Functional Properties of Psyllium in Wheat-Based Products[1]

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ABSTRACT

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Psyllium and a psyllium-derived mucilloid (psyberloid) were added at 2, 4, or 8% (replacement) levels to three soft wheat flours and one hard wheat flour. The blends then were evaluated and compared with wheat bran with regard to water-holding capacity, dough mixing time and water absorption, alveograph characteristics, and quality of Chinese steamed bread, Japanese *udon* noodles, Japanese sponge cake, and regular white pan bread (pup loaves). Psyllium and psyberloid contained 87.6 and 84.1% total dietary fiber (more than 70% in soluble form), 55.4 and 52.9% pentosans, and had water-holding capacities of 49.7 and 35.6 g/g, respectively. Psyllium and psyberloid increased water absorption and mixing time, increased *P* and *W* alveograph parameters (at a fixed water level), impaired volume and quality of steamed bread, increased cake volume (at the 2% level), discolored noodles (but did not affect their taste and texture), and increased the volume of pan bread. The higher water content of the pan bread crumb containing psyllium and psyberloid was not accompanied by an increase in water activity and showed improved softness retention (for 72 hr) as measured by bread crumb compressibility and differential scanning calorimetry.

The many uses of psyllium mucilloid have been the subject of many articles, dissertations, and patents. Psyllium mucilloid has been used as a natural-fiber laxative (Chan and Wypyszyk 1988), to lower serum cholesterol levels in hypercholesterolemic patients (Bell et al 1989) and glycemic and lipid levels in diabetic mice (Watters and Blaisdell 1989), to affect fecal and colonic microbial metabolism (Costa et al 1989), and for prophylaxis and treatment of intestinal disorders (Cappel and Rece 1989). Relatively little has been published on the uses of psyllium as an additive to food or feed to improve their handling properties, shelf life, and consumer acceptance. The high water-binding capacity of psyllium and its effectiveness in improving handling and reducing stickiness (even at very low dry matter concentrations) were described by Ibuki (1989a,b).

Furst et al (1989) proposed the use of psyllium in production of a water-dispersible compound containing psyllium powder as a dietary bulking agent. The use of psyllium as a natural fiber stabilizer was described in 1990 (Anonymous 1990, Meer Corporation 1990). Ingredients developed from psyllium husks may be used to prevent ice crystal formation, impart freeze-thaw stability, and replace monoglycerides and diglycerides in ice cream and sherbet formulations. According to a 1988 study (Anonymous 1988), psyberloid (a psyllium mucilloid, almost completely dispersible in water) is a natural dietary fiber that can be used to reduce the caloric value by replacing starch in cereals and snacks. It may improve the texture of dough for better cutting, drying, and puffing in the manufacture of cereals and snacks. Some potential uses of psyllium or psyllium mucilloid products were listed by Chan and Wypyszyk (1988). The uses include instant beverages, cookies, diet bakery products, soft gel puddings, a binder in meat products and pet foods, meat analogues, yogurt, sauces and gravies, soups, and confectioneries. The usefulness of incorporating psyllium into ready-to-eat breakfast cereals without loss of physiological effects and with potential gains in palatability was described by Wolever et al (1991). Absent from those reports were the effects of psyllium on functional properties of the main wheat-based products such as noodles, cakes, and breads. Such uses were the subject of our investigations.

MATERIALS AND METHODS

Three fiber sources were used in this study—the AACC standard wheat bran and two commercial samples of psyllium. The AACC bran was a mixture of soft white and hard red wheat bran. We used unground bran and bran ground to pass a sieve with 0.5-mm round openings. Some characteristics of the three soft wheat flours (for cookies, sponge cake, and oriental noodles) and a hard wheat bread flour used in this study are described in Table I.

The two psyllium samples represented commercial products—Psyberloid B&C and psyllium husk (Botanicals International, Long Beach, CA). Both samples were from *Plantago ovata* Forssk., commercially known as blond or Indian psyllium (BeMiller 1973, Chan and Wypyszyk 1988). Samples were characterized by the methods described below.

