FIBER IN BREADMAKING—EFFECTS ON FUNCTIONAL PROPERTIES

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ABSTRACT

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Bread was baked from wheat flour with up to 15% of the flour replaced by seven celluloses, four wheat brans, or two oat hulls. Adding 15% oat hulls somewhat reduced water absorption; bran increased absorption about 4%; celluloses increased absorption about 10%. Oat hulls increased mixing times little, celluloses increased them considerably, and wheat bran had no consistent effect. Adding up to 5% fiber materials decreased loaf volume to an extent expected from dilution of functional gluten proteins. At levels above 7%, fiber materials decreased loaf volume much more than expected from dilution of gluten. The large decrease resulted from lowered gas retention rather than unsatisfactory gas production. Effects of the fiber materials on bread crumb texture were confirmed by visual observations, light microscopy, and scanning electron microscopy. Oat hulls imparted to bread an objectionable gritty texture; the celluloses modified bread taste and mouthfeel little; bran modified the taste and mouthfeel somewhat but the modification was not objectionable. Overall effects on color from added fiber materials were smallest for the celluloses and largest for bran. Bran decreased bread softness more than celluloses did; oat hulls softened bread somewhat.

Epidemiological observations that several diseases of "civilization," such as coronary heart disease, diabetes, and some colon diseases, are most prevalent in western countries have heightened interest in the inclusion in our diets of nonnutritive fiber that resists human digestive secretions and intestinal flora. Burkitt's report (1) suggested that incidence of colonic cancer was associated with low levels of dietary fiber. If low fiber content of diets causes such diseases, they might be reduced by the addition of fiber to diets.

The importance of dietary fiber in food was reviewed by Eastwood (2), Southgate (3), Thomas (4), Leveille (5), and Spiller and Amen (6). The role of cereal bran in the etiology of certain diseases was discussed critically by Eastwood *et al.* (7).

Much has been reported on breadmaking properties of flours of different milling extractions. Little is known, however, about the effects on breadmaking of fibrous materials from various sources, in particular special microcrystalline celluloses used as fillers by several food industries. We compare here the effects on breadmaking of wheat bran, oat hulls, and several commercial celluloses.

MATERIALS AND METHODS

A composite (CS-74) of straight-grade flours (average 73% extraction), milled on a Miag Multomat from hard winter wheat cultivars harvested in 1974 at

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several locations throughout the Great Plains of the United States, had a protein content of 12.3% [N × 5.7, 14% moisture basis (mb)], good loaf-volume potential, and medium mixing time and oxidation requirement.

Cellulose

The seven celluloses evaluated in baking are described in Table I; the two Avicel PH powders are microcrystalline, purified, depolymerized α-celluloses derived from fibrous plants. Both are white, odorless, and tasteless. Both are free-flowing and insoluble in water, organic solvents, and dilute acids, but partially soluble in dilute alkali.[2] The four prototype celluloses[3] were developed as fillers in such products as semimoist foods, fabricated soya protein, and special dietary foods. The prototype powders are comparable or superior to Avicel powders in whiteness, softness, chemical purity, and mouthfeel. According to manufacturer's data, the Avicel PH microcrystalline cellulose

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[2] Bulletin PH-6 Avicel PH, microcrystalline cellulose, FMC Corp., Marcus Hook, PA 19061.
[3] W. R. Thomas, FMC Corp. Private communication.

TABLE I
Description of Cellulose Samples[a]

Cellulose Name or Type	Description
Floc	Ground α-cellulose
Avicel PH-101	Acid-hydrolyzed cellulose, 50-μm agglomerate
Avicel PH-105	Acid-hydrolyzed cellulose, 20-μm agglomerate
Prototype 170-2	Slight hydrolysis with a large fraction of fiber fragment 5–20 μm
Prototype 170-1	Same as 170-2 except CMC[b] was added to improve mouthfeel and increase water binding
Prototype 174-2	Slight hydrolysis with a large fraction of the fiber at 150–225 μm
Prototype 174-1	Same as 174-2 except CMC was added

[a] Manufacturers' data.
[b] Carboxymethyl cellulose.

TABLE II
Particle Size of Wheat Bran and Oat Hull Samples

Fiber Material	% Over Sieve with Opening of					% Through
	701 μm (28-mesh SS)	351 μm (54-mesh SS)	417 μm (35T)	208 μm (65T)	147 μm (100T)	147 μm (100T)
Oat hulls						
Medium (OHM)	...	...	6.7	62.3	19.0	12.0
Fine (OHF)	...	...	...	45.0	26.9	28.1
Bran						
Coarse (CB)	100	...	...	...	...	...
Coarse-medium (CBM)	...	...	27.4	33.2	9.5	29.9
Coarse-fine (CBF)	...	...	0.7	29.8	18.2	51.3
Fine (FB)	...	100	...	...	...	...
Fine-fine (FBF)	...	...	2.8	38.8	20.0	38.4

products are generally recognized as safe (GRAS) and are approved by the Food and Drug Administration (FDA). The Avicel products are not additives as defined by the Food Additives Amendment of 1958 and are, therefore, not subject to the requirements of that amendment. According to the manufacturer, the prototype celluloses also meet present FDA standards. Scanning electron micrographs of six celluloses are shown in Fig. 1. The celluloses, except for the cellulose floc (A), were tubular; particle size in each sample was fairly uniform.

Oat Hulls

The oat hulls were a commercial product from Quaker Oats Co. The large hulls were ground on a Weber mill to obtain two subsamples. Oat hulls-medium (OHM) were obtained by a single grinding, with a 0.040-in.-opening, round screen; oat hulls-fine (OHF) were obtained by three grindings with a 0.024-in.-opening, round screen.

