Fortifying Bread with a Mixture of Wheat Fiber and Psyllium Husk Fiber Plus Three Antioxidants[1]

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ABSTRACT

A 7:3 (w/w) mixture of wheat fiber (WF) and psyllium husk fiber (PHF) was substituted for 10wt% of flour on a 14% mb, and the protein in the blend was restored to 10.3% by incorporating vital wheat gluten. After adding 0.5% sodium stearoyl 2-lactylate, the blend (100 g) was fortified with a combination of fat-coated ascorbic acid (AsA), protein-encased (PE) β-carotene, and cold-water-dispersible (CWD) all-*rac*-α-tocopheryl acetate (ToAc) at levels of 72, 5.6, and 115 mg, respectively, of active material. Adding the fiber ingredients to the pup loaf formula increased water absorption 25% and mixing time 50% and imparted stickiness to the dough. The fiber and antioxidant bread showed a 10% reduction in loaf volume and a somewhat inferior crumb grain with an off-color caused by small, black specks on a dark gray background. The crumb of the fiber and antioxidant bread remained much softer than control bread during one to seven days of storage at room temperature. Caramel coloring masked the off-color. AsA was lost significantly faster in the fiber and antioxidant bread than in antioxidant bread; the losses of AsA were 97 and 86%, respectively, after three days at 25°C. Approximately 25% of β-carotene was lost from the fiber and antioxidant bread after three days, and 33% after seven days, but the loss of ToAc was <10%. One serving size (one slice, 28 g) of fiber and antioxidant bread was calculated to provide 2.1 g of dietary fiber, or ~8% of daily value, of which ~30% was soluble. The three-day-old slice also contained vitamin E and vitamin A (as β-carotene) at 120–150% and 12–15%, respectively, of the adult recommended daily allowances, but with 16% fewer calories than white pan bread.

Dietary fiber has interested nutritionists for over 20 years due to its beneficial physiological effects; soluble fiber is known for its hypocholesterolemic effect (Whitehead 1986), and insoluble fiber is known for a reduction in the risk of colon cancer (Anderson 1991). Along with dietary fiber, antioxidants, such as vitamin C, β-carotene, and tocopherol, also have been associated with a reduced risk of those two diseases. The U.S. Department of Health and Human Service (Anon 1986) recommends that adults consume 20–30 g of dietary fiber daily to promote good health and the Food and Drug Administration (CFR 1995a) has set the daily reference values of 25 g for labeling purposes. To meet this recommendation, Americans need to double their present daily consumption of fiber. For added protection, Americans also need to increase their intake of foods containing antioxidants.

In the United States, flours for breads are enriched with thiamin, riboflavin, niacin, iron, and optionally with vitamin D, calcium, magnesium, and vitamin B6. In 1998 folic acid will also be present in enriched flour and bakery foods (Yetley and Rader 1995, Anon 1996). The development of enriched bread that also contains antioxidants and dietary fiber is of interest. Fiber breads generally contain additional moisture and have reduced caloric density.

This investigation concerns fortification of bread with a combination of three antioxidants and dietary fiber. Wheat fiber (WF) and psyllium husk fiber (PHF) were chosen as fiber sources. Wheat fiber from wheat straw contains mostly insoluble cellulose, whereas PHF is mostly soluble pentosans (Chan and Wypyszyk 1988). Czuchajowska et al (1992) examined the use of PHF in wheat-based foods, and they showed its potential use in breadmaking at a 4% level in flour. Because soluble and insoluble dietary fiber differ in their physiological responses, a combination of WF and PHF was added to bread along with vitamin C, β-carotene, and all-*rac*-α-tocopheryl acetate (ToAc). The stabilities of the antioxidants were examined in dough and stored bread at room temperature.

