Oil-binding Ability of Heat-treated Wheat Starch

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ABSTRACT

Prime starch fractionated from heat-treated wheat flour was found to possess high oil-binding ability. Prime starch heat-treated at 100–160°C for 1 hr also possessed this ability. Treatment of heat-treated prime starch with 1% sodium dodecyl sulfate, water-saturated 1-butanol, or a mixture of chloroform-methanol (2:1) had no effect on this ability. Treatment with 7% HCl, 0.2% NaOH, α-amylase, or pepsin effectively caused oil-binding ability to be lost.

When wheat flour is heat-treated, its cake-baking qualities are improved (Russo and Doe 1970). The improvement is similar to that caused by chlorination. The mechanism of this improving effect has not been clarified. Kulp and Lorenz (1981) and Lorenz and Kulp (1981) observed that heat-moisture treatment of wheat starch changed physicochemical properties and that overall cake-baking potential of heat-moisture-treated wheat starch decreased. Clements and Donelson (1982) added heat-treated lipids to defatted chlorinated flour. The improved batter expansion caused by the heat-treated lipids was retained as cake volume because of the chlorination of the flour. In chlorination studies on wheat flour, Seguchi and Matsuki (1977a), Gaines (1982), and Gaines and Donelson (1982) observed that the change in mouthfeel results mainly from alteration of starch by chlorine. Seguchi and Matsuki (1977a) and Seguchi (1984) theorized that the improvement of pancake texture, such as increased springiness and reduced gumminess, was the result of a modification of protein on the surface of prime starch, which increased its hydrophobic (lipophilic) capacity. They theorized that hydrophobicity of chlorinated starch may enhance the interaction of starch granules or with other components such as proteins, easing the transfer of water to starch during swelling. The result would be a decrease of free water in cake crumb, which would in turn affect cake crumb dryness and springiness. When sucrose fatty acid esters were added, the improving effects of chlorination on pancake springiness and mouthfeel disappeared (Seguchi and Matsuki 1977a). Sucrose fatty acid ester probably coated the starch granules and separated them from other batter components. In theory this would delay or retard starch swelling. The effect of adding sucrose fatty acid esters did not change the cake crumb. This paper investigates the lipophilic nature of separated prime starch from heat-treated flour and that of directly heat-treated prime starch isolated from flour. Effects of several solvents and enzymes on the oil-binding properties of heat-treated prime starch are also investigated.

MATERIALS AND METHODS

Materials

The wheat flour used was a patent, commercially milled, U.S. Western white wheat flour with respective protein and ash contents of 7.6 and 0.35%. Prime starch was obtained from wheat flour by acetic-acid fractionation as previously described (Seguchi and Matsuki 1977b). Its protein content was 0.14%. Alpha-amylase type II-A, with an activity of 15.7 units per milligram of protein, was obtained from Sigma Chemical Co. Pepsin with an activity of 1,200–2,000 units per milligram of protein, and corn oil were obtained from Wako Junyaku Co. and Nissin Oil Co., respectively. Other materials were reagent-grade products. Sodium dodecyl sulfate (SDS) disc-gel electrophoresis of pepsin and α-amylase showed only one band.

Heat Treatment

Prime starch (0.5 g) was placed in an open petri dish (93 × 14 mm) in a layer 1–2 mm thick. Wheat flour (100 g) was placed as above in an open iron dish (210 × 285 × 65 mm). These samples were heated at the temperatures and times indicated in Table I in a Yanagimoto electric air oven. Air was not circulated. Moisture lost during heat treatment is shown in Table I. Heat-treated samples were left at room temperature for several hours before fractionation or determination of oil-binding capacity.

Determination of Moisture Content and Oil-binding Capacity

Determination of moisture content was performed by the method of Tsutsumi and Nagahara (1961). Oil-binding capacity was performed as reported previously (Seguchi 1984). Data in this paper were from triplicate determinations. Standard deviation was 0.09 ml with this method.

Treatment of Starch Samples with Water-saturated 1-Butanol (WSB), Chloroform-Methanol (2:1), SDS, Dilute Acid, or Various Enzymes

Starch samples were treated as previously described (Seguchi 1984), except that solutions were dialyzed after enzyme digestion.

Treatment of Starch Samples with 0.2% NaOH and Protein Determination of Surface Protein of Starch

Starch (500 mg in 10 ml of 0.2% NaOH) was mixed overnight at room temperature in a shaker that had a 140-mm vertical amplitude and was driven by a motor at 140 rpm. Starch samples were centrifuged and washed with a large volume of water, then were dialyzed against water overnight. When the amount of surface protein of starch was measured, the washed starch was treated again with 10 ml of 0.2% NaOH. The supernatant fraction obtained was combined with the first supernatant. Both were then dialyzed against a large volume of water before protein was assayed by the method of Lowry et al (1951).