The oat hulls contained, on a 14% mb, 1.9% protein and 5.2% ash. Particle sizes of the oat hulls varied widely (Table II). To determine the particle size of the ground oat hulls and bran, 20-g samples were sieved for 10 min on an 8-in. diameter Ro-Tap Testing Sieve Shaker, U.S. Tyler Co. Two Carmichael cleaners with nylon brushes were placed on each sieve to assist in separation. The samples were sieved through standard Tyler sieves. No large differences were evident from the microscopic examination of the oat hulls (Fig. 2, A–D).

Wheat Bran

One coarse (CB) and one fine bran (FB) were obtained during experimental milling of a hard red winter wheat. The protein and ash contents (on a 14% mb) were, respectively, 16.4 and 6.0% for CB, and 16.3 and 4.2% for FB. Part of the two brans was ground on a Weber mill to various particle sizes. Two subsamples were prepared from CB: coarse bran-medium (CBM) and coarse bran-fine (CBF). CBM was obtained by a single grinding, with a 0.040-in.-opening, round screen. CBF was obtained by three grindings, with a 0.024-in.-opening, round screen. After the whole coarse bran was ground, the overs of a 100-mesh screen were reground twice.

FB was reground twice to produce a fine bran-fine (FBF), with a 0.024-in.-opening, round screen; after all the sample was ground, the overs of a 100-mesh screen were reground. Table II lists the particle sizes of the five bran samples.

The bran was heterogeneous in size and composition. In Fig. 2, pericarp particles, aleurone cell material, and starch granules are apparent in sections E, F, and G, respectively.

Analytical Procedures

Moisture, protein, and ash were determined by AACC Approved Methods 44-15A, 46-11, and 08-01, respectively (8).

The baking procedure of Finney and Barmore (9,10,11) and Finney (12) for 100 g flour (14% mb) was used, except that 10 ppm potassium bromate and 100 ppm ascorbic acid were used as oxidizing agents.

The standard deviation for the average of duplicate loaf volumes was 20 cc. Mixograms of flour-water doughs were determined according to Finney and Shogren (13).

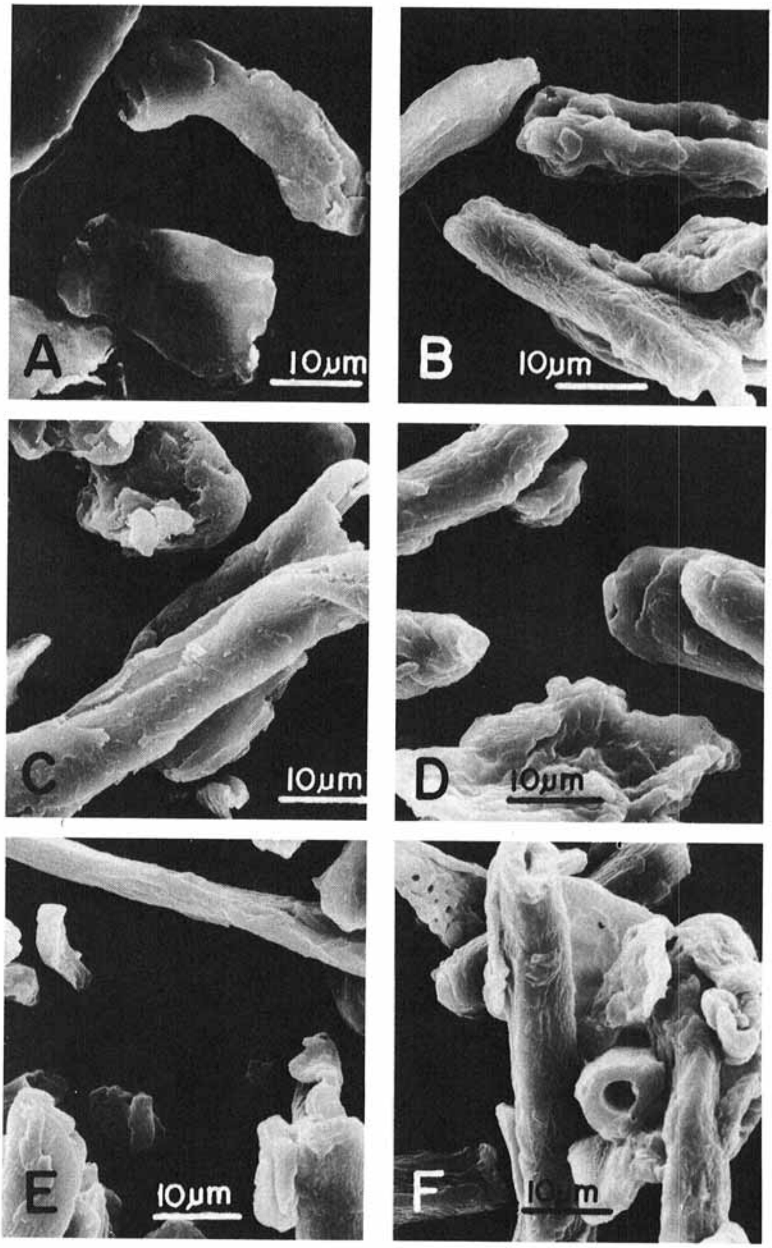

Fig. 1. Scanning electron microscopy (SEM) pictures of celluloses. A = Cellulose floc, B = Prototype 170-1, C = Avicel PH-105, D = Prototype 170-2, E = Prototype 174-2, F = Prototype 174-1.

