# High-Fiber Breads Containing Field Pea Hulls, Wheat, Corn, and Wild Oat Brans

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## ABSTRACT

Using a bakers' patent flour from hard red spring wheat, it was possible to formulate satisfactory high-fiber breads containing 20% corn bran, 20% wheat bran, 15% field pea hulls, or 15% wild oat bran. The bread formulations for the straight dough method of breadmaking were optimized at 45 ppm $KBrO_3$ and 0.5% SSL (sodium stearoyl-2-lactylate) without any supplemental gluten. Prehydration of the fiber sources enhanced baking absorption and loaf characteristics. Total dietary fiber contents of the acceptable fiber breads were 21% for corn bran, 13% for wheat bran, 15% for pea hull, and 6% for wild oat bran breads.


High-fiber diets based on whole grain cereals, legumes, fruits, and vegetables are now being prescribed in the treatment and management of various colonic and circulatory disorders (Staub et al 1983). The nonstarchy polysaccharides of the plant cell wall, which resist digestion by mammalian $\alpha$-amylases, are the principal sources of dietary fiber for humans. Interest in fiber-enhanced foods has resulted in the use of refined cellulose, cereal brans, and legume hulls to fortify target foods such as baked goods, breakfast cereals, and snack foods (Vetter 1984). The use of refined cellulose as a fiber ingredient is not permitted in some countries such as Canada, and certain natural sources of fiber have come into widespread use after only limited investigation.

Wheat bran is the traditional source of dietary fiber added to baked goods (Dubois 1978), and supplementation at the 7.5% level of flour replacement in the dough formulation is about the maximum level if product quality is to be maintained (Pomeranz et al 1977, Satin et al 1978, Cadden et al 1983).

Cadden (1986) demonstrated that up to 20% flour replacement in wheat bran breads is necessary to effect a substantial increase in fecal nitrogen and fat and reductions in fecal transit time and serum triglyceride levels. However, fortified breads at this level of flour replacement also require supplementation with wheat gluten to maintain the bread structure (Dubois 1978, Vetter 1984).

Because gluten is an expensive ingredient in bread formulations, a study was conducted using Canadian hard red spring (HRS) wheat flour, which was high in protein with strong gluten consistency. The bakers' patent wheat flour was supplemented with 0, 5, 10, 15, and 20% of wheat bran and two other commercial fiber sources—field pea hulls and refined corn bran. Due to the recent interest in oat bran as an effective treatment for hypercholesterolemic patients (Anderson and Chen 1986), wild oat bran, which is richer in dietary fiber than common oat (Sosulski et al 1985), was also included in the study.

## MATERIALS AND METHODS

### Materials

The control flour was a commercial bakers' patent wheat flour milled from a blend of No. 1 and No. 2 Canadian HRS wheat. The commercial wheat bran, free of germ, was obtained from the same mill run at the Robin Hood Multifoods Inc. flour mill at Saskatoon, SK. The bran was reduced to the same particle size range as other fiber sources by regrinding on the break rolls of an Allis-Chalmers three-stage experimental flour mill. Wild oat bran was obtained by milling the groats on the first two sets of corrugated rolls of the Allis-Chalmers mill, using three settings each. After each pass through a set of rolls, the product was sifted on 20W (wire), 30 GG (grit gauge, 630 $\mu$m), and 60 GG (265 $\mu$m) sieves. Wild oat bran, obtained in yield of 40%, was the product passing through 30 GG but retained on 60 GG sieves. Refined regular corn bran (A. E. Staley Mfg. Co., Decatur, IL) and Exlite field pea hulls (Pro-Star Mills Ltd., Saskatoon, SK) were screened to the same particle size range. Composite flours were prepared to contain 5, 10, 15, and 20% replacement by weight (14% mb) of the respective bran sources in the bakers' patent flour. Vital gluten was provided by Ogilvie Flour Mills, Montreal, PQ.

### Analytical Procedures

The wheat flour and fiber sources were analyzed for moisture (method 44-15A), protein (method 46-11), lipid (method 30-10), ash (method 08-01), and crude fiber (method 32-10) by AACC (1983) procedures. Starch content was determined by the enzymatic technique of Fleming and Reichert (1980).

The total dietary fiber (TDF) content was analyzed by the gravimetric method of the AOAC (1984) (method 43.A14-43.A20) based on digestion of the sample with a heat-stable $\alpha$-amylase, protease, and amyloglucosidase. The results were corrected for undigested protein (Kjeldahl N $\times$ 6.25) and ash (ignition at 525°C for 8 hr) associated with the fiber.

Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were analyzed on a Fibertec apparatus using the Goering and Van Soest (1970) procedures. The NDF residue was incubated with $\alpha$-amylase from porcine pancreas for 18 hr at 37°C to complete the starch digestion (method 32-20, AACC 1983). Hemicellulose was calculated as the difference between NDF and ADF. Cellulose content was estimated from the amount of ADF residue that dissolved in 72% sulfuric acid.

Water hydration capacities of the fiber sources were determined by the centrifuge procedure of Sosulski (1962). Optimum water absorptions of the bread doughs were obtained by adjusting the water addition during dough mixing and handling.

### Mixograph Curves

Mixing properties of the doughs made from the wheat and composite flours were based on 35.0 g of flour (14% mb) and constant water absorption of 65% (AACC method 54-40).

### Gassing Power

The gas-producing abilities of the composite flours were determined according to AACC method 22-11. Ten grams flour (14% mb) and 7 ml of water containing 0.3 g of yeast in suspension were placed in a pressure vessel that had been previously warmed to 30°C, and mixed. The gas produced was recorded as the pressure in mmHg after 5 hr of fermentation.

### Breadmaking

In preliminary experiments, baking procedures were compared using a modified straight dough procedure (method 10-10A, AACC 1983) and a scaled-down sponge and dough method (10-11). Composite flours containing 15% replacement of corn bran, wheat bran, field pea hulls, and wild oat bran with 45 ppm $KBrO_3$ as dough improver were used in the straight dough procedure, whereas the fiber sources were added in the second phase of the

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70:30 sponge and dough process. In a separate experiment to optimize the straight dough method, the effects of flour improvers were determined by adding 0, 15, 44, and 75 ppm $KBrO_3$ and 0.5% SSL (sodium stearoyl-2-lactylate) or 5.0% vital gluten.

The principal experiments were conducted with composite flours containing 5, 10, 15, and 20% replacement with each of the four fiber sources. The first series were blended dry; the second series were prepared from prehydrated fiber sources. Water was added at a 1:1 (w/w) ratio to each fiber source, except for wild oat bran, where the two highest replacement brans received one-half of the above water addition rate. The prehydrated samples were thoroughly mixed in sealed containers and hydrated for 20 hr at 4°C.

For these formulations, the baking performance was evaluated by the modified AACC (1983) straight dough method (10-10A). The baking formula included 100 g of composite flour (14% mb), 0.75 g of active dried yeast (db), 4.0 g of sucrose, 4.0 g of skim milk powder, 3.0 g of shortening, 1.75 g of salt, 0.3 g of malt, 0.1 g of ammonium phosphate monobasic, 45 ppm of $KBrO_3$, and 0.5 g of SSL and water calculated to 60% absorption. Additional water was added as required during mixing for 3.0 min in a Grain Research Laboratory dough mixer, and fermentation was for 3 hr at 30°C and 80% relative humidity. Baking time was 25 min at 230°C. Volumes of cooled loaves were measured by rapeseed displacement. Specific volumes were calculated from loaf volume and loaf weight taken 1 hr after baking. The exteriors of the loaves were scored for shape and degree of break and shred, and the interior crumb textures were also rated on a scale of very good, good, fair, and poor.

The colors of crust (top of loaf) and crumb were measured with the HunterLab D25 digital color difference meter equipped with an M optical head. A white tile (no. C2-5472; $L = 94.7$, $a = -0.9$, $b = 0.5$) was used to standardize the instrument, where $L = 100$ (white), $L = 0$ (black); $+a$ = red, $-a$ = green; $+b$ = yellow, $-b$ = blue. Total color difference was calculated according to the equation

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

Complete loaves of each treatment were freeze-dried and ground in a coffee mill to pass a 1.0-mm screen. The ground samples were analyzed for crude fiber and dietary fiber components by the methods used for the fiber sources. These values were compared with the dough ingredient composition, which was calculated from raw material analysis and their proportions in the blend. All composition data are reported on a dry basis. Statistical analysis of the data was based on duplicate determinations.

## RESULTS AND DISCUSSION

### Chemical Composition

Field pea hulls contained much higher concentrations of crude fiber (55.1%) than wheat or corn bran, and wild oat bran had only 4.0% crude fiber (Table I). Wild oat and wheat brans were rich in protein and lipid, and they also contained more ash than the other bran sources. Wheat flour was primarily starch, whereas the other constituents in the fiber sources (Table I) were predominantly fiber components not measured by the crude fiber analysis (Table II).