Analytical Methods

Moisture, ash, protein, free lipids, and water-holding capacity were determined according to AACC approved methods (AACC 1983). Total dietary fiber was determined as described by Prosky et al (1988). Total pentosans were measured according to Hashimoto et al (1987). Differential scanning colorimetry (DSC) enthalpy assays of fiber samples were performed as described by Czuchajowska et al (1991).

Dough Rheology

Mixing properties of doughs at 2, 4, and 8% of fiber replacement levels were examined by the mixograph method according to Finney and Shogren (1972). The alveograph was done at a constant water level with standard bread flour at the 2% replacement level according to the method of Addo et al (1990).

Products

The effects of fiber on end-use properties of Chinese steamed bread, Japanese sponge cake, Japanese *udon* noodles, and pan bread were investigated. The Chinese steamed bread and Japanese sponge cake were baked from the 10.8 and 8.8% protein soft white flours, respectively, with 2 and 4% fiber samples, according to methods used by the Western Wheat Quality Laboratory, U.S. Department of Agriculture, Agricultural Research Service (Rubenthaler et al 1990). The volume and texture of Chinese steamed bread were measured within 15 min after steaming. The volume of the combined seven pieces was determined by rapeseed displacement. The texture was measured using a Fudoh-Rheometer (model J, Fudoh Company, Inc., Tokyo, Japan) fitted with a 1-cm^2 disk probe and an automatic stop adjusted to permit a 1-cm penetration

TABLE I
Flour Properties

Flour	Percent Protein[a] (N × 5.7)	Ash[a] (%)	Mixing Time (min)	Water Absorption[b] (%)
Cookie	10.8	0.55	3.35	56.0
Sponge cake	8.8	0.34	2.80	54.0
Oriental noodles	10.6	0.44	3.30	62.5
Bread	16.1	0.55	3.00	68.5

[a] On a water-free basis.
[b] On a 14% moisture basis.

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into the bread. Japanese sponge cake was examined 24 hr after baking. The product, stored at room temperature, was evaluated by determination of volume, texture, and grain score.

Japanese noodles were prepared and evaluated according to Toyokawa et al (1989). The noodles were made with 4% fiber at three levels of water absorption: 33, 35, and 37%. The highest water absorption was used only with samples containing psyllium. The color of raw noodles was determined by using Colorgard 2000 (Pacific Scientific, Gardner/Neotec, Instrument Division, Silver Spring, MD). Changes in color were calculated as a total color difference (ΔE) between a standard white tile and raw noodles. Freshly cut 100-g samples of noodles were cooked for 18 min in 1,500 ml of water. The cooked noodles were drained, cooled in 1,000 ml of distilled water, drained, and weighed. The yield of cooked noodles was recorded. The cooking and cooling water portions from 100 g of noodles were combined and centrifuged at 1,700 $\times$ *g*. The residue left in the centrifuge tube was frozen and freeze-dried. The procedure was done at least in duplicate. The sensory evaluation of eating quality (texture) of noodles was performed immediately after cooking. The highest eating score of 32 was given to the standard noodles.

The pan bread was baked from bread flour with 4% fiber material at optimum mixing time and water absorption, which were determined on the basis of mixograph determinations and by an experienced experimental baker. The straight dough baking procedure was described by Finney (1984).

Immediately after baking, each loaf of bread was weighed and the volume was measured. The bread was allowed to cool for 1 hr, packed in a plastic bag, and stored at 21 $\pm$ 2°C for up to 72 hr. The bread crumb was examined during storage by determination of moisture, water activity, texture, and DSC enthalpy. Moisture content was determined by oven-drying at 130°C for 4 hr. Water activity was measured by the CX-1 water activity system (Decagon Devices, Inc., Pullman, WA). The rate of staling was assessed by changes in texture as measured by the Fudoh-Rheometer. The DSC measurements of bread crumbs were made as described by Czuchajowska and Pomeranz (1989). All determinations were made at least in duplicate.

RESULTS AND DISCUSSION

Composition and Physical Characteristics of Fiber Samples

Fibers were added to the flours described in Table I. Compositional and physical characteristics of AACC bran, psyberloid, and psyllium husk are described in Table II.