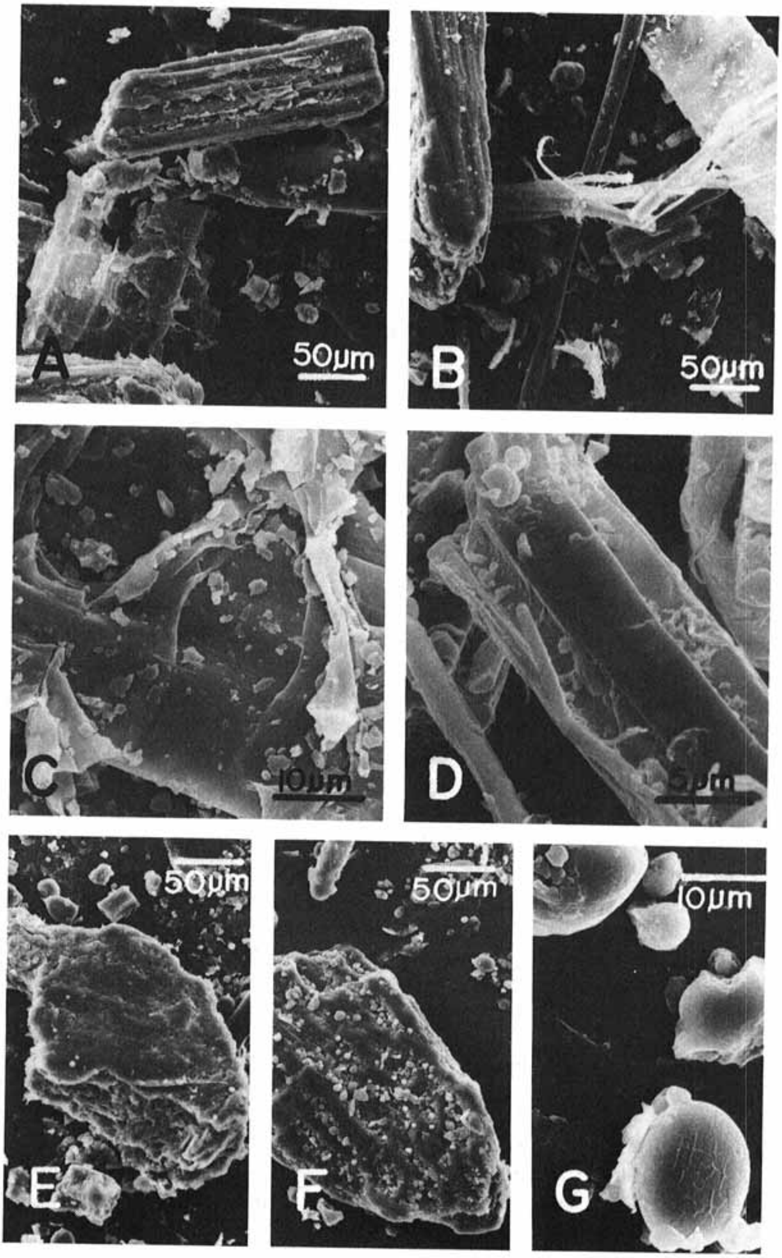

Fig. 2. SEM pictures of finely ground oat hulls (A–D) and coarse bran-finely ground (E = pericarp particles, F = aleurone cell material, G = starch granules).

Gassing powers were determined on 10 g flour at 30°C with gauge-type pressure meters and with the formula used in baking, except that shortening was omitted and water absorption was increased to 100%.

Crumb compressibility was measured with a Bloom gelometer. The plunger, 25 mm in diameter, was depressed 4 mm into the bread crumb after the crust was removed. The weight in grams required to depress the plunger was taken as compressibility measurement. Compressibility was measured 1 hr, 1 day, 2 days, and 3 days after baking on bread crumb from wrapped and sealed loaves, stored at room temperature (about 25°C).

Crumb and crust (top) color were determined with a Hunterlab color meter. To standardize the instrument, we used Hunterlab Tile Standard No. 025-931 ($L = 83.1$; $a_L = 4.0$; $b_L = 26.2$). To simplify bread color comparisons, we calculated total color difference (ΔE) according to:

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

Microscopic Examinations

The cellulose powders, bran, and hulls were placed on double-stick Scotch tape for scanning electron microscopy (SEM). Bread slices, cut about 1 hr after baking, were quick-frozen at −20° F. Small cubes were cut from the frozen slices and were freeze-dried. The samples were mounted either directly (powders) or with clear nail polish (bread) on 9-mm diameter aluminum specimen holders, coated with a 10-nm layer of graphite and a 15-nm layer of gold, and viewed and photographed in an ETEC Autoscan electron microscope at an accelerating voltage of 5 kV. For examination by light microscopy (LM), small sections from the frozen slices were fixed for 1 hr in 4% glutaraldehyde (pH 7, phosphate buffer) at 25°C, washed in buffer 1 hr, dehydrated through a graded ethanol series, passed through xylene, and embedded in paraffin. Sections of 8 μm were cut on a rotary microtome and fixed to glass slides with Haupt's adhesive. The staining procedure involved removing paraffin, hydrating through a graded ethanol series, and staining 30 sec in Paragon (Paragon C. & C. Co., Inc., New York). The sections were dehydrated in an ethanol series, passed twice through xylene, mounted with Permount, and viewed and photographed through a Zeiss microscope.

RESULTS

Whole oat hulls and coarse bran so adversely affected both mixing properties and bread quality that the data are not included.

Effects of fiber material on several breadmaking properties are summarized in Figs. 3 and 5 for averages at 0, 3, 5, 7, 10, and 15% and in Fig. 4 for typical 15% replacements with celluloses, bran, and oat hulls; Table III summarizes water absorption, mixing time, and breadmaking data for the 7 and 15% flour replacements with individual celluloses, wheat brans, and oat hulls.

