

Antioxidant Activity and Phenolic Contents of Oat Groats and Hulls

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ABSTRACT

Research was initiated to measure antioxidant activity of extracts from oat (*Avena sativa* L.) groats and hulls and the concentrations of phenolic substances that may contribute to antioxidant activity. Antioxidant activity of ethanolic extracts of four cultivars was evaluated by an in vitro assay that measures the inhibition of coupled autoxidation of linoleic acid and β -carotene. Total phenolic content was determined using Folin and Ciocalteu's phenol reagent and was expressed as gallic acid equivalents. Phenolic compounds were separated by reversed-phase HPLC and detected at 290 nm. Peaks were identified by comparing retention times and spectra with known standards and verified with internal standards. Groats had

significantly higher antioxidant activity than hulls. For two cultivars, total phenolic content was similar in groats and hulls, whereas one cultivar had higher and another lower total phenolic content in groats than hulls. Ten phenolic compounds were separated and identified in extracts, and one flavan-3-ol and three avenanthramides were tentatively identified. The concentrations of many of these compounds differed among cultivars and between fractions. In general, caffeic acid and the avenanthramides were predominantly found in groats, whereas many of the other phenolics were present in greater concentrations in hulls.

Phenolic compounds present in oats may contribute to functional and nutritional properties of the grain. It is well known that phenolic acids, which are abundant in whole grains, have antioxidant characteristics (Onyeneho and Hettiarachchy 1992). They function in the body as free-radical scavengers, complexers of prooxidant metals, reducing agents, and quenchers of singlet-oxygen formation (Andlauer and Fürst 1998). Antioxidants protect the body from degenerative diseases such as cancers (Bailey and Williams 1993) and heart disease. Hydroxycinnamates such as ferulic acid, caffeic acid, and *p*-coumaric acid reduce low-density lipoprotein oxidation (Castelluccio et al 1996, Meyer et al 1998), potentially protecting the body from atherosclerosis (Frankel et al 1993, Kinsella et al 1993, Steinberg 1993). In addition to the potential health effects, phenolic compounds affect the flavor of processed oat products (Molteberg et al 1996). Phenolic compounds with antioxidant activity have been identified in oats (Daniels et al 1963; Daniels and Martin 1967, 1968; Collins 1989), but quantitative data are highly variable and difficult to compare due to differences in methods of extraction and analysis (Durkee and Thivierge 1977, Sosulski et al 1982, Dimberg et al 1993, Xing and White 1997). The effects of processing on the content and activity of potential antioxidative compounds in oats are even less well characterized (Dimberg et al 1996). The phenolic acids are asymmetrically distributed within the grain (Fulcher 1986), and some, such as ferulic acid and *p*-coumaric acid, occur mostly bound to cell walls (Hartley and Keene 1984).

The objectives of this study were to 1) compare the antioxidant activity of whole oats, groats, and hulls from samples of four cultivars, and 2) identify and quantify phenolic compounds in these fractions that may contribute to antioxidant activity. Because only one sample of each cultivar was analyzed, these results are not necessarily characteristic of other samples of these cultivars from different growing environments.

MATERIALS AND METHODS

Reagents

Butylated hydroxytoluene (BHT), caffeic acid (CA), (+)-catechin (CAT), *trans*- β -carotene, *trans*-cinnamic acid (TCA), *p*-coumaric acid (PCA), ferulic acid (FA), Folin and Ciocalteu's phenol reagent, gallic acid (GA), *p*-hydroxybenzaldehyde (PHB), linoleic acid, protocatechuic acid (PRO), sinapic acid (SI), Tween 40, vanillic acid (VA), and vanillin (VAN) were purchased from Sigma Chemical Co. (St. Louis, MO).

