Function of the Starch Granule in the Formation of Layer Cake Structure

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ABSTRACT

A layer cake batter formulation in which granular starch is substituted entirely for cake flour has been used to demonstrate the essentiality of intact granular starch in the thermal-setting process of cake baking. However, for the necessary stability of batter emulsion during the early stages of baking, it is also essential that other types of functional ingredients be present: 1) polyvalent cations, 2) soluble proteins, and 3) surface-active lipids. Results are presented to show the effects of various types of granular starch as well as isolated amylose and amylopectin fractions, soluble and insoluble proteins, surface-active lipids, and polyvalent metal ions, on the baking performance of starch cakes.

In numerous publications the importance of the starch granule in bread and in starch pastes and gels is emphasized (1–13). It is generally agreed that the cohesiveness necessary to form a typical bread structure or a firm starch gel is largely dependent on the *intact* swollen granules still remaining after the baking or cooking process. The more recent work of Bushuk (14), for example, describes the essentiality of the granular starch in bringing about the proper water balance and relocation in bread; water initially associated with protein in the dough stage becomes associated with gelatinized starch by the end of baking.

The role of the starch granule in layer cakes, however, has not been studied so extensively. Some workers (15,16) have indicated a greater importance of protein over that of starch in the formation of the matrix constituting the structure of layer cakes.

Miller and Trimbo (17) recently described a method of evaluating cake flour in which the effects of changes in batter formulation and the addition of various types of starch and chemical additives on the gelation properties of starch in white layer cakes can be determined. Furthermore, it was found in this work that conditions which changed the gelatinization temperature of starch granules could be used to overcome certain deficiencies in cake flour performance.

Recent patents upon which this report is based (18,19) describe the use of granular starch as a total replacement for flour in layer cakes, provided additional ingredients were present to control the gravitational stability of the fluid batter in the early stages of baking. Of particular interest was the effect of water-soluble, polyvalent metal ion salts on the *early* stability of the fluid batter. The results reported in this paper support the thesis that the swollen, intact starch granule is the essential element in the thermal-setting stage of layer cake baking.

MATERIALS AND METHODS

Materials

The types of materials used and the sources of each are as follows: propylene glycol monostearate (50/50 mono/diester), Drew Chemical Co.;

stearic acid, Eastman Kodak Co.; wheat starch, Aytex, General Mills, Inc.; corn starch, A. E. Staley Mfg. Co.; potato, arrowroot, and rice starches, Matheson Scientific Co.; pineapple starch, Pineapple Research Institute, Honolulu, Hawaii; waxy-rice starch, Rice Products Co.; amylose and amylopectin (from corn starch), A. E. Staley Mfg. Co.

Cake Batter Formulations

One of the basic starch cake formulas used in this work was a low-ratio (low-sugar) formula in which the proteinaceous component was limited to one source (Table I, left). This was routinely prepared as a dry mix to which single proteinaceous materials were added either as dry ingredients or as dispersions in the 177 ml. water used to make up the batters. The low-sugar batters were mixed in a single stage, scaled into 8-in. round pans at a weight of 440 g. (from a total of 465 g.), and baked at 365°F. for 25 min.

TABLE I
WHITE STARCH CAKE FORMULAS

Low-Ratio (Protein-Free)			High-Ratio		
Ingredients	Batter Composition		Ingredients	Batter Composition	
	%	weight, g.		%	weight, g.
Granular starch[a]	26.00	121.00	Granular starch[a]	19.93	95.0
Powdered sugar	26.20	122.00	Granulated sugar	27.89	133.0
Fluid shortening[b]	7.20	33.00	Fluid shortening[c]	9.96	47.5
Baking powder[d]	1.65	7.70	Baking powder[e]	1.43	6.8
Salt	0.54	2.50	Salt	0.52	2.5
Dextrose	0.41	1.90	Whole milk	27.27	130.0
Water	38.00	177.00	Fresh egg whites	12.58	60.0
			Vanilla extract	0.42	2.0
	100.00	465.10		100.00	476.8

[a] 10% moisture basis.

[b] Cottonseed oil containing 14% propylene glycol monostearate (50/50 mono-/diester) + 2.0% stearic acid.

[c] Same as for low-ratio, except for stearic acid which was 0.5%.