Water Absorption

The fiber materials varied widely in effects on water absorption (Fig. 3). On the average, water absorption increased linearly from 64.2% in the control to 68.3%

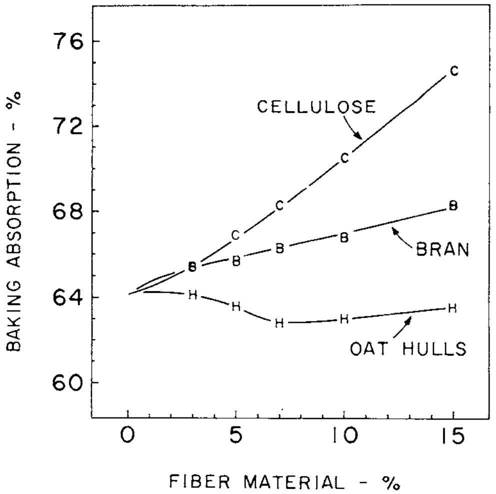

Fig. 3. Bake water absorption (%) of doughs from wheat flours in which 3, 5, 7, 10, or 15% was replaced by celluloses (C), wheat bran (B), or oat hulls (H). The values for C, B, and H are averages for 7, 4, and 2 samples, respectively.

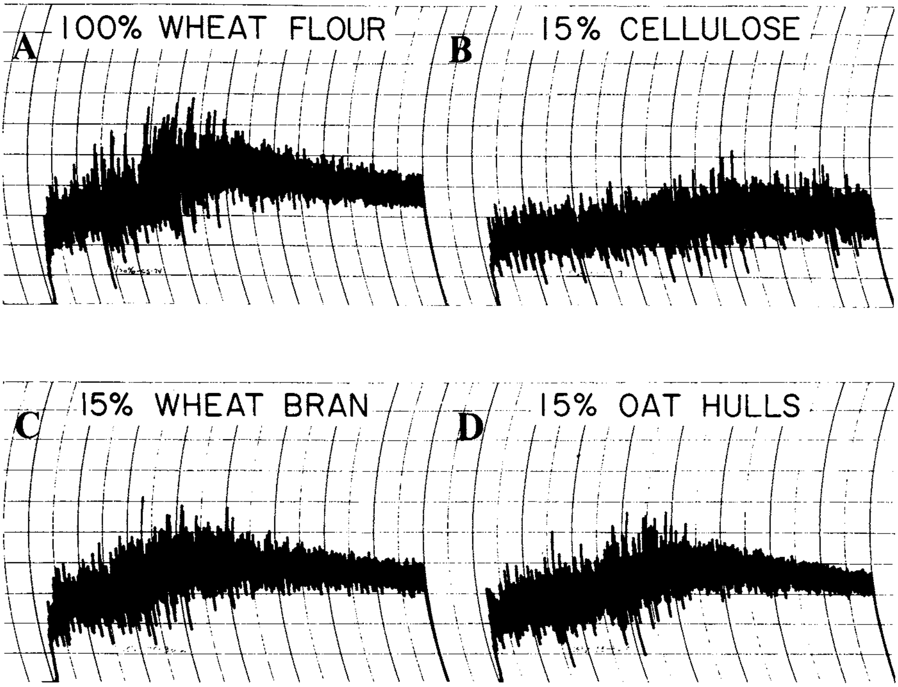

Fig. 4. Mixograms of control flour (A), and control flour in which 15% was replaced by Prototype cellulose 174-1 (B), finely ground fine bran (C), or finely ground oat hulls (D).

in the sample with 15% bran. The celluloses increased water absorption almost exponentially; average largest increase was 10.4% (from 64.2 to 74.6% at 15% replacement). Oat hulls reduced absorption from 64.2% in the control to 62.5% at 15% replacement.

Modified celluloses increased water absorption more than ground α-cellulose floc; the 50-μm Avicel agglomerate (PH 101) increased water absorption more than the 20-μm agglomerate (PH 105) (Table III). With the four prototype celluloses, water absorption increased more by the addition of either small fiber (No. 170) sample than by either large-fiber (No. 174) sample; adding carboxymethyl cellulose (CMC) generally increased water absorption somewhat. The wheat bran preparations differed little in effects on water absorption.

Mixing Properties

The fiber materials also differed in effects on bake mixing time, as tabulated:

	Average mixing time (min) with replacement (%) of				
	3	*5*	*7*	*10*	*15*
Celluloses	4 1/4	4 3/8	4 5/8	5 1/8	6
Wheat bran	3 5/8	3 5/8	3 1/2	3 5/8	3 7/8
Oat hulls	3 7/8	4 1/4	4 1/4	4 5/8	4 5/8

The mixing time of the control flour was 3-7/8 min. The above tabulation is for averages for the three fiber types at five replacement levels. Table III gives values for individual fiber materials at the 7 and 15% replacement levels.

Thus, replacing wheat flour with 15% bran had no consistent effect on bake mixing time; oat hulls increased mixing time consistently but much less than the celluloses.

Mixograms of flour-water doughs for the flour and flour with 15% cellulose, wheat bran, or oat hulls are shown in Fig. 4. The mixograms for the three mixtures are typical for the doughs containing the three types of fiber materials. Mixogram mixing times were almost identical with bake mixing times.

Effects of celluloses on mixing time differed little with 7% replacement (Table III); at 15%, celluloses that increased water absorption most, generally also increased mixing time most. CBM was the only bran that increased mixing time at 15% replacement; both oat hulls increased mixing times at both replacement percentages.

Loaf Volume and Crumb Grain

The effects of adding fiber materials on loaf volume are compared with the theoretical effect (Fig. 5). The theoretical line was calculated (14) from loaf-volume decreases expected from dilution of gluten proteins by the various fibrous materials. The loaf-volume change per percentage of the CS-74 flour protein was 72 cc.

