EFFECT OF THE KIND AND PROPORTION OF FLOUR COMPONENTS AND OF SUCROSE LEVEL ON CAKE STRUCTURE[1]

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ABSTRACT

A bleached cake flour was fractionated by an acetic acid method into water-solubles, gluten, starch tailings, and prime starch. Flours were reconstituted from various proportions of the fractions. White cakes were baked using two formulas containing 100 and 125% sugar based on flour weight. Tailings in increasing amounts had an improving effect on volume and internal structure. The optimum amount of tailings, beyond which little or no additional increase in volume occurred, was significantly less for high- than for low-ratio cakes. This was believed to be due to greater swelling of the hemicelluloses of tailings at the higher sugar level, compensating for the smaller amount of this fraction, and resulting in a stronger and more stable structural matrix within the batter during mixing and baking. The main protein fractions, gluten and water-solubles, also markedly affected volume and structure, and a significant interaction was found between the proportion of these fractions and the formula. The combined protein fractions appear to stabilize the batter by binding the ingredients and, as is generally accepted, provide adequate structure to retain expanding gases during baking. The protein fractions tend to minimize mutual binding of starch granules upon cooling.

The relation between the composition of flour and its baking characteristics has received much attention. The effect of crude and specific fractions of hard wheat flour on the rheological properties of doughs and the structure of bread has been investigated extensively. Less attention has been given to the structure-forming properties of the fractions of soft wheat flour.

Donelson and Wilson (1), using a multifactor design, studied the effect of the relative quantity of water-solubles, gluten, tailings, and starch upon the quality of cakes in which egg and milk were omitted from the formula. They concluded that the significance of each component in determining cake quality was dependent upon the amount of that component present in relation to the amount of the other fractions. The tailings fraction had a marked effect, increasing cake volume and improving internal appearance. The same workers (2) also studied the effect of interchanging the fractions of a flour of

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"good" quality and one of "poor" quality upon cake quality. The source and amount of gluten affected cake volume and crumb structure to a greater extent than any of the other fractions.

The significance of a given flour component in determining cake structure may be dependent upon other cake ingredients as well as on the relative proportion of the flour fractions. The work reported herein concerns: (a) possible functions of starch tailings and the main protein fractions of the flour, gluten and water-solubles, in determining white cake structure, and (b) the effect of the formula on the structure-forming properties of the fractions, with particular reference to sugar concentration. The following changes in flour composition were investigated in high- and low-ratio cakes: (a) the proportion of starch tailings to prime starch, (b) the proportion of gluten and water-solubles to prime starch, and (c) the proportion of gluten and water-solubles to starch tailings.

Materials and Methods

Flour. Commercial bleached cake flour was the source of all flour fractions. Two flour samples were used, both from the same source[4] and having the same ash content (0.35% at 14% moisture) and acidity (pH 4.9) but differing in protein (8.1 and 7.5%).

Flour Fractionation. The flour was fractionated into water-solubles, gluten, starch tailings, and prime starch by the procedure described by Sollars (3) for bleached cake flour. The water-solubles were

TABLE I

PROTEIN CONTENT, pH, AND PROPORTION OF FLOUR FRACTIONS

Material	Fractionation I			Fractionation II		
	Yield [a]	Protein [b]	pH	Yield [a]	Protein [b]	pH
	%	%		%	%	
Bleached cake flour	100.0	8.1	4.95	100.0	7.5	4.92
Water-solubles	4.1	24.5	3.98	4.0	21.3	4.34
Gluten	7.4	69.8	5.19	7.5	65.0	5.34
Starch tailings	14.9	2.9	4.03	18.0	2.0	4.15
Prime starch	73.6	0.3	4.86	70.5	0.2	4.81

[a] 14% moisture basis; fraction percentages adjusted to 100% yield.
[b] 14% moisture basis; protein = N × 5.7.

concentrated in a flash evaporator below 40°C. to a volume of 55 ml. for each 100 g. flour. The concentrate was frozen and stored at −18°C. until used. The gluten and starch tailings were lyophilized and the prime starch was air-dried. All dry fractions were ground in a Wiley mill to pass a 40-mesh sieve and stored in tightly sealed containers, the gluten and tailings at 5° C. and the starch at room temperature.