[d] A mixture of anhydrous monocalcium phosphate, sodium acid pyrophosphate, and soda.

[e] Double-acting; contained sodium aluminum sulfate as one of leavening acids.

In addition, a high-ratio starch cake formula was used which contained only whole milk and fresh egg white as the sources of proteins (Table I, right). This batter was also mixed in a single stage and 400 g. of batter (from a total of 477 g.) was scaled into 8-in. round pans and baked at 365° F. for 25 min. Cake volumes were determined from measurements of center and edge heights after the cake had cooled for 20 min.

Shortenings

The fluid shortening used in the low-ratio formula consisted of 14% propylene glycol monostearate + 2.0% stearic acid in cottonseed oil. For high-ratio starch cakes the fluid shortening contained 14% propylene glycol monostearate + 0.5% stearic acid. The use of these shortenings made it possible to begin with well-aerated batters in all baking experiments.

RESULTS

Essential Ingredients in the Starch Cake Formula

It was observed very early in the development of the starch cake formula that certain types of ingredients were necessary for proper batter stabilization during the early stages of baking and before gelatinization of the starch. These ingredients were polyvalent cations, soluble foamable proteins, and surface-active lipids. Examples in the low-ratio starch cake formula to demonstrate the importance of each of these classes of materials are discussed in the following sections.

Polyvalent Cations. The usual sources of polyvalent metal ions in layer cake formulas are flour, egg, milk, leavening ingredients, and any other added salts. The low-ratio starch cake batter was used to demonstrate the important role of polyvalent, water-soluble salts, such as calcium chloride, on the stability of the fluid batter in the early stages of baking. Figure 1 and Table II show a comparison of in-oven baking performance between batters containing added calcium ions and without calcium ions. (In each case, the only source of protein was egg white.)

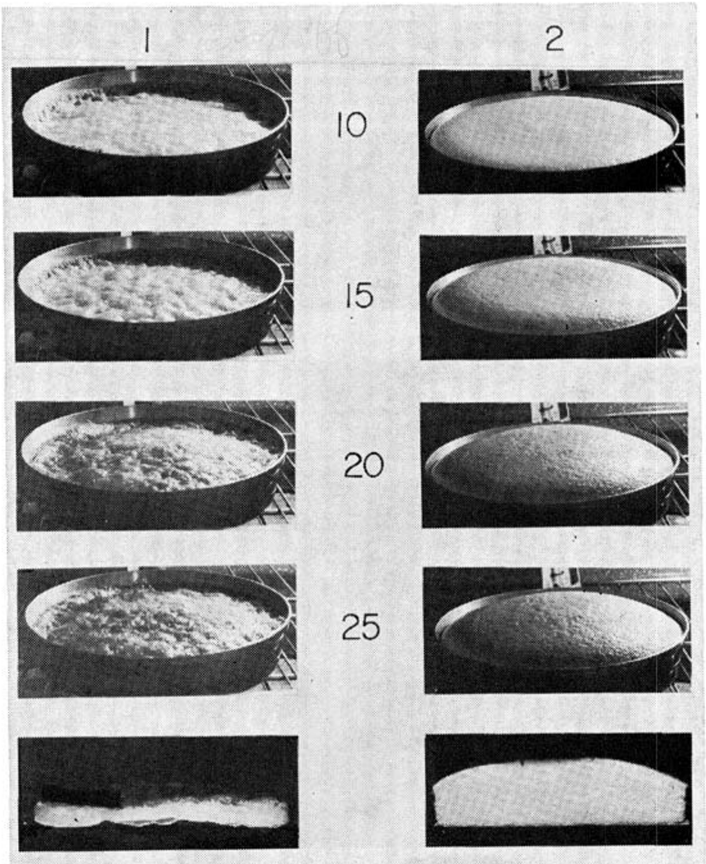

Fig. 1. In-oven photographs of low-ratio white starch cakes; center, baking times in oven (min.). Egg white was the source of protein. Left, control, no added calcium ions; right, with 285 mg. calcium chloride/440 g. batter.