MATERIALS AND METHODS

Wheat fiber (WF) was a gift from Watson Foods Co., Inc. (West Haven, CT), and contained 98% (db) dietary fiber, all of which was insoluble. Psyllium husk fiber (PHF) was from Zuelling Botanicals Inc. (Long Beach, CA), and contained 88% (db) dietary fiber of which 61% was soluble. The WF had a fine granulation with 98% through a 100 U.S. wire mesh (150 μm), whereas 99% of PHF passed through a 40 U.S. wire mesh screen (420 μm). The types and sources of the antioxidants added to bread were given in Park et al (1997).

Unless otherwise stated, a commercial wheat flour (Continental Baking Co., St. Louis, MO) was used for breadmaking. The commercial flour contained 10.3% protein (14% mb), and was enriched with thiamin, niacin, riboflavin, and iron as ferrous sulfate. A second flour, Regional Baking Standard-93 (RBS-93), was used for some baking. The sources and selected properties of RBS-93 flour, shortening, instant dry yeast, and dry malt were given in a companion article (Park et al 1997). Vital wheat gluten was a commercial sample with 67.3% protein at 14% mb. Sodium stearoyl 2-lactylate (SSL) and caramel coloring were from American Ingredients Co. (Kansas City, MO) and Malt Products Inc. (Saddle Brook, NJ), respectively. The liquid caramel color was diluted with distilled water to give 2.1% caramel solution.

General Methods

Moisture was determined by Method 44-15A of AACC (1995), except for bread, which was determined by AACC Method 62-05 (1995). Water activity was measured using a water activity meter

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(CX-1, Decagon Devices, Inc. Pullman, WA), and protein was measured by the Dumas method using a Nitrogen Determinator (Leco Corp., St. Joseph, MI). The levels of antioxidants added to bread and the determination of crumb color of bread were done as before (Park et al 1997).

Breadmaking and Bread Properties

Pup loaves were made by the straight-dough procedure (Finney 1984) and Method 10-10B (AACC 1995). Fiber breads were prepared using WF and PHF preblended with bread flour with or without gluten and SSL. The substitution levels of WF for flour were 5 and 10%, and 5% for PHF. In one experiment, PHF (5 g) was hydrated (Lai et al. 1985a) in water (40 mL) for 2 and for 24 hr at 25°C, and then added with the other ingredients to the mixer bowl. Gluten (0.98 or 1.91 g) was substituted for flour to restore protein to 10.3% in a final blend, and SSL was added at a level of 0.5 g per 100 g of composite flour.

The fiber and antioxidant bread was made with a mixture of WF and PHF and three antioxidants. The fiber in the loaf consisted of a 7:3 (w/w) mixture of WF and PHF, and the dry fiber blend was substituted for flour blend at 10% level. Gluten (1.91 g) was substituted for flour to restore protein to 10.3%. Finally, SSL (0.5 g) was added to 100 g of the blend. In one loaf, 2.1% aqueous caramel coloring solution (30 mL) was added per 100 g of composite flour. The PHF (3 g) was soaked in water (24 mL) for 24 hr, and the hydrated PHF added to the other ingredients in the mixer bowl. Fat-coated AsA, PE β-carotene, and CWD ToAc were added at levels of 72.0 mg, 5.6 mg, and 115 mg, respectively, based on 100 g (14% mb) of flour or composite flour. After baking, loaves were cooled for 1 hr, then stored in polyethylene bags at room temperature for up to seven days. Bread was sliced by a reciprocating slicer (Thomson Machine Co., Belleville, NJ) to a thickness of 0.5 in.

Crumb structure of one-day-old bread was rated by visual observation on a scale of satisfactory (S), questionable to satisfactory (Q-S), questionable (Q), questionable to unsatisfactory (Q-U), and unsatisfactory (U). The highest score of satisfactory was for crumb with small holes and thin cell walls, whereas the lowest score of unsatisfactory was for crumb with large holes and thick cell walls. Water activity of crumb was that measured on a center slice.

