Model Studies of Cake Baking. I. Continuous Observations of Starch Gelatinization and Protein Coagulation during Baking

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ABSTRACT

Model baking equipment is described for continuously observing starch gelatinization and protein coagulation in sponge cake batters during baking. Starch gelatinized between 79 and 88°C and egg protein coagulated between 82 and 96°C. Light transmission, viscosity, and microscopic changes took place at the same temperature and were interpreted as coinciding with starch gelatinization and protein coagulation.

An exact knowledge of the transitions that occur during cake baking is necessary to interpret the chemistry of the system. Despite the important role of heat setting (especially starch gelatinization) that many authors have emphasized (Derby et al 1975, Howard et al 1968, Kulp et al 1972, Lowe 1955, Miller and Trimbo 1965, Schoch 1965, Shepherd and Yoell 1976), data on continuous observation of both starch gelatinization and protein coagulation in the baking stage are meager. The lack of equipment to study the baking stage and the complexity of cake batters containing many ingredients, such as wheat flour, sugar, egg, fat, leavening agents, salt, nonfat dry milk solids, and water, has made it difficult to clarify the mechanism of the heat setting process during baking.

Miller and Trimbo (1965) studied the correlation between cake quality and structural development and found it to coincide with starch gelatinization at temperatures ranging from 30 to 96°C as measured in the farinograph. Shepherd and Yoell (1976) proposed a bricks and mortar structure for cake, in which starch granules are building blocks held together by strands of egg protein.

In this study, a model baking system was devised, and the dynamic processes of starch gelatinization and egg protein coagulation in a sponge cake batter were followed.

MATERIALS AND METHODS

The cake flour used in this study was Violet, made by Nisshin Flour Milling Co., Ltd. Sugar was obtained from Dai-Nippon Sugar Manufacturing Co., Ltd. Fresh shell egg was used. A foaming agent consisting of a mixture of 10 g of sucrose fatty acid esters, 10 g of glycerine fatty acid esters, 5 g of sorbitan fatty acid esters, 5 g of propylene glycol, 2.5 g of ethanol, 29 g of sorbitol, and 38.5 g of water was prepared.

A prime starch fraction was made from the cake flour by the method of Sollars (1954, Bean and Yamazaki 1974). Table I lists the analytical data for the cake flour and prime starch.

Preparation of Sponge Cake Batter

The composition of the cake batter is given in Table II. After sugar, whole egg, foaming agent, and water were mixed for 1 min at 150 rpm, cake flour was added and mixed for 3 min at 150 rpm and then whipped for 3 min at 360 rpm with a commercial cake mixer (CS-10, Kanto Kongoki Industrial Co., Ltd.). When light transmission and apparent viscosity were measured, these materials were mixed for 2 min at 150 rpm, and the whipping stage was omitted to avoid a bubble effect in the cake batter. Sponge cake batter (500 g) was weighed into 18-cm round pans and baked at 170°C for 40 min in an electric oven.

Temperature Measurement During Baking

The temperatures at six points in the cake batter were continuously recorded during baking in an electric oven by the use of thermistors connected to a recorder (TER-36 Takara Thermistor Instrument Co., Ltd.).

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Model Baking Equipment

Model baking equipment, devised to maintain temperatures approximately the same as at the center of the cake during baking, is shown schematically in Fig. 1. Temperature control of the bath for apparent viscosity measurements and the microscope heating stage was accomplished with a circulator (Themo-Uni, Mitamura Riken Kogyo Inc.). This controlled the heater's capacity and water volume of the supply tank. Batter samples were placed between two cover glasses (sealed with vacuum grease) and placed in the sample chamber of a glass microscope heating stage. Light transmission was measured with a phototransistor in a bridge circuit made in our laboratory. These data were recorded continuously with a pen recorder (VP-6531A, Matsushita Communication Industrial Co., Ltd.). OS-18 phototransistors (Tokyo Shibaura Electric Co., Ltd.) and 6 V, 30 W lamps were used. To take photomicrographs of the bake batters under polarized light, a polarizer and an analyzer (Nippon Kogaku K. K.) were placed on opposite sides of the microscope heating stage. Photographs were made on Tri-X film (Eastman Kodak Company) using a 20-sec exposure time through a microscope (SMZ, Nippon Kogaku K.K.) with camera (EFMB, Nippon Kogaku K.K.). Densities of film negatives were measured with the phototransistor bridge circuit and pen recorder. Apparent viscosities were measured with a viscometer (Type B, Tokyo Precision Instrument Co., Ltd.) using a No. 4 rotor at 6 rpm. Batter samples (12 g) for apparent viscosity measurements were placed in a 20-ml graduated cylinder and were kept in the bath during measurement. Temperatures of the supply tank, viscosity bath and sample, microscope heating stage sample chamber (ie, batter for the light transmission measurement), and microscope heating stage were continuously recorded with the temperature recorder. Light transmission and apparent viscosity measurements were duplicated for each sample.