In contrast to the crude fiber results, TDF in corn bran exceeded 90.0%, whereas field pea hulls had 82.3%, and wheat bran 54.2% (Table II). Wild oat bran contained only 20.0% TDF and wheat flour had only 3.4%.

The difference between TDF and NDF was soluble fiber (Mongeau and Brassard 1986) and, typical of cereal grains in general, the differences were small among wheat, corn, and wild oat brans (Table II). The negative value for soluble fiber in wild oat bran was associated with the difficulty in filtration of the NDF residue which contained fine starch granules. Field pea hulls exhibited over 8.0% soluble fiber, and about one-half of the fiber in Bakers' patent flour was soluble.

ADF values were high in field pea hulls, reflecting the predominance of cellulose in this fiber source (Table II). Hemicellulose was the major fiber component in wheat bran, corn bran, and wild oat bran as well as wheat flour. Wheat bran was substantially more lignified than field pea hulls or wild oat bran, whereas corn bran had a very low proportion of ADL.

### Water Hydration Capacity

High water hydration capacity of dietary fiber sources has been associated with low digestibility, high volume and weight of feces, and low serum triglycerides in rat experiments (Sosulski and Cadden 1982). The water hydration capacity of wheat bran was higher than predicted by the comparative fiber values, but all of the values presented in Table II were quite high compared to other fiber sources except for pectin and mucilage-containing seed materials (Sosulski and Cadden 1982). Even wild oat bran absorbed 3.3 g/g of sample, due primarily to an indigestible $\beta$-glucan that is found in the cell walls of the outer endosperm (Englyst and Cummings 1985).

TABLE I
Proximate Composition and Starch Content of Fiber Sources and Wheat Flour (% dry basis)

| Fiber Source | Crude Fiber | Crude Protein (N × 5.7) | Crude Lipid | Ash | Starch | Other Constituents |
|---|---|---|---|---|---|---|
| Bakers' patent | 0.5 | 16.8 | 1.3 | 0.66 | 70.1 | 10.6 |
| Wheat bran | 13.7 | 16.0 | 6.4 | 7.03 | 0.3 | 56.6 |
| Corn bran | 18.3 | 4.7 | 1.9 | 0.42 | 2.8 | 69.9 |
| Field pea hulls | 55.1 | 5.9 | 0.4 | 2.98 | 1.5 | 34.1 |
| Wild oat bran | 4.0 | 23.6 | 12.2 | 4.40 | 0.1 | 55.7 |
| LSD (0.05) | 0.4 | 0.6 | 0.2 | 0.24 | 0.4 | ... |

TABLE II
Composition of Total Dietary Fiber in Pea Hulls, Cereal Brans, and Wheat Flour (% dry basis)

| Fiber Source | Total Dietary Fiber[a] | Neutral Detergent Fiber | Acid Detergent Fiber | Acid Detergent Lignin | Hemicellulose | Cellulose | Water Hydration Capacity |
|---|---|---|---|---|---|---|---|
| Bakers' patent | 3.4 | 1.6 | 0.5 | 0.1 | 1.1 | 0.4 | 209 |
| Wheat bran | 54.2 | 52.7 | 18.4 | 5.3 | 34.3 | 13.1 | 537 |
| Corn bran | 90.3 | 87.6 | 22.4 | 0.9 | 65.2 | 21.5 | 450 |
| Field pea hulls | 82.3 | 74.0 | 65.8 | 3.5 | 8.2 | 62.3 | 429 |
| Wild oat bran | 20.0 | 21.3[b] | 5.4 | 3.1 | 15.9 | 2.3 | 331 |
| LSD (0.05) | 0.6 | 1.4 | 0.8 | 0.1 | ... | ... | 19 |

[a] Including soluble pentosans, pectins, and $\beta$-glucans.
[b] Sample difficult to filter and values tended to be high.

The incorporation of fiber ingredients into wheat flour increased water hydration values in proportion to the level of replacement (Table III). Composite flours containing 20% of fiber sources had water hydration capacities that were 8% greater than that of the control flour.