A force-distance instrument (model TA-XT2, Stable Micro Systems, Haslemere, Surrey, UK) equipped with a 3.7 cm dia. acrylic probe was used to determine the firmness of bread crumb. Two slices of bread were taken from the center of a loaf and were stacked on top each other to give a thickness of 25.4 mm (1 in.). The crumb was compressed a total distance of 10 mm (40%) at a crosshead speed of 1.7 mm/sec, and the force (N) reading was taken at 6.2 mm compression. Stress (N/m^2) , defined as firmness, was calculated by dividing the compression force (N) by the contact area ($1.018 \times 10^{-3} m^2$) of the probe.

Statistical Analysis

All experiments were replicated at least twice, and levels of antioxidant were determined in duplicate with two injections per replicate. Statistical analyses were performed by using the Statistical Analysis System (SAS 1990). Means were compared by the least significant difference (LSD) test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Fiber and Bread Dough

Wheat fiber added to replace 5 and 10% of wheat flour increased optimum breadmaking absorption by 8 and 11%, respectively, whereas PHF added to replace 5% flour increased absorption by 24–30% (Table I). Gluten added to restore flour protein raised absorption another 1–4%. When PHF was hydrated with eight parts of water before addition to the mixer, baking absorption increased by 2–6% more than when dry PHF was added. This extra baking absorption was attributed to the somewhat coarse granulation of the PHF, which resulted in incomplete hydration of dry PHF added to the mixer.

Both WF and PHF increased optimum mixing time, but PHF increased it more. Also, adding the dough conditioner SSL increased mixing time in all blends, except for those with the hydrated psyllium husk (Table I). Czuchajowska et al (1992) also reported 4% PHF increased the mixing time of white bread dough. Chen et al (1988) suggested there is a possible interaction between fiber and gluten that prevents their complete hydration and results in poor gluten development during mixing. Michniewicz et al (1991) found increased mixing time of dough with 1–2% added wheat and rye pentosans, which was attributed to their effects on the aggregation and disaggregation of high molecular weight protein in wheat.

Dough made with 5% PHF had undesirable stickiness that especially complicated dough mixing. However, the stickiness of the PHF dough declined at the time of first punch and further at molding, perhaps due to gradual transfer of water from PHF to wheat flour components.

TABLE I
Baking Absorption and Mixing Time of Wheat Fiber (WF) and Psyllium Husk Fiber (PHF) Doughs

Treatment	Water Absorption, %	Mixing Time, min
Control	67.7	6.4
5% WF		
No added gluten	75.7	7.1
Added gluten[a]	76.7	8.0
Added gluten and SSL[b]	76.7	9.1
10% WF		
No added gluten	78.7	9.3
Added gluten	82.7	8.8
Added gluten and SSL	81.7	10.5
5% PHF, dry		
No added gluten	91.2	9.8
Added gluten	91.2	10.5
Added gluten and SSL	95.2	11.5
5% PHF, hydrated[c]		
No added gluten	95.2	11.5
Added gluten	97.7	11.3
Added gluten and SSL	97.2	11.3

[a] Gluten was substituted for flour to restore the protein content of the final blend to 10.3%.
[b] Sodium stearoyl 2-lactylate (0.5 g) was added to the final blend of flour containing fibrous ingredient, but not to the control loaf.
[c] Psyllium husk fiber (5 g on 14% mb) was hydrated in distilled water (40 mL) and the mixture held for 2 or 24 hr before mixing.

TABLE II
Effect of Wheat Fiber (WF) on Volume, Weight, and Crumb Grain of Bread

Bread	Loaf Volume, cm^3	Weight, g	Crumb Grain[a]
Control	928	148.7	Q–S
5% WF			
No added gluten	883	158.3	Q
Added gluten[b]	895	158.4	Q
Added gluten and SSL[c]	883	157.8	Q–S
10% WF			
No added gluten	788	161.3	Q–U
Added gluten	808	166.0	Q–U
Added gluten and SSL	808	164.4	Q
LSD[d]	18	1.8	. . .