[4] One purchased in 1960 and one in 1961.

A 94% recovery of fractions was obtained. Losses were assumed to be proportionally distributed among all fractions and the total percentage of components used in reconstituted control flours was adjusted to 100% yield as shown in Table I.

Reconstituted Flour Blends. Thirty-one flour blends, including reconstituted "controls," were investigated: two series from flour sample 1 and one series from flour sample 2. (See Tables III, IV, and V.) In each series the formula using the fractions in the proportions obtained from the flour served as the control. The water-solubles were thawed and added as the total or part of the liquid in the cake formulas.

Series I was designed to investigate the function of the tailings/prime starch ratio. Eleven blends were prepared in which the gluten and water-solubles were held constant at the proportion obtained on fractionation of the flour (7.4 and 4.1%); the starch tailings were varied from the proportion in the flour, by 20% intervals, from −100 to +100% (0 to 29.8%); and the prime starch adjusted as needed (from 88.5 to 58.7%). The protein content of the blends ranged from 6.3 to 7.1%, an increase of about 0.1% with each increment of tailings.

Series II was designed to investigate the function of the gluten and water-solubles/prime starch ratio. Nine blends were prepared in which the starch tailings were held constant at the proportion obtained on fractionation of the flour (14.9%); the gluten and water-solubles were varied from the proportion in the flour, by 20% intervals, from −100% to +60% (0 to 18.4%); and the prime starch adjusted as needed (from 85.1 to 66.7%). The gluten and water-solubles were always in the same proportion as in the original flour fractions (7.4:4.1). The protein content of the blends ranged from 0.7 to 10.3%, an increase of 1.2% with each increment of the main protein fractions.

Series III, from the second flour sample, was designed to investigate the function of the gluten and water-solubles/starch tailings ratio. Eleven blends were prepared in which the prime starch was held constant at the proportion obtained on fractionation of the flour (70.6%); the gluten and water-solubles were again varied from the proportion in the flour, by 20% intervals, from −100 to +100% (0 to 22.8%). The starch tailings were adjusted as needed (from 29.4 to 6.6%). The gluten and water-solubles were always in the same proportion as in the original flour fractions (7.5:4.0). The protein content of these blends ranged from 0.8 to 11.7%, an increase of about 1.1% with each increment of the main protein fractions.

TABLE II
WHITE CAKE FORMULAS

Ingredients	High-Ratio		Low-Ratio	
	Flour Basis	Total	Flour Basis	Total
	%	%	%	%
Flour	100.0	22.9	100.0	27.4
Sugar	125.0	28.7	100.0	27.4
Shortening, hydrogenated veg. oil	50.0[a]	11.4[a]	40.0[b]	10.9[b]
Nonfat dry milk	12.4	2.8	8.0	2.2
Water and/or concentrated water-solubles	82.6	18.9	60.0	16.4
Egg white (liquid)	60.0	13.7	50.0	13.6
Salt	2.0	0.4	2.0	0.5
Baking-powder (double action)	4.5	1.0	4.5	1.2

[a] Sweetex (Procter and Gamble).
[b] Crisco (Procter and Gamble).

Cake Baking. The two cake formulas used (Table II) contained 100 and 125% sugar based on the flour weight. A preliminary dough step as reported by Sollars (3) and Donelson and Wilson (1) was necessary for the reconstituted flours. Generally 5 min. of dough development in a Hobart C-100 mixer was required. The amount of liquid needed for a well-formed dough varied with the flour composition.

The mixing method was essentially the same for both cake formulas. Cake ingredients were conditioned so that the batter temperature was 27° to 28°C. The shortening, sugar, and salt were creamed in the mixer. The dough was added to the creamed mixture and blended for 0.5 min. at low speed. The balance of the water required, the milk solids, and baking powder were added and the batter mixed for 0.5 min. at low speed and 2.5 min. at medium speed. The unbeaten egg white was added slowly, while mixing was continued for 0.5 min. at low speed and 1.5 min. at high speed. The high-ratio cake was mixed for another 1 min. at high speed.