TABLE I
Analytical Data of Cake Flour and Prime Starch

Material	Protein (%)	Lipid (%)	Ash (%)	Moisture (%)
Cake flour	7.20[a]	0.93[a]	0.33[a]	13.8
Prime starch	0.21[b]	0.09[b]	0.13[b]	14.0

[a]13.8% moisture basis.
[b]14.0% moisture basis.

TABLE II
Formulation of Cake Batter

Ingredient	Weight (g)
Cake flour	400
Sugar	480
Whole egg	600
Foaming agent	20
Water	80

TABLE III
Compositions of Simple Model Systems for a Cake Batter

	System							
Ingredient	**F-S-FA-W**	**F-W**	**WE-S-FA-W**	**WE-S-W**	**WE**	**PS-S-FA-W**	**PS-S-W**	**PS-W**
Cake flour (F)	100	100						
Sugar (S)	120		120	120		190	190	
Whole egg (WE)			150	150	150			
Foaming agent (FA)	5		5			8		
Water (W)	40	151	40	40		240	240	240
Prime starch (PS)						100	100	100

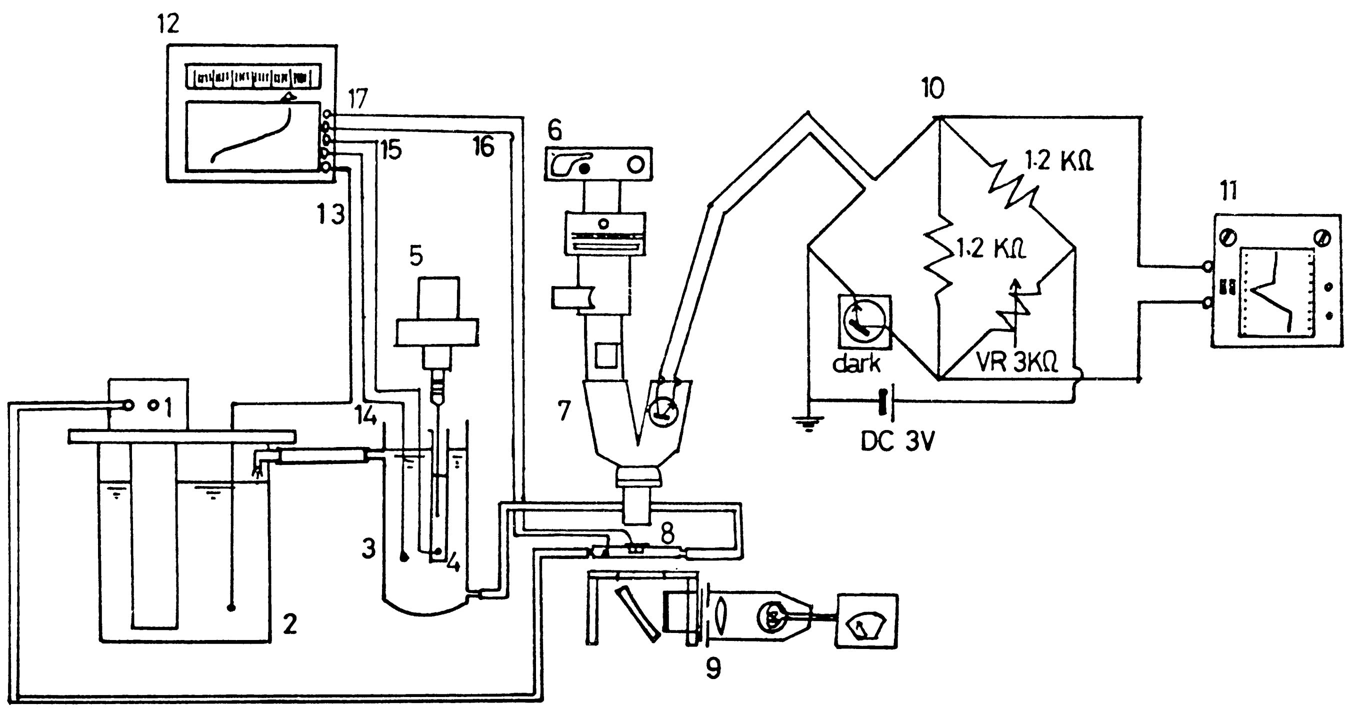

Fig. 1. Schematic diagram of model baking equipment. 1, Circulator; 2, supply tank; 3, bath for viscosity measurement; 4, graduated cylinder; 5, B type viscometer; 6, microscope camera; 7, microscope; 8, microscope heating stage; 9, lamp; 10, phototransistor bridge circuit; 11, pen recorder; 12, temperature recorder; 13–17, thermistor.