[a] Q–S: questionable to satisfactory; Q: questionable; Q–U: questionable to unsatisfactory; U: unsatisfactory.
[b] Gluten was substituted for flour to restore the protein content of the final blend to 10.3%.
[c] Sodium stearoyl 2-lactylate (0.5 g) was added to the final blend of flour containing fibrous ingredient, but not to the control loaf.
[d] Least significant difference ($\alpha = 0.05$).

Fiber and Bread Volume

Wheat fiber (WF) decreased loaf volume by 5 and 15%, respectively, when added at 5 and 10% flour replacement levels (Table II). Restoring the protein to 10.3% in the flour blend, with or without 0.5% SSL, gave only a marginal improvement in loaf volume. According to Pomeranz et al (1977), exceeding a certain flour replacement level with insoluble fiber causes loaf volume to decrease more than can be explained by the dilution of gluten alone. They attributed the decrease in loaf volume in high-bran bread to poor gas retention of dough. Rogers and Hoseney (1982) reported that whole wheat dough, which contains mostly insoluble fiber, had a normal proof height and a normal spread ratio but gave only a slight oven-spring, which they attributed to an early solidifying of the loaf structure because of premature starch gelatinization at the high level of water in the dough. But Lai et al (1989b) found that whole wheat bread with good loaf volume was produced by: 1) adding lipoxygenase (enzyme-active soy flour) to oxidize glutathione (dough weakener); 2) increasing water absorption to the highest tolerable level; and 3) replacing sodium chloride with disodium phosphate or sodium citrate to strengthen the dough. They also found certain salts and surfactants improved loaf volume.

PHF, when added in powder form to replace 5% flour, was much less detrimental to loaf volume at optimum absorption than WF (Table III), which agrees with results of Czuchajowska et al (1992). Moreover, when PHF was hydrated before dough mixing, loaf volume was not significantly different from that of control bread. Previously, guar gum was found to be functional in maintaining loaf volume if added at <7% to flour (Apling et al 1978). Guar gum and psyllium gum, like wheat pentosans, give highly viscous aqueous solutions with gel-forming properties.

Fiber and Color of Bread and Crumb Grain

Bread containing WF showed a more pale crust color (L^* = 48.3) than the control (L^* = 41.9), but crumb color was little affected. The pale crust color of WF bread could result from the increased moisture in WF doughs, which would retard browning by diluting the concentrations of the sugar and amino acid reactants. PHF, when added dry to flour, had little effect on crust color but caused a considerably darker crumb (L^* = 69.6) when compared to the control (L^* = 76.9). Bread made with prehydrated PHF had a dark crumb that also contained small black specks. Darkening of PHF was obvious during its prehydration, which was attributed to enzymatic browning catalyzed by polyphenol oxidase.

Both WF and PHF were detrimental to crumb grain, which is in agreement with previous reports on fiber bread (Pomeranz et al 1977). At the 5% level of substitution, PHF was more detrimental than WF. Addition of SSL, but not gluten, improved crumb grain noticeably in all blends (Tables II and III). Only the bread containing 5% WF gave crumb grain comparable to that of the control. Hydration of PHF before it was mixed with the other ingredients including SSL also improved crumb grain (Table III).