The specific gravity of the batters was determined by the use of a pycnometer. Portions of 300 g. of batter were weighed into 6-in. layer pans and baked in a reel-type oven at 360°F. for approximately 27 min. Each experiment was replicated three times.

Measurements of Cake Quality. Volume, which appeared to be the most reliable index of the structural quality of the baked cakes, was measured by an E-shaped device proposed by Wilbur and Johnson (4). Internal structure was judged by the workers, who observed size of cells and thickness of cell walls. Microscopic observations of internal structure were made of cake sections embedded in bioplastic; the samples were prepared in a manner similar to that described by

Sandstedt *et al.* (5) for bread crumb. The surface exposed by grinding was stained with 1% solutions of fast green and of iodine in 80% glycerin.

Results and Discussion

No significant alterations appeared to have occurred in the flour components attributable to fractionation; cakes made with the reconstituted control flours were standard products of good quality comparable to those baked from the corresponding normal flours. Both formulas gave products slightly rounded in contour with a crumb of even grain, medium-sized cells, and fine cell walls; the high-ratio cakes were of slightly finer texture than the low-ratio cakes. The batters of the reconstituted control flours always appeared slightly curdled, but apparently this did not adversely affect the quality of the baked cake.

Although the high- and low-ratio formulas differed in the relative proportions of most ingredients, for the purpose of this study and from the standpoint of interaction with the flour components, the primary variation was considered to be the relative quantity of sugar and water. The effects of other cake ingredients can not be overlooked, but here they are considered significant only to maintain a balanced formula when the weight of the sugar exceeds the weight of the flour.

Since the volume of the control samples varied with the flour sample from which the fractions were obtained and with the cake formula used, the volumes of the experimental cakes were plotted as the percentage change from the control (Figs. 1 and 3). This is believed to be a more reliable index of cake volume response to flour composition than would be comparison of the actual cake volumes.

Proportion of Starch Tailings to Prime Starch. As the proportion of tailings to starch increased from the lowest to the highest level, the liquid required for adequate dough formation increased from 60 to 68%, and the total liquid used in the cakes was increased accordingly. The doughs from flour blends containing a small proportion of tailings, 0 to 6%, were soft and lacked elasticity. The improved dough formation with increasing amounts of tailings may have been due to the highly hygroscopic insoluble hemicelluloses which originate in the endosperm cell walls. There may be a binding of the other flour components by these swollen and highly branched polysaccharides.

Batters prepared from flours containing normal, or higher than normal, proportions of tailings were only slightly curdled. Increasing the amount of this hygroscopic fraction apparently resulted in sufficient binding of batter ingredients and less separation of the aqueous and solid phases. The specific gravity of the batters appeared unrelated to the proportion of tailings in the flour and to the quality of the baked cakes.

Cake volume as affected by the proportion of tailings to starch, by the cake formula, and by the interaction between the two factors was significant at the 0.01 level of probability. As the proportion of tailings increased, cake volume increased up to a maximum and then remained relatively constant. The increases were more marked for cakes prepared from the 100% than from the 125% sugar formula (see Table III and Fig. 1). The volume of the low-ratio cakes increased progressively with an increase in the concentration of tailings up to 20.9% of the flour (+40%), whereas the volume of the high-ratio cakes increased rapidly but only to a concentration of 8.9% tailings (−40%).

