

High-Fiber, Noncaloric Flour Substitute for Baked Foods. Effects of Alkaline Peroxide-Treated Lignocellulose on Dough Properties

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ABSTRACT

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Replacing up to 30% of the flour in a dough with alkaline hydrogen peroxide (AHP)-treated lignocellulose increased the height of the mixograph peak obtained during dough mixing by as much as 40% compared with an all flour dough. Substantially more water could be

incorporated into the dough without loss of dough integrity when AHP-treated lignocellulose was used as a replacement for a portion of the flour. Loaf volumes of white bread were essentially unchanged when 10% of the flour was replaced with AHP-treated lignocellulose without added gluten.

A number of high-fiber additives (brans, seed hulls, purified celluloses) are currently available for use in baked foods. Unfortunately, gritty textures and degradation of dough properties are often associated with the use of these materials, probably because both natural plant cell walls and purified cellulose fractions tend to hydrate more completely on the particle surface than in the particle interior, reducing the extent to which the particle can soften and swell in the dough matrix (Gould et al 1989). The incompletely hydrated cellulose particles function as inclusions that weaken the dough by cutting gluten strands (Dubois 1978) so their use in bakery formulations must be restricted to relatively low levels.

We have recently found that the physical properties of a wide range of natural lignocellulosic materials, including brans, seed hulls, vegetable and beet pulps, stems, and leaves, can be dramatically improved by treatment with a dilute alkaline solution of hydrogen peroxide (Gould 1984, 1985, 1987, 1989; Gould et al 1989). This treatment solubilizes a portion of the lignin present in the lignocellulosic matrix, leaving a cell wall material with higher water absorbency and improved softening and swelling characteristics. In this paper we describe the effects of an alkaline peroxide-treated lignocellulosic fiber on the properties of wheat flour dough as measured in a mixograph.

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MATERIALS AND METHODS

Preparation of Treated Lignocellulose

Lignocellulosic substrates were treated with a dilute, alkaline solution of hydrogen peroxide (pH 11.5) as described in detail elsewhere (Gould 1985, 1987). After treatment, the materials were washed with water and dried in a forced-air oven (Proctor Schwartz) at 40°C for 24 hr. Dried, treated samples were ground in a pin mill (14,000 rpm, Alpine model 160Z, Augsburg, Germany). Portions of the pin-milled materials were further ground in a ball mill (U.S. Stoneware Co., 19-L jar, 54 rpm, 25-mm granite balls, 40% charge, 1:1 material/void volume ratio) for 7 hr. For one experiment, the treated substrate (wheat straw) was partially dewatered after the washing step using a hydraulic press (Williams-White, Moline, IL) with a total force of 600 tons (approximately 100 kg/cm²). The pressed material (approximately 50% solids) was then dried and ground as described above. Samples of never-dried material were also taken immediately after the washing step, and stored at 4°C until use. Commercially available food-grade celluloses were obtained from James River Corp. (ground wood pulp, Solka Flocc SW-40 [pin-milled] and BW-40 [ball milled]), ICN Biochemicals (alpha-cellulose), FMC Corp. (microcrystalline cellulose, Avicel), and ConAgra (ground oat hulls). Water absorbencies of the various cellulosic materials used in this study were determined as described earlier (Gould 1984).

Mixograph Assay

The 10-g mixograph method of Finney and Shogren (1972) was used to study replacement of flour (commercially available Pillsbury's Best Bread Flour) by cellulosic additives. All ingredients were measured on 14% moisture basis and water content was adjusted accordingly. In the standard procedure, flour and the cellulosic additive were thoroughly blended before adding water. In an alternate procedure, the flour only was placed in the

mixograph bowl. An amount of water, calculated to give 61% absorption for the amount of flour present, was added and the mixograph was run for 4 min (1 min less than the time required to reach the peak as determined in a separate experiment). The mixograph was then stopped, the cellulosic additive (prewetted with the amount of water necessary to give the desired final dough absorption) was added, and the mixograph restarted. In both procedures, sufficient time was allowed for the dough to reach a peak and begin to decay. Time to peak (minutes) and peak height (centimeters) were determined from strip chart recordings of the mixograph response. All experiments were performed with a 10-g National Mfg. Co. mixograph (Lincoln, NE).