TABLE III
Effect of Psyllium Husk Fiber (PHF) on Volume, Weight, and Crumb Grain of Bread

Bread	Loaf Volume, cm^3	Weight, g	Crumb Grain[a]
Control	935	150.8	Q-S
5% PHF, dry			
No added gluten[b]	905	169.7	U
Added gluten	922	168.4	U
Added gluten and SSL[c]	895	171.5	Q-U
5% PHF, hydrated[d]			
2 hr holding			
No added gluten	922	171.6	U
Added gluten	943	174.7	U
Added gluten and SSL	900	173.9	Q
24 hr holding			
No added gluten	933	168.4	U
Added gluten	958	173.7	U
Added gluten and SSL	908	174.9	Q
LSD[e]	30L	3.8	· · ·

[a] Q–S: questionable to satisfactory; Q: questionable; Q–U: questionable to unsatisfactory; U: unsatisfactory.
[b] Gluten was substituted for flour to restore the protein content of the final blend to 10.3%.
[c] Sodium stearoyl 2-lactylate (0.5 g) was added to the final blend of flour containing fibrous ingredient, but not to the control loaf.
[d] Psyllium husk fiber (5 g on 14% mb) was hydrated in distilled water (40 mL) and the mixture held for 2 or 24 hr before mixing.
[e] Least significant difference (α = 0.05).

TABLE IV
Properties of Bread Prepared with Added Fiber and Antioxidants

Property	Control	Fiber and Antioxidant[a]
Water absorption, %	68	93
Mixing time, min	6.4	9.8
Loaf volume, cm^3	933	838
Weight, g	151	171
Moisture content, %	37	45
Water activity	0.97	0.98
Specific volume, cm^3/g	6.18	4.90
Crumb grain	Q–S[b]	Q–U

[a] Bread made with a mixture (7:3, w/w) of wheat fiber and psyllium husk fiber substituted for flour at 10% level. Gluten was substituted for flour to restore protein content of the final blend to 10.3%. Sodium stearoyl 2-lactylate (0.5 g) was added to the final blend. Fat-coated ascorbic acid (AsA), protein-encased (PE) β-carotene, and cold-water-dispersible all-*rac*-α-tocopheryl acetate (ToAc) were added into the final blend at a level of 7.0 mg of AsA eq, 5.63 mg of β-carotene eq, and 115 mg of ToAc, respectively.
[b] Q–S: questionable to satisfactory; Q–U: questionable to unsatisfactory.

TABLE V
Crust and Crumb Color of Fiber and Antioxidant Bread[a] With or Without Caramel Coloring

	Color Values[b]			
Bread	L^*	a^*	b^*	ΔE^*
Without caramel coloring				
Crust				
Control	42.0	11.6	17.0	· · ·
Fiber and antioxidant	45.4	11.1	19.0	3.5
LSD[c]	2.2	0.5	1.7	· · ·
Crumb				
Control	76.9	–2.2	13.4	
Fiber and antioxidant	70.0	–0.7	11.6	7.3
LSD	3.8	0.2	3.7	· · ·
With caramel coloring				
Crust				
Control	42.1	11.6	18.4	· · ·
Fiber and antioxidant	44.3	9.3	16.5	3.7
LSD	2.8	0.7	2.0	· · ·
Crumb				
Control	55.2	4.8	17.4	· · ·
Fiber and antioxidant	53.5	4.9	16.2	2.1
LSD	3.1	0.3	2.3	· · ·

[a] Bread made with a mixture (7:3, w/w) of wheat fiber and psyllium husk fiber substituted for flour at 10% level. Gluten was substituted for flour to restore protein content of the final blend to 10.3%. Sodium stearoyl 2-lactylate (0.5 g) was added to the final blend. Fat-coated ascorbic acid (AsA), protein-encased (PE) β-carotene, and cold-water-dispersible all-*rac*-α-tocopheryl acetate (ToAc) were added into the final blend at a level of 7.0 mg of AsA eq, 5.63 mg of β-carotene eq, and 115 mg of ToAc, respectively. Caramel coloring was added with other liquid ingredients before mixing.
[b] Color measured with a Minolta Chroma Meter CR-210. L^* indicates lightness, $-a^*$ to $+a^*$ indicates green to red, and $-b^*$ to $+b^*$ indicates blue to yellow. Total color difference ΔE^* was calculated as: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)]^{1/2}$.
[c] Least significant difference (α = 0.05).