Replacing up to 5% of the wheat flour with fiber materials reduced loaf volume by the expected theoretical amount (within experimental error limits). At the 10% replacements, reductions in loaf volume were greater than expected, but did not differ significantly with type of fiber. The deviation from the theoretical line increased almost exponentially with increase in amount of fiber material; at 15%, the celluloses reduced loaf volume, on the average, somewhat more than either bran or oat hulls did.

No consistent effects on loaf volume were related to cellulose particle size or composition, but the two samples of Prototype No. 174 probably decreased loaf volume slightly less than the other celluloses (no data given). Among bran samples, the two fine ones seemed to decrease volume slightly less than the two coarse samples. All fiber additives at 15% replacement impaired (coarsened) bread crumb texture. At 7% replacement, celluloses generally produced bread crumbs superior to the bran bread crumbs. Crumbs of the oat hull breads generally were poorest.

Gassing Power

To determine whether loaf volume was depressed more than expected by impaired gas formation or gas retention, we determined gassing power at 1-hr intervals for 5 hr on 10- and 8.5-g flour doughs, and on doughs prepared with 8.5 g flour plus 1.5 g Prototype 174-1, finely ground fine bran, or finely ground oat hulls. We detected no significant differences in gassing power the first 3 hr but

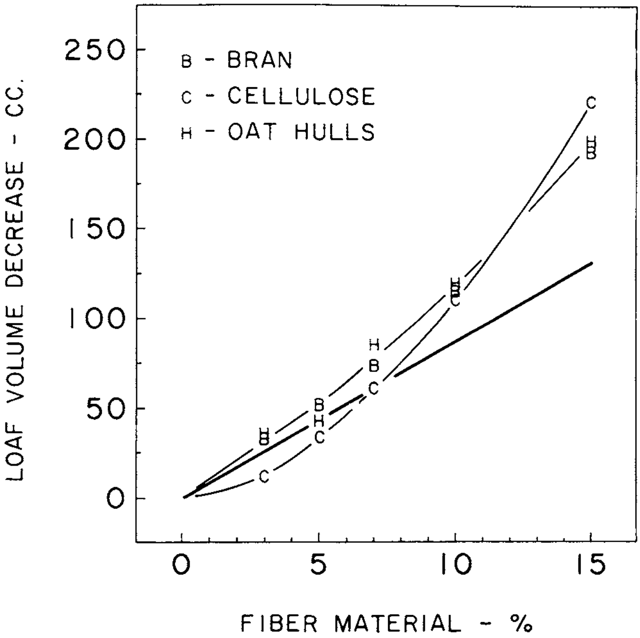

Fig. 5. Effects on loaf volume decrease of replacing 3, 5, 7, 10, and 15% wheat flour by celluloses (C), wheat bran (B), or oat hulls (H). The values for C, B, and H are averages of 7, 4, and 2 samples, respectively, and are compared with the theoretical loaf volume decrease (heavy straight line).

TABLE III

Effects on Breadmaking Properties of Replacing 7 or 15% Wheat Flour with Indicated Fiber Materials

Material Added	Water Absorption (%) at Replacement			Mixing Time (min) at Replacement			Loaf Volume (cc) at Replacement			Bread Crumb[a] at Replacement		
	0%	7%	15%	0%	7%	15%	0%	7%	15%	0%	7%	15%
None	64.2	...	...	3-7/8	...	...	973	...	...	S	...	...
Celluloses												
Floc	...	66.9	70.8	...	4-3/4	5-1/2	...	888	760	...	S	U
Avicel PH-101	...	68.5	75.8	...	4-7/8	6-7/8	...	928	723	...	S	U
Avicel PH-105	...	67.7	74.2	...	4-3/8	5-3/8	...	915	730	...	S	U
Prototype 170-2	...	69.1	76.2	...	4-3/8	6-1/2	...	913	713	...	S	U
Prototype 170-1	...	69.4	77.0	...	4-5/8	6-5/8	...	893	746	...	S	U
Prototype 174-2	...	67.9	74.5	...	4-1/2	6	...	928	784	...	S	U
Prototype 174-1	...	68.6	73.7	...	4-3/8	5-1/4	...	920	799	...	Q-S	U
Wheat bran												
Coarse-medium	...	66.3	68.2	...	3-5/8	4-1/8	...	870	760	...	Q	U
Coarse-fine	...	66.4	69.1	...	3-5/8	3-7/8	...	890	771	...	Q	U
Fine	...	66.6	68.4	...	3-3/4	3-7/8	...	923	810	...	Q-S	U
Fine-fine	...	65.8	67.3	...	3-3/8	3-5/8	...	914	775	...	Q-S	U
Oat hulls												
Medium	...	62.4	62.5	...	4-1/4	4-7/8	...	883	765	...	Q-U	U
Fine	...	63.0	62.5	...	4-1/4	4-1/4	...	891	781	...	Q	U

[a] S = satisfactory, Q = questionable, U = unsatisfactory.

recorded the following pressures after 4 and 5 hr:

	Pressure (mm Hg) at the end of	
	4 hr	*5 hr*
10 g flour	552	722
8.5 g flour	514	660
8.5 g flour + 1.5 g cellulose (174-1)	542	701
8.5 g flour + 1.5 g bran (FBF)	610	832
8.5 g flour + 1.5 g oat hulls (OHF)	569	746

None of the fiber materials depressed gassing power; on the contrary, bran increased it considerably. Consequently, loaf-volume-depressing effects of fiber materials seem to result from reduced gas retention rather than reduced gas formation.