Sample Processing and Extractions

Grain samples of oat cultivars Dane, Gem (Duerst et al 1999), and Belle (Forsberg et al 1999) were provided by H. Kaeppler, Department of Agronomy, University of Wisconsin-Madison. Dane, Gem, and Belle are early, midseason, and late-maturing spring cultivars, respectively, adapted to the midwestern United States. Whole oats (subsequently referred to as oats) were separated into hulls and groats using an impact dehuller. Grain of oat cultivar, Otana, a western United States midseason spring cultivar (Stewart et al 1978), was provided by G. Paul, The Quaker Oats Company, Barrington, IL. Hulls from Otana were collected from oats using a hand-fed mechanized wringer that separated individual groats from hulls. Oat, groat, and hull samples (10 g) from each cultivar were ground in a Retsch ZM-1 mill (Brinkman, Westbury, NY) to pass through a 0.5-mm screen. Four subsamples (1.0 g) from each ground sample were extracted with 80% ethanol (3×10 mL, 20 min, with shaking) at room temperature. Following centrifugation (5 min at $1,250 \times g$), the supernatants were filtered through glass wool, combined, and solvent was removed under vacuum at 40°C. Phenolic compounds were resolubilized in 2 mL of methanol, filtered through a 0.2- μ m polyvinylidene difluoride (PVDF) membrane, and stored under N_2 at -20°C. Based on the total phenolic content of five sequential extractions, $\approx 85\%$ of the alcohol-soluble phenolics are removed by the first three extractions.

Antioxidant Activity Assay

Antioxidant activity was measured by monitoring the coupled autoxidation of β -carotene and linoleic acid (Marco 1968, Miller 1971, Lee et al 1995). β -Carotene (2 mg) was dissolved in 20 mL of chloroform, and 3 mL of this solution was added to 40 mg of linoleic acid and 400 mg of Tween 40. The chloroform was removed under a stream of N_2 gas. Oxygenated deionized water (100 mL) was added and the solution was mixed well. Aliquots (3 mL) of the β -carotene and linoleic acid emulsion were mixed with 40 μ L of phenolic extracts (diluted with methanol to the equivalent of 2 mg of starting material) and incubated in a water bath at 50°C. Oxi-

¹ United States Department of Agriculture, Agricultural Research Service, Cereal Crops Research Unit, 501 Walnut St., Madison, WI 53705. Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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dation of the emulsions was monitored spectrophotometrically by measuring absorbance at 470 nm at 15-min intervals for 60 min. Controls contained 40 mL of methanol in place of the extract. Antioxidant activity (AOA) was expressed as percent of inhibition relative to the control after a 60-min incubation period (Al-Saikhhan et al 1995):

$$AOA = 100(DR_C - DR_S)/DR_C$$

where: DR_C = degradation rate of control = $\ln(a/b)/60$; DR_S = degradation rate of sample = $\ln(a/b)/60$; a and b = absorbance at 0 and 60 min.

Activities of extracts were compared with a standard curve of BHT activity over a concentration range of 0–1.2 μg in 40 μL of sample (Fig. 1).

Total Phenolic Assay

Determination of total phenolic content (TPC), measured as GA equivalents, was made using Folin and Ciocalteu's phenol reagent (Ragazzi and Veronese 1973). Sample (1 mL, diluted to 50 or 25% of original concentration with methanol), 0.5 mL of Folin and Ciocalteu's phenol reagent (2.0N), and 3.0 mL of Na_2CO_3 (200 mg/mL) were mixed in the given order. The mixture was vortexed and the reaction was allowed to proceed for 15 min at room temperature. The reaction mixtures were diluted with 10 mL of deionized water. A white precipitate that formed from the Folin and Ciocalteu's reagent was removed by centrifuging for 5 min at $1,250 \times g$. Absorbance of the supernatants was measured at 725 nm. Methanol was used as a control in place of the sample. GA equivalents (mg/kg) were determined from a standard concentration curve.