Cake volume is largely dependent upon the strength and stability of the structural matrix of the batter. In these cakes, although the structural gluten proteins were at a fixed level, a reduction in the proportion of tailings obviously weakened the batter and cake structure. That a decrease in the level of tailings decreased the stability of the batters has already been indicated. That cake volume was not

TABLE III

EFFECT OF PROPORTION OF STARCH TAILINGS TO PRIME STARCH ON VOLUME OF HIGH- AND LOW-RATIO CAKES[a]

Flour Composition (Series I)			Average Cake Volume	
Starch Tailings	Prime Starch	Total Protein	125% Sugar Formula	100% Sugar Formula
%	%	%	cc.	cc.
0.0	88.5	6.3	542	544
3.0	85.5	6.4	660	605
6.0	82.5	6.5	722	594
8.9	79.6	6.5	768	611
11.9	76.6	6.6	765	644
14.9[b]	73.6[b]	6.7[b]	749	700
17.9	70.6	6.8	767	750
20.9	67.6	6.8	774	786
23.8	64.7	6.9	779	774
26.8	61.7	7.0	772	786
29.8	58.7	7.1	771	759
Original cake flour		8.1	712	807

[a] Reconstituted flours (14% m.b.) contained 7.4% gluten and 4.1% water-solubles.
[b] Control samples; normal proportions of all components with fraction percentages adjusted to 100%.

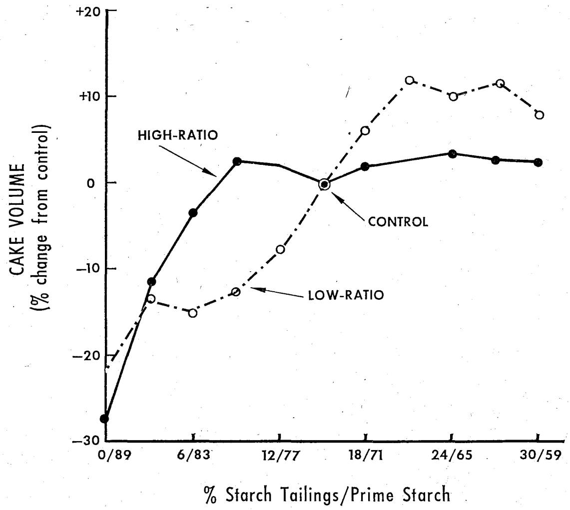

Fig. 1. Relation between the proportion of starch tailings and prime starch in reconstituted cake flours and the volume of white cakes. Gluten and water-solubles were respectively 7.4 and 4.1% of the flour. The volumes of control samples were 749 and 700 cc. respectively for the high- and low-ratio cakes.

as greatly reduced in high-ratio as in low-ratio cakes when the proportion of tailings in the flour was decreased by 20 to 60% (only 6 to 12% of the flour) may be explained by an interaction between the hemicelluloses of the tailings and the higher sugar-water level to produce a more stable batter and a stronger, gellike structure during baking. Apparently with a reduction in the amount of tailings below 6% (60% less than normal) there was an inadequate amount present to function effectively as a structural material.

Previous and unpublished work in this laboratory lends support to the hypothesis of an interaction between tailings and sugar affecting batter and cake structure. In investigations of the thickening properties of soft wheat flour fractions in water and sugar solutions, whenever the starch tailings fraction was present in the normal proportion, either with prime starch alone or in combination with the main protein fractions of flour, hot paste viscosity and gel strength increased as the concentration of the sucrose solution increased up to 28%. The paste viscosity and gel strength of fraction blends from which tailings were omitted were generally reduced, often markedly so, at the higher sugar concentrations. Since sucrose, in relatively high concentrations, is known (6) to have a depressing effect upon the swelling and gel strength of starch, it is unlikely that the small starch-granule fraction of tailings would account for the stronger paste and gel structure or superior cake structure provided by the tailings.

Although an increase in the proportion of tailings above 9% of the flour composition did not significantly affect the volume of the high-sugar cakes, it did improve the cell structure. Perhaps a higher proportion of tailings is needed in a low-ratio cake formula to provide equivalent structure to the batter and baked cakes; approximately the same cake volume was obtained with 9 to 15% tailings and 125% sugar as with 18% tailings and 100% sugar. At levels of tailings higher than normal, actual cake volumes were similar for the two formulas; but the percentage increase in volume, as compared with the control, was greater for low-ratio cakes.

When the amount of tailings exceeded the normal proportion, cakes made from either the high- or low-sugar formula became increasingly fine and silky in texture; they had small cells with fine cell walls. These cakes were desirably moist and tender; similar results were found by Donelson and Wilson (1). Cakes made with low concentrations of tailings fell during the final stages of baking, the crumb texture was coarse, and the cell walls were thick. Cross-sections of cakes containing 40% less tailings than normal are shown in Fig. 4, C.

