STUDIES ON PAN-CAKE BAKING. I. EFFECT OF CHLORINATION OF FLOUR ON PAN-CAKE QUALITIES

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ABSTRACT

At constant temperature, the consistency of wheat-flour slurry with water or oil was increased by chlorination. The pan-cake baking test with reconstituted wheat flour showed that improvements in springiness and gumminess by chlorination were brought about by the chlorinated prime starch fraction, and increase in cake volume by the chlorinated gluten fraction. The improving effects on springiness and gumminess disappeared with the addition of sucrose fatty acid ester to the improved formula. Microscopic observation of nonchlorinated and chlorinated starch, with and without sucrose fatty acid ester, showed that the chlorination of wheat flour made the starch granule surface more hydrophobic. These experiments indicate that the improvement in springiness and gumminess were dependent on the change of surface of the starch granule by chlorination.

Pan-cake, the so-called "Hot Cake" in Japan, is always eaten just after baking. The most suitable temperature for eating is about 87° C, and cake texture at this temperature is very important. Among the properties of pan-cake, high springiness and low gumminess just after baking are preferred in Japan, but these properties are changed on cooling. Chlorination of wheat flour improved these properties. The volume of pan-cake is also improved by chlorination, although performance is reduced at high ratios of chlorination.

Many researchers (1–10) studied the effects of chlorination on cake-baking properties of flour. Sollars (5,6) indicated that the improvement by chlorination was due to the prime starch and gluten fractions. Although Uchino and Whistler (11), Ingle and Whistler (12), and Whistler *et al.* (13) clarified the mechanism of oxidative degradation of wheat starch, Kulp and Tsen (9) and Kulp (10) examined the pasting characteristics, swelling power, solubility, and water-binding capacity, and suggested that commercial chlorination levels of wheat flour did not cause oxidative degradation of starch, but activated the surface of starch granules and caused the resulting chlorinated starch to react with other flour components. Shuey *et al.* (14) indicated the change of lipid binding capacity of wheat flour and starch by chlorination. Youngquist *et al.* (15) suggested that the chlorination effect was due to the formation of lipid derivatives in starch granules.

Thus, the actual mechanism of chlorination is still unclear. The common formulas of cake batters contain many ingredients, including wheat flour, sugar, leavening agents, salt, dry egg albumin, shortening, nonfat dry milk solids, and water, which makes it difficult to clarify the mechanism of chlorination. The simple pan-cake formula used in this paper contains only wheat flour, sugar, leavening agent, and water. It is designed to simplify the study of the mechanism of chlorination.

MATERIALS AND METHODS

Wheat flour used in this study was the brand name Ⓚ Alps, made by Nitto

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Milling Co. Ltd., from Western white wheat. The protein content was 7.2% and ash was 0.39% at 12.8% moisture. Sucrose fatty acid ester was Nitto ester of the Dai-Nippon Sugar Mfg. Co. Ltd. and HLB value was 14–15. Oil was Nissin vegetable oil of Nissin Oil Co. Ltd.

Chlorination of wheat flour was carried out in a buret-type chlorine apparatus—the Wallace and Tiernan Laboratory Demonstrator (16). The flour agitator was rotated at 35 rpm. Flour was treated with varied amounts (0.2–2.0 g/kg flour) of chlorine gas for 10 min at room temperature.

Consistency of Flour-Water Slurry or Flour-Oil Slurry at Constant Temperature

Wheat flour (150 g) and 150 ml of water or vegetable oil were mixed with a Hitachi hand mixer for 1 min at a low speed, then subjected to the Brabender Amylograph® for 10 min at constant temperature (25° C) as a model of cake batter. Consistency of flour-water slurry first fell to a minimum B.U. value and then raised at an angle of $\theta°$. The minimum B.U. value is described as the consistency of batter; the angle $\theta°$ indicates the rate of water absorption. The consistency of flour-oil slurry did not change.

Consistency of Model Cake Batter at Increasing Temperature

The temperature of model cake batter prepared as above was raised at a rate of 1.5° C/min in the amylograph. The consistency decreased at first and then increased when the temperature exceeded a fixed level. The temperature at minimum consistency is described.

Brabender Amylograph Test

Wheat flour (65 g) and 450 ml of water were mixed and subjected to the Brabender Amylograph® over a temperature range of 20°–95° C (17).