Bread Loaf Volume Tests

White bread loaves were baked according to the basic straight dough method (AACC 1983). Loaf volume was determined by displacement of rapeseed. Bread samples for moisture analysis were prepared using AACC method 62-05 (thinly slicing an entire loaf). Moisture was measured by a vacuum-oven method (AACC method 44-40).

RESULTS AND DISCUSSION

The height of the mixograph peak for doughs made with flour alone decreased linearly as the water content of the dough increased (Fig. 1). Replacement of 10% of the flour (dry weight basis) with any of several commercially available cellulosic food additives caused a decrease in the height of the mixograph peak at all dough moisture levels tested. In contrast, replacement of 10% of the flour (dry blended) with alkaline peroxide-treated corn stalks (AHP-CS) caused a significant increase in the height of the mixograph peak for doughs containing a wide range of moisture levels. Replacement of a portion of the flour with AHP-CS allowed the incorporation of increased water levels in the dough without unacceptable reductions in dough tensile strength (estimated by

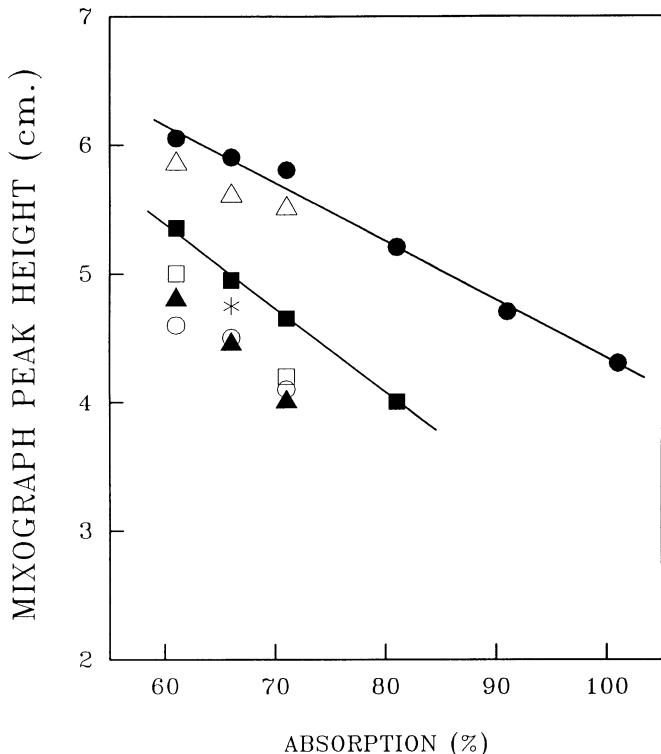


Fig. 1. Effects of various cellulosic and lignocellulosic materials on mixograph peak height of a wheat flour dough at different absorptions. The materials were substituted for 10% (1 g) of the flour in a 10-g mixograph assay: flour without substitution (■); alkaline hydrogen peroxide treated corn stalks (AHP-CS), pin milled (●); AHP-CS, ball milled (Δ); alpha-cellulose (○); ground oat hulls (□); wood pulp cellulose (▲); and microcrystalline cellulose (*).

mixograph peak height) compared with flour alone. The effects of AHP-CS on doughs were largest when AHP-CS was ground in a pin mill after oven drying. Ball milling AHP-CS slightly reduced the increase in the height of the mixograph peak.