Reversed-Phase HPLC

Phenolic compounds were separated by reversed-phase HPLC. Samples (20 μL) were injected onto a C_{18} reversed-phase column ($\mu\text{Bondapak}$, 250×4.6 mm, 10- μm particle size, Waters, Milford, MA), eluted for 75 min with a linear gradient of 1–40% acetonitrile in water adjusted to pH 2.8 with acetic acid (flow rate 1 mL/min), and monitored at 290 nm. Peaks were identified by comparing retention times and UV scans (200–360 nm), using a diode array detector (model SD-M10VP, Shimadzu, Columbia, MD), with known standards. Peak identities were further verified by adding internal standards to samples. Quantitation was achieved by comparing peak areas with external standards (712 software, Gilson, Inc., Middleton, WI).

Statistical Analysis

Cultivar, fraction, and cultivar-by-fraction effects were determined by analysis of variance using the four subsamples as replicates. Means separation was by least squares analysis.

RESULTS AND DISCUSSION

Ethanol-soluble extracts from oat fractions and cultivars differed significantly ($P < 0.05$) in their ability to inhibit the coupled autoxidation of linoleic acid and β -carotene (Table I). The cultivar-by-fraction interactions were not significant. Groats and oats had significantly higher AOA than hulls, in agreement with the report of Xing and White (1997). In all fractions, Otana had significantly lower AOA than the other cultivars. Gem hulls were lower than Belle and Dane, but higher than Otana. Fractions ranged from 0.24 μg (Otana hulls) to 1.11 μg (Belle groats) of BHT equivalent to 2 mg of starting material.

Cultivar and fraction means were significantly ($P < 0.05$) different, and the cultivar-by-fraction interaction was significant for TPC (Table II). Comparing fractions, Dane hulls were higher than groats, whereas Otana groats were higher than hulls. For Gem and Belle, hulls and groats were not significantly different in TPC. Comparing cultivars, Gem groats were higher than the others, whereas Dane and Belle hulls were highest and Otana hulls lowest. The levels of TPC are lower than those reported by Xing and White (1997) for cultivar Ogle (560 and 400 mg/kg for hulls and groats, respectively), but this may be attributed to the different cultivar and extraction method.

Phenolic compounds were identified and quantified by reversed-phase HPLC (Fig. 2, Table III). Eight compounds were identified and measured in concentrations that were within ranges previously reported for oats using HPLC or thin-layer chromatography (Sosulski et al 1982, Dimberg et al 1993, Dimberg et al 1996). Xing and White (1997), using an exhaustive methanol extraction and gas

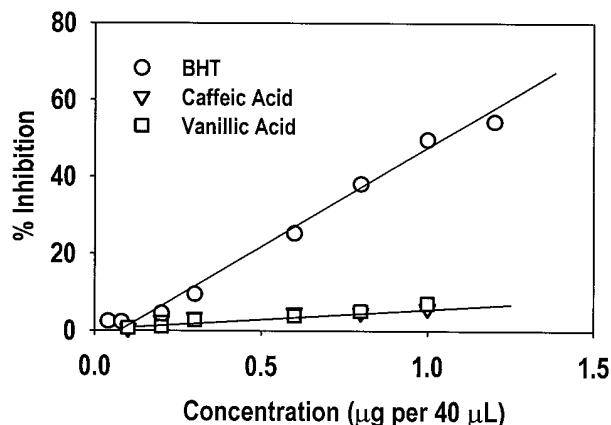


Fig. 1. Antioxidant activity of butylated hydroxytoluene (BHT), caffeic acid (CA), and vanillic acid (VA).

TABLE I
Antioxidant Activity (%) of Oat Fractions and Cultivars^{a,b}

	Belle	Dane	Gem	Otana	Mean
Groats	63.5 ± 2.9ax	57.8 ± 3.5ax	59.3 ± 3.4ax	30.5 ± 3.0ay	53.4 ± 3.5a
Hulls	38.9 ± 3.8bx	42.1 ± 3.6bx	28.0 ± 2.2by	12.2 ± 2.9bz	30.3 ± 3.3b
Oats	57.5 ± 5.1ax	50.6 ± 4.3abx	52.4 ± 4.6ax	30.5 ± 3.8ay	47.1 ± 3.4a

^a Inhibition (%) of coupled autoxidation of linoleic acid/ β -carotene emulsion ± standard error of the mean.

