

Composition of Oat Bran and Flour Prepared by Three Different Mechanisms of Dry Milling

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ABSTRACT

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Three mechanisms of oat milling were tested for laboratory-scale oat bran production. Oat bran consistent with AACC definition and commercially obtained product was generated with either roller-milling or impact-milling of groats, followed by sieving to retain larger particles. These bran preparations were enriched ≈ 1.7 -fold in β -glucan and ash, 1.4-fold in protein, and 1.1-fold in lipid. Bran finishing made further enrichments in protein, β -glucan, and ash. Tempering oat (to 12% moisture for 20 min) improved bran yield from roller-milling nearly two-fold but had little

effect on bran composition. Bran yield from the impact-type mill was significantly affected by grinding screen size. Oat bran obtained from a pearling mill was only slightly enriched in β -glucan and protein, but it was more heavily enriched in ash and oil than brans from roller or impact mills. The pearling mill isolated the outer layers of the groat directly, but because of its low β -glucan composition it did not meet the AACC definition of oat bran, indicating a relatively uniform distribution of β -glucan in the groat.

Oat bran is defined by the American Association of Cereal Chemists (AACC) to be the food produced by grinding clean oat groats or rolled oats and separating the resulting fractions by sieving or other mechanisms. Bran is the milling fraction enriched in β -glucans (minimum 5.5%) and dietary fiber and should not comprise more than 50% of the starting material (AACC 1989). Interest in the production of oat bran has been stimulated recently with the proposed regulations by the U.S. Food and Drug Administration (FDA 1996) that allow foods containing sufficient quantities of β -glucan to be labeled with statements indicating that consumption of oat bran products may reduce the risk of heart disease. A number of studies have demonstrated the hypocholesterolemic effect that oat bran generates when included in diets of animals (Schinnick and Marlett 1993) and humans (Anderson and Bridges 1993).

The term *bran* usually denotes a product derived from the outer layers of a cereal grain (Fulcher and Miller 1993). The large-particle fraction derived from wheat milling is primarily derived from the outermost layer of the kernel (Pomeranz 1988). Oat bran products are less easily defined, in that the starchy endosperm flour does not separate from outer tissue layers as easily (Fulcher and Miller 1993). A review by Paton and Lenz (1993) indicated that the two options for oat bran production are the utilization of a hammer (impact-type) mill or a roller mill. They described the basic process developed by the Quaker Oats Co., which involves steaming and flaking oat groats, hammer-mill grinding, followed by sieving over a 36-mesh (538- μ m) screen to yield a coarse bran fraction. Subsequent studies on oat bran have utilized either impact-type mills (Wu and Stringfellow 1973, 1995; Gould et al 1980; Wood et al 1991; Knuckles et al 1992) or roller mills (Wu et al 1972, Youngs 1974, D'Appolonia and Youngs 1978, Frölich and Nyman 1988, Westerlund et al 1993) to produce oat bran, although no study has compared these two mechanisms.

It is well known that grain moisture affects milling characteristics (Bass 1988). Wheat is routinely tempered before milling by

adding defined amounts of water. Tempering toughens the bran, facilitating the separation of wheat bran and flour. Apparently, there are no published studies comparing different tempering regimes for oat milling characteristics.

The primary objective of this study was to develop a laboratory-scale oat dry-milling process that produces oat bran comparable to commercially produced oat brans and is therefore useful in selecting for improved milling characteristics of experimental oat breeding lines. We sought to compare brans produced from roller and impact mills and determine the effect of tempering on bran yields. Because the flour often adheres to the bran, we tested the application of a bran finisher to further purify starchy components from bran preparations. Finally, we tested the utility of an attrition (pearling) mill, which grinds away the outermost layers of a grain as a means to produce an oat bran product. We hypothesized that this third dry-milling mechanism might produce an oat bran higher in β -glucan concentration because of its ability to exclude starchy endosperm material.

MATERIALS AND METHODS

The oat (*Avena sativa* L.) breeding line, ND900117, was used for all studies. Grain had been grown in Prosper, ND, in 1994, and was provided by Michael S. McMullen, Department of Plant Sciences, North Dakota State University, Fargo, ND. All grain was steamed in a vegetable steamer for 20 min before dehulling to inactivate enzymes, which is similar to commercial oat processing operations as described by Paton and Lenz (1993). Whole oats were dehulled with a laboratory oat huller (Codema Inc., Eden Prairie, MN). Grain was tempered by adding specified amounts of water to grain in jars, mixing well by shaking, and allowing samples to equilibrate at room temperature for specified time intervals.