### Mixograph Characteristics

All fiber sources except wild oat bran reduced time to peak and increased mixogram area in proportion to the level of fiber addition up to the 18 or 20% level (Table III). Flours containing wild oat bran had longer mixing times with lower peak height and mixograph areas. However, the mixograms were generally of the strong type, characteristic of HRS wheat flours, and the incorporation of the bran or hull products did not have a marked adverse effect on mixing properties.

### Gassing Power

A test for gassing power was conducted on flours supplemented with 10% of the fiber sources to determine if the latter constituents had an adverse effect on yeast fermentation. All fiber blends gave gassing powers (277–311 mmHg) that were not significantly different than that of the control flour (293 mmHg). It appeared that the composite flours were capable of producing sufficient gas for loaf expansion, and that any differences in loaf volume between formulations would be caused by variations in ability of the dough structure to retain the gas.

### Baking Test

In preliminary experiments, it was determined that the straight dough procedure (AACC method 10-10A) gave slightly higher loaf volumes than were obtained with the 70:30 sponge and dough process (AACC method 10-11) (Table IV), which has been employed advantageously by some investigators for fiber-supplemented breads (Satin et al 1978).

Many formulations for protein- or fiber-fortified breads include gluten to improve breadmaking properties. In the present study, the formulation was designed to optimize bread quality (malt, shortening, sucrose) and nutrition (skim milk powder), but gluten was not necessary because the bakers' patent flour contained a high level of strong gluten-forming proteins that should respond well to additives ($KBrO_3$, SSL). The composite flours, containing 15% of each fiber source, gave an average loaf volume of 820 $cm^3$ by the straight dough method when 45 ppm of $KBrO_3$ was added (Table IV). The incorporation of 5.0% vital gluten by replacement in the formulation, in combination with 45 ppm $KBrO_3$, resulted in an average loaf volume of 871 $cm^3$.

Similarly, the optimum $KBrO_3$ response over the range of 0–75 ppm was found to be 45 ppm, for which the loaf volume increases ranged from 75 to 200 $cm^3$ in the series of 15% fiber supplemented breads (Table V). Responses in loaf volume to the dough conditioner, SSL, were lower than to $KBrO_3$, but the texture and grain size of high-fiber breads were improved quite noticeably.

The control flour without $KBrO_3$ or SSL gave an attractive loaf

**TABLE III**
**Effect of Levels of Flour Replacement with Fiber Sources on Water Hydration Capacity and Mixograph Characteristics of the Doughs at 65% Water Absorption**

| Fiber Source and Replacement Level (%) | Water Hydration Capacity (%) | Mixograph Characteristics | | Mixograph Curve | |
|---|---|---|---|---|---|
| | | Time to Peak (sec) | Peak Height (cm) | Area ($cm^2$) | Height at 6 min (cm) |
| Bakers' patent | | | | | |
| 0 | 209 | 210 | 7.2 | 66.9 | 6.0 |
| Wheat bran | | | | | |
| 5 | 208 | 210 | 6.9 | 63.8 | 5.6 |
| 10 | 214 | 190 | 6.9 | 65.3 | 5.5 |
| 15 | 219 | 180 | 7.1 | 69.3 | 5.8 |
| 20 | 224 | 190 | 6.8 | 64.2 | 5.3 |
| Corn bran | | | | | |
| 5 | 209 | 190 | 6.8 | 64.9 | 5.4 |
| 10 | 217 | 190 | 6.9 | 65.6 | 5.6 |
| 15 | 220 | 180 | 7.1 | 68.9 | 5.6 |
| 20 | 227 | 185 | 7.3 | 69.8 | 5.7 |
| Field pea hulls | | | | | |
| 5 | 212 | 200 | 6.4 | 62.5 | 5.4 |
| 10 | 216 | 200 | 6.4 | 63.6 | 5.4 |
| 15 | 220 | 180 | 6.8 | 66.0 | 5.5 |
| 20 | 225 | 180 | 7.0 | 64.7 | 5.1 |
| Wild oat bran | | | | | |
| 5 | 212 | 230 | 6.7 | 62.7 | 5.5 |
| 10 | 214 | 220 | 6.4 | 60.9 | 5.3 |
| 15 | 223 | 225 | 6.3 | 60.3 | 5.4 |
| 20 | 229 | 225 | 6.3 | 61.1 | 5.4 |