Pan-Cake Baking

The baking tests were performed on a laboratory scale. The basic formula was composed of 100 g of wheat flour, 20 g of powdered sugar, 1.6 g of sodium bicarbonate, 2.3 g of sodium acid pyrophosphate, and 110 ml of water. Dry ingredients were sifted into a bowl and water (24° C) was added to the mixture, which was blended for 30 sec in a Kitchen Aid Mixer (The Hobart Mfg. Co., Model K45) using a flat beater at 112 rpm. The batter (200 g) was placed in an iron pan (kept at room temperature) whose diameter, depth, and thickness were 25 cm, 2.5 cm, and 0.5 mm, respectively. The pan was greased with vegetable oil before it was used. The cake was baked 10 min before it was turned, and then 3 more min in an electric oven at 170° – 180° C. The cake was removed from the pan and cooled for 5 min at room temperature, after which the cake temperature was measured by an electronic thermometer. Cake volume was measured by the method of rapeseed displacement. Duplicate bakes were made and repeated again if the volume difference was over 2%. The standard deviation of cake volume was 3.69 cc with this method. After its volume was measured, the cake was cut in half vertically, and springiness was measured by pressing the cake surface strongly with the finger. Gumminess was detected by chewing a portion of the cake crumb. Crust and symmetry were also measured by external appearances. The baking properties were scored numerically as follows: (a), gumminess or springiness, 0 = none; 1 = slight; 2 = some; 3 = moderate; 4 = very;

and (b), crust or symmetry score was assigned on a scale from extremely poor = 0, to excellent = 4. A high scale for springiness, crust, or symmetry, and a low scale for gumminess, are preferred.

These sensory tests were done by a panel of five trained panelists, and average values were indicated.

Baking with Reconstituted Flour

Acetic acid fractionation of wheat flour was performed by the method of Sollars (5). The observed percentages of prime starch, tailings, gluten, and water-solubles fractionated from 100 g of flour were 73.0, 15.0, 5.38, and 5.31, respectively. Gluten and tailings fractions were lyophilized and ground in a mortar grinder for 10 min and sifted with a 30-mesh sieve before use. Prime starch fraction was dried at room temperature.

The flour was reconstituted by sifting together pulverized gluten, prime starch, and tailings fractions, then the water-solubles fraction was added with water in a Kitchen Aid Mixer with flat beater at 205 rpm until gluten was developed. In order to further clarify the springiness and gumminess, the volume of the mixture of water-solubles fraction and water was 110 ml when prime starch fraction was exchanged; otherwise, it was 100 ml when the gluten fraction was exchanged. The pH of batter was adjusted to 5.3 by the addition of NaOH in order to avoid decrease of cake volume by lower pH. Then powdered sugar, sodium bicarbonate, and sodium acid pyrophosphate were added, followed by 0.5 g of sucrose fatty acid ester to 200 g of batter. The baking method was as described above.

Microscopic Observation of Starch in Water

Starch was suspended in water and examined under a light microscope by the hanging drop method. When the micro-melting point measuring apparatus was used, silicone grease was used for sealing the cover glasses. The starch suspension was made in such a way that 50–100 starch granules could be seen in one drop under the microscope. One per cent of sucrose fatty acid ester suspended in water was used.

Oil Adsorption of Starch

One milliliter of rapeseed oil, 0.5 g of starch, and 20 ml of water were vigorously mixed by shaking in a Gerber Butyrometer, and the mixture was centrifuged at 3000 rpm for 30 min. Oil adsorbed was calculated from Butyrometer readings. For confirmation, the oil adsorbed on the starch was stained with Sudan black B and examined under the microscope.

RESULTS AND DISCUSSION

Consistency of Flour Slurry with Chlorinated Flour at Constant and Increasing Temperature

When pan-cake baking was performed, the increase in consistency of cake batter was always observed as the degree of chlorination increased. As a model of cake batter, a slurry of wheat flour, which had the same flour-water ratio as cake batter, was subjected to the Brabender Amylograph test for 10 min at constant temperature (25° C). With increasing chlorination the slurry consistency was raised, as shown in Fig. 1, curve A.

The value of θ° indicates the absorption rate of water by wheat flour, and this value was zero at the saturated-condition level. The value of θ° increased at higher rates of absorption of water to flour (Fig. 2a). In Fig. 2b, greater values of θ° were shown by highly chlorinated flour.

When the model cake batter was heated in the Amylograph, the consistency of

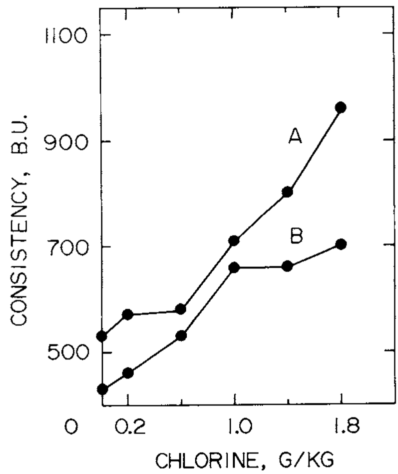

Fig. 1. Effect of chlorination on viscosity of flour-water slurry (A) and flour-oil slurry (B) at constant temperature (25° C).

