Chemical, Physical, and Baking Properties of Apple Fiber Compared with Wheat and Oat Bran[1]

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ABSTRACT

Apple fiber was characterized by chemical and physical methods and found to be a good dietary fiber source and superior water binder to wheat and oat brans. Addition of 4% hydrated apple fiber to bread reduced loaf volume by 14%. Apple fiber was added to cookie and muffin at a replacement level of at least 4% without a large adverse effect on cookie and muffin quality.

Key words: water-holding capacity, water activity, baking property

Dietary fiber is the indigestible component of foods that includes cellulose, hemicellulose, lignins, pectins, gums, and mucilages (Williams 1985). Its beneficial effects on human health have received much attention. Lack of adequate dietary fiber in the diet is associated with constipation, diverticulosis, cardiovascular disease, and cancer (Trowell et al 1985), and increased consumption of dietary fiber has been advocated. For instance, when the British Health Education Council (1983) recommended multiple changes in the national diet, a 50% increase in dietary fiber was proposed, the largest single-component change in the present diet (Trowell et al 1985).

High-fiber foods are becoming more available in the United States. Wheat and oat bran are the conventional dietary fiber sources, but other fiber sources, such as potato peel, have been added to bread and cereal products (Toma et al 1979). Tree Top Inc. has developed a method of producing apple fiber powder from the pomace after juice extraction. The apple pomace is separated from the juice using an improved mechanical filtering system. The residue is dehydrated with a spray dryer and screened through USS 40-mesh screens (Morris 1985). The fiber is brown to brownish red in color, bland in taste, and has no musty or "off" flavors.

The objectives of this study were to characterize the apple fiber chemically and physically and evaluate its effects on bread, cookies, and muffins. Wheat and oat brans were used for comparison.

MATERIALS AND METHODS

Materials

Spray-dried apple fiber used in this investigation was obtained from Tree Top Inc. The fiber sample was stored in glass jars at −20° C until analysis. Soft white wheat bran was obtained from the American Association of Cereal Chemists, and Mother's oat bran (creamy high-fiber hot cereal, Quaker Oats Company, Chicago, IL) was obtained from a local store. All chemicals used in this study were reagent grade and purchased from Sigma Chemical Company (St. Louis, MO). Amyloglucosidase (no. A-9268), protease (no. P-5380), pectinase (no. P-5146), and pepsin (no. P-7000) were obtained from Sigma. Termanyl (heat-stable α-amylase) was obtained from Novo Laboratories Inc. (Willon, CN).

Chemical Analysis

The procedures used for determinations of moisture, ash, and fat were given by Meloan and Pomeranz (1980). The standard AOAC micro-Kjeldahl method (2.045) was used for protein determination (AOAC 1965). Total dietary fiber (TDF) was determined according to the proposed AOAC procedure (Prosky et al 1985). For fiber components analysis, the scheme of Jeltema and Zabik (1980) was adopted.

Physical Analysis

For water-holding capacity determination, 1 g of fiber in 50 ml of distilled water was mixed in a Sorvall mixer (Ivan Sorvall Inc., Norwalk, CT) at high speed for 1 min, and then centrifuged at 10,000 × g for 15 min at 20° C. The supernatant was removed, and the tube was inverted for 10 min. Moisture content of the precipitate was determined by predrying at 70° C for 1 hr in a forced-air oven and then drying at 70° C in a vacuum oven for 24 hr.

The water sorption isotherm of apple fiber was determined by equilibrating 1–2 g of dried sample (24 hr at 50° C in vacuum oven) on glass petri dishes in vacuum desiccators containing saturated salt slurries at 20° C (Labuza 1975). The saturated salt solutions and water activities were lithium chloride (0.11), potassium acetate (0.23), magnesium chloride (0.33), potassium carbonate (0.43), magnesium nitrate (0.54), sodium chloride (0.75), potassium bromide (0.81), potassium chloride (0.85), barium chloride (0.91), potassium nitrate (0.95), and potassium sulfate (0.97).

Particle size distribution of apple fiber was determined using a set of U.S. Standard sieves (40, 50, 80, and 100 mesh); 10 g of sample was placed on the largest sieve, and the weight of samples retained on each sieve after 10 min of manual shaking was recorded. The particle size was expressed as the percentage of particles retained on each sieve (Toma et al 1979).

For the bulk density (loose) determination, a graduated cylinder was filled with sample, shaken slightly, and weighed. The volume of sample was also recorded. The packed density was determined by pressing the sample in the graduated cylinder using a rubber stopper attached to a glass rod.