Fiber and Crumb Firmness

Firming at 25°C was faster in control bread with no fiber and no SSL than in breads containing 5 and 10% WF with SSL (Fig. 1), even though the control bread was 4–14% larger in volume (Table II). Bread made with 5% PHF and added SSL showed the slowest firming, probably because the PHF bread had good loaf volume and contained almost the highest moisture level (~43%) among the breads (moisture levels ranged from 40–45%). Czuchajowska et al (1992) previously noted that 4% PHF increased the softness of bread crumb. All breads had water activity of 0.97–0.98. It is known that the specific volume (Axford et al 1968) and moisture content of bread (Rogers et al 1988) are inversely proportional to the rate of crumb firming.

Bread Made with WF and PHF and Three Antioxidants

A 7:3 (w/w) mixture of WF and PHF was chosen to replace 10% of wheat flour, and gluten and SSL were also added to the formula as before. Bread made from that mixture was calculated to contain ~2.1 g of total fiber per slice with 30% soluble fiber (see below). According to Anderson (1991), an intake of ~6 g per day of soluble fiber decreased serum cholesterol concentration. Considering the 20–30 g of total daily dietary fiber recommended by the U.S. Department of Health and Human Service, a ratio of soluble and insoluble fiber in bread >1:4 seemed appropriate.

Addition of those fiber ingredients increased dough absorption ~25% and mixing time by ~50% (Table IV). Again the dough was somewhat sticky and less extensible when compared to the control, and the bread had 10% reduced loaf volume and a somewhat inferior crumb grain (Table IV). The crust of the fiber bread was paler, but the crumb was darker than that of the control (Table V). When caramel coloring was added to both the control loaf and the fiber and antioxidant loaf, the difference in crumb color could not be seen, which was verified by the low ΔE^* values (Table V). Caramel coloring also masked the small black specks in the crumb of the loaves caused by PHF in the bread. The fiber and antioxidant bread contained 8–9% more moisture and was softer than the control bread over seven days of storage (Fig. 1).

When a high-protein flour (RBS-93) was used to produce the fiber and antioxidant bread, mixing time increased by only 15%, the dough was less sticky and more extensible, and the bread showed increased loaf volume and improved crumb grain when compared to that of the low-protein flour (Fig. 2).

Ranhotra and Gelroth (1988) found that white pan bread (38% mb) made from 10 different flours contained 2.5 ± 0.5% total dietary fiber and 1.0 ± 0.2% of soluble fiber. Compared to the ~0.7 g of total dietary fiber in one serving size (28 g, as-is basis, one slice) of white bread, the fiber and antioxidant bread was calculated to contain ~2.1 g of total dietary fiber per 28 g (45% mb), assuming that the dietary fiber in wheat bread arises from flour only. That 2.1 g of dietary fiber equals 8% of the daily value of dietary fiber, with ~30% of it in soluble form.

The net energy value of insoluble and soluble fiber in the human diet has been calculated, respectively, to be 0 and 8.4 kJ/g (2.0 kcal/g) (Livesey 1995). Using those values for the soluble (0.6 g) and insoluble fiber (1.5 g), and 4.4 kcal/g for the white bread solids (13.3 g) in one slice of fiber and antioxidant bread, its calculated food energy was 59 kcal or ~16% below that of white pan bread (~69 kcal). Increasing the level of WF and PHF to ~15% replacement would further increase fiber and reduce calories by 25%, which would allow label claims on the bread of a "good source of fiber" with "reduced calories" (CFR 1995b)

Stabilities of Antioxidants in Fiber and Antioxidant Bread

The AsA retention in the proofed dough, immediately before baking, was 98% for the fiber and antioxidant dough, which was close to the retention in the proofed dough of the control loaf. The baking loss of AsA in the fiber and antioxidant bread was 41%, which was greater than that of the control bread by 13%. Over a seven-day storage period, AsA also disappeared significantly faster in the fiber and antioxidant bread than in the control bread (Fig. 3). That was probably caused by the higher moisture content in the fiber bread (45%) as compared to the control bread (37%).