Roller Mill

Samples were milled on a Quadrumat Jr. laboratory roller mill (Brabender, South Hackensack, NJ). Milled samples were initially fractionated into bran and flour using a 35-mesh U.S. standard screen (0.5 mm). Flour was subsequently fractionated into coarse and fine flour fractions by sieving on a 60-mesh U.S. standard (0.25 mm) screen. Bran was also sieved on 60-mesh screens to separate additional fine flour from bran, which was combined with the other fine flour fraction.

Untempered oats had 12% moisture without any further treatments. Where indicated, samples were conditioned and tempered before roller-milling by drying the grain overnight at 40°C then

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adding water to samples to defined final moisture levels. Moisture content of oven-dried groats was determined on burr-milled samples by determining weight loss after drying in a 130°C convection oven for 2 hr. The tempering process consisted of placing samples in 473-mL glass jars and spraying distilled water on the grain until the weight increased sufficiently to reach the desired moisture content. Jars were sealed and the contents were mixed well and kept at room temperature for either 20 min, 6 hr, or 18 hr before milling. Portions of some oat bran fractions were additionally processed with a laboratory impact-type bran finisher (MCU-302, Buhler Corp., Minneapolis, MN).

Impact Mill

For impact-type milling, a Retsch ZM-1 Ultracentrifugal mill (Brinkmann Instruments, Westbury, NY) was used. The design of this mill is very similar to that of a hammer mill (Haque 1991). Oat groats were adjusted to 12% moisture 24 hr before milling. Groats were then ground in the impact mill with collar screen sizes of 0.5, 1.0, 2.0, and 3.0 mm. Ground groats were initially sieved over U.S. standard 30-mesh (0.61 mm) screens, then over a 60-mesh (0.25 mm) screen. Particles retained by either the 30- or 60-mesh screens were pooled and designated as bran. The small particle-size fraction was designated as flour.

Pearling Mill

A bench-scale pearling mill (Satake model TM-05, Philip Rahm, Inc., Houston, TX) assembled with a 30-grit stone was

TABLE I
Composition and Yield (%) of Roller-Milled Fractions of Oat Groats at 12% Moisture with No Tempering as Compared with the Composition of Whole Groat Flour

Fraction	Yield	Starch	Protein	Lipid	β -Glucan	Ash
Whole groats	...	66.5	15.8	4.73	3.88	1.98
Bran	18.1	48.6	22.1	4.81	8.57	3.74
Coarse flour	34.9	57.6	19.1	4.59	5.14	2.85
Fine flour	45.2	82.7	11.1	3.89	1.25	0.80
HSD ^a	4.4	7.1	1.3	0.73	0.41	0.26

^a Honestly significant difference. Tukey's critical value for comparison ($P < 0.05$) ($n = 3$).

TABLE II
Effect on Bran Yield (%) of Added Moisture and Tempering Time in Roller-Milled Oats^a

Final Moisture ^b (%)	Bran Yields (%) for Three Tempering Times ^c		
	20 min	6 hr	18 hr
9	20.0	13.5	10.7
11	31.3	22.5	22.1
12	33.7	26.2	25.7
13	31.6	31.4	29.3

^a $n = 3$.

^b Tukey's honestly significant difference for comparing different moisture levels is 2.7.

^c Tukey's honestly significant difference for comparing different tempering times is 2.2.

TABLE III
Yield and Composition (%) of Roller-Milling Fractions of Oat Tempered to 12% Moisture for 20 min as Compared with Whole Groat Flour

Fraction	Yield	Starch	Protein	Lipid	β -Glucan	Ash
Whole groat	...	67.3	15.6	4.62	4.08	1.97
Bran	34.9	47.8	22.4	5.28	7.78	3.65
Coarse flour	18.8	65.7	16.3	4.91	3.96	2.19
Fine flour	45.4	84.0	10.1	3.50	1.46	0.56
Finished bran ^a	22.3	34.5	26.6	5.81	11.00	5.10
Finished flour ^a	9.1	80.1	15.0	4.01	1.26	1.14
HSD ^b	2.2	2.8	0.4	0.40	0.62	0.15

^a Fractions derived from further processing of bran with bran finisher. Yield value represents proportion of total groat mass recovered in this fraction.

^b Tukey's honestly significant difference for comparison ($P < 0.05$) ($n = 3$).

used to pearl outer layers from oat groats. Samples (200 g) were loaded into the milling chamber and milled for 2, 3, 4, and 6 min to achieve different levels of bran removal. The extent of pearling was determined from the loss of mass from the pearled endosperm. The bran yield was determined from the mass recovery of the pearled bran.

