

Soluble and Insoluble Dietary Fiber Content and Composition in Oat

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ABSTRACT

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Six oat genotypes were grown in nursery yield trials during 1989–1992 at Lisbon, ND. Groats were analyzed for soluble and insoluble dietary fiber content and composition. Genotype-by-growing year interaction was not significant for soluble or insoluble dietary fiber. Soluble and insoluble dietary fiber differed with genotype (6.0–7.1% and 4.1–4.9%, respectively) and with growing year (6.0–6.9% and 3.9–5.2%, respectively). The genotype-by-growing year interaction was significant for soluble β -glucan content but not for total neutral sugar or uronic acid content of the soluble dietary fiber. Genotypes did vary in total neutral sugar content but not in uronic acid content. The genotype-by-growing year interaction was

not significant for total neutral sugar, β -glucan, uronic acid, or Klason lignin content of insoluble dietary fiber. Genotypes did vary in total neutral sugar, β -glucan, and Klason lignin content but not in uronic acid content of insoluble dietary fiber. The neutral sugar content of soluble dietary fiber was composed of glucose, arabinose, xylose, and galactose. The neutral sugar content of insoluble fiber was composed of glucose, arabinose, and xylose. The content and composition of soluble and insoluble dietary fiber varied with oat genotype. Therefore, oat genotypes could be bred for specific dietary fiber content and composition.

The health benefits from consumption of dietary fiber from cereal grain has increased interest in oat dietary fiber. Dietary fiber is the portion of plant cells that is not digested in the human small intestine and can affect utilization of food by the body. Physiological effects of dietary fiber partly depend on the extent of fermentation in the large intestine, and this is influenced by chemical composition and physical form, such as solubility, of the fiber (Stephen 1994).

Dietary fiber can be subdivided into water-soluble and water-insoluble fractions. Water-soluble fiber in cereals is composed of nonstarchy polysaccharides such as β -glucan and arabinoxylan. Water-soluble dietary fiber can form viscous solutions. Increased viscosity in the intestine slows intestinal transit, delays gastric emptying (Wisker et al 1985, Anderson and Chen 1986), and slows glucose and sterol absorption by the intestine (Wood et al 1990, Wood 1991, Kahlon and Chow 1997). Viscous soluble fiber can lower serum cholesterol, postprandial blood glucose, and insulin levels. Insoluble fiber contains lignin as well as nonstarchy polysaccharides. Lignin is not a polysaccharide but is a lipophilic phenolic polymer that can absorb bile acids. Insoluble dietary fibers usually have high water-holding capacity which contributes to increased fecal bulk.

Soluble and insoluble dietary fiber content has been shown to be affected by genotype and environment for barley (Aalto et al 1988), potatoes (Mullin et al 1993), and durum wheat (Kunerth and Youngs 1984). β -Glucan, a component of both the soluble and insoluble dietary fiber of oats, has been reported to vary with genotype and growing environment for oat (Peterson 1991, Saastamoinen et al 1992, Longland and Valentine 1993, Brunner and Freed 1994). Soluble β -glucan content of oat varied with genotype and environment (Longland and Valentine 1993). However, the ratio of soluble to total β -glucan was not affected by genotype or by environment (Lee et al 1997). Miller et al (1993) reported that variation in β -glucan content of oat was due more to genetics than to the environment. There is little information concerning the effect of genotype and growing environment on other components of oat dietary fiber.

The effect of genotype, environment, and their interaction on dietary fiber content and composition of oat groats would be useful information when breeding oat for human consumption. Those traits that vary with genotype but lack a significant genotype-by-environment interaction could be selected at one location. This

research was conducted to determine the soluble and insoluble dietary fiber content and composition of groats from six oat genotypes grown in four years.

MATERIALS AND METHODS

Grain Samples

Oats were supplied by M. McMullen, North Dakota State University, Fargo, ND. The agronomic performance of oat genotypes was evaluated in yield trial experiments conducted at Lisbon, ND, in 1989, 1990, 1991, and 1992. Oat samples were stored in a cool dry storage facility until after the 1992 harvest. All oat samples were processed at the same time. Oat hulls were removed with an impact dehuller (Quaker Oats Company, Barrington, IL). Groats were milled in a centrifugal mill (Retsch model ZM-1, Brinkman Instruments, Westbury, NY) through a 0.5-mm screen.