TABLE II

EFFECT OF CALCIUM IONS ON STABILITY OF LOW-RATIO WHITE STARCH CAKE BATTERS[a]

VARIABLE	BATTER DENSITY	BATTER	HOT/COLD VOLUMES
	g./ml.	*pH*	*cc./440 g.*
Without Ca^{++} (control)	0.71	7.19	<800 (failure)
285 mg. $CaCl_2$/440 g. batter	0.75	7.14	1,435/1,385

[a] Shortening: 14% propylene glycol monostearate (50/50 mono-/diester) + 2.0% stearic acid in cottonseed oil. Protein source: egg-white solids (2.75 g./440 g. batter).

In the absence of added calcium ions the batters were unstable, and this resulted in rapid separation of the shortening and aqueous phases along with loss of leavening gas as evidenced by the formation and rupture of very large (0.5–1.0 in. in diameter) gas bubbles. A level of 285 mg. of calcium chloride in 440 g. of batter was sufficient to stabilize the batter early in baking and produced typical cake structure. There was no significant change in batter pH from addition of the calcium salt.

In the discussion which follows, references to baking performance will in all cases be about metal ion-stabilized batters, the source of metal ions being either calcium chloride added to the other batter ingredients or sodium aluminum sulfate contained in the leavening.

Soluble Proteins. It was also found very early in this study that the thermal stability of the foam structure in starch cake batters was very dependent on protein[1] and, more specifically, on unhydrolyzed or only slightly hydrolyzed proteins of high water solubility and/or dispersibility. Proteins severely hydrolyzed to peptides (e.g., some commercial whipping aids) were not effective in stabilizing starch cake batters containing polyvalent metal ions. Cross-sections of cakes in Fig. 2 show the cake structures formed when proteins from milk, egg white, and flour water-solubles were used as single protein sources in wheat starch cake batters stabilized with calcium

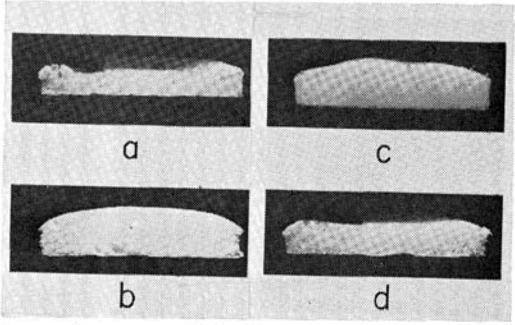

Fig. 2. Baking performance of single protein sources in low-ratio starch cakes: a, no protein; b, nonfat dry milk (7.20 g./440 g. batter); c, egg-white solids (2.75 g./440 g.); d, cake flour water-solubles (3.60 g./440 g.). These proteins were added at a level often found in low-ratio white layer cakes.

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[1] The use of the word "proteins" in this paper refers to complex mixtures consisting mainly of proteinaceous matter with smaller amounts of carbohydrates and lipid components normally found in natural sources of proteins.

ions. These proteins were used at the levels normally found in cake batters. It is evident that the foaming properties of proteins are very important in stabilization of fluid batter in the early stages of baking.

Surface-Active Lipids. Surface-active lipids used as emulsifiers in layer cake are generally added to the shortening. The importance and function of alpha-tending additives, such as mixtures of propylene glycol monostearate and stearic acid, in the air-incorporation stage of batter preparation has been described previously (20,21). Surface-active lipids which form a stable alpha-crystalline phase formed a strong, plasticlike membrane at the shortening-water interface, which prevented the oil from inhibiting the foaming properties of the soluble proteins during mixing of batter. In this way very well aerated batters could be obtained; hence, the surface-active lipids were *indirectly* acting as enhancers of air incorporation. The results (Table III) show the importance of the surface-active lipid in the formation of acceptable cake size and structure.

TABLE III

EFFECT OF SURFACE-ACTIVE LIPIDS ON BAKING PERFORMANCE OF LOW-RATIO WHITE STARCH CAKES[a]

SHORTENING COMPOSITION	BATTER DENSITY	HOT/COLD VOLUMES
	g./ml.	*cc./440 g.*
Cottonseed oil (control)	1.00	1,075/1,035
14% PGMS[b] + 2% (oil basis) stearic acid in cottonseed oil	0.77	1,460/1,405

[a] Protein source: egg-white solids (2.75 g./440 g. batter) + nonfat dry milk (7.2 g./440 g. batter).

[b] Propylene glycol monostearate (50/50 monodiester).