For viscosity measurement, one part of apple fiber and 50 parts of distilled water were mixed in a Sorvall mixer at high speed for 20 sec. The slurry was transferred to a 100-ml glass beaker, heated on a hot plate-magnetic stirrer from 30 to 80° C and then cooled at room temperature from 80 to 20° C. Viscosity readings were taken at 30, 40, 50, 60, 70, and 80° C using a Brookfield model RVT viscometer with a no. 2 spindle at 20 rpm (Brookfield Enginering and Laboratory Inc., Stoughton, MA). During cooling, viscosity readings were taken in the same manner as during heating.

Baking Studies

The wheat flour used for bread baking was a blend of Montana hard wheat flour with 12.6% moisture, 12.8% protein, and 0.44% ash. The 100-g straight dough method was used throughout the study. The basic formula included 100 g of flour (14% mb), 5 g of compressed bakers' yeast (Fleishman's Standard Brands), 6 g of sucrose, 3 g of shortening (Crisco), 1.5 g of salt, 4 g of nonfat dry milk, 0.3 g of malt, 40 ppm ascorbic acid, and different concentrations of fibers on a flour replacement basis. The doughs were fermented for 90 min and proofed to optimum height (7.9 cm)

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at 30° C and 95% relative humidity. Doughs were degassed after 52 and 78 min and immediately before panning. Breads were baked at 218° C (425° F) for 24 min and weighed immediately after removal from the oven. Loaf volume of the bread was determined by rapeseed displacement. Crumb grain was scored by the procedure used for test baking at the U.S. Department of Agriculture Western Wheat Quality Laboratory (Rubenthaler et al 1986).

To prepare the hydrated fibers, seven parts of distilled water were added to one part of apple fiber to hydrate for 12 hr. The excess water was decanted and discarded before baking. The fibers were transferred to the dough mixer and mixed with wheat flour and other ingredients. The baking procedure was as described above, with water and mixing time adjusted to optimum.

For cookie baking, the crisp formula of Hong and Brabbs (1983) was used. The basic formula included 73.2 g of flour (Western Family all-purpose flour), 62.4 g of sucrose, 33 g of shortening, 14 g of high-fructose corn syrup (Cornsweet 90, 90% fructose corn syrup), 1 g of salt, 1 g of baking soda, and 12.4 g of distilled water. Apple fiber was added at 4, 8, 12, and 16% concentrations on a flour replacement basis. The cookies were baked at 190.5° C (375° F) for 8.5 min. Weight, diameter, and thickness of each cookie were recorded.

For muffin baking, a plain muffin method was adopted (Sultan 1985). The basic formula included 677 g of sugar, 14 g of salt, 85 g of nonfat milk powder, 451 g of shortening, 677 g of distilled water, 1,128 g of flour (Western Family all-purpose flour), and 56 g of baking powder. The batter was divided into six muffin cups half full (approximately 55 ± 1 g). Apple fiber was added at different concentrations on a flour replacement basis. The muffins were baked at 196° C (385° F) for 15 min. The weight and volume of each muffin were recorded.

In all baking experiments, the wheat and oat brans were ground in a Hobart burr mill and screened through a 130-μm sieve to make their particle size similar to that of the apple fiber.

TABLE I
Composition of Apple Fiber and Wheat and Oat Brans

Constituent	Apple Fiber	Wheat Bran	Oat Bran
Moisture, %	1.18 ± 0.05	9.45 ± 0.05	7.69 ± 0.11
Ash, % db	1.27 ± 0.00	5.95 ± 0.05	2.81 ± 0.01
Lipid, % db	2.45 ± 0.05	0.44 ± 0.10	1.00 ± 0.69
Protein, % db	7.25 ± 0.55	16.20 ± 0.20	5.54 ± 0.11
TDF,[a] % db	61.90 ± 0.10	38.00[b]	26.40 ± 0.90

[a]TDF = Total dietary fiber.
[b]Data obtained from AACC.

TABLE II
Dietary Fiber Components of Apple Fiber

Component (% db)	Water-Soluble Fiber	Water-Insoluble Fiber
Galacturnic acid	0.74 ± 0.04	...
Hemicellulose	19.20 ± 0.06	4.26 ± 0.52
Pectin	...	8.70 ± 0.70
Cellulose	...	39.90 ± 3.40
Lignin	...	15.30 ± 0.50

RESULTS AND DISCUSSION

Chemical Analysis

The results of chemical analyses of spray-dried apple fiber is shown in Table I. Compared with wheat and oat brans, apple fiber contains more TDF and lipid, but less water, ash, and protein. The dietary fiber components of apple fiber are shown in Table II. The major dietary fiber component of apple fiber is cellulose. The TDF content in apple fiber (Table I) is 61.9%, which is about 30% lower than the sum of water-soluble and insoluble fibers determined according to Jeltema and Zabik (1980)(Table II). The apparent discrepancy between the TDF content and the sum of soluble and insoluble fiber was probably due to the different methods used. In the TDF analysis, after ethanol extraction, the precipitate was filtered with a crucible having pores of 40–60 μm in diameter, which may be too large to retain the water-soluble fiber. The macromolecules, such as proteins and polysaccharides, usually range from 36 to 160 μm (Lehninger 1982). Therefore, the water-soluble fiber components may not be accounted for in the TDF method.