The increase in mixograph peak height of doughs containing AHP-CS (pin-milled) in place of a portion of the flour was positively correlated with the amount of flour replaced (up to about 30%) over a wide range of absorption levels (Fig. 2). These data demonstrate that substitution of AHP-CS for a portion of the flour allowed the formation of acceptable doughs at moisture levels too high for the formation of doughs made from flour alone.

The method of drying and grinding alkaline peroxide-treated lignocellulose had a dramatic effect on the height of the mixograph peak (Fig. 3). Alkaline peroxide-treated wheat straw (AHP-WS) (oven-dried, pin-milled) substituted for 10% of the flour increased the mixograph peak height by about 20% compared with flour alone. Ball-milled AHP-WS caused a much smaller increase in the mixograph peak height. AHP-WS that had been partially dewatered in a hydraulic press, and then oven dried, reduced the height of the mixograph peak in a manner similar to untreated lignocellulose or purified cellulosic additives (Fig. 1), independent of the grinding method employed. These data indicate that the beneficial effects of treating lignocellulose with alkaline hydrogen peroxide, in terms of improving dough properties in the mixograph, can be reversed by processing methods that destroy or reduce the highly open internal structure of the treated cell wall particles (Gould et al 1989).

The increase in mixograph peak height caused by AHP-CS and AHP-WS represents previously unobserved behavior for a cellulosic additive in a flour dough. Assuming that the height of the mixograph peak correlates with the tensile strength of the dough, substitution of a cellulosic component for a portion of the flour in a dough should reduce peak height because 1) the gluten content in the dough mixture is reduced, and 2) the cellulosic component acts as a diluent, interfering with the formation of the starch-gluten matrix. When stretched during mixing and raising, gluten strands would tend to break at the interface between the particle and the

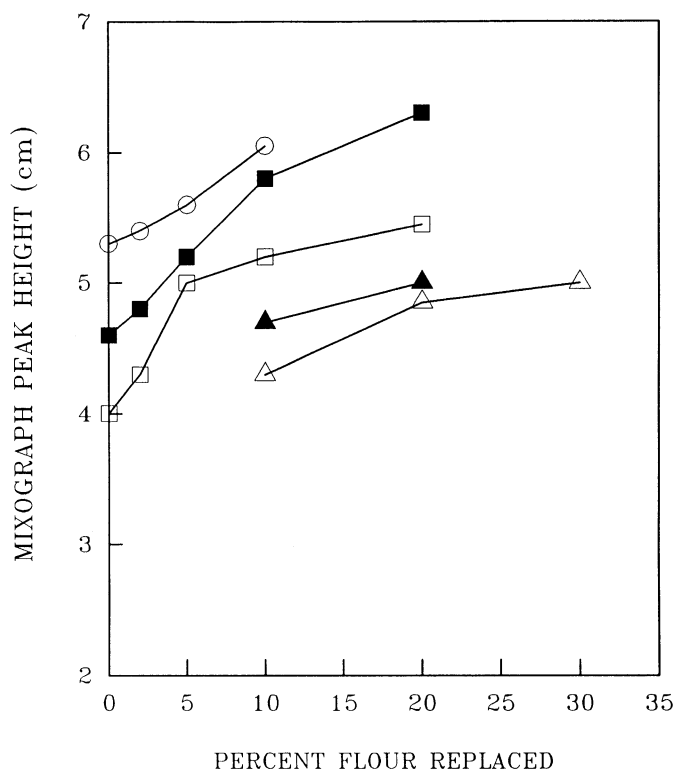


Fig. 2. Effects of substituting pin-milled alkaline hydrogen peroxide treated corn stalks for flour in a wheat flour dough on mixograph peak height. Final dough absorptions were 61% (○), 71% (■), 81% (□), 91% (▲), and 101% (Δ).

starch-gluten matrix. If this is so, there may be a correlation between the water-absorbing characteristics of a cellulosic additive and its effects on the height of the mixograph peak.