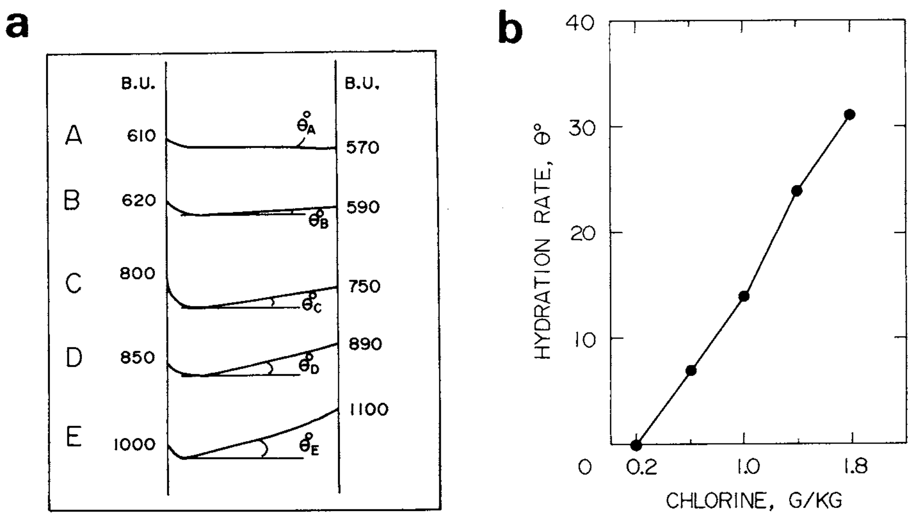

Fig. 2a. Brabender amylograms of flour-water slurry at constant temperature (25° C) for 10 min. Cl_2-rate: A) 0.2 g/kg; B) 0.6 g/kg; C) 1.0 g/kg; D) 1.4 g/kg; and E) 1.8 g/kg. Fig. 2b. Effect of chlorination on hydration rate (θ°) of water to flour at 25° C.

slurry first decreased to a minimum B.U. value and then increased with the rise of temperature.

The temperature at which the model cake batter reached the minimum consistency is shown in Fig. 3. It was plausible that heat treatment caused more activation of water absorbing capacity through chlorination of wheat flour.

Consistency of Flour-Oil Slurry at Constant Temperature

When water was replaced by vegetable oil and subjected to the Brabender Amylograph® at 25° C for 10 min, the consistency of slurry increased with chlorination, as was found for the water and flour mixture (Fig. 1, curve B). These experiments indicate that chlorination of wheat flour involves two opposing characteristics: the hydrophobic and the hydrophilic.

Amylograph Test of Chlorinated Flour

In order to clarify the relationship of wheat flour and water at higher temperatures, flour was subjected to the Brabender Amylograph® over the range of 70°–95° C. Figure 4 shows the B.U. value at various temperatures for six levels of chlorination. B.U. value was found to increase with increasing chlorination from 70°–85° C; however, it was constant at 92.5° C when chlorination level was lower than 1.2 g/kg. The maximum B.U. values are also constant at the lower chlorination levels. In all cases, consistency was increased at chlorination levels above 1.2 g/kg.

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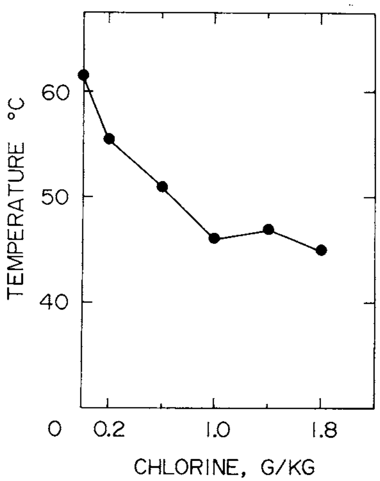

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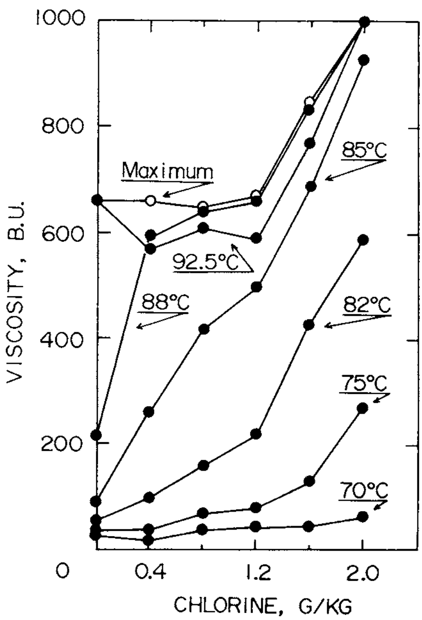

Fig. 3. Effect of chlorination on temperature at the starting point of flour viscosity increase. Fig. 4. Effect of chlorination on viscosity of flour at temperatures ranging from 70° to 95°C.