Evaluation of Granular Starch and Isolated Starch Fractions

Evaluation of Various Types of Granular Starch. A number of different samples of unmodified granular starch were compared in high-sugar batters which contained proteins from whole milk and fresh egg white. The variations in performance which were observed are shown in Fig. 3. It was concluded that the variation in performance was due to the gelatinization properties of the various starch samples. A comparison of the average particle size, gelatinization temperature, and ratio of amylopectin:amylose in Table IV shows only a partial correlation of gelatinization temperature with thermal-setting properties.

TABLE IV

PROPERTIES OF GRANULAR STARCH FROM VARIOUS SOURCES[a]

SOURCE	AVERAGE PARTICLE SIZE	GELATINIZATION TEMPERATURE	AMYLOSE
	μ	°C., *in water*	%
Wheat	20 (5, 25)	52–63	25
Corn	15	62–72	24
Potato	33 (15–100)	56–66	22
Rice	5	61–78	17
Arrowroot	36	72–79	25
Waxy rice	6	....	2
Pineapple	5	85–90	~25

[a] See refs. 22, 23, 24.

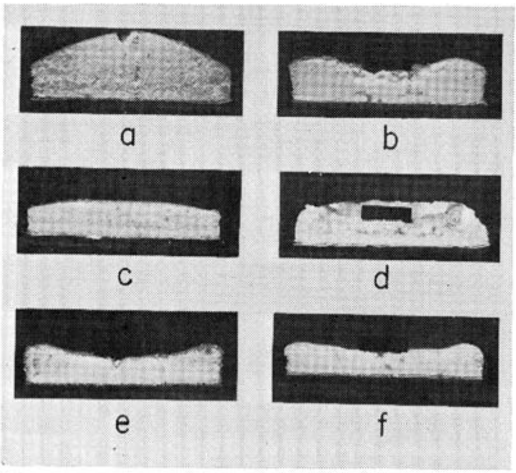


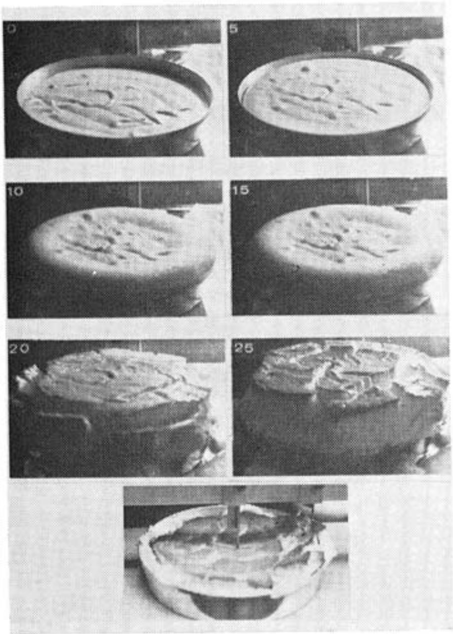
Fig. 3. Baking performance of different types of granular starch in high-ratio white cakes. Shortening composition: 14% propylene glycol monostearate + 0.5% stearic acid in cottonseed oil. a, Wheat; b, corn; c, potato; d, rice; e, arrowroot; f, waxy rice.

The extremes in performance were shown by the potato starch cake, which set very early to yield a cake of low volume because of early gelatinization, and the rice starch cake which never reached the point of a "set" structure within the standard baking time of 25 min. In-oven pictures taken of the rice starch-containing batter are shown in Fig. 4. Microscopic examination of the rice starch cake structure revealed that more than 90% of the starch granules were only slightly swollen and were still strongly birefringent in contrast to wheat starch granules, which appeared fully gelatinized. Pineapple starch, which has a gelatinization temperature of 85°–90°C. (22), behaved in a manner similar to that of the rice starch.

Mixtures of granular wheat and rice starches produced cakes which were better in over-all baking performance than cakes from either of the two starches alone. Cross-section views of cakes from a 60/40 wheat/rice starch mixture and from wheat starch and rice starch alone are shown in Fig. 5.

Effect of Amylopectin and Amylose Fractions in High-Ratio White Cakes. The isolated starch polymers, amylopectin- and amylose-rich fractions, were used alone and combined in mixtures as total substitutes for granular starch. Because of the high water-absorption capacity of the starch fractions, these batters were almost doughlike and had to be scraped into the baking pans. Some expansion occurred during baking, but on cooling, the cake structure in each case collapsed to produce the "starch gels" shown in Fig. 6.