Microscopic observation often revealed only subtle differences among samples. The presence of many small starch granules with increasing proportions of tailings may have obscured differences. Grinding the embedded samples to a smooth surface presented certain problems. Generally the cell structure was easily observed microscopically, but often photomicrographs were not clear because of small surface irregularities and an insufficiency of light reflected from the sample.

In general, when the proportion of tailings was above normal in amount, the large granules of the prime starch were thinner and smaller, and spaces between the granules were somewhat greater than in the control samples (Fig. 2, A and B). This suggests an interference in mutual starch-starch bonding by the hemicelluloses, which could account for the fine and silky texture of these products. Differences in microscopic appearance were more apparent between samples of the high- and low-sugar cakes containing approximately 9% tailings in which the volume was 768 and 611 cc. respectively; the larger starch granules of the low-ratio cakes appeared to be more swollen and in closer contact. The differences in granule size might be explained by a greater swelling of the starch at the lower sugar concentration.

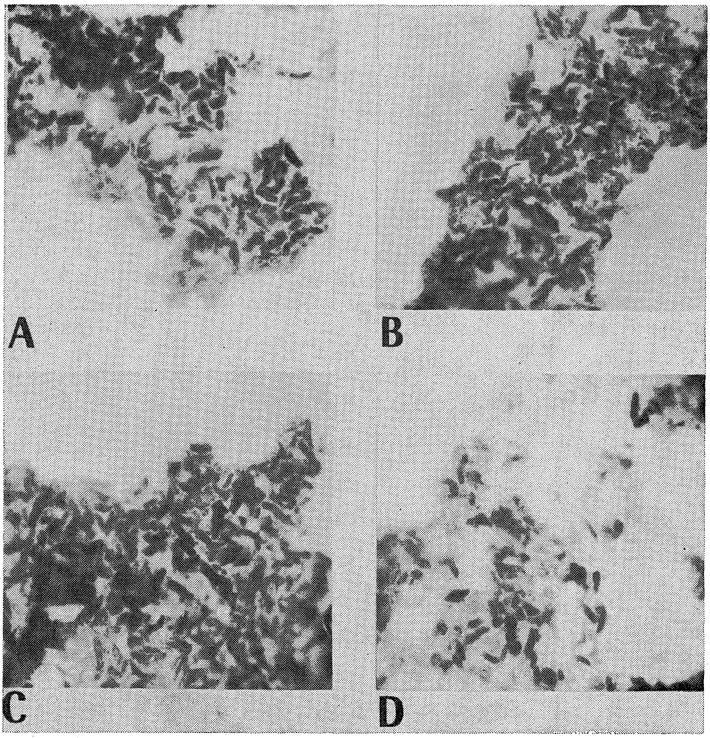

Fig. 2. Structure of cell walls in the crumb of low-ratio cakes as affected by flour composition (magnification 100 ×).

	A	*B*	*C*	*D*
Starch tailings, %	8.9	20.9	14.9	14.9
Prime starch, %	79.6	67.6	80.5	66.7
Gluten + WS, %	11.5	11.5	4.6	18.4

Proportion of the Main Protein Fractions to Prime Starch and Starch Tailings. Only the combined effect of the main protein fractions, gluten and the water-solubles (a concentrate containing 21 to 25% proteins and approximately 11% pentosans), was investigated. As the proportion of gluten and water-solubles increased above normal amounts, the flour doughs became increasingly cohesive and extensible and little separation of the batters occurred upon incorporation of the other cake ingredients. When the combined protein fractions were decreased by 60 to 100%, the doughs were crumbly and the cake batters curdled. The extent of curdling was more pronounced when prime starch, rather than tailings, replaced the gluten and water-solubles. These observations are further evidence of the water-holding and batter-binding capacity of the tailings fraction.