RESULTS AND DISCUSSION

Oil-binding Ability of Prime Starch from Heat-treated Wheat Flour

An upper limit of 120°C for 2 hr (Table I) was observed for heat-treatment of wheat flour because prime starch could not be separated from tailings by acetic-acid fractionation if these

TABLE I
Time Course of Heat Treatment (120°C) of Prime Starch

Heating Time (min)	Moisture Content After Heat Treatment (%)	Oil-binding Capacity (ml of oil/g of starch)
0	23.10	0.3
5	7.59	0.2
10	5.96	0.3
15	5.93	0.4
20	5.40	0.6
30	3.40	0.8
40	3.59	1.0
80	2.51	1.0
120	0.00	1.0

conditions were exceeded. Separated prime starch from heat-treated wheat flour exhibited high oil-binding capacity (Table II).

A photomicrograph of the unheated starches after vigorous mixing with oil in water is shown in Fig. 1a. Figure 1b shows oil droplets adhering to heat-treated prime starch after vigorous shaking in water, indicating the lipophilic character of prime starch. A similar phenomenon was previously shown with chlorinated starch (Seguchi and Matsuki 1977a).

Oil-binding Ability of Heat-treated Prime Starch from Unheated Wheat Flour

Direct heat treatment (120°C for 2 hr) of starch fractionated from unheated wheat flour was found effective in imparting a lipophilic character (Table II). Many starch granules were observed on oil droplets after vigorous shaking with water and oil (Fig. 2). To obtain the optimum conditions for creating the highest oil-binding capacity, the moisture content of starch before heat treatment and the effect of the temperature and time of heating at 120°C were investigated. Table II shows the importance of the moisture content of starch before heat treatment. Starch with less than 10% moisture had almost no increase in oil-binding, whereas starch with a higher moisture content (34.5%) treated by the same conditions had high oil-binding capacity. Because of these results, prime starch with a moisture content of 34.5% was used in subsequent treatments. As temperature was increased at a constant heating time (2 hr), oil-binding capacity gradually increased to 150°C. Dextrinization or roasting of the starch occurred above 160°C, causing the starch to easily dissolve in water and oil-binding capacity to be suddenly lost. When heating time at 120°C was varied, the oil-binding capacity of prime starch gradually increased for 40 min, after which time no increase occurred (Table I). Isolated starch was heat-treated at 120°C for 2 hr so that the oil-binding capacity of heat-treated starch and of starch from heat-treated wheat flour could be easily compared.

Chemical Treatment of Heat-treated Prime Starch

Chemicals that had little effect on the oil-binding capacity of heat-treated starch were WSB, a solvent often used for extraction of bound and polar lipids (Seguchi 1984) and chloroform-methanol (2:1), a solvent used for extraction of whole lipids. This indicates that lipids on prime starch bear little relationship to oil-binding capacity (Table III).

Treatment with 1% SDS solution also had little effect on oil-binding, which shows that lipophilic sites on starch were not affected by this anionic detergent. The lipophilic character of heat-treated prime starch was lost, however, by treatment with 7% HCl or 0.2% NaOH solution. Although starch granules were not disrupted under weakly acidic or alkaline conditions, the surface structure, normally covered with lipophilic sites, was assumed to be disrupted or dissolved. As reported previously, the lipophilic character of chlorinated starch disappeared with treatment by 7% HCl (Seguchi 1984). Treatment of starch with 0.2% NaOH is commonly used for extraction of protein from the surface of starch granules. Results obtained in our study were similar to those of previous papers (Seguchi and Matsuki 1977a, Seguchi 1984), which used 7% HCl. The effect of weak alkali also suggests that protein is related to the oil-binding ability of starch.

Enzyme Treatment of Heat-treated Prime Starch

Oil-binding was found to be greatly reduced by treatment with α-amylase or pepsin (Table III). Alpha-amylase has an effect upon the amylose and amylopectin components of starch, which are probably linked to a protein film.

TABLE II
Oil-binding Capacity of Heat-treated Prime Starch and of Prime Starch from Heat-treated Wheat Flour

Prime Starch	Oil-binding Capacity (ml of oil/g of starch)
From unheated flour	0.2
From wheat flour heated 2 hr at 120°C	0.8
Heated 2 hr at 120°C	
7.7% Moisture content	0.2
34.5% Moisture content	1.0
Heated 2 hr at	
80°C	0.6
100°C	1.0
120°C	1.0
140°C	1.2
150°C	1.6
160°C	1.4
174–184°C	0.3