In general, water absorbencies of untreated oat hulls and the highly purified cellulose preparations were significantly lower than the water absorbencies of AHP-WS and AHP-CS, as were their effects on the height of the mixograph peak (Table I). The water absorbencies of AHP-WS and AHP-CS were reduced substantially by oven drying, although the decreased absorbency was not accompanied by a concomitant decrease in the mixograph peak height (Fig. 4). As noted above, samples that had been pressed before drying, or that had been ball milled, tended to have significantly lower mixograph peak heights than unpressed, pin-milled samples. Interestingly, unpressed AHP-WS was apparently

TABLE I
Water Absorbency and Effect on Mixograph Peak Height of Several Lignocellulose and Purified Cellulose Preparations

Sample	Water Absorbency (ml/g)	Mixograph Peak Height ^a (cm)
Flour alone ^b	...	4.6
Alpha-cellulose	3.8	4.1
Microcrystalline cellulose	1.7	4.2
Ground oat hulls	3.6	4.2
AHP-treated wheat straw ^c		
never dried	22.0	5.4
pin milled	14.0	5.5
ball milled	9.3	4.8
pressed, ball milled	5.9	4.2
AHP-treated corn stalks		
never dried	22.0	5.8
pin milled	10.3	5.8
ball milled	7.5	5.5

^a 10% replacement level, 71% absorption.

^b Pillsbury's Best Bread Flour brand.

^c AHP = Alkaline hydrogen peroxide.

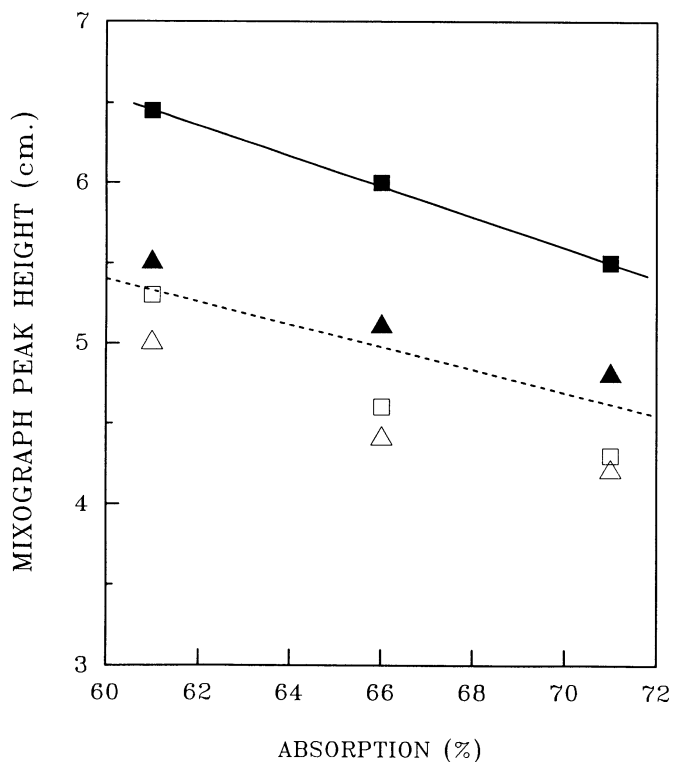


Fig. 3. Effects of processing conditions on the increase in mixograph peak associated with substituting alkaline hydrogen peroxide treated wheat straw for 10% of the flour in a wheat flour dough. The dashed line indicates the mixograph peak height of flour alone: pin-milled (■); ball-milled (▲); pressed, pin-milled (□); pressed, ball-milled (△).

more seriously affected by ball milling than was unpressed AHP-CS (Figs. 1 and 3, Table I).

These data indicate that a rough correlation may exist between the water absorbency characteristics of a cellulosic additive and its effects on the height of the mixograph peak. Gould et al (1989) found that water retention after hydraulic compression was much higher for peroxide-treated lignocellulose than for purified celluloses such as wood pulp. The open internal structure of alkaline peroxide-treated lignocellulose allows water penetration into the particle interior, resulting in more thorough particle hydration.