It should be mentioned that over seven days of storage, AsA in the control bread (Fig. 3) disappeared more rapidly than observed previously (Park et al 1997). The control bread in the present work was prepared from a commercial flour that had been enriched with ferrous sulfate. Wang et al (1996) found that enrichment with iron salts accelerated AsA loss in bread, whereas reduced iron had no effect. The fiber and antioxidant dough also contained PE β-carotene at a level of 5.63 mg of β-carotene eq per loaf. The retention of β-carotene was excellent in the fresh bread, but a 40% loss

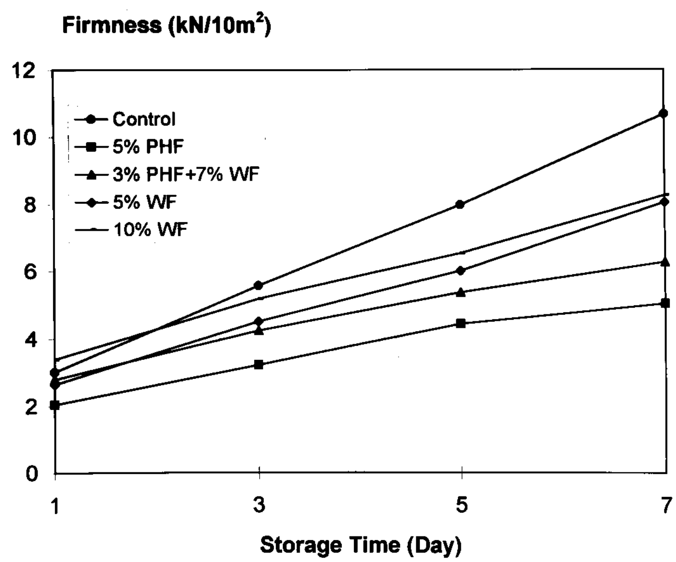

Fig. 1. Firmness of bread crumb containing wheat fiber (WF) and psyllium husk fiber (PHF) and stored at 25°C. Control bread was prepared from commercial flour containing no added fibrous ingredients and no sodium stearoyl 2-lactylate (SSL). Gluten was substituted for flour in the fiber breads to restore the protein content of the flour blend to 10.3%. SSL (0.5 g) was added to the final blend of flour and fibrous ingredients.

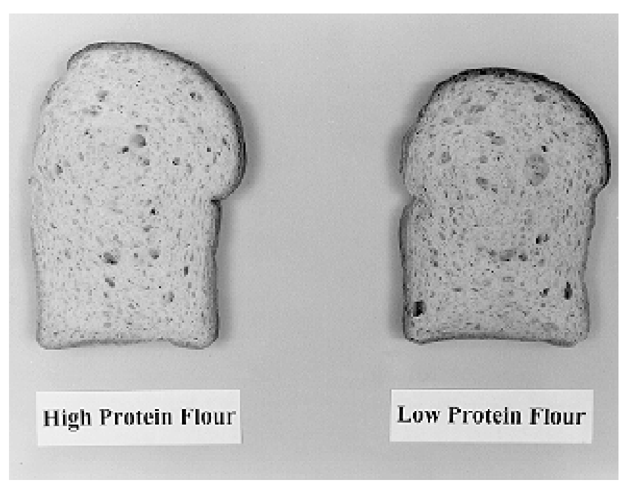

Fig. 2. Fiber and antioxidant bread prepared from commercial bread flour (protein 10.3% on a 14% mb) and baking standard flour (protein 12.0% on a 14% mb). A 7:3 (w/w) mixture of WF and PHF was substituted for flour at 10% level. Gluten was substituted for flour to restore the protein content of the final flour blends containing fibrous ingredients to 10.3 or 12%.