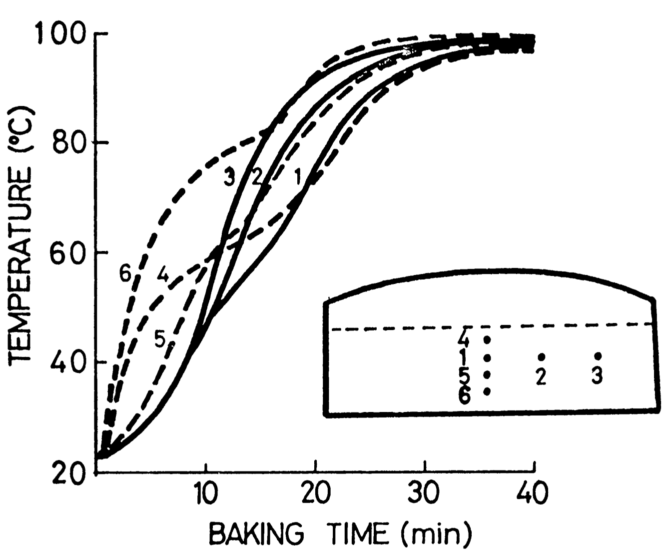

Fig. 2. Temperature profile of a sponge cake during baking.

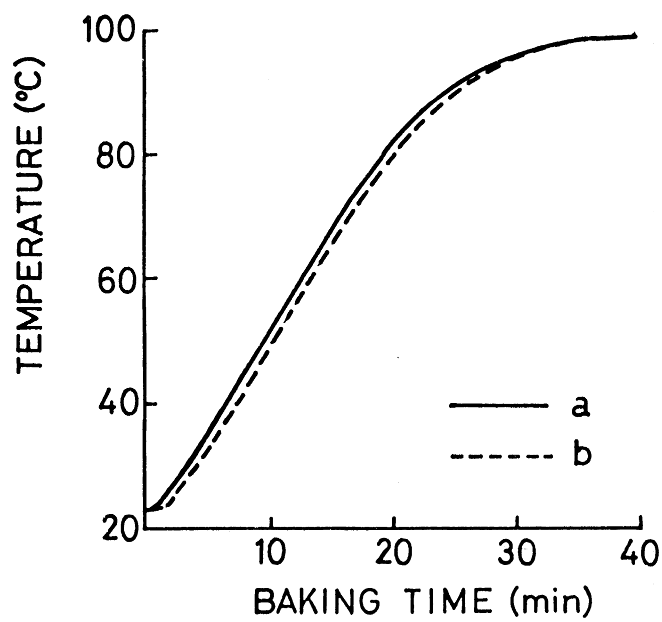

Fig. 3. Temperature profile of the baking model. Temperature of cake batter for measurement of: **a**, light transmission and **b**, apparent viscosity.

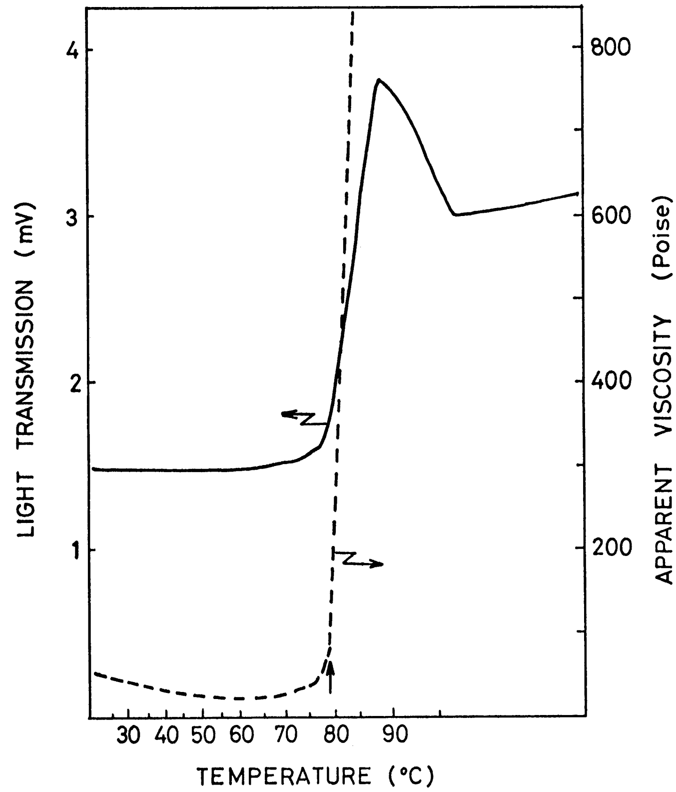

Fig. 4. Light transmission and apparent viscosity of the cake batter during model baking.