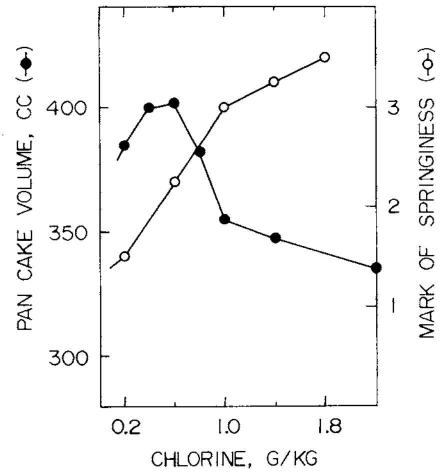

Fig. 5. Effect of chlorination on pan-cake volume and springiness.

TABLE I
Baking Results of Reconstituted, Unchlorinated Wheat Flour Replacing the Prime Starch Fraction only from Chlorinated Flour

Cl_2-Rate g/kg	Volume cc	Gumminess[a]	Springiness[a]	Crust	Symmetry
0.0	331	4.0(...)	0.0(...)	2.0	2.0
0.4	345	3.5(3.5)	1.0(1.5)	2.0	3.0
0.8	360	2.0(4.0)	2.5(1.0)	2.0	3.0
1.2	355	0.5(4.0)	3.5(1.5)	2.0	3.0
1.6	355	0.5(4.0)	3.5(1.5)	1.5	2.5
2.0	328	0.0(3.0)	4.0(3.0)	1.5	0.5

[a]A number in parentheses indicates the value when sucrose fatty acid ester is added.

TABLE II
Baking Results of Reconstituted, Unchlorinated Wheat Flour Replacing the Gluten Fraction only from Chlorinated Flour

Cl_2-Rate g/kg	Volume cc	Gumminess	Springiness	Crust	Symmetry
0.0	460	3.5	1.0	2.0	2.7
0.4	450	3.5	1.0	2.3	2.7
0.8	400	2.5	1.5	1.5	3.0
1.2	345	3.0	2.5	1.7	2.7
1.6	310	3.5	1.0	1.5	2.0
2.0	340	4.0	1.5	1.5	2.0

Pan-Cake Baking Test with Wheat Flour

Results of cake-baking with flours of various chlorination treatments are shown in Fig. 5. Whereas pan-cake volume was increased at chlorination levels up to 0.6 g/kg, it was reduced sharply at first, then more gradually, at higher ratio. Spinginess of pan-cake when hot was increased by greater chlorination, but was not reduced by over-chlorination as in the case of cake volume.

Pan-Cake Baking Test using Reconstituted Flour with Prime Starch Fractions from Chlorinated Flour

With the aid of acetic acid fractionation and reconstituted flour baking technique, chlorination effects on the prime starch fraction were examined with reconstituted flour replaced with the prime starch fraction from each chlorinated flour and with other fractions from normal unchlorinated flour. Table I presents the results of pan-cake baking tests.

With reconstituted wheat flour, springiness and gumminess were gradually improved with a starch from chlorinated flour. These effects were similar to those with chlorinated whole wheat flour. It was reasonably concluded that the chlorination effect on prime starch decreased the gumminess and improved the springiness of pan-cake. In each baking formula, the fixed amount of water was used; however, the cakes were gummy and moist with nonchlorinated prime starch, and dryness increased with chlorinated prime starch. It appears that the relation between water and starch was changed by chlorination without producing an effect on cake volume, crust, and symmetry.

Pan-Cake Baking Test using Reconstituted Flour with Gluten Fractions from Chlorinated Flour

Baking tests were carried out with reconstituted flour replaced with the gluten fraction from chlorinated flour and with other fractions from normal unchlorinated flour. It was found that the baking properties of springiness, gumminess, crust, and symmetry were not changed by chlorination, but the cake volume was changed by chlorination of the gluten fraction (Table II).

With increasing chlorination, cake volume for whole flour first increased and then decreased (Fig. 5). When reconstituted flour was used, volume decreased gradually with increasing chlorination. The difference might be attributed to the longer mixing time for the formation of cake batter with the reconstituted system. From the results obtained with reconstituted flour, it was concluded that reduction of cake volume by chlorination was mainly due to a change of the gluten fraction.