Fiber Isolation

Dietary fiber composition was determined by a modification of the methods of Theander and Westerlund (1986) and Shinnick et al (1988). Extractive free residue was prepared from 11 g of ground material by sonication, followed by centrifugation and vacuum filtration (Whatman No. 54). Samples were extracted twice with 80% ethanol to remove free sugars and twice with petroleum ether to remove lipids. Air-dried extracted samples were ground with a mortar and pestle.

Extractive free residue (5 g) was weighed into a glass screw-capped centrifuge container and incubated at 100°C with Termamyl (A0164, Sigma Chemical Co., St. Louis, MO) and 70 mL of 0.1M sodium acetate, pH 5.0, containing 70 ppm of Ca from CaCO₃ for 45 min. Samples were mixed thoroughly at 0, 15, and 30 min during the

TABLE I
Mean Soluble, Insoluble, and Total Dietary Fiber Content (% db) of Six Oat Genotypes, Averaged Across Growing Years 1989–1992

Genotype	Dietary Fiber		
	Soluble	Insoluble	Total ^a
Dumont	4.3	6.1	10.4
Hyttest	4.1	6.6	10.7
Marion	4.9	7.1	12.1
Monida	4.5	6.6	11.0
Otana	4.4	6.0	10.4
Valley	4.2	6.1	10.2
LSD ^b	0.3	0.5	0.6

^a Sum of soluble and insoluble dietary fiber.

^b Least significant difference at $P = 0.05$ level of probability.

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incubation. Samples were cooled to 50°C and amyloglucosidase (A9913, Sigma Chemical Co., St. Louis, MO) was added to the samples. The incubation solution was mixed thoroughly and placed in a shaking water bath at 50°C overnight.

The samples were cooled to room temperature, centrifuged at 2,500 × g for 15 min, and vacuum-filtered (Whatman No. 54). The pellet was washed with 70 mL of distilled water, sonicated 5 min, centrifuged, and vacuum-filtered. The original filtrate and wash filtrate were pooled and dialyzed against distilled water (4 L) for 48 hr, changing the water every 12 hr. The dialysate was freeze-dried and weighed (soluble fraction). The pellet was washed twice in 50 mL of 100% ethanol and once in acetone. Each wash was followed by 10 min of centrifugation at 2,500 × g, and vacuum filtration. The supernatant was discarded. The remaining pellet was dried at 50°C overnight, cooled to room temperature, and weighed (insoluble fraction).

Soluble and insoluble dietary fiber was corrected for residual starch and protein. Residual starch was quantified using 50 mg of soluble or 100 mg of insoluble fiber using Approved Method 76-11 (AACC 1995) for starch analysis. Protein content of soluble and insoluble fiber fraction was determined on 150-mg samples by the combustion method (Approved Method 46-30, AACC 1995) using N × 6.25 as the conversion factor.

Fiber Composition

β-Glucan content of soluble and insoluble fiber fractions was determined on 100-mg samples by the enzymatic method of McCleary and Codd (1991). Uronic acid content was determined on 100-mg samples using the colorimetric method of Blumenkrantz and Asboe-Hansen (1973), with D-galacturonic acid as the standard. Lignin was measured as Klason lignin from 150-mg samples by the gravimetric method described by Flint and Camire (1992). Klason lignin is the fiber material not soluble in 12M sulfuric acid.

Neutral sugars were quantified by gas chromatography as alditol acetates. Myo-inositol (100 μg) was added to each sample as the internal standard. A standard mixture containing arabinose, galactose, glucose, mannose, ribose, and xylose was prepared. Samples (5 mg) and the standard mixture were hydrolyzed with 250 μL of 2M trifluoroacetic acid at 121°C for 1 hr. Samples were evaporated to dryness and reduced to alditols with 100 μL of 1M ammonium hydroxide and 500 mL of sodium borohydride in dimethylsulfoxide (20 mg/mL) at 40°C for 1.5 hr. Samples were neutralized with 0.3 mL of glacial

acetic acid. Samples were O-acetylated by 100 μL of 1-methylimidazole and 500 μL of acetic anhydride for 10 min. The per-O-acetylated alditols were partitioned three times in methylene chloride, dried, and redissolved in acetone. An HP5890 Series II gas chromatograph (Hewlett Packard, Inc., Palo Alto, CA) fitted with a flame ionization detector and equipped with a SP-2380 fused silica capillary column, 30 m × 0.25 mm i.d., and 0.2-μm film thickness (Supelco, Inc., Bellefonte, PA) was used for analysis at oven temperature 230°C, injector temperature 275°C, and carrier gas (helium) flow rate 44.7 mL/min.