The samples of psyberloid and psyllium husk differed slightly in protein content (6.1 and 6.9%), free lipids (2.7 and 3.2%), and total pentosans (55.4 and 52.9%), respectively. They showed little difference in ash content. The fiber contents as determined by the Prosky et al (1988) method showed comparable amounts in the two psyllium samples. Although both psyllium samples contained as much as 70% of their dietary fiber in a soluble form, the dietary fiber in wheat bran is almost entirely in an insoluble form.

TABLE II
Compositional and Physical Characteristics[a] of Fiber Samples

Characteristic	Unground Bran	Psyberloid B&C	Psyllium Husk
Compositional			
Percent protein (N $\times$ 5.7)	17.5	6.1	6.9
Ash, %	6.6	3.0	3.0
Free lipids, %	4.5	2.7	3.2
Total dietary fiber, %	43.9	84.1	87.6
Total pentosans, %	15.1	55.4	52.9
Physical			
Water-holding capacity, g/g fiber-rich material	4.7	49.7	35.6
DSC[b] enthalpy, J/g	...	18.0	21.0

[a] Water-free basis.
[b] Differential scanning colorimetry.

The two psyllium samples differed in water-holding capacity, which is one of the criteria of high-quality gums. Psyberloid bound about 50 times its weight, and psyllium bound about 36 times its weight (Fig. 1). These unique hydrocolloidal properties of psyllium can be of major importance, not only from a physiological standpoint, but also from the standpoint of food processing in general and of wheat-based products in particular.

The DSC thermographs of psyberloid and psyllium gave peaks with melting enthalpies of 18 and 21 J/g, respectively, at about 130°C, which is in between an amylose-lipid complex (approximately 110°C) and retrograded amylose (approximately 150°C). The 130°C enthalpy is probably typical of soluble fiber in the presence of water.

Rheological Properties

The fiber materials differed in their effects on rheological properties of doughs, as illustrated by the mixographs of the bread standard flour at the 4% fiber level (Fig. 2). Bran had little effect and psyberloid and psyllium increased mixing times. Although the bran did not influence water absorption, psyberloid and psyllium husk increased absorption by about 5 and 15% at the 4 and 8% replacement levels, respectively.

Changes in dough properties also were measured by the alveograph, when 2% standard bread flour was replaced by fiber. The *L* (extensibility) alveograph value was reduced from 133 to 86 and from 133 to 110 with unground and ground bran, respectively, and to 90 by psyllium. The alveograph *P* (elasticity) of 96 was not affected by the addition of bran. The *W* value (index of flour strength) was reduced from 405 to 309 by the addition of the unground bran and to 376 by the addition of the ground bran sample. Similar results (not shown) were obtained for mixes of cookie flour and 2% wheat bran or psyberloid. The alveograph *P* and *W* parameters showed large increases for both samples of psyllium (to 173–176 and 521–528, respectively). Such large changes could be explained by the fact that the effects of psyllium