The time required for a dough to reach its peak in the mixograph increased when a portion of the flour was replaced with a cellulosic additive such as AHP-CS (Fig. 5). The increase in time was dependent upon the amount of flour replaced by AHP-CS, and was much greater when never-dried AHP-CS was added than when oven-dried, pin-milled AHP-CS was added. The final height of the mixograph peak depended only on the amount of flour replaced by AHP-CS (Fig. 4), not mixing time.

These data suggest that it may be possible to reduce the total mixing time required to reach the mixograph peak by incorporating AHP-CS into dough using a two-step method in which the starch-gluten matrix is allowed to partially develop before the addition of hydrated AHP-CS. When dry AHP-CS and flour were premixed before adding water, the mixing time was reduced somewhat, especially at higher absorption levels (Fig. 6). Mixing the flour portion of the dough with water in the mixograph (flour absorption = 61%) for 4 min, and then adding hydrated AHP-CS, decreased the time to mixograph peak to about 2-3 min of additional mixing. This was observed regardless of the final dough absorption or flour replacement level. The two-step mixing method did not affect the height of the mixograph peak.

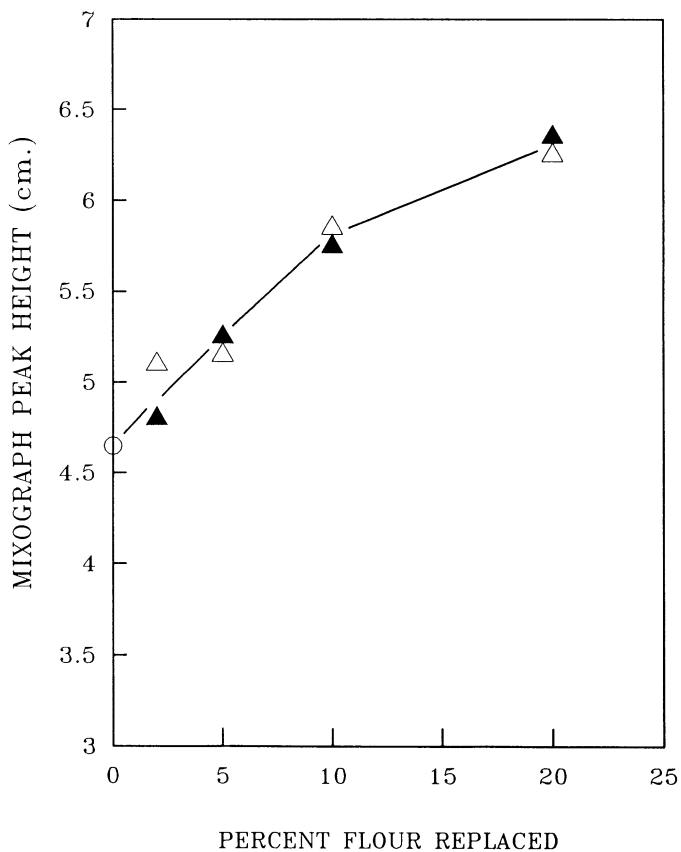


Fig. 4. Increase in mixograph peak height of a wheat flour dough containing alkaline hydrogen peroxide treated corn stalks (AHP-CS). Freshly prepared and never dried (△) or dried, pin-milled (▲) AHP-CS were added to replace (dry weight basis) the indicated amount of flour in the mixograph bowl. Final dough absorption for all assays was 71%. The circle indicates the mixograph peak height for a dough containing flour alone.