Relative response factors were calculated from the peak area of each standard sugar derivative. Neutral sugars in the samples were identified by comparison to the retention times of the sugar standards. Sugars were expressed as the normalized percent using internal standard, and corrected to anhydro-sugar values where appropriate.

Statistical Analysis

The experimental design was a randomized complete block with a split-plot arrangement where the whole plot was growing year and subplot was genotype. Each experimental unit had three replicates. Each field replicate was kept separate for all analyses and each analysis was conducted in duplicate. Data were subjected to analysis of variance (ANOVA). Means were separated using Fisher's protected least significant difference (LSD) test at P = 0.05. Comparison of the growing year main effect was not possible because one location per growing year did not allow measurement of error associated with growing year. All quantitative results are expressed on a dry moisture basis.

RESULTS AND DISCUSSION

Genotype-by-growing year interaction was not significant for soluble, insoluble, or total dietary fiber. However, genotypes differed in soluble (4.1–4.9%), insoluble (6.0–7.1%), and total dietary fiber content (10.2–12.1%) (Table I). These values are similar to those reported by other researchers (Anderson and Bridges 1988, Vollendorf and Marlett 1991). Marion had a markedly greater soluble, insoluble, and total dietary fiber content than did the other oat genotypes. Genotype variation in fiber content indicates that oats could be selected for improved dietary fiber content. The lack of genotype-by-growing year interaction indicates that genotype evaluation for dietary fiber content could be evaluated at one location.

Total dietary fiber content averaged across genotypes was 11.1% for 1989, 10.8% for 1990, 10.5% for 1991, and 10.8% for 1992

TABLE II
Chemical Components of Soluble Dietary Fiber (% db) in Six Oat Genotypes Averaged Across Growing Years 1989–1992

Genotype	Neutral Sugars			Total
	Total ^a	β-Glucan	Uronic Acids	
Dumont	4.2	3.5	0.1	4.3
Hyttest	4.0	3.2	0.1	4.1
Marion	4.8	3.9	0.1	4.9
Monida	4.4	3.7	0.1	4.5
Otana	4.2	3.5	0.1	4.4
Valley	4.0	3.3	0.1	4.2
LSD ^b	0.3	0.3	ns ^c	

^a Total neutral sugars includes β-glucans.

^b Least significant difference at P = 0.05 level of probability.

^c Not significant.

TABLE III
β-Glucan Content (% db) in Soluble Dietary Fiber as Influenced by Genotype and Growing Year

Genotype	Growing Year			
	1989	1990	1991	1992
Dumont	4.1	4.1	3.0	2.9
Hyttest	3.7	3.0	2.7	3.2
Marion	4.3	4.2	3.5	3.6
Monida	4.7	3.7	3.3	3.1
Otana	4.2	3.3	3.1	3.2
Valley	4.4	3.1	3.1	2.6
LSD ^a		0.5		

^a Least significant difference at P = 0.05 level of probability.

TABLE IV
Monthly Precipitation and Mean Temperature at Lisbon, ND

Month	Precipitation (cm)				Temperature (°C)			
	1989	1990	1991	1992	1989	1990	1991	1992
May	7.0	0.7	9.8	15.4	13.5	18.5	20.1	15.3
June	6.1	11.2	10.0	13.6	17.2	20.0	21.0	16.1
July	8.1	2.6	1.7	6.2	23.2	20.3	22.0	17.1

(data not shown). These data indicate little or no differences among growing years for total dietary fiber. Aalto et al (1988) reported that growing location did not have a significant effect on the total fiber content of 2- or 6-row barley grown in Finland. Soluble and insoluble dietary fiber content averaged across genotypes for each growing year ranged from 3.9 to 5.2% and from 6.0 to 6.9%, respectively, indicating possible effect of growing season (data not shown).