**TABLE IV**
**Effect of Breadmaking Procedure and Gluten Supplementation on Loaf Volume of Control and Composite Flours Containing Four Fiber Sources ($cm^3$)**

| Flour and Fiber Source | Replacement Level | Sponge and Dough Method | Straight Dough Method | Straight Dough + 5.0% Gluten Replacement |
|---|---|---|---|---|
| Bakers' patent | 0 | 935 | 985 | 1,030 |
| Wheat bran | 15 | 805 | 840 | 885 |
| Corn bran | 15 | 840 | 870 | 910 |
| Field pea hulls | 15 | 725 | 825 | 870 |
| Wild oat bran | 15 | 675 | 745 | 820 |
| Average[a] | 15 | 761 | 820 | 871 |

[a] Average for composite flours.

that was only intermediate in volume and specific volume (Table VI). The addition of 45 ppm $KBrO_3$ and 0.5% SSL resulted in a much larger loaf with excellent shape, crumb grain, and texture.

The protein contents of the control loaves, 15.0% db, were maintained in the wheat bran breads, but the levels declined with degree of substitution of fiber source in corn bran and pea hull breads (Table VI). The high-protein level in wild oat bran (Table I) resulted in progressive increases in protein content with level of fiber substitution in the bread formulation (Table VI). Among the fiber sources, wild oat bran had the most adverse effects on loaf volume and bread structure, and the high crude protein in the product may have been one of the causative factors.

The substitution of wheat bran, corn bran, or pea hulls increased water absorption in proportion to the increment of fiber replacement of wheat flour (Table VI). Wild oat bran failed to increase water absorption to the same degree as other fiber sources. This limited response was partially due to the lower water hydration capacity (Table II) of the wild oat bran. Also, doughs containing wild oat bran at the 15 and 20% replacement levels tended to become soft and sticky when additional water was added. D'Appolonia and Youngs (1978) reported high water absorptions in oat bran breads.

The high moisture retention properties of the fiber-supplemented breads would have major effects on organoleptic properties, freshness, shelf life, and microbial growth. Detailed studies on changes in the fiber bread characteristics during storage are warranted as well as the requirements for antistaling and antimicrobial agents.

The incorporation of 5% of field pea hulls, wheat bran, or corn bran into hard wheat flour reduced loaf volume and specific volume only slightly, and the loaf characteristics were rated as comparable to the control bread (Table VI). Additional increments of these fiber sources progressively and significantly reduced all bread quality characteristics and, at the 20% replacement level, the loaf volumes and appearance ratings ranged from good (wheat and corn bran) to poor (wild oat bran). The poor bread rating assigned to loaves containing 20% of wild oat bran was attributable to shredding of the crust despite a low "oven-rise" and the large grain size and thick cell walls in the crumb.

Prehydration of the fiber sources before blending into composite flours increased water absorption by an average of 3.3 percentage units, but the actual levels were proportional to fiber addition (Table VII). At the 20% replacement level, the water absorptions of corn bran and pea hulls exceeded 75.0%, which was 5.0 and 6.0%, respectively, greater than required in the dry blend experiment (Table VI). In addition, loaf volumes in most cases were improved by the prehydration process whereas specific volumes were largely unchanged. Breads supplemented with prehydrated corn and wild oat brans showed the greatest improvement in bread quality characteristics.

**TABLE V**
**Effect of Flour Improvers on Loaf Volume of Control and Composite Flours Containing Four Fiber Sources ($cm^3$)**

| Flour and Fiber Source | Replacement Level | $KBrO_3$ (ppm) Level | | | | $KBrO_3$ (ppm)-SSL[a] (g) Levels | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 15 | 45 | 75 | 0-0 | 45-0 | 0-0.5 | 45-0.5 |
| Bakers' patent | 0 | 810 | 925 | 975 | 915 | 770 | 970 | 845 | 1,000 |
| Wheat bran | 15 | 720 | 860 | 890 | 820 | 760 | 845 | 780 | 900 |
| Corn bran | 15 | 775 | 835 | 850 | 795 | 775 | 835 | 810 | 875 |
| Field pea hulls | 15 | 640 | 825 | 840 | 730 | 693 | 835 | 775 | 845 |
| Wild oat bran | 15 | 630 | 700 | 755 | 720 | 660 | 765 | 735 | 790 |
| Average[b] | 15 | 691 | 805 | 834 | 766 | 722 | 820 | 775 | 852 |

[a] SSL = sodium stearoyl-2-lactylate.
[b] Average for composite flours.