Other Bread Characteristics

Untrained taste panels consistently indicated that, at all replacement levels, none of the cellulose samples modified bread taste or mouthfeel; that oat hulls imparted an undesirable, gritty texture; and that the detectable change from added bran was not objectionable (no data given).

Crumb and crust color were determined for the control and all experimental breads with cellulose 174-1, FBF, or OHF. Data for the control and 7 and 15% replacements are in Table IV.

Cellulose had little effect on loaf interior lightness but lightened the crust somewhat; bran darkened crumb and crust most. Oat hulls darkened crumb but had little effect on crust lightness. The fiber materials reduced the green component in crumb color and shifted it somewhat to gray-red; only bran shifted the red color component in crust toward gray-red. Wheat bran and oat hulls imparted a yellowish tint to the crumb. Effects on color were least for cellulose and most for bran.

TABLE IV
Bread Crumb and Crust Color

Material Added	**Loaf Interior**				**Loaf Crust (Top)**			
	L[a]	**a**[a]	**b**[a]	**ΔE**[b]	**L**[a]	**a**[a]	**b**[a]	**ΔE**[b]
None	44.4	−2.1	6.6	...	21.6	2.3	3.5	...
Prototype Cellulose 174-1								
7%	44.3	−1.3	6.7	0.81	21.9	2.6	3.7	0.05
15%	44.2	−0.9	6.7	1.22	24.0	2.5	5.1	2.89
Fine bran-fine								
7%	39.9	−1.5	7.2	4.58	20.7	1.1	2.6	1.75
15%	35.5	−0.5	7.5	9.09	20.9	1.1	2.8	1.56
Oat hulls-fine								
7%	40.7	−1.3	8.1	4.07	21.7	2.3	3.8	0.03
15%	37.2	−0.8	8.7	7.61	22.6	2.6	4.4	1.38

[a] Hunterlab color meter values: L = lightness; a = redness or greenness; b = yellowness or blueness.

[b] $\Delta E = \sqrt{(\Delta L^2) + (\Delta a_L^2) + (\Delta b_L^2)}$.

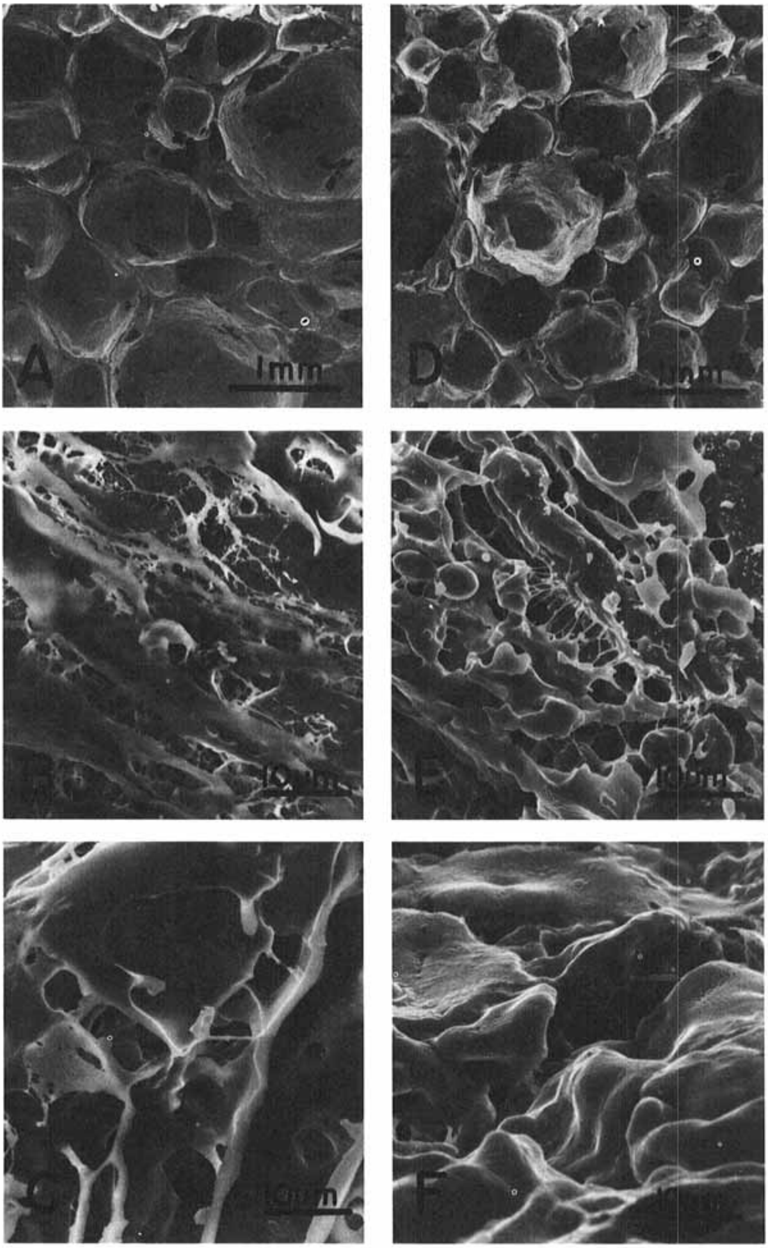

Fig. 6. SEM micrographs of control bread. A, B, and C from top part and D, E, and F from bottom part of the loaf. B, C, and E are cross-sections of crumb; F is surface of a gas vacuole.

In the 1-hr-old bread, up to 7% of Prototype 174-1, finely ground fine bran, or finely ground oat hulls had little effect on crumb compressibility (no data given). At 7 and 15%, oat hull bread was softest, bran bread hardest, and cellulose bread intermediate. Differences among control, cellulose, and oat hull breads decreased with storage time; but bran bread was still hardest, especially for the 7 and 15% replacements, even after 2 and 3 days' storage.