Soluble dietary fiber is composed of neutral sugars and uronic acid (Table II). Total neutral sugars accounted for 98% of the total soluble dietary fiber. β -Glucan accounted for at least 80% of the total neutral sugars in the soluble dietary fiber. Total neutral sugar and β -glucan content of the soluble dietary fiber was greatest with Marion; intermediate with Dumont, Monida, and Otana; and least with Hystest and Valley. Uronic acid content represented a minor component of soluble dietary fiber and did not vary with genotype. The low uronic acid content in the soluble dietary fiber is similar to that reported by other researchers (Anderson and Bridges 1988, Shinnick et al 1988, Vollendorf and Marlett 1991).

Genotype-by-growing year interaction was significant for soluble β -glucan content but not for total neutral sugar or uronic acid content. Soluble β -glucan content of these genotypes varied from 0.8 percentage units in 1991 to 1.2 percentage units in 1990 (Table III). The range in β -glucan content for growing year varied from 0.8 percentage units for Marion to 1.8 percentage units for Valley. These data indicate that the effect of growing year on β -glucan content varied with genotype.

For a given genotype, soluble β -glucan content was greater when grown in 1989 than in 1991 or 1992 (Table III). Soluble β -glucan content of oat reportedly varies with genotype and environment (Åman and Graham 1987, Longland and Valentine 1993). β -Glucan content has been associated negatively with precipitation (Miller et al 1993, Brunner and Freed 1994) and positively with air temperature (Saastamoinen et al 1992, Miller et al 1993, Saastamoinen 1995). A drought occurred during the 1988 growing season which greatly depleted the subsoil moisture available for the 1989 crop. Precipitation during the 1989 growing season was similar to that of 1991 but less than that of 1992 growing season (Table IV).

TABLE V
Chemical Components of Insoluble Dietary Fiber (% db) in Six Oat Genotypes Averaged Across Growing Years 1989–1992

Genotype	Neutral Sugars		Uronic Acids	Klason Lignin	Total
	Total ^a	β -Glucan			
Dumont	3.0	1.4	0.5	2.6	6.1
Hystest	3.4	1.5	0.4	2.7	6.6
Marion	3.8	1.7	0.5	2.8	7.2
Monida	3.2	1.5	0.5	2.8	6.5
Otana	2.8	1.2	0.5	2.7	6.0
Valley	2.9	1.3	0.5	2.7	6.1
LSD ^b	0.5	0.1	ns	0.1	

^a Total neutral sugars include β -glucans.

^b Least significant difference at $P = 0.05$ level of probability; ns = not significant.

Furthermore, the mean daily air temperature was higher in 1989 than in the 1992 growing season. Thus, the greater soluble β -glucan content in oat grown in 1989 than in 1991 and 1992 might be related to the relatively low precipitation and resultant low soil moisture and high air temperature in 1989 as compared to 1991 and 1992. Information on the timing of high or low temperature or precipitation relative to developmental stage of the groat would be needed to make more definitive statement concerning soluble β -glucan content and environment.

Insoluble dietary fiber contains nonstarchy polysaccharides and Klason lignin (Table V). Klason lignin is a noncarbohydrate part of dietary fiber and can consist of lignin, modified lignin, unavailable cell wall protein, polymers originating from Maillard reactions, and tannin-protein complexes (Theander et al 1993).

Genotype-by-growing year interaction was not significant for any of the insoluble dietary fiber components. Insoluble dietary fiber was composed of $\approx 50\%$ neutral sugars, 43% Klason lignin, and 7% uronic acid (Table V). β -Glucan accounted for at least 42% of the total neutral sugars found in the insoluble dietary fiber fraction. Uronic acid content did not vary significantly with genotype. Insoluble fiber contained more uronic acid than did the soluble fiber (Tables II and V). These data are in agreement with other research that reported more uronic acid in the insoluble than in the soluble dietary fiber of oat groats (Vollendorf and Marlett 1991).

Genotypes varied in total neutral sugar, β -glucan, and Klason lignin content (Table V). Marion had the greatest insoluble total neutral sugar content, while Valley and Otana had the least. β -Glucan content was greater in soluble ($\approx 3.5\%$) than in the insoluble fiber ($\approx 1.4\%$) (Tables II and V). Oats contain a greater proportion of soluble than insoluble β -glucan (Åman and Graham 1987, Lee et al 1997). Longland and Valentine (1993) reported 67–87% of total β -glucan was soluble and the concentration varied with genotype and environment. Klason lignin was greatest with Marion and Monida; intermediate with Hystest, Otana, and Valley; and least with Dumont. Values for Klason lignin were similar to those reported by Vollendorf and Marlett (1991), Shinnick et al (1988), and Anderson and Bridges (1988).