Physical Properties

Water sorption isotherms of spray-dried apple, wheat, and oat brans are presented in Figure 1. In general, wheat and oat brans were considerably less hygroscopic than apple fiber. This difference could be due to the structural difference of cell wall materials between grain brans and fruit fibers, or the lower fiber contents of wheat and oat brans, or the larger particle size of wheat and oat brans compared with apple fiber (Table III). Water-

TABLE III
Physical Properties of Apple Fiber and Wheat and Oat Brans

Property	Apple Fiber	Wheat Bran	Oat Bran
WHC,[a] g water/g solid	9.36 ± 0.10	5.03 ± 0.10	2.10 ± 0.20
Loose density, g/cm^3	0.46	0.39	0.42
Packed density, g/cm^3	0.66	0.43	0.61
Particle size[b]			
40 mesh	0.06	95.30	92.20
50	1.30	3.30	6.60
80	11.40	1.20	1.20
100	15.20	0.20	0.00
>100	72.00	0.00	0.00

[a]WHC = Water-holding capacity.
[b]Percent of sample retained on U.S. Standard sieves.

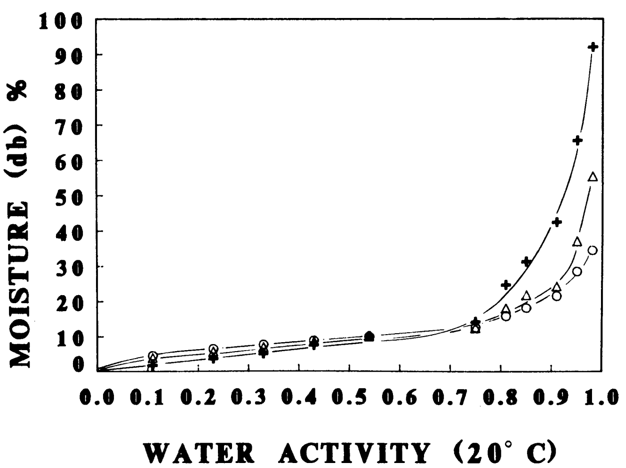

Fig. 1. Water sorption isotherms of apple fiber and wheat bran and oat bran: + = apple fiber, △ = wheat bran, o = oat bran.

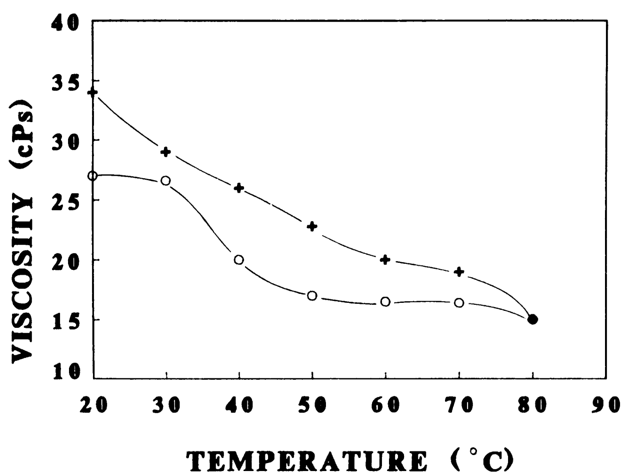

Fig. 2. Effect of temperature on the viscosity of apple fiber slurry (1:50, w/w): o = heating, + = cooling.