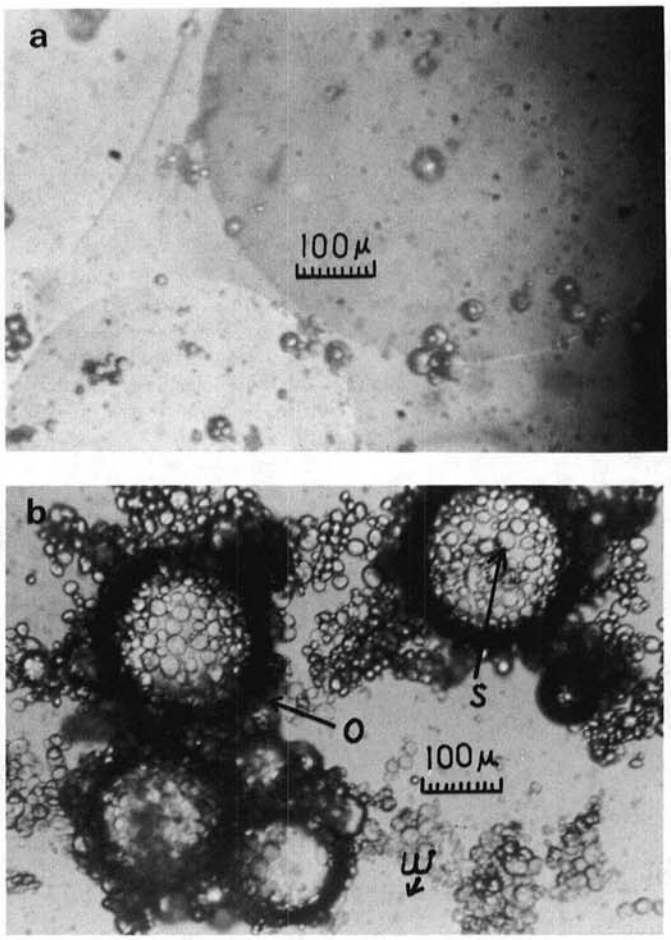

Fig. 1. Oil droplets in water with adhering starch granules after mixing with prime starch fractionated from **(a)** unheated wheat flour from **(b)** and heat-treated wheat flour (120°C for 2 hr). O = oil droplet, S = starch granule, and W = water.

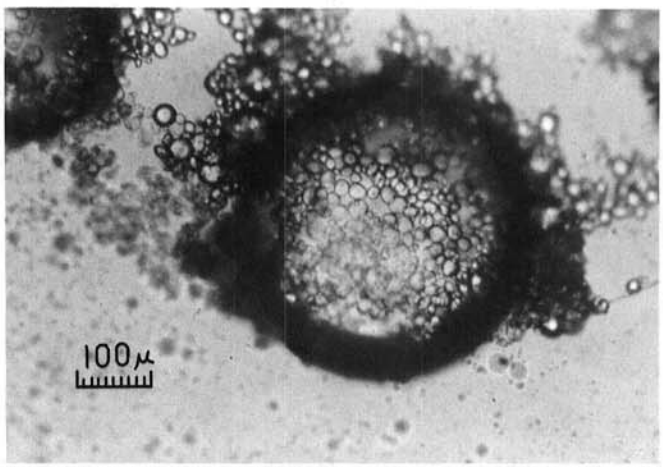

Fig. 2. Oil droplets in water with starch granules adhering after mixing with prime starch that was fractionated and then heat-treated (120°C for 2 hr).

TABLE III
Effects of Various Treatments on Oil-binding Capacity of Heat-treated Prime Starch

Treatment	Retained Oil-binding Capacity of Prime Starch Heated 2 hr at 120°C	
	ml of oil/g of starch	Percent
None	1.0	100
WSB[a]	0.9	90
$CHCl_3$-CH_3OH (2:1)	0.8	80
1% SDS[b]	0.9	90
7% HCl	0.2	20
0.2% NaOH	0.2	20
α-Amylase, 0.5 mg	0.3	30
Pepsin		
5.0 mg	0.2	20
0.5 mg	0.4	40
0.05 mg	0.7	70
Heat-denatured pepsin,[c]		
0.5 mg	1.0	100

[a]Water-saturated 1-butanol.
[b]Sodium dodecyl sulfate.
[c]Heat denaturation was performed by boiling for 5 min.

With decreasing levels of pepsin, oil-binding capacity gradually increased. Heat-denatured pepsin had no effect. These data suggest that increased lipophilic properties are brought about by denaturation of the protein film on the surface of heat-treated starch. The lipophilic nature of this protein film is probably disrupted by α-amylase or pepsin but is probably not affected by SDS.

The amount of surface protein of starch extracted with 0.2% NaOH was 0.44 mg/g of starch, about 3% of the total protein (N × 625) of the starch. Oil-binding capacity of the heat-treated starch (1.0 ml of oil/g of starch) is probably caused by the lipophilization of this heat-treated surface protein.

I conclude that both heat treatment and chlorination produce similarly increased lipophilic properties in the surface proteins of wheat starch. This investigation should be expanded to examine why these two treatments produce these results.

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