Differences occurred among oat genotypes in their proportion of various neutral sugars in the soluble and insoluble fiber (Table VI). Soluble dietary fiber was composed primarily of glucose, with intermediate amounts of arabinose, galactose, and xylose, and minor amounts of mannose and ribose. Insoluble fiber was composed primarily of arabinose, glucose, and xylose, with small quantities of galactose, mannose, and ribose. MacArthur and D'Appolonia (1980) reported the presence of galactose in water-soluble and insoluble nonstarchy polysaccharide of oat, with a greater proportion of galactose in the water-soluble fraction than in the water-insoluble fraction.

The β -glucan content of soluble and insoluble fiber accounts for the glucose content in these fractions. The relative content of glucose (≈ 64.7 or 58.2% as anhydro-glucose) in the soluble dietary fiber fraction (Table VI) is 24.2 percentage units lower than what would be expected based on the amount of β -glucan ($\approx 82.4\%$ anhydro-glucose) in the total neutral sugars of the soluble dietary fiber

TABLE VI
Composition of Total Neutral Sugars in the Soluble and Insoluble Fiber Fractions of Oat Groats

	Soluble Fiber Fraction						Insoluble Fiber Fraction					
	Arabinose	Galactose	Glucose	Mannose	Ribose	Xylose	Arabinose	Galactose	Glucose	Mannose	Ribose	Xylose
Dumont	15.2	10.6	64.6	1.9	1.4	6.4	20.6	2.5	39.9	2.6	2.2	32.1
Hystest	13.7	8.1	67.1	2.2	1.2	8.0	22.1	2.3	41.3	2.7	2.4	29.2
Marion	13.5	8.2	68.8	0.6	1.2	7.7	20.0	2.2	42.7	2.7	1.8	30.6
Monida	16.7	10.3	62.0	1.3	1.4	8.2	20.3	2.4	43.5	2.6	2.0	29.2
Otana	15.1	9.7	63.5	1.4	1.3	9.0	22.3	2.7	37.4	2.9	2.3	32.4
Valley	16.0	9.8	62.3	1.6	1.4	8.9	21.9	2.5	40.6	2.8	2.3	29.9
LSD ^a	1.2	0.6	2.7	0.4	0.2	0.9	0.8	0.3	3.4	ns	0.3	ns

^a Least significant difference at $P = 0.05$ level of probability; ns = not significant.

(Table II). Similarly, the relative content of glucose (≈ 40.9 or 36.8% as anhydro-glucose) in the insoluble dietary fiber fraction (Table VI) is 8.2 percentage units lower than what would be expected based on the amount of β -glucan ($\approx 45\%$ anhydro-glucose) in the total neutral sugars of the insoluble dietary fiber (Table V). These discrepancies might be due to incomplete hydrolysis by the trifluoroacetic acid (Henry 1986). Thus, the relative proportion of glucose in the soluble and insoluble fiber fractions is probably underreported and the relative proportion of the other sugars overreported. The composition of the total neutral sugars indicates that soluble fiber contains β -glucan, arabinoxylan, and arabinogalactan, and the insoluble fiber contains β -glucan and arabinoxylan.

CONCLUSIONS

Oat is an excellent source of dietary fiber. The genotypes evaluated contained 10.2–12.1% total dietary fiber. Soluble fiber accounted for $\approx 40\%$ of the total dietary fiber. Much of the healthful effects of dietary fiber have been associated with soluble fiber (Wood et al 1990, Wood 1991, Kahlon and Chow 1997).

Genotype and genotype-by-growing year interaction was not significant for soluble or insoluble uronic acid content. Genotype-by-growing year interaction was significant only for soluble β -glucan content. Soluble, insoluble, and total dietary fiber content, and total soluble and insoluble neutral sugar, insoluble β -glucan, and lignin content varied with oat genotype. A significant genotype and a nonsignificant genotype-by-growing year interaction indicates that the genotype rank for a given component was similar for each growing year. Thus, oats could be selected for these dietary fiber components at a single location.

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