Chemical Analyses

Starch was analyzed according to standard method 76-11 (AACC 1995). Protein was analyzed by combustion analysis with a nitrogen analyzer (FP-428, Leco Corp., St. Joseph, MI) ($N \times 6.25$). Ash of a 2-g sample was determined in an ashing oven by initially ashing samples in crucibles for 1 hr at 350°C, then increasing the oven temperature to 450 and 590°C after 1-hr intervals, then maintaining 590°C for 18 hr. After ashing, crucibles were removed from the ashing oven and allowed to cool in a desiccator before measuring ash weight. Total (1 \rightarrow 3),(1 \rightarrow 4)- β -D-glucan (β -glucan) was determined by the method of McCleary and Glennie-Holmes (1985). Lipid was determined by solvent extraction with the chloroform-methanol-water system (Bligh and Dyer 1959). Flour (0.5 g, dwb) was weighed into a 15-mL screw-cap tube. Distilled water (0.8 mL) and 3 mL of methanol and chloroform (2:1, v/v) were added. After homogenization (Polytron Homogenizer, Brinkmann Instruments, Westbury, NY), 1 mL of water and 1 mL of chloroform were added to the homogenates, after which they were vortexed and centrifuged (1,200 \times g, 10 min). The lower chloroform layer was removed and placed in a new tube. A 50- μ L aliquot of acetic acid and 3 mL of chloroform were added to the homogenate, and it was vortexed and centrifuged as before. Again, the lower chloroform layer was removed and pooled with the previous chloroform extract. The chloroform extracts were dried with NaSO₂ and filtered into weighed tubes. Tubes and filters were rinsed with an additional 2 mL of chloroform. The chloroform was evaporated, and tubes were reweighed to determine total lipid extracted from flour samples.

Statistical Analyses

Each experiment included three separate milling replicates. Chemical analyses of each replicate in every experiment contained a sample of whole groat flour. All experiments were of a randomized block design. Analyses of variance, Tukey's honestly significant differences (HSD), and two sample *t*-tests were calculated with the Statistix computer program (Analytical Software, Tallahassee, FL).

RESULTS

Roller Mill

Groats were initially milled with a roller-type mill (Brabender Quadrumat Jr.) with no tempering. Whole groat composition and composition and yield of roller-milling fractions is shown in Table I. Bran and coarse flour fractions contained higher concentrations of protein, β -glucan, lipid, and ash than did the fine flour or the whole groat, whereas the fine flour contained a higher concentration of starch than did the whole groat or the bran or coarse flour fractions.

Tempering time and final moisture content both had significant effects on bran yield from the roller-type mill (Table II). Analysis of variance (data not shown) indicated a significant interaction effect of tempering time and moisture levels on bran yield, as well as significant main effects of tempering time and moisture. Higher bran yields were obtained using higher moisture contents and shorter tempering times (Table II). There were no significant interaction effects or main effects of tempering time and moisture on starch, protein, lipid, or ash concentrations in bran preparations. However, there were significant main effects of both tempering time and moisture on bran β -glucan concentration (data not shown). Bran β -glucan concentrations ranged from 7.21 to 8.73 and were negatively correlated with the bran yields ($r = -0.73$, $P < 0.01$; data not shown).

Tempering for 20 min and 12% moisture was most favorable for recovery of protein and β -glucan in the bran. Composition of the milling fractions and recovery efficiency of components obtained under these milling conditions are given in Ta Tukey's honestly significant difference for comparison ($P < 0.05$) ($n = 3$).bles III and IV. Tempering nearly doubled the bran yield (Table III) compared to the nontempered experiment (Table I), which was highly significant by t -test ($P < 0.01$). Although t -tests indicated that β -glucan concentration was lower ($P < 0.05$) in the bran from the tempered grain than from nontempered grain, the starch, protein, lipid, and ash concentrations were not significantly ($P < 0.05$) different between the two bran preparations. Fine flour yield from tempered grain was not significantly different from nontempered grain ($P < 0.05$). The t -tests indicated that starch and β -glucan concentrations did not differ significantly ($P < 0.05$) between the tempered and nontempered fine flours. However, protein, lipid, and ash concentrations were significantly ($P < 0.05$) lower in tempered fine flours (Table III) as compared to nontempered fine flours (Table I). More than 50% of the protein and 65% of the β -glucan and ash in the grain was recovered in the bran (Table IV). In contrast, nearly 60% of the starch in the whole grain was recovered in the fine flour (Table IV).