Bread Crumb Structure

The effects of the fibrous materials on bread crumb structure were studied by SEM and LM. Figure 6 depicts SEM micrographs of control-bread crumbs in the top (A–C) and bottom (D–F) parts of the loaf. Comparison of A and D reveals that the cells from the upper part of the loaf were larger than those from the lower part. Higher magnification of cross-sections of cell walls (B, C, and E) reveals that the cell walls had a fine structure composed of numerous thin filaments connecting adjacent regions. Figure 6C depicts an area in which the fine structure was less pronounced than in the other examined areas. However, even in Fig. 6C a thin sheet-like region and some fine filaments are present. Figure 6F is a micrograph from the inside surface of a gas cell. These surfaces generally lacked fine structure in all bread samples that were examined.

Low-magnification SEM micrographs of cross sections through upper parts of experimental breads showed a wide variation in gas cell size and shape and in number and size of holes (Fig. 7, A, B, and D). Cellulosic particles were not depicted in the bread crumb by SEM. Oat hull and wheat bran particles were, however, tentatively identified (Fig. 7, C and E).

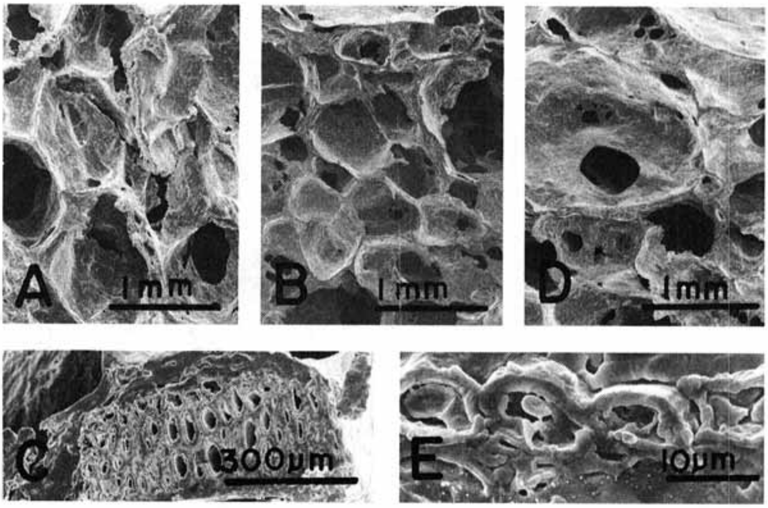

Fig. 7. SEM micrographs of bread baked with 15% of the flour replaced by Prototype cellulose 174-1 (A), finely ground oat hulls (B), and finely ground fine wheat bran (D). A piece of oat hull imbedded in the bread crumb is shown in C and a piece of bran in E.

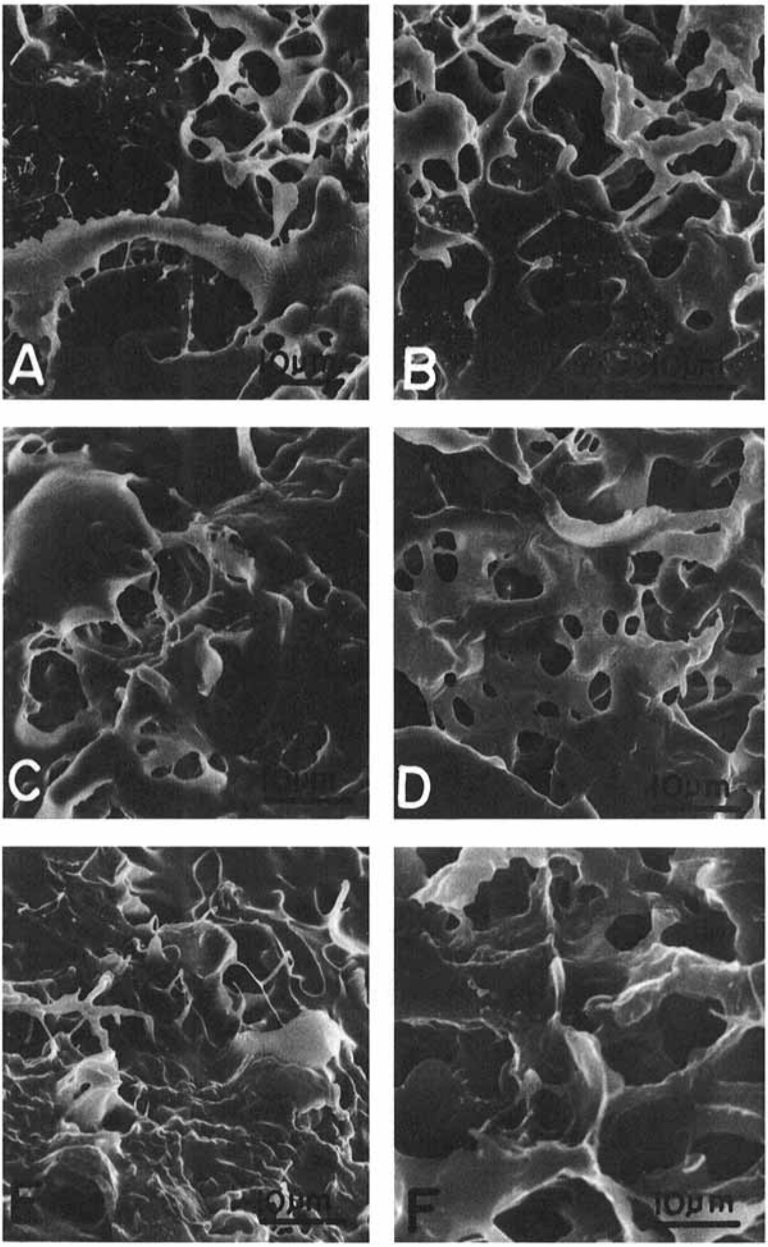

Fig. 8. SEM micrographs of bread baked from flour in which 15% was replaced by cellulose 174-1 (A and B), finely ground oat hulls (C and D), and finely ground fine wheat bran (E and F).