TABLE II
Effects of Alkaline Peroxide Treated Corn Stalks on Bread

Sample No.	Fiber Type ^a	Mixing Method ^b	Absorption (%)	Dough Character	Moisture (%)	Loaf Volume	
						% of Control ^c	Dry Wt Basis (%) ^d
Control	none	1	66	OK	34.8	100	100
A	CS, PM	1	81	OK	nd ^e	71	76
B	CS, PM	1	71	Sticky	nd	5	53
C	CS, PM	2	81	Sticky	nd	55	55
D	CS, PM	3	81	OK	40.8	83	89
E	CS, PM	3	86	OK	39.2	87	97
F	CS, BM	3	81	OK	39.7	92	100
G	WP (SW-40)	3	81	Sticky	41.6	66	71
H	WP (BW-40)	3	81	Sticky	39.1	78	83

^aCS = Alkaline hydrogen peroxide treated corn stalks; PM = pin milled; BM = ball milled; WP = wood pulp cellulose.

^b1 = Blend all dry ingredients, add water mix to mixograph peak; 2 = blend all dry ingredients, add water, mix until 2 min after mixograph peak; 3 = blend all dry ingredients except fiber, add water to achieve 66% absorption, mix 1 min before mixograph peak (about 4 min), add fiber wetted with additional water required to achieve desired final dough absorption, continue mixing for 2 min.

^cBased upon 175-g portions of dough.

^dBased upon 100-g (dry weight) portions of flour.

^end = Not determined.

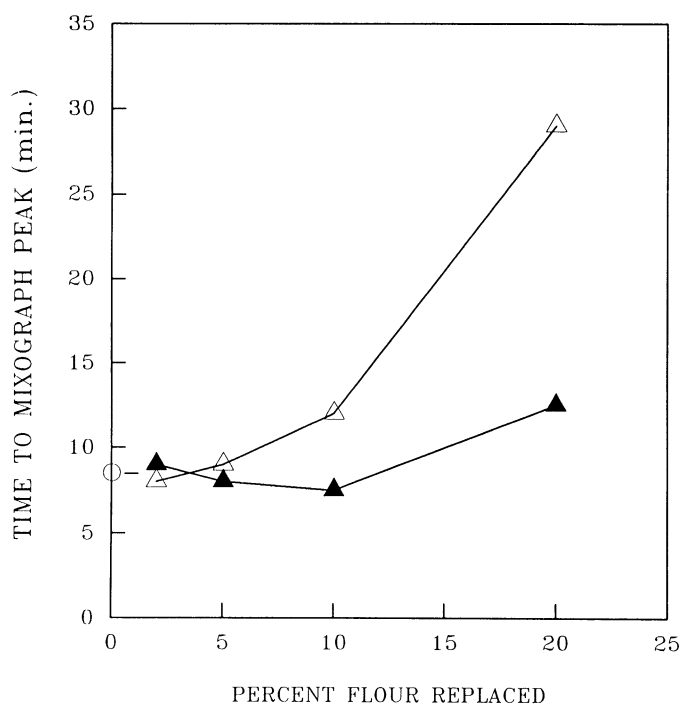


Fig. 5. Effect of replacing flour in a wheat dough with alkaline hydrogen peroxide treated corn stalks (AHP-CS) on the time required to reach the mixograph peak. Freshly prepared, never-dried (Δ) or dried, pin-milled (\blacktriangle) AHP-CS were added to replace (dry weight basis) the indicated amount of flour in the mixograph bowl. Final dough absorption for all the assays was 72%. The circle indicates the mixing time required to reach the peak for a dough containing flour alone.

The unusual properties of doughs containing alkaline peroxide-treated lignocellulose as a substitute for a portion of the flour suggest that these materials may be used as high-fiber, noncaloric flour substitutes in high-fiber and/or reduced caloric breads and similar yeast-leavened products. Results of preliminary baking tests in which AHP-CS replaced 10% of the flour in a white bread formulation are shown in Table II. Using the two-step mixing procedure described above, it was possible to prepare AHP-CS containing loaves at greater than 80% absorption (samples E and F) that had loaf volumes very close to that of the control loaf at 61% absorption. Substituting pin-milled or ball-milled wood cellulose for AHP-CS in the formulation (samples G and H, respectively) yielded loaves with significantly reduced volumes. The higher volumes observed for the AHP-CS containing loaves were obtained without adding gluten to the formulation. At absorption levels below 80%, volumes of the AHP-CS containing loaves decreased dramatically, possibly because of an insufficient