Since a considerable amount of starchy endosperm will adhere to the bran fraction (Fulcher and Miller 1993), a bran finisher was used for the further purification the oat bran. Oat bran from the laboratory bran finisher had significantly higher protein, β -glucan, lipid, and ash concentrations, and lower starch concentration than

TABLE IV
Recovery of Chemical Components^a (%) in Different Milling Fractions of Oats Subjected to Roller-Milling After Tempering to 12% Moisture for 20 min

Fraction	Starch	Protein	Lipid	β -Glucan	Ash
Bran	25.0	50.3	40.0	65.6	66.3
Coarse flour	18.5	19.7	20.0	18.0	21.4
Fine flour	57.2	29.6	34.5	16.0	11.8
Finished bran ^b	11.0	36.5	26.8	56.7	56.5
Finished flour ^b	10.6	8.6	7.8	2.8	5.3
HSD ^c	4.1	1.6	3.3	6.3	2.0

^a Expressed as % of component present in whole grain recovered in fraction.
^b Fractions derived from further processing of bran with bran finisher. Values represent proportion of component in the whole groat recovered in this fraction.
^c Tukey's honestly significant difference for comparison ($P < 0.05$) ($n = 3$).

TABLE V
Effect of Grinding Screen Size of Retsch ZM-1 Ultracentrifugal Mill on Bran Yield and Composition (%)

Screen (mm)	Yield	Starch	Protein	Lipid	β -Glucan	Ash
Whole groat	...	66.7	15.6	4.63	4.04	1.96
0.5	27.4	45.5	20.8	5.29	8.85	3.38
1.0	29.6	47.7	21.1	5.25	8.25	3.37
2.0	45.6	50.9	19.9	5.28	6.76	2.98
3.0	51.5	55.1	19.3	5.09	6.28	2.81
HSD ^a	7.9	3.9	0.7	0.66	0.78	0.16

^a Tukey's honestly significant difference for comparison ($P < 0.05$) ($n = 3$).

the original bran (Table III). Flour recovered from the bran finisher was high in starch and low in β -glucan, similar to roller-mill fine flour, but its ash and protein concentrations were higher than roller-mill fine flour (Table III).

Impact Mill

Yields and composition of oat bran produced by an impact-type milling process are given in Table V. The bran yield increased with increasing grinding screen size. Bran yield with the 3.0-mm grinding screen exceeded the 50% limit established by the AACC definition of oat bran. Bran isolated with a 1.0-mm screen on the impact mill (Table V) did not differ significantly ($P < 0.05$) from the tempered roller-mill bran (Table III) in starch, protein, lipid, or β -glucan concentration, although it did have significantly ($P < 0.05$) lower ash concentration. Bran generated with 2.0- and 3.0-mm grinding screens on the mill had significantly higher starch concentration and significantly lower protein, β -glucan, and ash concentrations than brans produced with 0.5- and 1.0-mm grinding screen sizes. However, recovery of starch, protein, lipid, and ash into the bran fraction all increased with increasing grinding screen size (Table VI).

Pearling Mill

Processing of oat groats with a pearling mill yielded a small particle bran and whole pearled endosperms. Visual inspection of pearled endosperms suggested that fairly uniform attrition of the entire surface had occurred, and only a small amount of groat breakage had occurred. About 8 g (from 200 g of sample) of bran pearlings were lost in the mechanisms of the mill with each milling. Thus, relative bran yields were poorest at the lowest level of pearling (17%). Yields and composition of bran fractions produced by a pearling mill are given in Table VII. All of the bran fractions obtained by pearling were significantly ($P < 0.05$) higher in starch and significantly ($P < 0.05$) lower in protein, β -glucan, and ash from the tempered roller-mill bran (Table III). Most notably, the β -glucan concentration in the pearled brans (Table VII) were very low: only 60% of that in the tempered roller-milled bran (Table III). Pearled bran derived from a larger proportion of the groat contained higher starch concentration and lower protein, β -glucan, and ash concentrations than pearled bran derived from a lower proportion of the total groat (Table VII). Although the enrich-

TABLE VI
Effect of Grinding Screen Size on the Recovery of Different Chemical Components^a (%) in the Bran Fraction of Groats Subjected to Grinding with Ultracentrifugal Mill

Screen (mm)	Starch	Protein	Lipid	β -Glucan	Ash
0.5	19.2	36.8	31.6	59.6	48.3
1.0	21.2	39.9	33.5	60.4	51.9
2.0	34.8	58.3	52.2	64.9	70.6
3.0	42.6	63.9	57.0	79.7	75.4
HSD ^b	6.4	11.3	8.2	ns ^c	14.9

^a Expressed as % of component present in whole grain recovered in fraction.
^b Tukey's honestly significant difference for comparison ($P < 0.05$) ($n = 3$).
^c Not significant.