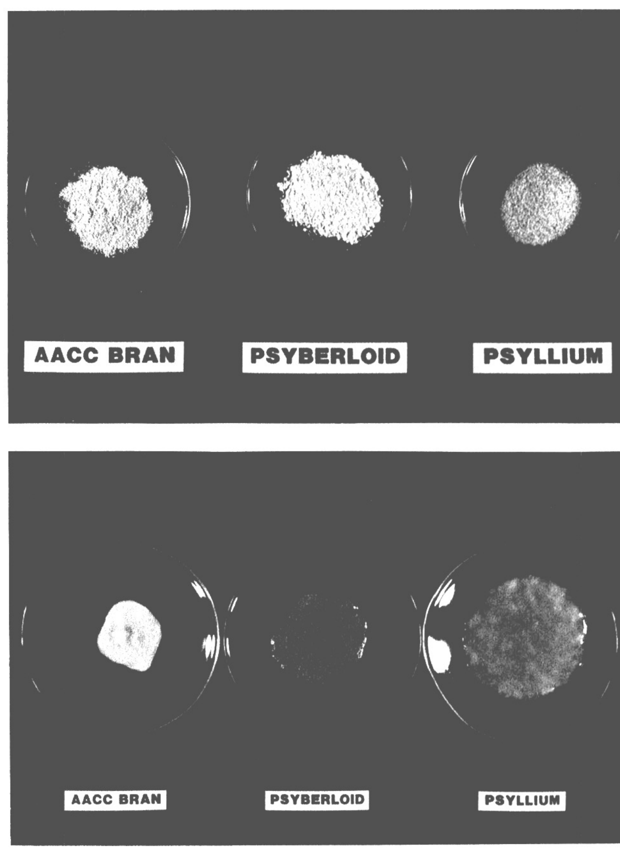

Fig. 1. One-gram samples of AACC bran, psyberloid, and psyllium. **Top,** dry material. **Bottom,** wetted with water according to water-holding capacity.

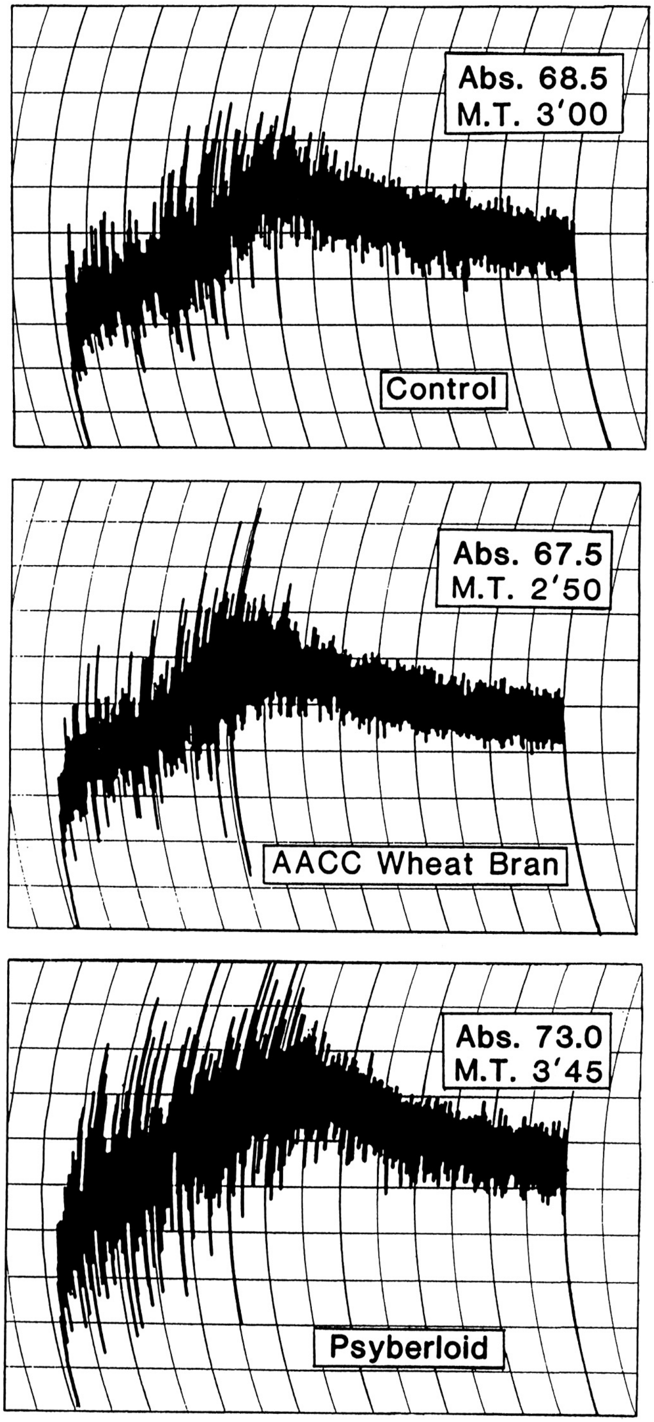

Fig. 2. Mixograms of blends in which 4% bread wheat flour was replaced by bran or psyberloid. Abs. = absorption. M.T. = mixing time.

samples, which have very high water-holding capacities, were determined according to the standard AACC method for alveograph tests at fixed water absorption.