Effect of Sucrose Fatty Acid Ester on Test Baking

Batters containing chlorinated prime starch fractions were examined with the addition of 0.5 g sucrose fatty acid ester/100 g of reconstituted flour. The improving effects on springiness and gumminess produced by chlorination disappeared with the addition of sucrose fatty acid ester (Table I). The result might be attributed to a change in condition of the surface of the chlorinated starch granule.

Chlorinated prime starch which was defatted with ether or with water-saturated 1-butanol was examined in the baking test. It was observed that the improving effects by chlorination were not lost; however, data are not shown.

Oil-Binding Capacity of Chlorinated Starch

In order to measure the hydrophobic character of the chlorinated starch granule, oil-binding capacity was determined. Figure 6 shows the increase in oil-binding capacity of starch found with increasing chlorination.

Microscopic Observation of Chlorinated and Nonchlorinated Starch Suspensions

Nonchlorinated prime starch granules suspended in water remained evenly distributed, did not interact with one another, and did not cohere when observed under a light microscope. Chlorinated prime starch granules gradually cohered to form clusters when observed under the same condition. In the latter case, the starch granules constantly changed their positions when another granule approached, as if there were some active sites on the surface of the starch granule, and finally they combined together. This characteristic of cluster formation was not lost even if starches were heated and swollen. The addition of urea did not break clusters, but they were broken by the addition of sucrose fatty-acid ester.

It might be concluded that chlorination made the surface of the starch granule hydrophobic and clusters were formed by hydrophobic bonding, which was broken by addition of sucrose fatty acid ester.

Since this ability to form clusters did not disappear even if the starch was washed with ether or with water-saturated 1-butanol, lipid on the surface of the starch granules seemed to have no relation to cluster formation. When starch was kept suspended for 2 weeks in 7% HCl at room temperature, this ability was lost. When starch was suspended with oil, chlorinated starch gathered around oil drops, and the rate of gathering was increased with chlorination (Fig. 7, b–f) when observed under the microscope.

Nonchlorinated starch granules remained suspended in the water phase (Fig. 7a). The chlorinated starch granules gathered at the interface of water and oil phases (Fig. 8).

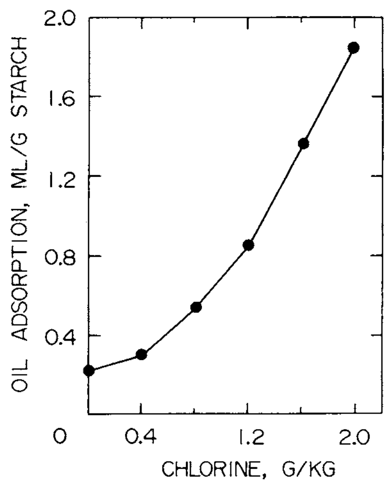

Fig. 6. Effect of chlorination on oil absorption of wheat starch.

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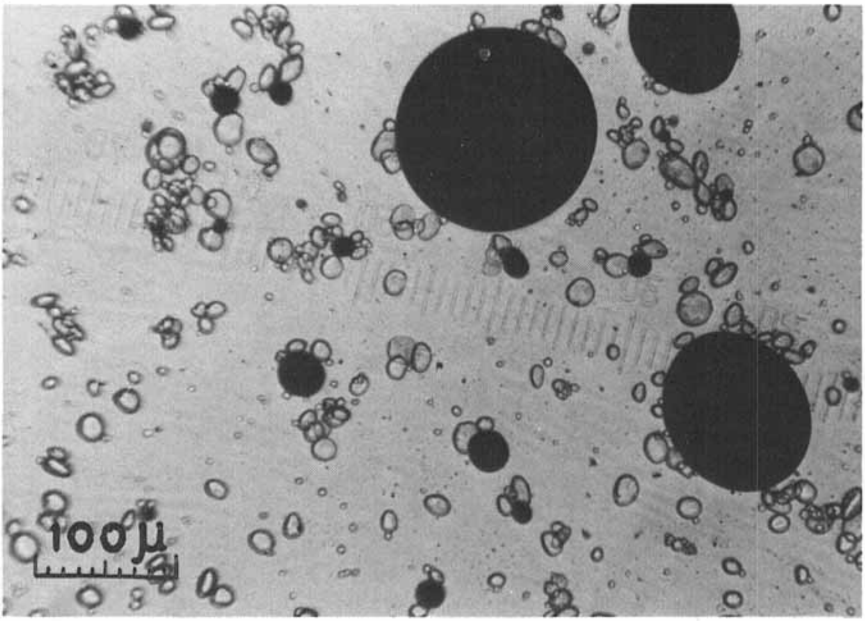