The necessity of having some threshold level of granular starch in the cake batter system is shown by the results in Table V and cake pictures in Fig. 7. In this series 25 g. of an 80/20 amylopectin/amylose mixture was used with 0, 25, and 50 g. of granular wheat starch. These are compared to cakes containing 50 and 95 g. (only) respectively of granular wheat starch; there was *no* added amylopectin and amylose in these last two cakes.



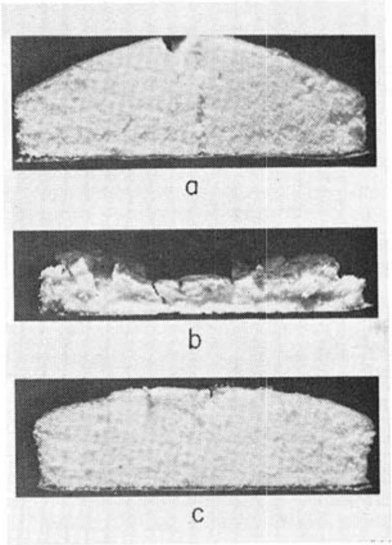


Fig. 4 (left). Baking performance of high-ratio white cake containing rice starch. Time in min. is indicated in each frame; last frame shows collapsed appearance of cake after 20 min. of cooling.

Fig. 5 (right). Comparison of: a, wheat starch; b, rice starch; and c, a 60/40 wheat/rice starch mixture in high-ratio white starch cake.

TABLE V

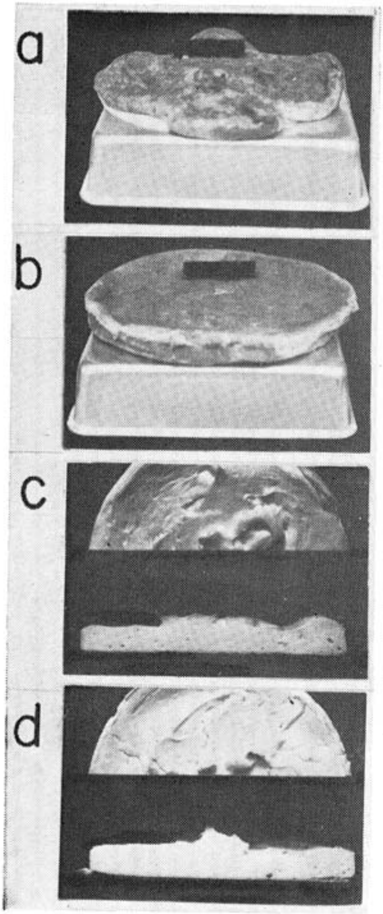
BAKING RESULTS FROM BATTERS CONTAINING 25 g. OF AN 80/20 AMYLOPECTIN/AMYLOSE MIXTURE AND VARIOUS AMOUNTS OF GRANULAR WHEAT STARCH

WEIGHT OF GRANULAR WHEAT STARCH	HOT/COLD VOLUME	Δ VOLUME (LOSS IN COOLING)
g.	*cc./440 g.*	*cc.*
0	1,210/< 800	> 400
25	1,940/< 800	> 1,100
50	1,980/1,305	675
50 (only)[a]	1,800/1,570	230
95 (only)[a]	1,820/1,765	55

[a] Granular wheat starch used only. The amylopectin/amylose mixture was not used in these two examples.

Of particular interest was the "mushroom" effect produced by the nongelling tendency of the amylopectin/amylose mixture in the absence of any granular starch. The cake batter containing 25 g. of granular starch added to 25 g. of the amylopectin/amylose mixture remained within the baking pan, although there was still a complete collapse of the structure owing to shrinkage during the cooling period.

