	1.3 ± 0.15	1.9	7.2	5.8
methionine	1.5	1.3	1.5	1.4 ± 0.12	1.4	2.8	2.5
cystine	3.2	3.3	3.3	3.3 ± 0.06	2.3	0.5	
threonine	2.8	2.7	2.7	2.7 ± 0.06	2.8	4.0	3.4
tryptophan	2.6	2.7	3.1	2.8 ± 0.26	1.2	1.0	1.1
isoleucine	3.5	3.6	3.5	3.5 ± 0.06	2.8	4.5	2.8
leucine	7.0	7.1	7.0	7.0 ± 0.06	5.3	8.7	6.6
valine	4.8	4.5	4.6	4.6 ± 0.15	3.8	6.0	3.5
phenylalanine	6.5	7.1	6.4	6.7 ± 0.38	5.4	4.8	6.3
tyrosine	3.3	3.2	3.2	3.2 ± 0.06	3.5	5.1	
histidine	1.7	1.7	1.9	1.8 ± 0.12	2.1	2.6	1.9
alanine	4.1	4.1	4.2	4.1 ± 0.06	3.0	2.6	
arginine	7.0	7.0	6.8	6.9 ± 0.12	5.1	3.7	
aspartic acid	4.5	4.6	4.6	4.6 ± 0.06	4.4	7.4	
glutamic acid	30.8	30.4	30.7	30.6 ± 0.21	33.0	20.2	
glycine	3.0	3.0	3.1	3.0 ± 0.06	3.8	1.7	
proline	5.4	5.3	5.4	5.4 ± 0.06	8.6	9.5	
serine	4.2	4.2	4.1	4.2 ± 0.06	4.3	5.0	
total essential AA	38.0	38.5	38.6	38.4 ± 0.32	32.5	47.2	33.9
total AA	97.0	97.1	97.5	97.2 ± 0.26	94.7	97.3	
AA score[a]	19 (Lys)	22 (Lys)	24 (Lys)	22 ± 2.5	33 (Lys)	91 (Try)	100
protein[b] (% WB)	18.2	18.6	14.0	16.9 ± 2.5	15.0	92.5	
PD[c] (%)	84.1	83.3	84.7	84.0 ± 0.7	86.6	97.6	

[a] Amino acid score is based on FAO/WHO/UNU (1985) pattern for preschool child (2−5 years). [b] N × 5.7. [c] Protein digestibility.

Table 4. Protein Fractions of Canaryseed Groat and Wheat Grain Grown at Three Sites in Central Saskatchewan (Percent Dry Basis)

	albumin		globulin		prolamin		glutelin		residual protein[a]	
protein source	protein (%)	% of total protein	protein (%)	% of total protein	protein (%)	% of total protein	protein (%)	% of total protein	protein (%)	% of total protein
canaryseed groat										
Saskatoon	0.99	4.9	1.58	7.8	8.62	42.6	7.60	37.5	1.46	7.2
Kernen	1.07	5.3	1.42	7.1	9.35	46.6	5.90	29.4	2.32	11.6
Elrose	1.06	6.8	1.14	7.3	7.39	47.4	4.63	29.7	1.38	8.8
mean	1.04	5.7	1.38	7.4	8.45	45.5	6.04	32.2	1.72	9.2
SD ($n = 6$)	0.04	1.0	0.22	0.4	0.99	2.6	1.49	4.6	0.52	2.2
wheat grain	2.23	13.2	1.74	10.4	6.24	37.1	6.12	36.4	0.51	3.0

[a] By difference.

Table 5. Lipid and Fatty Acid (FA) Compositions of Canaryseed Groat and Wheat Grain Grown at Three Sites[a] in Central Saskatchewan (Percent Dry Basis)

	crude total lipid					purified total lipid					crude fat				
	canaryseed groat					canaryseed groat					canaryseed groat				
lipid class	S	K	E	mean ± SD	wheat	S	K	E	mean ± SD	wheat	S	K	E	mean ± SD	wheat
total	15.7	15.8	16.2	15.9 ± 0.3	4.4	11.5	10.6	11.0	11.0 ± 0.5	2.6	8.4	8.9	8.9	8.7 ± 0.3	2.3
FA (% of total FA)															
myristic	0.0	0.1	0.0	0.1 ± 0.06	0.0	0.2	0.2	0.1	0.2 ± 0.06	0.0	0.2	0.2	0.1	0.2 ± 0.06	0.2
palmitic	12.0	10.0	10.8	10.9 ± 1.00	16.6	10.9	11.4	11.3	11.2 ± 0.30	15.9	11.0	10.6	10.5	10.7 ± 0.30	15.8
stearic	1.1	1.1	0.9	1.0 ± 0.10	0.8	1.1	0.9	0.9	1.0 ± 0.10	0.9	1.1	1.0	1.0	1.0 ± 0.10	0.8
oleic	30.2	28.2	29.5	29.3 ± 1.00	16.2	30.2	29.0	29.4	29.5 ± 0.60	16.9	29.8	28.2	29.4	29.1 ± 0.80	16.6
linoleic	53.5	56.6	55.3	55.1 ± 1.60	62.1	54.1	55.1	55.1	54.8 ± 0.60	61.5	54.5	56.4	55.4	55.4 ± 1.00	61.2
linolenic	2.3	2.8	2.5	2.5 ± 0.30	4.0	2.4	2.6	2.5	2.5 ± 0.10	3.9	2.5	2.9	2.7	2.7 ± 0.20	4.6
arachidic	0.0	0.1	0.1	0.07 ± 0.06	0.0	0.1	0.0	0.1	0.07 ± 0.06	0.0	0.1	0.0	0.1	0.07 ± 0.06	0.0
unknown	0.9	0.8	0.9	0.9 ± 0.06	0.4	1.0	0.9	0.8	0.9 ± 0.10	0.8	0.9	0.8	0.9	0.9 ± 0.06	0.7
behenic	0.1	0.1	0.0	0.07 ± 0.06	0.0	0.1	0.0	0.1	0.07 ± 0.06	0.1	0.1	0.1	0.0	0.07 ± 0.06	0.2
erucic	0.1	0.1	0.0	0.07 ± 0.06	0.0	0.1	0.0	0.1	0.07 ± 0.06	0.0	0.1	0.0	0.1	0.07 ± 0.06	0.0