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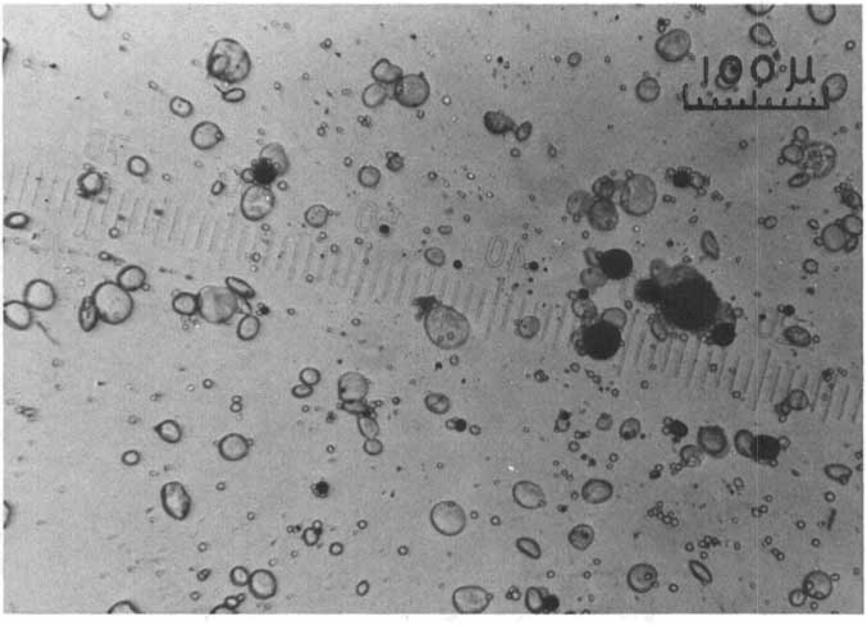
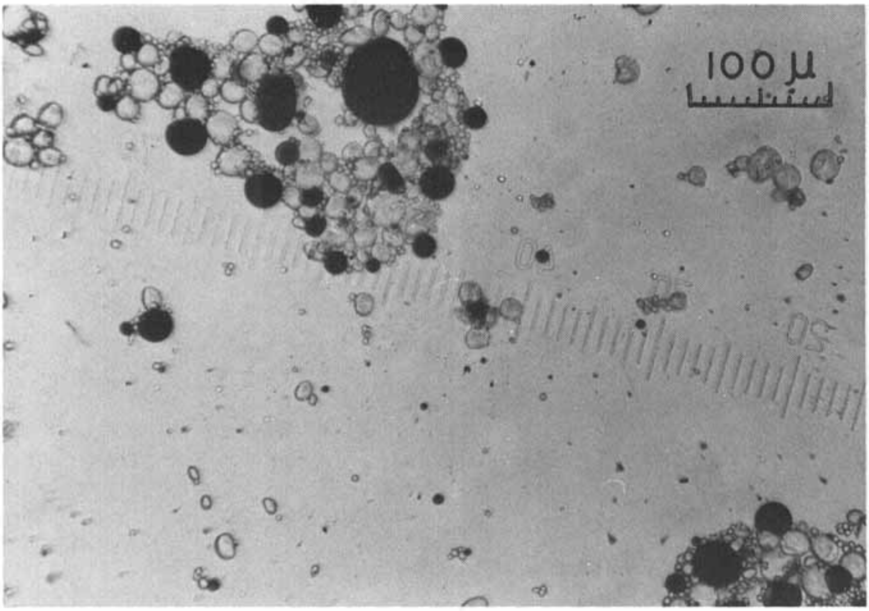


Fig. 7. Microphotographs of oil drops and starch granules from chlorinated wheat flour. Cl_2-rate: a) 0.0 g/kg; b) 0.4 g/kg. 1 scale division = 10 μ.