**TABLE VI**
**Effect of Level of Flour Replacement with Fiber Sources on Breadmaking Characteristics of the Composite Flours**

| Fiber Source and Replacement Level (%) | Protein Content[a] (%) | Water Absorption (%) | Loaf Volume ($cm^3$) | Specific Volume ($cm^3$/g) | Bread Quality[b] Shape and Shred | Bread Quality[b] Grain and Texture |
|---|---|---|---|---|---|---|
| Bakers' patent flour | | | | | | |
| No improvers | 15.0 | 61.7 | 775 | 5.4 | VG | VG |
| With improvers | 14.9 | 61.7 | 993 | 7.0 | VG | VG |
| Wheat bran | | | | | | |
| 5 | 15.7 | 64.7 | 948 | 6.6 | VG | VG |
| 10 | 15.8 | 66.2 | 918 | 6.3 | VG | VG |
| 15 | 15.7 | 68.2 | 840 | 5.7 | G | G |
| 20 | 15.9 | 69.2 | 773 | 5.1 | G | G |
| Corn bran | | | | | | |
| 5 | 15.0 | 64.7 | 960 | 6.6 | VG | VG |
| 10 | 14.8 | 67.2 | 908 | 6.1 | VG | VG |
| 15 | 14.3 | 69.2 | 860 | 5.8 | G | G |
| 20 | 13.8 | 70.2 | 773 | 5.1 | G | G |
| Field pea hulls | | | | | | |
| 5 | 14.7 | 64.2 | 978 | 6.8 | VG | VG |
| 10 | 14.6 | 66.2 | 880 | 6.1 | VG | VG |
| 15 | 14.2 | 67.7 | 825 | 5.6 | G | G |
| 20 | 14.1 | 69.2 | 710 | 4.7 | F | F |
| Wild oat bran | | | | | | |
| 5 | 15.5 | 63.2 | 913 | 6.0 | VG | VG |
| 10 | 16.2 | 63.7 | 825 | 5.7 | G | G |
| 15 | 16.5 | 64.2 | 758 | 5.1 | F | F |
| 20 | 16.8 | 64.7 | 710 | 4.8 | P | P |
| LSD (0.05) | 0.3 | ... | 51 | 0.4 | ... | ... |

[a] N × 5.7, db.
[b] VG = Very good, G = good, F = fair, P = poor.

TABLE VII
Effect of Level of Flour Replacement with Prehydrated Fiber Sources on Breadmaking Characteristics of the Composite Flours

| Fiber Source and Replacement Level (%) | Water Absorption (%) | Loaf Volume ($cm^3$) | Specific Volume ($cm^3/g$) | Bread Quality[a] | |
|---|---|---|---|---|---|
| | | | | Shape and Shred | Grain and Texture |
| Bakers' patent flour | | | | | |
| No improvers | 61.7 | 765 | 5.2 | VG | VG |
| With improvers | 61.7 | 1,010 | 7.1 | VG | VG |
| Wheat bran | | | | | |
| 5 | 66.7 | 965 | 6.6 | VG | VG |
| 10 | 68.2 | 945 | 6.3 | VG | VG |
| 15 | 70.2 | 840 | 5.5 | G | G |
| 20 | 72.2 | 775 | 5.0 | G | G |
| Corn bran | | | | | |
| 5 | 67.7 | 950 | 6.3 | VG | VG |
| 10 | 71.2 | 925 | 6.1 | VG | VG |
| 15 | 74.2 | 880 | 5.7 | VG | VG |
| 20 | 75.2 | 830 | 5.3 | G | G |
| Field pea hulls | | | | | |
| 5 | 67.2 | 965 | 6.7 | VG | VG |
| 10 | 70.2 | 890 | 6.0 | VG | VG |
| 15 | 72.7 | 840 | 5.6 | G | G |
| 20 | 75.2 | 750 | 4.9 | F | F |
| Wild oat bran | | | | | |
| 5 | 65.2 | 920 | 6.3 | VG | VG |
| 10 | 65.2 | 875 | 5.9 | VG | VG |
| 15 | 66.2 | 805 | 5.4 | G | G |
| 20 | 67.2 | 765 | 5.1 | F | F |
| LSD (0.05) | ... | 45 | 0.4 | ... | ... |

[a] VG = Very good, G = good, F = fair, P = poor.