The amount of moisture needed for dough formation varied from 60 to 67%, the amount increasing as the protein content of the flour decreased. This finding was contrary to that expected; it is in agreement with other work in this laboratory, however, in which water-solubles have been observed to reduce the moisture requirement of cake flour as judged by mixograms. Therefore, the differences reported here may have been due to the water-soluble fraction rather than to total protein *per se*.

Differences in the proportion of the main protein fractions to tailings did not affect the specific gravity of the batters significantly. Changes in the proportion of these fractions to prime starch resulted, however, in a highly significant positive correlation, 0.005 level of probability, between batter specific gravity and cake volume. This relationship will be discussed subsequently.

The volume of the baked cakes was affected significantly by the proportion of the protein fractions in relation both to prime starch and to starch tailings. The cake formula was not a significant factor affecting volume, but there was a significant (0.01 probability) interaction between the cake formula and flour composition.

Increasing the level of the protein fractions above normal amounts had only a slight effect on cake volume; whereas decreasing the proportion of these fractions, especially by more than 20%, generally resulted in cakes with a marked reduction in volume and a flat or concave top. (See Tables IV and V, and Fig. 3.)

TABLE IV
EFFECT OF PROPORTION OF GLUTEN AND WATER-SOLUBLES TO PRIME STARCH ON VOLUME OF HIGH- AND LOW-RATIO CAKES[a]

Flour Composition (Series II)				Average Cake Volume	
Protein Fractions		Prime Starch	Total Protein	125% Sugar Formula	100% Sugar Formula
Gluten	Water Solubles				
%	%	%	%	cc.	cc.
0.0	0.0	85.1	0.7	445	531
1.5	0.8	82.8	1.9	434	497
3.0	1.6	80.5	3.1	468	487
4.5	2.4	78.2	4.3	520	600
5.9	3.2	75.9	5.5	702	634
7.4[b]	4.1[b]	73.6[b]	6.7[b]	749	711
8.9	4.9	71.3	7.9	772	744
10.4	5.7	69.0	9.1	763	716
11.9	6.5	66.7	10.3	769	717
Original cake flour			8.1	716	768

[a] Reconstituted flours (14% m.b.) contained 14.9% starch tailings.
[b] Control samples; normal proportions of all components with fraction percentages adjusted to 100%.

TABLE V

EFFECT OF PROPORTION OF GLUTEN AND WATER-SOLUBLES TO STARCH TAILINGS ON VOLUME OF HIGH- AND LOW-RATIO CAKES[a]

Flour Composition (Series III)				Average Cake Volume	
Protein Fractions		Starch Tailings	Total Protein	125% Sugar Formula	100% Sugar Formula
Gluten	Water Solubles				
%	%	%	%	cc.	cc.
0.0	0.0	29.4	0.8	462	427
1.5	0.8	27.1	1.9	471	427
3.0	1.6	24.8	3.0	476	471
4.5	2.4	22.5	4.1	623	543
6.0	3.2	20.2	5.1	722	739
7.5[b]	4.0[b]	18.0[b]	6.2[b]	812	816
9.0	4.7	15.7	7.4	788	833
10.4	5.5	13.4	8.4	809	841
11.9	6.3	11.1	9.5	746	828
13.4	7.1	8.8	10.6	771	828
14.9	7.9	6.6	11.7	771	802
Original cake flour			7.5	785	822

[a] Reconstituted flours (14% m.b.) contained 70.6% prime starch.
[b] Control samples; normal proportions of all components with fraction percentages adjusted to 100%.