c



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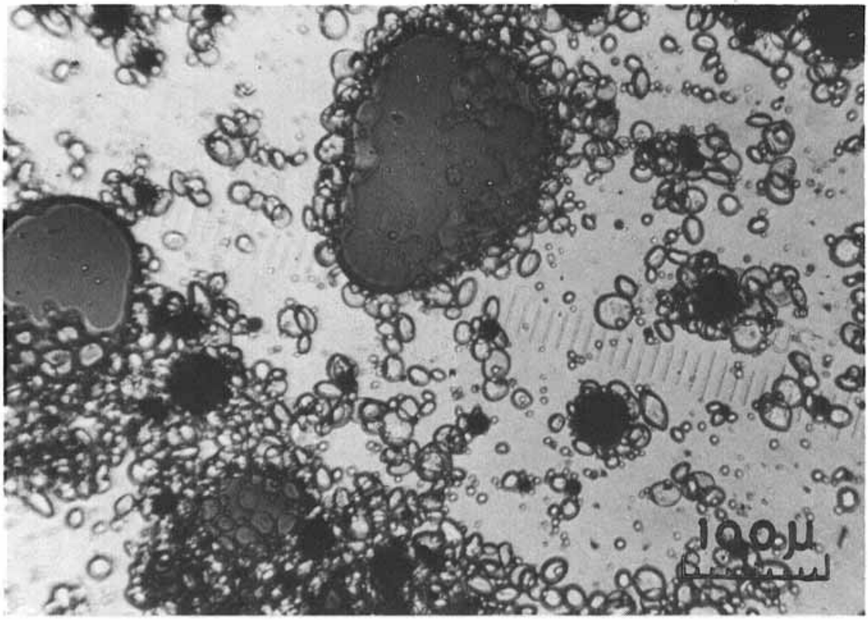
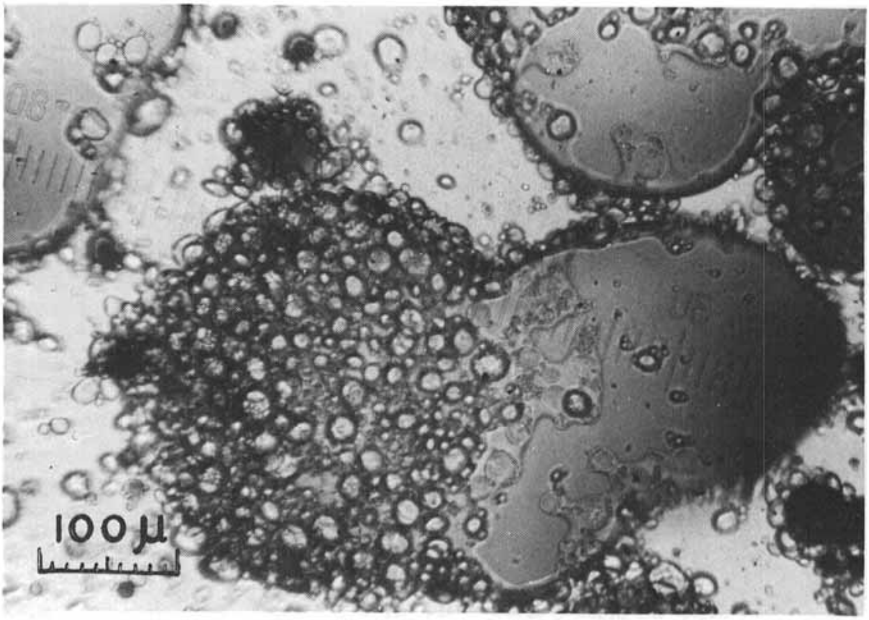


Fig. 7. Microphotographs of oil drops and starch granules from chlorinated wheat flour. Cl_2-rate: c) 0.8 g/kg; d) 1.2 g/kg. 1 scale division = 10 μ.

e



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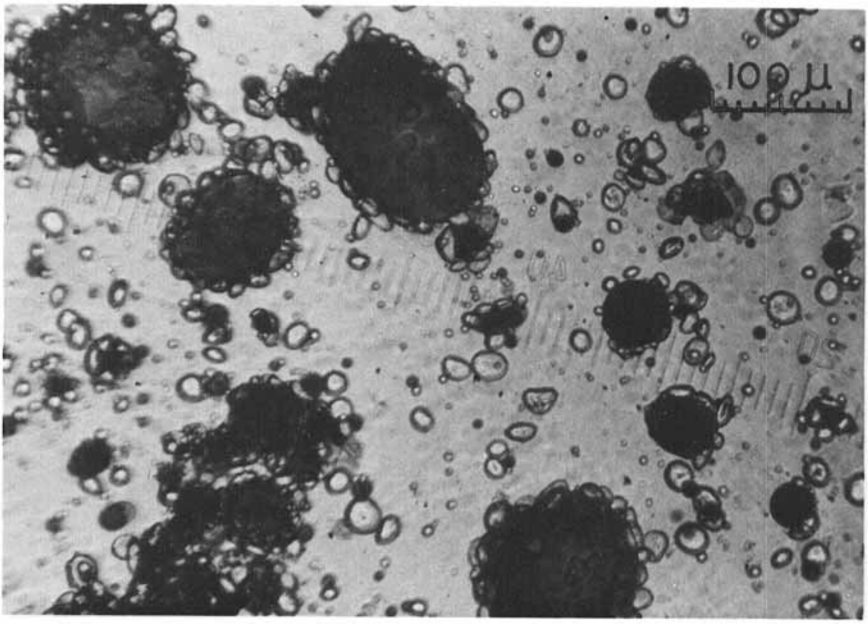

Fig. 7. Microphotographs of oil drops and starch granules from chlorinated wheat flour. Cl_2-rate: e) 1.6 g/kg; f) 2.0 g/kg. 1 scale division = 10 μ.