Chinese Steamed Bread

Chinese steamed bread is highly sensitive to additives (Rubenthaler et al 1990). At the 2% level of replacement, unground bran and psyllium reduced volume (Table III and Fig. 3). At the 4% level of replacement, psyberloid and psyllium reduced the volume and the product was of poor quality.

Japanese Sponge Cake

Japanese sponge cake was baked with two levels of fiber: 2 and 4%. The baked products were examined after 24 hr of storage at room temperature. Fiber materials at the 2% level slightly influenced the texture and color but did not impair overall sensory

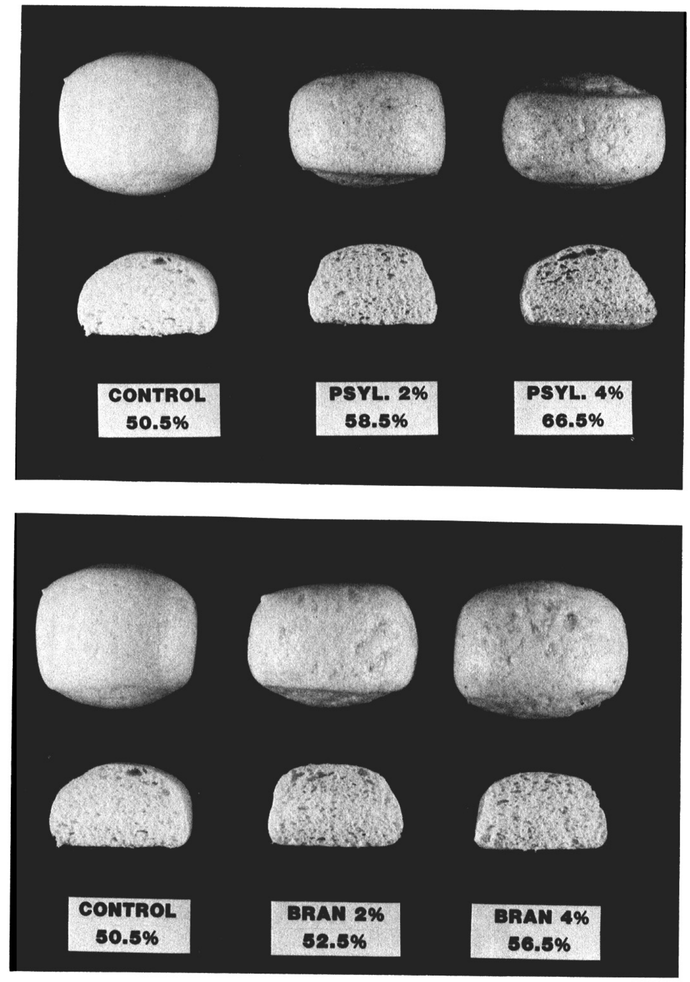

Fig. 3. Chinese steamed bread baked with 2 or 4% psyllium (Psyl.) (top) or bran (bottom).

TABLE III
Effects of Replacing 2 or 4% Soft Wheat Flour by Fiber-Rich Additives on Chinese Steamed Bread[a]

	2%			4%		
Fiber Source	Water Absorption (%)	Bread Volume (cm^3)	Texture (g/cm^2)	Water Absorption (%)	Bread Volume (cm^3)	Texture (g/cm^2)
None	50.5	580	60.6	50.5	580	60.6
Unground bran	52.5	560	59.8	54.5	575	63.5
Ground bran	52.5	575	59.0	54.5	600	62.5
Psyberloid	58.5	565	60.5	66.5	490	73.0
Psyllium	58.5	550	62.0	66.5	520	73.0

[a] Differences of 18 cm^3 in volume and 10 g/cm^2 in compressibility (texture) were significant at the 5% level.

attributes of the product. At the 4% level of replacement, the volume of the sponge cake decreased and the texture and overall score were affected negatively. Some of the cakes are compared in Table IV and Figure 4.