TABLE VIII
Hunterlab Color Values[a] for Crumb of Composite Flour Breads Containing Graded Levels of Dietary Fiber Sources

| Fiber Source and Replacement Level (%) | $L$ | $a$ | $b$ | $\Delta$E[b] |
|---|---|---|---|---|
| Bakers' patent flour | | | | |
| No improvers | 71.3 | −0.9 | 18.2 | 6.8 |
| With improvers | 77.7 | −1.2 | 15.9 | 0.0 |
| Wheat bran | | | | |
| 5 | 67.9 | 1.2 | 15.8 | 10.1 |
| 10 | 63.6 | 2.6 | 16.0 | 14.5 |
| 15 | 56.6 | 4.1 | 16.3 | 21.7 |
| 20 | 54.5 | 4.8 | 16.3 | 24.0 |
| Corn bran | | | | |
| 5 | 74.1 | −0.9 | 18.2 | 4.3 |
| 10 | 71.2 | −0.7 | 19.8 | 7.6 |
| 15 | 69.3 | −0.2 | 20.8 | 9.8 |
| 20 | 67.0 | 0.3 | 21.7 | 12.3 |
| Field pea hulls | | | | |
| 5 | 75.3 | −0.7 | 16.3 | 2.5 |
| 10 | 72.6 | −0.4 | 16.8 | 5.2 |
| 15 | 69.8 | −0.2 | 17.5 | 8.1 |
| 20 | 68.1 | 0.1 | 17.7 | 9.9 |
| Wild oat bran | | | | |
| 5 | 73.4 | −0.4 | 16.9 | 4.5 |
| 10 | 69.9 | 0.3 | 17.9 | 8.2 |
| 15 | 67.0 | 1.0 | 18.2 | 11.2 |
| 20 | 64.7 | 1.3 | 18.6 | 13.5 |
| LSD (0.05) | 1.6 | 0.3 | 0.6 | ... |

[a] $L$ (100 white, 0 black), $a$ (+ red, − green), $b$ (+ yellow, − blue).
[b] $\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$.

## Crust and Crumb Color

With respect to the reddish brown crusts, the wheat bran contributed little additional color over the control crust color values of $L = 32.1$, $a = 11.5$, and $b = 12.4$. Similarly, the crust colors of wild oat bran breads exhibited only a slight darkening at the higher replacement levels. In the pea hull breads, the higher replacement levels resulted in lighter, more yellow, crusts ($L = 44.2$, $a = 10.0$, $b = 17.4$) compared with the control bread. With corn bran, the trend to a lighter, more yellow, crust color was more evident with each increment of fiber added to the formulation; at 20% replacement the values were $L = 53.8$, $a = 9.2$, and $b = 21.6$.

The whitest crumb was achieved with the control flour to which improvers were added (Table VIII). The deviation of the $L$ value of 77.7 from 100 was caused primarily by the yellow carotenoid pigments in the wheat flour, which contributed $+b$ values of about 16. Pea hulls caused the least reduction in $L$ value, followed by corn bran, which contributed additional yellowness to the crumb, and wild oat bran, which showed a net deviation from the control bread crumb of 13.5 units at the 20% replacement level. Wheat bran gave red ($+a$) colors to the crumb that darkened the crumb more severely than the pigments in the other fiber sources.

## Overall Evaluation

Prehydration of the fiber sources and conditioning for 20 hr before flour blending and breadmaking increased baking absorption, loaf volumes, and bread quality. On the basis of the prehydrated fiber treatments, and with added $KBrO_3$ and SSL, it appeared possible to incorporate 20% of wheat or corn bran into bakers' patent flour without the need for gluten supplementation. Field pea hulls and wild oat bran gave satisfactory dough and loaf characteristics at the 15% level of replacement.

## Fiber Recovery in Bread

The contents of crude fiber and dietary fiber components in the breads corresponded quite closely to the values calculated from the flour and fiber ingredients (Table IX). On the average, the fiber contents of the control and fiber breads exceeded the expected values slightly, especially for crude fiber and NDF in corn bran. The ADL in the breads ranged from 0.3 to 1.2% which, although low, exceeded the proportions in the dough ingredients. It is possible that the products of the browning reactions that are formed during baking would, in part, be indigestible to the 72% sulfuric acid treatment and contribute to the ADL residues.