TABLE IV
Effect of Apple Fiber and Wheat and Oat Brans on Bread Baking

Sample Concentration (%)	Water Absorption (%)	Mixing Time (min)	Loaf Volume (cm^3)	Loaf Weight (g)	Crumb Grain[a]
Control					
0	71.2	3.8	1038 ± 22.0	156.3 ± 1.0	S
Apple					
4	76.7	3.5	858 ± 20.0	167.0 ± 3.0	QS
8	82.7	3.8	648 ± 25.0	172.0 ± 0.3	QU
12	88.7	4.2	450 ± 60.0	176.0 ± 6.5	U3
Hydrated apple					
4	93.0	4.0	893 ± 17.0	168.0 ± 2.0	QS
8	114.6	4.5	675 ± 25.0	180.0 ± 1.0	QU
Wheat bran					
4	74.2	3.7	960 ± 5.0	158.0 ± 1.8	S
8	79.2	4.3	878 ± 87.0	167.0 ± 5.0	QS
Hydrated wheat bran					
4	86.5	3.8	938 ± 12.0	162.0 ± 6.0	QS
8	119.5	4.5	823 ± 7.0	170.0 ± 3.0	Q
Oat bran					
4	74.7	4.3	983 ± 23.0	163.5 ± 2.5	S
8	79.2	4.8	973 ± 7.5	158.0 ± 2.0	QS
Hydrated oat bran					
4	76.4	3.8	978 ± 47.0	157.0 ± 1.0	S
8	89.4	4.0	958 ± 7.0	160.0 ± 3.0	S

[a] S = Satisfactory, QS = questionable satisfactory, QU = questionable unsatisfactory, U3 = very unsatisfactory.

holding capacity data also confirmed that the cereal brans imbibed less water than the apple fiber (Table III).

The loose and packed densities of apple fiber were greater than those of wheat and oat brans (Table III). The particle-size distributions of apple fiber and wheat and oat brans are also shown in Table III. In apple fiber only a small percentage of particles is greater than 50 mesh. About 70% of particles passed through 100 mesh. In contrast, most particles were retained on 40 mesh in both wheat and oat brans.

The apparent viscosity change of a 1:50 (w/w) apple fiber/water suspension during heating and cooling is shown in Figure 2. Heating caused a decrease in viscosity of the fiber slurry. Upon cooling, the viscosity increased and exceeded the initial viscosity at 20° C. This indicated that heating caused some irreversible change in the apple fiber, possibly aggregation of some macromolecules. No gelation was observed after the heating-cooling cycle. Separation of fiber and water occurred after standing at room temperature for over an hour.

TABLE V
Cookie Baking Properties of Apple Fiber and Wheat and Oat Brans

Sample Concentration (%)	Diameter (cm)	Thickness (cm)
Control		
0	9.66 ± 0.22	0.37 ± 0.05
Apple		
4	8.48 ± 0.11	0.44 ± 0.02
8	7.90 ± 0.14	0.66 ± 0.09
12	7.40 ± 0.07	0.80 ± 0.00
Wheat bran		
4	9.82 ± 0.26	0.34 ± 0.05
8	9.70 ± 0.37	0.32 ± 0.05
12	8.98 ± 0.19	0.38 ± 0.05
Oat bran		
4	9.74 ± 0.21	0.36 ± 0.06
8	9.42 ± 0.15	0.38 ± 0.05
12	9.58 ± 0.13	0.42 ± 0.08

Baking Properties

The bread-baking data are shown in Table IV. The fibers were incorporated into the bread dough in both dry powder form and hydrated form.

In all bread-baking experiments, as the concentrations of fiber material increased, the water absorption, mixing time, and bread weight increased, and the loaf volume decreased. The increasing water absorption may be caused by the strong water-binding ability of fibers. The longer mixing time could result from the dilution of gluten and the difficulty of mixing fibers and wheat flour homogeneously. The increasing bread weight was caused by high water retention. The decreasing loaf volume was due to the dilution of gluten (Pomeranz et al 1977), and also could result from the interaction between gluten and fiber material (Chen et al 1988).

In the bread baked with dried fibers, addition of 4, 8, and 12% apple fiber to bread decreased the loaf volume by 17, 38, and 57%, respectively. The crumb grain of bread with added apple fiber was unacceptable. Compared with apple fiber, addition of 4 and 8% wheat bran and oat bran to bread decreased the loaf volume by 8 and 15% for wheat bran breads, and 5 and 6% for oat bran breads. The crumb grain of both wheat and oat bran breads was acceptable.

The hydrated apple fiber was less harmful than the dry apple fiber to bread loaf volume. Addition of 4 and 8% of hydrated apple fiber resulted in loaf volume reduction of 14 and 30%, respectively. This compares favorably with the 17 and 38% reduction caused by addition of 4 and 8% dry fiber, respectively.

Several factors may contribute to the observed differences in baking properties between dry and hydrated apple fiber. First, prehydration of apple fiber decreased the water absorption required in the dough making, which was helpful for the dough development procedure. When using dry fiber, doughs were excessively slack in the early mixing stages. Second, prehydration of apple fiber provided less competition for water between fiber and dough components that were activated by water during dough development, such as yeast action and gluten structure. Finally, higher water absorption in the dough may have diluted some of the fiber components' detriment to dough properties.