Japanese Noodles

Some properties of the Japanese noodles (at the 4% replacement level) are summarized in Table V. The dough containing psyllium had good handling properties, especially at 35% water absorption. However, as shown in Table V for 33% water absorption, the freshly cut (as well as cooked) noodles changed significantly in color (violet tint). The change in color affected the total noodle score. The yield of cooked noodles at 33% water absorption with bran and psyberloid did not differ from the control sample; psyllium increased the yield. The increase of absorption to 35% had a beneficial effect on the noodle yield (about 7–12%). Further

TABLE IV
Effects of Replacing 2 or 4% Soft Wheat Flour by Fiber-Rich Additives on Japanese Sponge Cake[a]

	2%			4%		
Fiber Source	Cake Volume (cm^3)	Texture (g/cm^2)	Overall Score	Cake Volume (cm^3)	Texture (g/cm^2)	Overall Score
None	1,315	62	80	1,315	62	80
Unground bran	1,330	50	78	1,250	72	71
Ground bran	1,320	64	80	1,235	64	73
Psyberloid	1,360	64	76	1,295	68	70
Psyllium	1,320	62	76	1,215	72	67

[a] Differences of 22 cm^3 in volume and of 2 g/cm^2 in compressibility (texture) were significant at the 5% level.

TABLE V
Effects of Replacing 4% Noodle Standard Flour by Fiber-Rich Additives on Some Noodle Properties

	Color of Raw Noodles[a]			Yield of Cooked Noodles	Cooking Residue	Noodle
Fiber Source	a	b	ΔE	(g/100 g of fresh noodles)	(g/100 g of fresh noodles)	Eating Score
None	−1.37	16.45	18.78	262.7	2.38	32.0
Ground bran	0.46	19.01	26.05	262.5	3.76	29.5
Psyberloid	0.50	13.73	28.18	260.4	3.32	29.0
Psyllium	0.72	15.71	26.87	266.6	4.91	30.0

[a] $a(+)$ = red, $a(-)$ = green, b = yellow, and ΔE = total color difference. Least significant differences at the 5% level were: $a = 0.066$; $b = 0.064$; $\Delta E = 0.066$; yield = 3.39%; cooking residue = 0.52%; and noodle score = 0.98.

TABLE VI
Effects of 4% Bran or Psyberloid on Volume, Moisture, and Water Activity of Bread Stored for up to 72 Hours

Bread Description	Volume of Bread[a] (cm^3)	Time After Baking (hr)	Moisture[b] (%)	Water Activity
Control	1,012	24	44.1	0.948
		48	43.7	0.960
		72	43.7	0.962
Baked with 4% fiber	965	24	45.6	0.959
Ground bran		48	45.1	0.955
		72	44.5	0.957
Psyberloid	1,069	24	49.8	0.969
		48	49.8	0.967
		72	49.3	0.970
Psyllium	1,080	24	...	...
		48	49.8	0.965
		72	49.6	0.963

[a] Differences of 25 cm^3 were significant at the 5% level.
[b] In bread crumb.

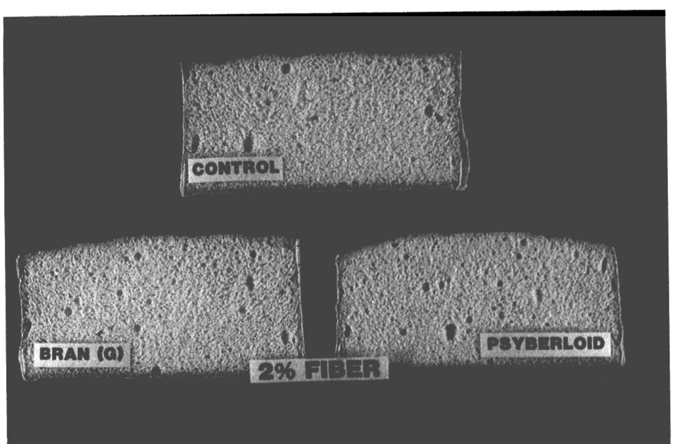

Fig. 4. Japanese sponge cakes baked with 2% psyberloid or bran.