When 50 g. of granular starch was added to the amylopectin/amylose mixture, the behavior of the cake batter in the oven was fairly typical but there was excessive shrinkage on cooling. When 50 or 95 g. of wheat starch



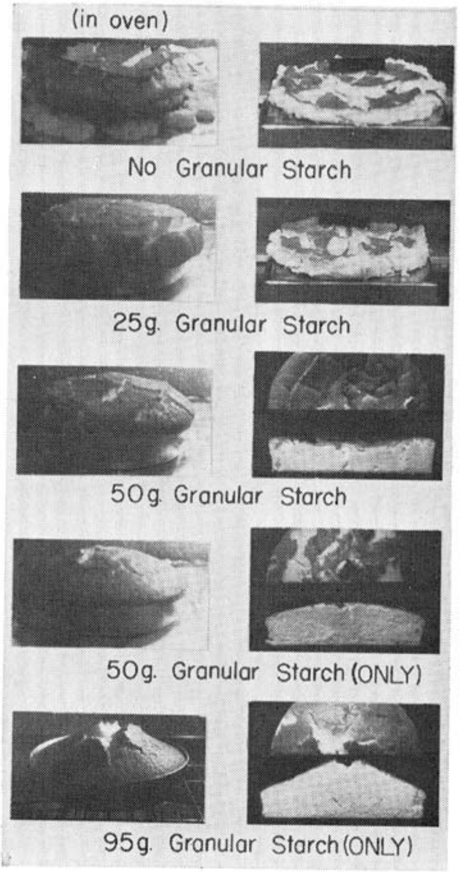


Fig. 6 (left). Baking performance of high-ratio white cake batters containing 95 g. isolated starch fractions instead of 95 g. granular starch: a, 100% amylopectin; b, 80/20 amylopectin/amylose; c, 20/80 amylopectin/amylose; d, 100% amylose.

Fig. 7 (right). Appearance of high-ratio cakes containing 25 g. of an 80/20 amylopectin/amylose mixture and various amounts of granular wheat starch. Left, appearance of cake in oven at end of 25-min. baking period; right, appearance of cake after cooling. The last two examples contained granular starch only; the amylopectin/ amylose mixture was not added.

was used *in the absence* of the amylopectin/amylose mixture, the batter behavior and cake structure were normal. The use of 95 g. of wheat starch without addition of the amylopectin/amylose mixture resulted in very rapid formation of a "set" structure with low edge height and bold crust contour. The last two examples can be considered as a demonstration of the control of starch gelatinization temperature by changing the granular starch:water ratio.

These baking results clearly indicate that some threshold amount of normal or unmodified granular starch is required to form a typical cake structure.

DISCUSSION

The mechanism of layer cake baking consists of at least three important stages: 1) initial aeration of batter, 2) thermal stability of fluid batter, and 3) thermal setting of batter to form a rigid and porous expanded structure at the end of the baking cycle.

Aeration of Batter during Mixing

Soluble proteins were found essential for well-aerated batters made with a fluid shortening containing surface-active lipids and alpha-tending emulsifiers. The role of granular starch was thought not to be of prime importance in aeration of batter, although it served to increase the viscosity of the batter.

Thermal Stability of Fluid Batter

Polyvalent metal ions and the acidic lipid (i.e., stearic acid) in the surface-active lipid mixture were most important during the early stages of baking. In the types of experimental systems used, it was found that both calcium or aluminum ions and stearic acid were necessary for complete batter stabilization before the thermal setting stage. It is believed that the interaction of polyvalent metal ions with the acidic lipid resulted in stabilization of the various interfaces present in the fluid batter.

Granular starch is also considered important during the early heating of fluid batter in the oven. The rate of swelling of the granule, which is accompanied by some water absorption, affects the viscosity of the fluid batter and thus increases the emulsion stability of the batter, as described previously (17).

Thermal Setting of Batter

One of the important steps in baking is the thermal-setting stage, at which time the batter changes from a fluid, aerated emulsion to a solid, porous structure which will not shrink appreciably or collapse when the cake is removed from the oven. For this to occur it appears that there has to be an absorption of the "free" water present in the system. It is at this point that the water-absorption properties of the starch granule control the final physical properties of the baked cake.

A number of ingredients can act as competitors with starch for the absorption of water, namely: proteins from egg, milk, and flour; sugar, and thickening agents. Although all of these materials are important for the proper water balance, unless there is a minimum amount of granular starch, providing sufficient water-absorption capacity under the baking conditions used, the typical final cake structure will not be attained. The extent of water absorption of the starch granules has to be great enough to change the aqueous fluid phase into a solid porous network or spongelike structure.

The ingredients or materials found essential for successful baking of starch layer cakes were: 1) polyvalent cations, 2) soluble proteins, 3) surface-active lipids, and 4) granular starch with the proper gelation properties.

Acknowledgments

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