In bread baking with hydrated wheat and oat bran, addition of 4 and 8% oat bran resulted in loaf volume reduction of 6 and 8%, which was about the same as the reduction caused by dry oat bran. Addition of 4 and 8% hydrated wheat bran resulted in loaf volume reduction of 10 and 21%, which was worse than the reduction caused by dry wheat bran.

In general, wheat and oat brans were less detrimental to bread quality than apple fiber at the same concentrations. However, wheat and oat brans were lower in TDF than apple fiber (Table I). If the comparison is based on TDF content, the deleterious effect of apple fiber on loaf volume was greater than that of oat bran but less than that of wheat bran (Fig. 3). Therefore, apple fiber may be

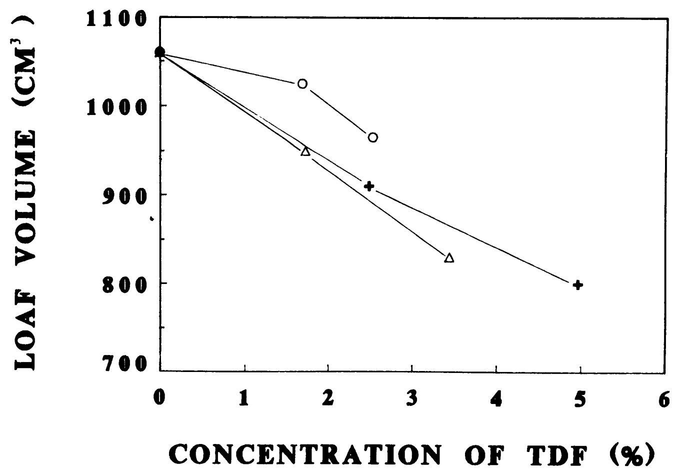

Fig. 3. Loaf volume of bread vs. concentration of total dietary fiber (**TDF**): + = apple fiber, △ = wheat bran, o = oat bran.

TABLE VI
Muffin-Baking Properties of Apple Fiber and Wheat and Oat Brans

Sample Concentration (%)	Weight (g)	Volume (cm^3)	Density (g/cm^3)
Control			
0	47.5 ± 0.72	105.0 ± 5.00	0.452
4	48.0 ± 1.56	98.3 ± 2.89	0.488
8	50.7 ± 0.21	96.7 ± 5.77	0.524
12	51.2 ± 0.12	88.3 ± 2.36	0.580
Wheat bran			
4	48.6 ± 0.66	91.7 ± 7.64	0.530
8	49.7 ± 0.49	100.0 ± 0.00	0.497
12	48.0 ± 1.50	90.0 ± 0.00	0.533
Oat bran			
4	48.9 ± 0.31	102.0 ± 2.89	0.479
8	49.2 ± 0.39	96.7 ± 5.77	0.509
12	49.4 ± 1.11	93.3 ± 11.6	0.530

an alternative dietary fiber source in bread baking.

As the concentration of apple fiber increased, the diameter of cookie decreased, and the thickness of cookie increased (Table V). Addition of 4, 8, and 12% apple fiber in cookies caused reductions in diameter of 12, 18, and 23%, respectively. The thickness of cookies increased 20, 78, and 116% when 4, 8, and 12% apple fiber were added. The strong water-binding characteristics of apple fiber rendered cookie dough "drier" in appearance than the dough containing wheat and oat brans. As a consequence, the dough could not spread well, and the cookies were small and thick.

With increasing apple fiber concentration, densities of muffins increased (Table VI). Addition 4, 8, and 12% apple fiber caused 8, 16, and 28% increase in muffin density. Generally, low density is associated with good muffin quality. Similar to the cookie baking experiments, the strong water-binding properties of apple fiber caused dough to spread poorly, which resulted in high density muffins.

Compared with apple fiber, cookies and muffins with added wheat and oat bran had better qualities (Tables V and VI). For example, addition of 12% wheat and oat bran caused only 7 and 1% reduction in cookie diameter, respectively. As discussed previously, however, if the comparison is based on TDF basis, apple fiber may be an alternative dietary fiber source for cookie and muffin baking.

CONCLUSION

Apple fiber is higher in TDF than wheat and oat brans. Apple fiber is a good water binder based on studies of water sorption isotherm and water holding capacity. Apple fiber can be used as a dietary fiber source as well as a humectant in certain food products. Apple fiber may have a potential use in bread baking. Hydration of apple fiber before addition to wheat flour can partially alleviate the detrimental effects on bread loaf volume. Apple fiber also can be added into cookie and muffin at a replacement level of 4% or less without large adverse effects on cookie and muffin quality.

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