TABLE VII
Effects of 4% Bran or Psyberloid on Differential Scanning Colorimetry (DSC) Characteristics and Texture of Crumb in Bread Stored for up to 72 Hours

Bread Description	Time After Baking (hr)	Enthalpy[a] (J/g)		Peak Temperature (°C)	Texture (g/cm^2)
Control	24	0.70 de		56.1	92.3 b–d
	48	0.95 bc	(0.25)	58.5	99.5 ab
	72	1.16 a	(0.21)	56.8	113.7 a
Baked with 4%	24	0.51 fg		55.9	81.0 cd
Ground bran	48	1.05 ab	(0.54)	58.9	97.0 a–c
	72	1.12 ab	(0.07)	56.9	111.0 a
Psyberloid	24	0.34 g		60.6	77.3 d
	48	0.58 ef	(0.24)	60.6	85.0 b–d
	72	0.81 cd	(0.23)	58.3	91.0 b–d

[a] Means with the same letters are not significantly different. The correlation coefficients between DSC enthalpy and Fudoh-Rheometer texture of bread crumb during storage was $r = 0.954$. Values in parentheses are for increases in enthalpy per day.

increase in water absorption was detrimental, especially as far as texture is concerned. Residue (after 18 min of cooking) was increased in fiber-enriched noodles (Table V). As far as eating properties are concerned, however, psyllium did not adversely affect the texture (bite) and taste.

Pan Bread

We determined the effects of fiber on pup loaves of pan bread. The volume of pan bread baked with 4% bran decreased about 4%. Both psyllium samples increased the volume by about 6% (Table VI).

For all samples of fiber, moisture of the bread crumb in the center of the loaf remained practically constant during 72 hr of storage. Moisture levels in the bread crumb that contained bran and psyberloid were about 1 and 5% higher, respectively, than moisture of the control bread crumb. The much higher moisture of bread crumb containing psyllium was not reflected by increases in water activity. After 72 hr of storage, the water activity of bread crumb was 0.962 for the control bread and 0.970 for the bread crumb with psyberloid (Table VI). The rate of staling as measured by changes in texture was followed by the Fudoh-Rheometer, which measures compressibility, and by DSC, which measures retrogradation of starch (Table VII). Bran- and psyberloid-containing bread had softer crumbs than the control when measured 24 hr after baking. The differences were more pronounced 72 hr after baking. The bread with psyllium was softer than both the control and the bran-containing bread. Similarly, the DSC enthalpy of bread crumb with psyberloid was lower and showed a slower rate of retrogradation than did the crumb in bread with bran.

CONCLUSIONS

The highly concentrated, soluble psyllium fiber of natural origin affects dough mixing properties little, significantly increases water absorption, and makes it possible to control the water content of foods. It is inferior to bran in its effects on volume of Chinese steamed bread, is somewhat superior in the effect on the volume of Japanese sponge cake and of pan bread, and is comparable in the effect on the texture of *udon* noodles. The effect on retarding staling in pan bread is desirable and merits additional investigation.

Thus, it is possible to obtain the well-documented beneficial physiological effects of psyllium without affecting end-use properties to a significant extent. In some cases, the effects of psyllium on end-use properties is beneficial. Some of the beneficial effects of psyllium probably can be attributed to its effects on water absorption. As reported by Haseborg and Himmelstein (1988), some quality problems with high-fiber bread can be remedied by the use of hemicellulose enzymes. In the case of psyllium, instead of solubilizing hemicelluloses by enzymes, a readily soluble gum is added. Those findings also are of interest in light of the contribution of soluble pentosans to both loaf volume and freshness retention in rye and wheat-rye bread as described by Drews (1965), Cassier et al (1973), and Pomeranz (1987). The relatively stable water activity in bread crumb, despite the increase in water content from adding hydrated psyllium, is of particular interest as it makes it possible to improve bread softness without significantly increasing the hazards of microbial deterioration.

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