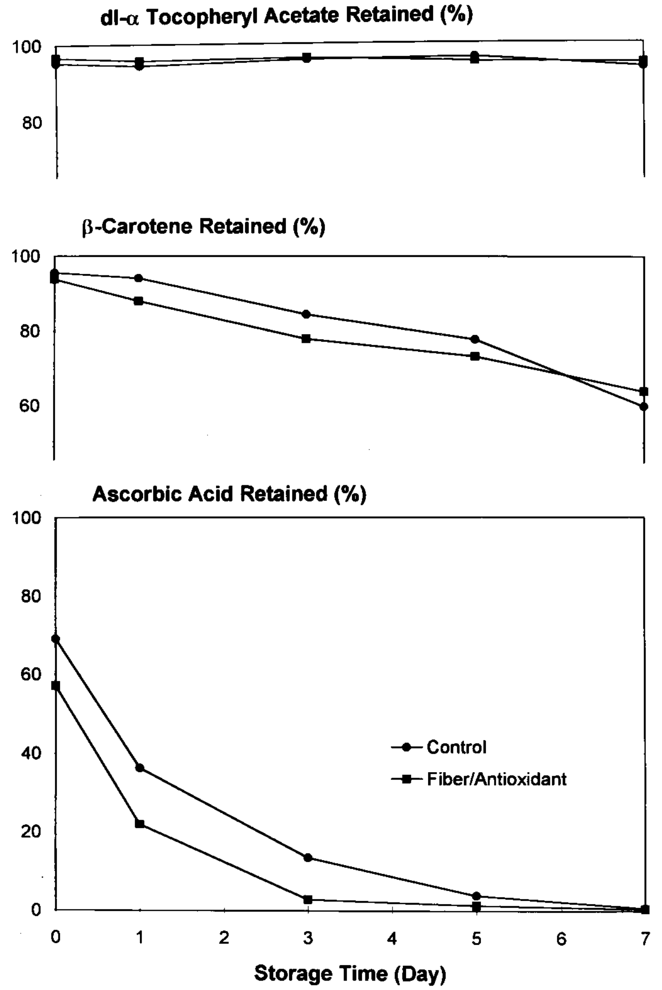

Fig. 3. Storage stability of ascorbic acid (AsA), β-carotene, and all-*rac*-α-tocopheryl acetate (ToAc) in fiber-antioxidant bread at 25°C. Control and fiber breads were baked from flour or a flour-fiber blend containing fat-coated AsA, protein-encased β-carotene, and cold-water-dispersible ToAc at a level of 72.0 mg AsA eq, 5.63 mg β-carotene eq, and 115 mg, respectively, of active material per loaf. Fiber bread formulation is given in Fig. 2. Values of antioxidants retained in bread were reported in percent retained per pup loaf. LSD was 1.5, 5.0, and 4%, respectively ($\alpha = 0.05$).

occurred after seven days of storage (Fig. 3). The test bread also was fortified with 115 mg of all-*rac*-α-tocopheryl acetate per loaf. Loss during breadmaking and bread storage up to seven days were <10% (Fig. 3). The adult RDA (NAS 1989) of vitamin A (0.8 and 1.0 retinol eq) and *E* (8 and 10 α-tocopherol eq) in one slice of the three-day-old bread were calculated to be 12–15% and 120–150%, respectively. It should be noted that our results were obtained on pup loaves, and that some differences may occur in large loaves.

CONCLUSIONS

A specialty bread can be produced that contains vitamin E and β-carotene (provitamin A), reduced caloric density, and soluble and insoluble dietary fiber. PHF is not detrimental to loaf volume, but tends to give sticky dough. In the preparation and storage of the fiber and antioxidant bread with a moisture content of 45%, α-tocopheryl acetate is stable, β-carotene is moderately stable, but L-ascorbic acid is unstable.

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