^b Means followed by the same letters within rows (x–z) or columns (a,b) are not significantly different ($P < 0.05$) by least squares means analysis.

TABLE II
Total Phenolic Content (gallic acid eq, mg/kg) of Oat Fractions and Cultivars^a

	Belle	Dane	Gem	Otana	Mean
Groats	246 ± 12ay	209 ± 4cy	294 ± 11ax	226 ± 6ay	245 ± 11b
Hulls	306 ± 6axy	308 ± 8ax	272 ± 2ay	193 ± 10bz	261 ± 18a
Oats	278 ± 20ax	264 ± 2bx	269 ± 11ax	238 ± 4ax	259 ± 6a

^a Means followed by the same letters within rows (x–z) or columns (a–c) are not significantly different ($P < 0.05$) by least squares means analysis.

chromatographic determination, reported much higher concentrations in cultivar Ogle. GA and TCA were tentatively identified in this study but have not been reported previously. An unidentified compound, F3OL, had spectral qualities of flavan-3-ols, such as catechin. It may be the same as the unidentified peak reported to be a flavonoid by Dimberg et al (1996). This compound was present in the range of 9.8–44.4 mg/kg of catechin equivalents, higher than any of the monophenolics. The peaks labeled AV1, AV3, and AV4 are tentatively identified (by retention times and spectra) as

avenanthramides that were previously described (Collins and Mullin 1988, Collins 1989, Dimberg et al 1996). These peaks were quantified as FA equivalents and were present in the ranges of 0.6–9.2, 0.4–14.5, and 0.1–15.3 mg/kg for AV1, AV3, and AV4, respectively. Dimberg et al (1993, 1996) reported avenanthramide 1, 3, and 4 from groats in the range of 33–132 mg/kg. Because we expressed concentrations of the putative avenanthramides as FA equivalents, direct comparisons of absolute quantities cannot be made.

TABLE III
Phenolic Contents (mg/kg \pm standard error) of Oat Cultivars by Fraction^{a,b}