Mongeau and Brassard (1979) reported that 10 brands of white bread had NDF values of 0.7–1.3% compared with 4.6 ± 0.1% for 60% whole wheat bread and 7.2 ± 0.2% for 100% whole wheat bread. In the present study, the control bread was within the above

TABLE IX
**Comparison of the Dietary Fiber Components in the Dough Ingredients and Their Recovery in Baked Bread (% dry basis)**

| Fiber Source and Replacement Level (%) | Crude Fiber | | TDF[a] | | NDF[b] | | ADF[c] | | ADL[d] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Flour | Bread | Flour | Bread | Flour | Bread | Flour | Bread | Flour | Bread |
| Patent flour | | | | | | | | | | |
| 0 | 0.4 | 0.4 | 3.1 | 4.0 | 1.4 | 1.3 | 0.4 | 0.5 | 0.1 | 0.3 |
| Wheat bran | | | | | | | | | | |
| 5 | 0.7 | 0.8 | 5.8 | 5.9 | 3.6 | 3.3 | 1.1 | 1.5 | 0.3 | 0.5 |
| 10 | 1.3 | 1.5 | 8.4 | 8.4 | 5.7 | 5.9 | 1.8 | 2.3 | 0.5 | 1.0 |
| 15 | 1.9 | 2.1 | 10.9 | 10.5 | 8.0 | 8.2 | 2.6 | 3.1 | 0.8 | 1.1 |
| 20 | 2.4 | 2.5 | 13.5 | 13.3 | 10.2 | 10.4 | 3.4 | 3.7 | 1.0 | 1.2 |
| Corn bran | | | | | | | | | | |
| 5 | 1.0 | 1.3 | 7.7 | 8.5 | 5.2 | 6.0 | 1.2 | 1.5 | 0.1 | 0.7 |
| 10 | 1.8 | 2.1 | 12.1 | 12.4 | 7.7 | 9.1 | 2.2 | 2.5 | 0.2 | 0.4 |
| 15 | 2.5 | 3.0 | 16.5 | 16.8 | 12.6 | 13.5 | 3.1 | 3.3 | 0.2 | 0.3 |
| 20 | 3.2 | 3.8 | 20.8 | 20.8 | 16.3 | 17.8 | 4.1 | 4.7 | 0.2 | 0.3 |
| Field pea hulls | | | | | | | | | | |
| 5 | 2.6 | 2.8 | 7.3 | 7.7 | 4.5 | 4.9 | 3.2 | 3.5 | 0.2 | 0.4 |
| 10 | 4.9 | 5.2 | 1.3 | 11.5 | 7.6 | 8.1 | 6.0 | 6.9 | 0.4 | 0.7 |
| 15 | 7.3 | 7.7 | 15.2 | 15.0 | 10.7 | 11.6 | 8.8 | 9.5 | 0.5 | 0.9 |
| 20 | 9.7 | 10.6 | 19.1 | 19.8 | 13.8 | 14.3 | 11.7 | 12.4 | 0.7 | 1.0 |
| Wild oat bran | | | | | | | | | | |
| 5 | 0.2 | 0.4 | 4.0 | 4.5 | 2.2 | 1.8 | 0.5 | 0.7 | 0.2 | 0.5 |
| 10 | 0.4 | 0.5 | 4.9 | 5.2 | 3.0 | 2.4 | 0.7 | 0.9 | 0.4 | 0.6 |
| 15 | 0.5 | 0.7 | 5.7 | 6.4 | 3.8 | 3.4 | 1.0 | 1.0 | 0.5 | 0.8 |
| 20 | 0.7 | 0.7 | 6.8 | 6.8 | 4.7 | 3.9 | 1.2 | 1.4 | 0.6 | 0.8 |
| Mean, blends | 2.6 | 2.9 | 10.6 | 10.8 | 7.5 | 7.8 | 3.3 | 3.7 | 0.4 | 0.7 |
| LSD (0.05) | 0.14 | | 0.62 | | 0.40 | | 0.22 | | 0.13 | |

[a] TDF = Total dietary fiber.
[b] NDF = Neutral detergent fiber.
[c] ADF = Acid detergent fiber.
[d] ADL = Acid detergent lignin.

range for white bread (Table IX). The 10% replacement with corn bran or pea hulls, or 15% wheat bran, would provide the equivalent NDF of 100% whole wheat. At the 20% replacement level, corn bran bread provided 18% NDF compared with only 10% in wheat bran bread. The 15% pea hull bread also provided over 11% of NDF, whereas the wild oat bran bread had only 4%. The corresponding TDF contents of these acceptable fiber breads would be 21% for corn bran, 13% for wheat bran, 15% for pea hull, and 6% for wild oat bran breads.

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