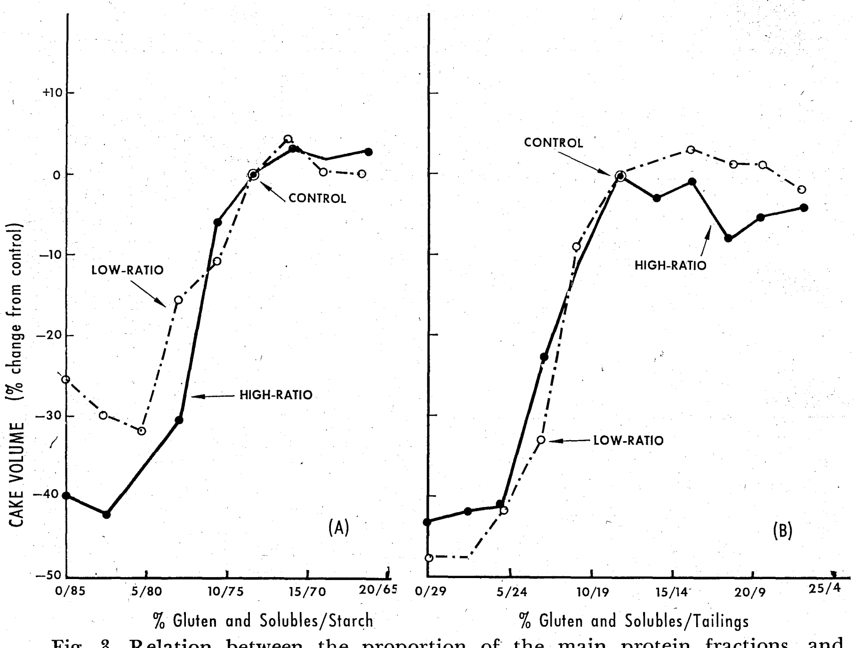

Fig. 3. Relation between the proportion of the main protein fractions, and prime starch or starch tailings, in reconstituted cake flours and the volume of white cakes. (A) Tailings were 14.9% of the flour. The volumes of the control samples were 749 and 711 cc. respectively for the high- and low-ratio cakes. (B) Prime starch was 70.6% of the flour. The volumes of the control samples were 812 and 816 cc. respectively for the high- and low-ratio cakes.

When the main protein fractions were present in decreased amounts, a more marked reduction in cake volume was anticipated in the high-ratio than in the low-ratio cakes, since the higher sugar level places greater stress on the structure-contributing properties of the proteins. The expected decrease in volume was observed in cakes in which prime starch was increased as the main protein fraction was decreased. When the protein fractions were replaced with starch tailings, however, the decrease in cake volume was more marked in the low-ratio cakes. This further indicates an interaction between the sugar-water level and the tailings fraction of flour. The differences can be more clearly observed in Fig. 4, A and B, which illus-