High-magnification SEM micrographs of cross-sections of cell walls of experimental breads (Fig. 8, A–F) revealed a substantial reduction in fine structure from adding the fibrous materials; the bread crumb filaments and sheets were coarse and massive.

Degradation of the fine crumb structure in fiber containing breads was further shown by LM (Fig. 9). Figure 9, A–D shows low-magnification LM micrographs of four bread crumbs (A = control; B = cellulose 174-1; C = oat hull; and D = bran) indicating the locations of fiber particles. Under oil immersion, the thin filaments of the finely structured control bread were clearly visible (Fig. 9E). Crumbs of breads baked with cellulose 174-1 (Fig. 9F) or oat hulls (Fig. 9G) contained few thin filaments.

DISCUSSION

Our results show that none of the evaluated fiber additives was ideally suited

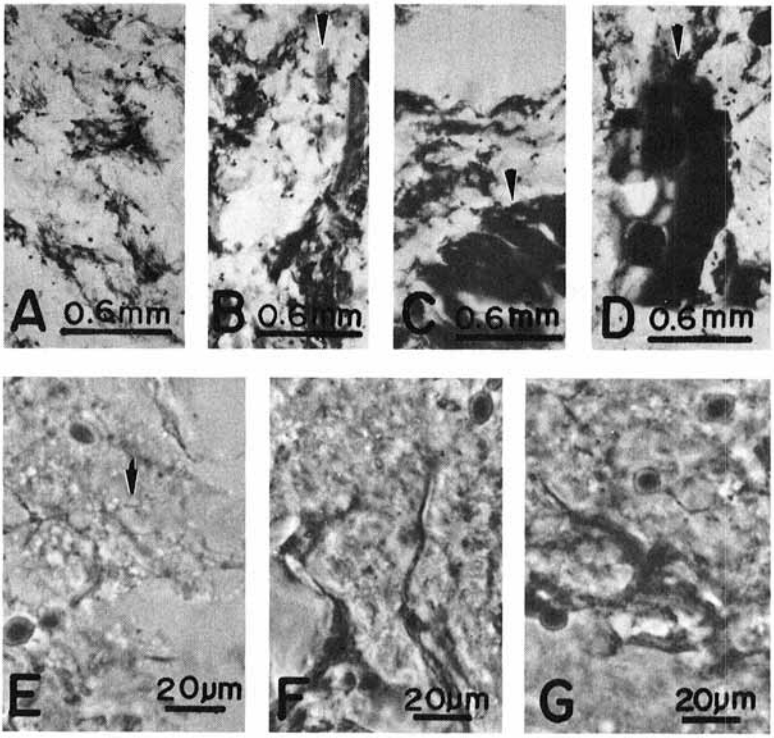

Fig. 9. Photomicrographs of bread under the light microscope. A = Control bread; B = Prototype cellulose 174-1 bread; C = oat hulls—fine bread; the arrow points to an oat particle; D = fine bran-fine bread; the arrow points to a bran particle that shows aleurone cells; E = control bread—viewed under oil immersion; arrow points to fine strands; F = Prototype cellulose 174-1 bread—viewed under oil immersion; and G = oat hull—fine bread, viewed under oil immersion.

for breadmaking and that all affected some functional properties. The undesirable and unacceptable grittiness (presumably from the silica) and splinter-like particles of oat hulls in bread would exclude their use in breadmaking, despite their limited effect on water absorption, mixing time, and bread color, and their small improving effect on softness retention. Bran had little effect on mixing time, moderately increased water absorption, and modified both taste and bread color; it reduced softness at all storage stages. The celluloses were acceptable with regard to bread taste, color, and shelf-life. However, both the high increase in mixing time and water absorption were undesirable. The long mixing time would increase processing cost, and cellulose-containing bread is likely to have more than the 38% water content permitted by present U.S. regulations for regular white bread.

Adverse effects of the fiber materials increased with increase in their levels in the bread. If medical studies establish 5% fiber as desirable, acceptable bread can be produced by adding commercial cellulose or fine bran. The celluloses offer the advantages of maximum preservation of the character of regular white bread; bran modifies bread character but it is a natural additive and a relatively rich source of high-quality protein as well as of minerals and vitamins. However, bran and cellulose are not equal as fiber sources. Bran contains nonfibrous materials, and compositions of the fibrous materials in bran and cellulose differ widely. If additives are to provide equal amounts of fibrous materials, much less cellulose than bran may be required.

At the high replacement levels, all tested fibrous materials decreased loaf volume substantially more than expected from their gluten-diluting effect. Gassing power determinations suggested that the fibrous materials impaired gas retention rather than gas production. An explanation for this deleterious effect was sought by microscopic techniques.

Microscopy revealed a major difference between the crumb structure of the control and experimental breads. The control bread had a fine crumb structure composed of thin sheets and filaments. Such a structure was essentially absent in the fiber-containing breads. The mode of this fine structure disruption is not known; it is not merely a dilution effect.

Further studies are needed to establish the mechanism and mode of the crumb-structure-disrupting effect. An ideal fiber material (in terms of functional breadmaking properties) would eliminate or at least minimize crumb-structure-disrupting effects.

In conclusion, acceptable bread was produced from wheat flours in which about 7% was replaced by microcrystalline celluloses or wheat bran. Oat hulls were unsuitable for production of an acceptable bread.

Acknowledgments

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