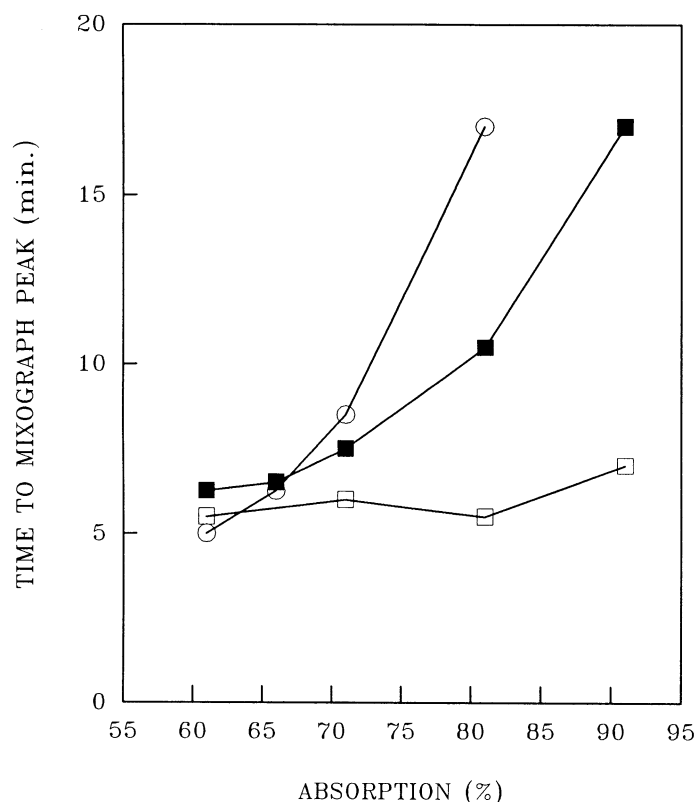


Fig. 6. Effect of mixing method and dough absorption on the time required to reach the mixograph peak for wheat flour doughs containing alkaline hydrogen peroxide treated corn stalks (AHP-CS). Open circles (o) indicate the mixing times required for 10 g of wheat flour at various absorption levels. Solid squares (\blacksquare) indicate the mixing times required for a mixture containing 9 g of flour plus 1 g of AHP-CS (pin milled), where the flour and AHP-CS were blended before adding water. The open squares (\square) indicate the mixing times required when 9 g of flour was mixed at 61% absorption for about 4 min (1 min less than the time required to reach the mixograph peak at that absorption), and then 1 g (dry weight) AHP-CS, wetted with any additional water required to achieve the desired final consistency, was added, and the mixing continued.

amount of water in the formulation to fully hydrate both the flour and the AHP-CS.

The data presented in this paper suggest that alkaline hydrogen peroxide treatment may be a useful method for improving the functionality of natural lignocellulosic substrates for use in baked formulations. Although corn stalks and wheat straw were employed as model lignocellulosic substrates in the studies reported here, the alkaline peroxide treatment has been shown to be effective on a wide range of lignocellulosic materials more

suitable for use in human foods, including brans, seed hulls, fruit and beet pulps, etc. (Gould et al 1989). Jasberg et al (1989) showed that AHP-WS can replace up to 40% of the flour in a cake formulation without adversely affecting either baking performance or taste panel scores. In some batter systems, such as pancakes, as much as 50% of the flour can be replaced without deterioration of baking or sensory performance (*unpublished results*). The ability to replace such significant portions of the flour in baked foods with a noncaloric, high-fiber material without sacrificing product quality should prove useful in the development of products with lower caloric density and increased dietary fiber.

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