	Belle	Dane	Gem	Otana	Mean
GA					
Groats	0.9 \pm 0.1y	1.1 \pm 0.1y	1.1 \pm 0.1ay	2.0 \pm 0.2ax	1.3 \pm 0.1a
Hulls	0.8 \pm 0.2	1.4 \pm 1.2	0.3 \pm 0.0b	0.1 \pm 0.1c	0.6 \pm 0.3b
Oats	1.6 \pm 0.9	1.0 \pm 0.3	1.0 \pm 0.1a	1.6 \pm 0.0b	1.3 \pm 0.2a
PRO					
Groats	0.5 \pm 0.1b	0.7 \pm 0.2	0.5 \pm 0.1b	0.9 \pm 0.1b	0.7 \pm 0.1c
Hulls	2.0 \pm 0.2a	1.2 \pm 0.3	2.0 \pm 0.4a	2.8 \pm 0.6a	2.1 \pm 0.3a
Oats	0.8 \pm 0.6aby	1.2 \pm 0.2xy	1.3 \pm 0.2axy	2.1 \pm 0.1ax	1.4 \pm 0.2b
PHB					
Groats	0.5 \pm 0.0cx	0.3 \pm 0.0cy	0.2 \pm 0.0by	0.2 \pm 0.0cy	0.3 \pm 0.0c
Hulls	2.0 \pm 0.0az	5.7 \pm 0.3ay	7.8 \pm 1.0ay	12.8 \pm 0.9ax	7.7 \pm 1.5a
Oats	1.0 \pm 0.2bz	1.9 \pm 0.2by	1.1 \pm 0.0bz	4.0 \pm 0.2bx	2.2 \pm 0.5b
VA					
Groats	1.1 \pm 0.1cz	0.7 \pm 0.0bz	2.2 \pm 0.1aby	2.6 \pm 0.1cx	1.6 \pm 0.2c
Hulls	3.6 \pm 0.0ay	1.2 \pm 0.1az	3.1 \pm 0.6ay	6.7 \pm 0.5ax	4.0 \pm 0.8a
Oats	2.5 \pm 0.4by	0.9 \pm 0.1bz	1.3 \pm 0.1bz	4.6 \pm 0.1bx	2.6 \pm 0.5b
CA					
Groats	1.8 \pm 0.5y	2.2 \pm 0.8xy	2.1 \pm 0.1axy	3.6 \pm 0.3ax	2.4 \pm 0.3a
Hulls	1.7 \pm 0.5x	1.4 \pm 0.7x	0.3 \pm 0.1by	0.4 \pm 0.0by	0.9 \pm 0.3c
Oats	1.3 \pm 0.5xy	1.8 \pm 0.5x	0.5 \pm 0.0by	0.9 \pm 0.1bx	1.1 \pm 0.2b
VAN					
Groats	0.9 \pm 0.2by	0.8 \pm 0.1by	0.3 \pm 0.1bz	2.0 \pm 0.1cx	1.0 \pm 0.2c
Hulls	2.5 \pm 0.7ay	4.0 \pm 0.8ay	4.2 \pm 0.8ay	11.7 \pm 0.8ax	6.3 \pm 1.4a
Oats	1.2 \pm 0.3aby	1.4 \pm 0.2by	0.8 \pm 0.1by	4.5 \pm 0.3bx	2.2 \pm 0.6b
PCA					
Groats	0.8 \pm 0.1c	0.6 \pm 0.2c	1.0 \pm 0.2c	1.0 \pm 0.1c	0.9 \pm 0.1c
Hulls	5.5 \pm 0.6az	13.5 \pm 0.6ax	10.9 \pm 0.5axy	9.2 \pm 0.8ay	9.7 \pm 1.0a
Oats	3.2 \pm 0.1by	6.0 \pm 0.1bx	3.7 \pm 1.0by	3.4 \pm 0.2by	4.0 \pm 0.4b
FA					
Groats	0.7 \pm 0.0y	0.8 \pm 0.1cy	0.7 \pm 0.1by	2.4 \pm 0.1ax	1.2 \pm 0.2b
Hulls	1.1 \pm 0.2y	3.0 \pm 0.2ax	1.4 \pm 0.2ay	1.2 \pm 0.0by	1.7 \pm 0.3a
Oats	1.2 \pm 0.0xy	1.9 \pm 0.2bx	0.8 \pm 0.0by	1.4 \pm 0.2bx	1.3 \pm 0.2b
SI					
Groats	0.5 \pm 0.0	0.5 \pm 0.1	0.4 \pm 0.0b	0.6 \pm 0.1	0.5 \pm 0.0
Hulls	0.5 \pm 0.1y	0.5 \pm 0.1y	1.1 \pm 0.0ax	0.4 \pm 0.0y	0.6 \pm 0.1
Oats	0.4 \pm 0.0	0.5 \pm 0.2	0.6 \pm 0.1b	0.4 \pm 0.1	0.5 \pm 0.1
F3OL ^c					
Groats	22.0 \pm 0.1by	12.3 \pm 1.3bz	34.1 \pm 0.7aw	31.0 \pm 0.6ax	24.9 \pm 2.6b
Hulls	39.8 \pm 9.8ax	58.7 \pm 7.5ax	9.8 \pm 4.1cy	10.8 \pm 1.6by	27.7 \pm 7.5a
Oats	22.5 \pm 0.1aby	16.6 \pm 5.6by	20.8 \pm 2.8by	32.6 \pm 2.0ax	24.2 \pm 2.5b
AV3 ^d					
Groats	8.8 \pm 1.0ay	1.8 \pm 0.1z	14.5 \pm 0.4ax	0.9 \pm 0.1az	6.5 \pm 1.7a
Hulls	4.5 \pm 0.8bx	1.6 \pm 0.5yz	2.2 \pm 1.3cxy	0.4 \pm 0.1bz	2.0 \pm 0.6c
Oats	9.0 \pm 0.0ax	1.4 \pm 0.2y	9.9 \pm 1.9bx	0.8 \pm 0.0ay	4.8 \pm 1.5b
TCA					
Groats	3.0 \pm 0.9y	2.3 \pm 0.3by	9.8 \pm 0.4x	3.7 \pm 0.9ay	4.7 \pm 1.0a
Hulls	1.6 \pm 0.1xy	4.2 \pm 0.7axy	5.5 \pm 3.5x	0.0 \pm 0.0by	2.5 \pm 1.0b
Oats	2.0 \pm 1.7y	2.5 \pm 0.3aby	7.2 \pm 0.8x	2.7 \pm 0.8ay	3.5 \pm 0.8ab
AV4 ^d					
Groats	8.7 \pm 0.4bx	1.9 \pm 0.1y	15.3 \pm 0.3aw	1.0 \pm 0.1az	6.7 \pm 1.7a
Hulls	6.5 \pm 0.3cx	0.9 \pm 0.6yz	3.7 \pm 1.8bxy	0.1 \pm 0.1bz	2.5 \pm 0.9b
Oats	11.1 \pm 0.5ax	2.0 \pm 0.1y	13.6 \pm 0.3aw	0.8 \pm 0.1az	6.2 \pm 2.0a
AV1 ^d					
Groats	7.1 \pm 0.3bx	2.1 \pm 0.1ay	8.0 \pm 0.2aw	0.9 \pm 0.1z	4.5 \pm 0.9a
Hulls	5.1 \pm 0.4cx	1.3 \pm 0.2byz	1.6 \pm 0.0cy	0.7 \pm 0.1z	2.0 \pm 0.6b
Oats	9.2 \pm 0.6ax	1.8 \pm 0.1az	5.0 \pm 0.8by	0.6 \pm 0.2z	3.8 \pm 1.2a