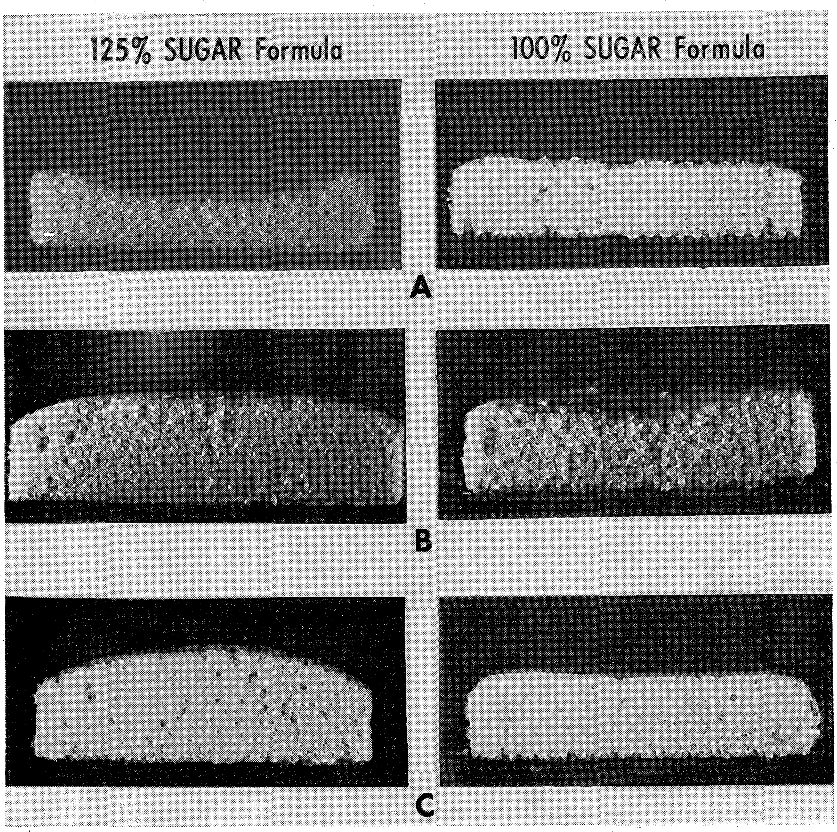

Fig. 4. Cross-sections of white cakes illustrating the interaction between the cake formula and the flour formula. The amount of each flour fraction for which a substitution was made is 40% less than the normal proportion.
A. 4.6 g. protein fractions (G + WS) replaced by prime starch.
B. 4.5 g. protein fractions (G + WS) replaced by starch tailings.
C. 6.0 g. starch tailings replaced by prime starch.

trate cross-sections of cakes containing 40% less than the normal amount of the protein fractions and an increase in the proportion of prime starch or starch tailings.

Volume of baked cakes paralleled the specific gravity of the batter when the ratio of gluten and water-solubles to starch was changed. Batters of relatively high specific gravity, 0.95 to 1.02, and of normal or higher than normal protein content produced cakes of larger volume. A tighter batter network may have existed in the higher protein blends, preventing the inclusion of as much air as might have been incorporated in a looser batter structure where less protein, particularly gluten, was present. The lower protein flour blends gave batter densities of 0.86 to 0.95; but the structural matrix, apparently favoring incorporation of air, was too loose and disorganized to hold the expanding gases during baking, and the cells coalesced. With an increase in protein, the stronger network would tend to retain more of the air during the early stages of baking and gradually set into an organized and stable cellular structure.

The internal quality of the cakes was closely related to volume when the proportion of the protein fractions was less or only slightly higher than normal. The high-ratio cakes prepared from flour blends of from 11.5 to 18.4% (normal to +60%) of the combined protein fractions were moist and fine in texture with small cells, thin cell walls, and a tender crumb. Higher levels of protein, at the expense of tailings, produced cakes of good volume and cell structure, but the crumb was dry. When the combined protein fractions were 11.5 and 13.8% of the flour in low-ratio cakes, the internal structure was of good quality; at higher levels, the crumb tended to be more compact and drier than control samples.

At levels of the protein fractions below 9.2% (−20%) the cake crumb became increasingly coarse with thick cell walls; at the lowest levels the cakes were tough and gummy. If these fractions were omitted or reduced to the lowest level of 2.3% of the flour and replaced by starch, the cakes formed three layers: a thin white dense bottom layer, a gellike middle layer, and a coarse dry top layer. Although cake volume was small and internal crumb poor when tailings replaced the protein fractions at the same levels, layering did not occur.

Plastic-embedded samples stained with fast green appeared to have more numerous and larger densely stained protein networks as the protein content of the flour increased. Very thin and lightly stained protein films, present in all samples, appeared continuous and intermeshed with the more densely stained protein areas. Small and round starch granules, stained with iodine, appeared to be enmeshed within the dense protein areas; elongated starch granules were observed as clumps between the dense areas and within the lightly stained and thin protein meshwork.

In samples containing low concentrations of gluten and water-solubles, the dense protein areas were very infrequent and unevenly distributed in the cell walls; more protein (probably egg protein) was present in thin films and did not appear to form as continuous a network as observed in samples of a higher protein content. As the protein content of the flour decreased, the clumps of associated starch granules appeared larger and more granules were at the periphery of the cell wall (Fig. 2). The main difference between the use of starch and tailings as a replacement for the protein fractions was the presence of many more small starch granules in samples containing a higher than normal proportion of tailings. The greater association of starch granules in samples of low protein content may be attributed to a combination of factors: (a) the simple presence of more starch in the flour; (b) a collapsed cake structure in which the thick cell walls would contain a greater concentration of starch per unit area than thin cell walls; and (c) insufficient material to cross-bond with starch to minimize mutual starch-starch bonding or to physically surround starch granules and thereby minimize their association.

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