TABLE VII
Yield and Composition (%) of Oat Bran Fractions Generated by a Pearling Mill

Fraction ^a	Yield ^b	Starch	Protein	Lipid	β -Glucan	Ash
Whole groat	...	67.0	15.6	4.64	3.97	2.02
17	9.3	51.0	18.8	6.30	4.73	4.10
25	16.9	58.0	18.2	6.12	4.82	3.56
30	22.9	59.9	17.7	6.64	4.64	3.27
57	52.8	62.8	16.2	4.62	4.06	2.33
HSD ^c	1.8	4.5	0.5	0.6	0.42	0.11

^a Groat (%) removed by pearling. Calculated from mass recovery of pearled endosperm.
^b Calculated from mass recovery of pearled bran.
^c Tukey's honestly significant difference for comparison ($P < 0.05$) ($n = 3$).

ment of components in pearled bran was much less than that of the roller mill or impact mill, significant enrichment of protein, lipid, β -glucan, and ash occurred in all pearled brans, except at the 57% pearling level (Table VII).

DISCUSSION

Oat bran derived from roller and impact mills were similar in composition, whereas oat bran derived from a pearling mill was distinctly different. A review by Marlett (1993) indicated that published compositions of oat brans ranges were 12–26% protein, 2–11% fat, 2–9% ash, 47–53% starch, and 6.6–7.4% β -glucan. The oat brans obtained in this study, from both the roller mill and the impact mill, fit into these ranges and are consistent with the AACC definition of oat bran composition (AACC 1989). In contrast, pearling-mill bran had lower β -glucan concentration than that allowed by the AACC definition. Bran obtained from the roller mill after tempering was enriched 1.9-fold in β -glucan and ash, 1.4-fold in protein, and 1.1-fold in lipid, but contained only 71% of the starch concentration of the whole groat (Table III). Bran further processed with a bran finisher was enriched 1.7-fold in protein and 2.7-fold in β -glucan and ash over the whole groat (Table III), indicating that bran finishing significantly ($P < 0.05$) increased enrichment of these components. Much greater enrichments of protein and β -glucan in oat dry-milling fractions have been obtained by air-classification (Wu and Stringfellow 1973, 1995) or by certain extensive sieving procedures (Knuckles et al 1992). Bran finishing is perhaps a simpler and more readily available procedure for obtaining a more highly enriched oat bran fraction with reasonably good yields. Although the bran finisher in this study was applied to only the roller-milled bran, there is no obvious reason that it could not be applied to impact-mill brans.

Tempering of grain significantly affected bran yield and recovery of components in the bran fraction, although it had a relatively small effect on the composition of the bran recovered (data not shown). The short tempering time (20 min) with a final moisture of 11–13% allowed for the highest recovery of bran (Table II), which differs considerably from tempering conditions for wheat (Bass 1988).

It is interesting that the pearling mill bran was not more highly enriched in β -glucan (Table VII). We conclude from this that the β -glucan in this genotype of oat is not concentrated in the outer layer of the groat. Quantitative scanning microspectrofluorometry has been used to examine the distribution of β -glucan in the oat groat by Fulcher and Miller (1993). They concluded that oat cultivars with lower total β -glucan concentration had a higher proportion of the β -glucan in the subaleurone layers, whereas cultivars with higher total β -glucan concentration had a more uniform β -glucan distribution. Even though the cultivar used in the current study (ND900117, 4.0% β -glucan) would be classified as a low β -glucan cultivar, the pattern of β -glucan concentrations in differing pearling levels (Table VII) suggest that the distribution of β -glucan is fairly uniform throughout the groat in this genotype.

β -Glucan is localized in the endosperm cell walls of the groat (Fulcher 1986). Because bran fractions isolated by roller and impact mills are enriched in β -glucan, they are obviously enriched in endosperm cell walls. The crushing and grinding actions of the mills appear to break the starchy contents of these cells into fine particles, whereas the cell walls hold together as larger pieces and are separated by the sieving process. Protein and mineral components of the groat appear to adhere to these larger particles. Tempering appears to strengthen the cell walls so that a larger proportion of these hold together as larger particles. The success of the bran finisher indicates that increased mechanical agitation can improve the separation of the starchy particles from the cell wall particles. These experiments indicate that the composition and yield of oat bran and flour can be manipulated by adjusting dry milling conditions to meet a wide range of applications.

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