^a Means with the same letters within rows (w–z) and columns (a–c) are not significantly different ($P < 0.05$) by least-squares means. Means without letters are not significantly different.

^b GA = gallic acid; PRO = protocatechuic acid; PHB = *p*-hydroxybenzaldehyde; VA = vanillic acid; CA = caffeic acid; VAN = vanillin; PCA = *p*-coumaric acid; FA = ferulic acid; SI = sinapic acid; TCA = *trans*-cinnamic acid.

^c Unidentified compound with spectral qualities of flavan-3-ols such as catechin.

^d Avenanthramides quantified as ferulic acid equivalents.

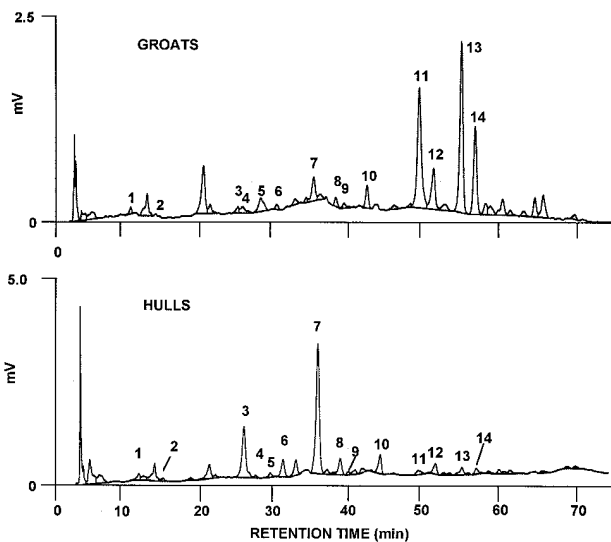


Fig. 2. Separation of phenolic components from representative groat and hull samples by reversed-phase HPLC on C_{18} column using a 1–40% acetonitrile gradient, pH 2.8, detected at 290 nm. Peaks are (1) gallic acid, (2) protocatechuic acid, (3) *p*-hydroxybenzaldehyde, (4) vanillic acid, (5) caffeic acid, (6) vanillin, (7) *p*-coumaric acid, (8) ferulic acid, (9) sinapic acid, (10) F3OL, (11) AV3, (12) *trans*-cinnamic acid, (13) AV4, and (14) AV1.