[a] S, Saskatoon; K, Kernen; E, Elrose.

grain (Table 5). After purification with calcium chloride solution to remove the non-lipid components, the purified total lipid in canaryseed averaged 11.0% compared to 2.6% of wheat. Clearly, the total lipids in canaryseed are a very major component of the groat, of which a high proportion was polar lipids that were not extracted with the nonpolar solvent, diethyl ether, that extracted only 8.7% crude fat. As for protein fractions, detailed evaluations of the polar lipids have been undertaken.

Despite the large differences in yield of lipids with the two solvent systems, the fatty acid compositions were similar in the three extracts (Table 5). Also, differences between locations were relatively small, as evidenced by the low standard deviations. Essentially, canaryseed lipids contained 55% linoleic, 29% oleic, 11% palmitic, 2.5% linolenic, and 1% stearic acids. The pattern for wheat lipids was 62% linoleic, 17% oleic, 16% palmitic, 4% linolenic, and 1% stearic acids. Both lipids

Table 6. Sugar Composition of Canaryseed Groat Grown at Three Sites in Central Saskatchewan (Percent Dry Basis)

sugar	retention time (min)	Saskatoon	Kernen	Elrose	mean ± SD
arabinose	4.8	tr[a]	tr	tr	tr
fructose	8.2	0.07	0.09	0.05	0.07 ± 0.02
glucose	8.8	0.05	0.05	0.07	0.06 ± 0.01
unknown	10.1	0.37	0.41	0.31	0.36 ± 0.05
unknown	10.5	0.31	0.28	0.33	0.31 ± 0.03
unknown	13.2	0.12	0.10	0.14	0.12 ± 0.02
sucrose	13.9	0.83	0.89	0.77	0.83 ± 0.06
total		1.75	1.82	1.67	1.75 ± 0.08

[a] tr, traces.

were highly unsaturated and potentially subject to rapid rancidity. However, canaryseed lipid had a higher ratio of unsaturated to saturated fatty acids, 7.5, than the 5.0 obtained for wheat lipids. On the other hand, canaryseed lipids contained less polyunsaturated fatty acids, 57.5%, than the 68% for wheat lipids. The present data on fatty acid composition of canaryseed lipids are consistent with the findings of Malik and Williams (1966).

Sugar Composition. Sucrose was the major soluble sugar in canaryseed, constituting about 47% of total soluble sugars (Table 6). The wheat kernel was also found to contain from 0.7% to 1.5% sucrose with only 0.1% in the flour (Lineback and Rasper, 1988). Fructose and glucose were present in very small concentrations (<0.1%) in the canaryseed meal. In addition, two unknown sugars were found at levels of 0.4% and 0.3%. These unknowns were likely monosaccharides or their derivatives on the basis of their retention times. A third unknown sugar was recovered with a retention time of 13.2 min and concentration of about 0.1%. The latter sugar was likely a disaccharide or a derivative as indicated by its retention time. The total soluble sugars in canaryseed groat was about 1.8%, a level that would be too low to have a major effect on storage of canaryseed or utilization of the flour.

Conclusions. SEM of control and chemically treated canaryseed and a glabrous genotype, and their respective ash samples, demonstrated that the hulls were free of silicious spicules. Roller milling the groat was effective in separation of dietary fiber and ash into the bran fraction, but the flour was similar to groats in protein content and the high starch concentration was only increased by 10%. The starch granules were small and distinctly polygonal in shape, with diameters ranging from 1.5 to 3.5 μm, which could complement the starches currently available on the market. The high protein contents (average 18.7%) and predominance of prolamin and glutelin fractions (78%) in the proteins suggest unique functional properties. Canaryseed proteins were very low in lysine and threonine but were exceptionally rich in tryptophan, cystine, and phenylalanine, which could be important in nutritional protein blends. The high contents of polar and nonpolar lipids could be valuable byproducts of component-extracted canaryseed. Their high compositions of polyunsaturated fatty acids are reported to be stabilized by antioxidants such as esters of caffeic acid.

ABBREVIATIONS USED

FAO/WHO/UNU, Food and Agriculture Organization/World Health Organization/United Nations University; HPLC, high-performance liquid chromatography; HRS, hard red spring; SEM, scanning electron microscope; STOX, oxime, internal standard reagent for sugar determination.

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