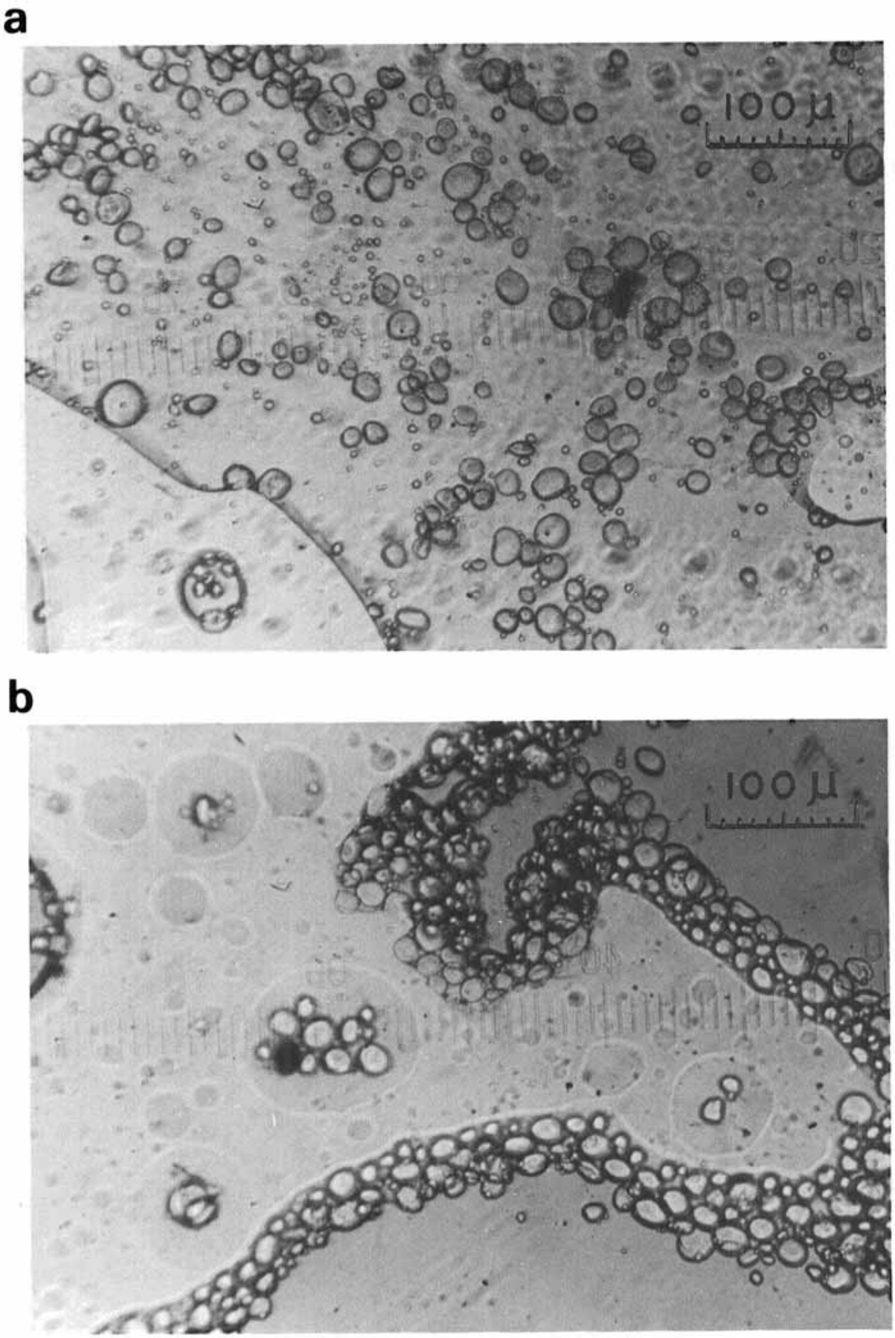

Fig. 8. Starch granule near the surface of water and oil. a) Nonchlorinated starch; b) chlorinated starch. 1 scale division = 10 μ.

From this study we may conclude that the improvements of baking properties such as springiness and gumminess in fresh pan-cakes are due mainly to the altered character of chlorinated wheat starch.

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