CA, GA, AV3, AV4, and AV1 occurred in significantly higher quantities in groats than hulls, whereas hulls contained significantly more PRO, PHB, VAN, PCA, FA, and VA than groats (Table III). The putative flavan-3-ol, F3OL, occurred in significantly higher quantities in groats than hulls for Gem and Otana, but in higher quantities in hulls than groats for Belle and Dane. In Otana, there was significantly more TCA in groats than hulls, with the same, but nonsignificant, trend for Belle and Gem, whereas in Dane, significantly more TCA was present in hulls than groats. Fractions did not differ significantly in SI content. Xing and White (1997) found that hulls contained more VA, PCA, VAN, and SI than groats, whereas groats contained more CA. The fractions in that study did not differ greatly in FA. These workers did not identify avenanthramides in their extracts.

There were wide variations among the samples of the four cultivars in groat, hull, and whole oat concentrations of the various phenolics (Table III). Among groats, Otana was high in GA, VA, VAN and FA; whereas Gem had the highest F3OL, TCA, and AV1, AV3, and AV4. In the hulls, Otana was high in PHB, VA and VAN; Dane was high in FA, F3OL, and PCA; whereas Belle had the highest AV levels. For oats, Dane was highest in CA and PCA; Otana was highest in PHB, F3OL, VA, and VAN; and Gem and Belle had the highest AV levels.

The oat fractions tested in this study contained various levels of total phenolics as well as each of the identified phenolic compounds, but the limited number of samples did not allow for estimation of contribution of each component to AOA by correlation or regression analyses. Hulls contained significantly higher TPC but lower AOA than the other fractions, suggesting that hulls may contain components that counteract the antioxidant activity of the phenolics. To test this hypothesis, hull and groat extracts from each cultivar were combined in the same 1:3 ratio of hulls to groats by weight, and AOA of the mixtures (duplicate assays) were compared with the expected AOA calculated from individual hull and groat AOA values. The difference between the mixtures and expected AOA was not significantly different from zero ($t = 0.44$, $n = 8$, $P = 0.67$), causing us to reject the hypothesis. Low hull AOA may be due to the lower concentration of active phenolics rather than the presence of counteracting substances. Hulls were relatively higher than groats in PHB and PCA, components that had low AOA in our tests (unpublished data). Previous studies have shown that CA, SI, PRO,

FA, VAN, and flavan-3-ols such as catechin possess significant AOA (Burri et al 1989, Cuvelier et al 1992, Laranjinha et al 1996, Teissedre et al 1996), and the avenanthramides such as AV1 have higher AOA than FA, CA, or VAN (Dimberg et al 1993). Each phenolic component for which a standard was available was tested and found to exhibit AOA in the concentration range found in the oat fractions, but possible synergistic or antagonistic interactions between the components have not been determined.

CONCLUSIONS

Ethanol extracts from oat fractions contained phenolic compounds that contribute to total antioxidant activity. Groats and oats were higher in avenanthramides and CA and exhibited higher AOA than hulls. Differences in AOA due to cultivar were minor among the oats tested from the midwestern United States, but the western United States cultivar had significantly lower AOA. This could be attributed to the significantly lower levels of avenanthramides 4 and 1, which are positively associated with AOA (unpublished data), and significantly higher levels of VA, VAN, and PHB, which are negatively associated with AOA (unpublished data) as compared with the cultivars of the midwestern United States. Testing samples of a wider range of cultivars from multiple growing environments is needed to estimate the extent of variation in phenolic content available for possible breeding efforts. Information about the direct and interactive contributions of phenolic components, in both soluble and bound forms, to overall AOA is important in determining which components should be the focus of breeding efforts. Knowledge of the effects of cultivation practices, storage, and processing on antioxidant activity and important individual phenolic components is needed to minimize losses during all phases of production and processing. These studies are currently being conducted.

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