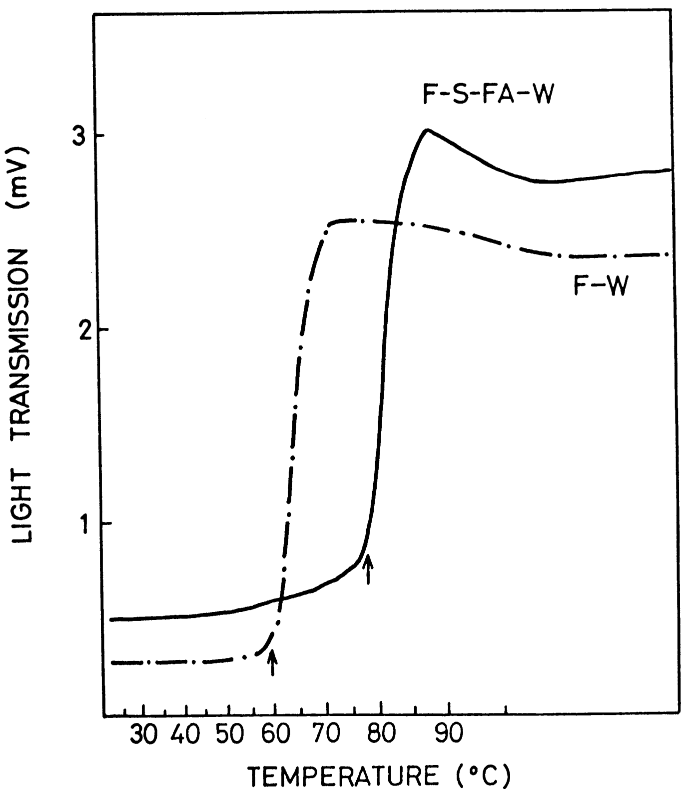

Fig. 5. Light transmission of flour-water system (F-W) and flour-sugar-foaming agent-water system (F-S-FA-W). Arrows show points at which apparent viscosities began to rise abruptly.

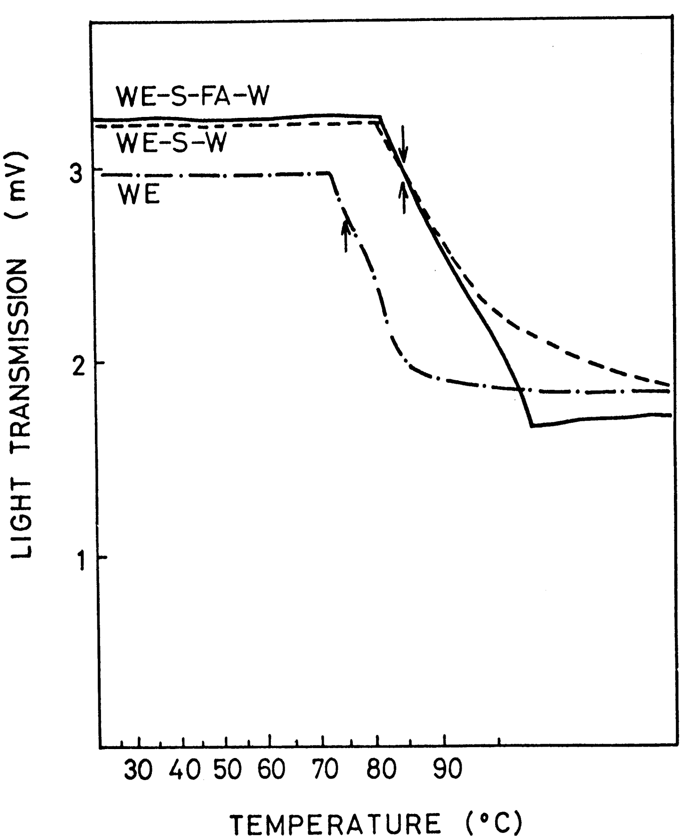

Fig. 6. Light transmission of whole egg system (WE), whole egg-sugar-water system (WE-S-W), and whole egg-sugar-foaming agent-water system (WE-S-FA-W). Arrows show points at which apparent viscosities began to rise abruptly.

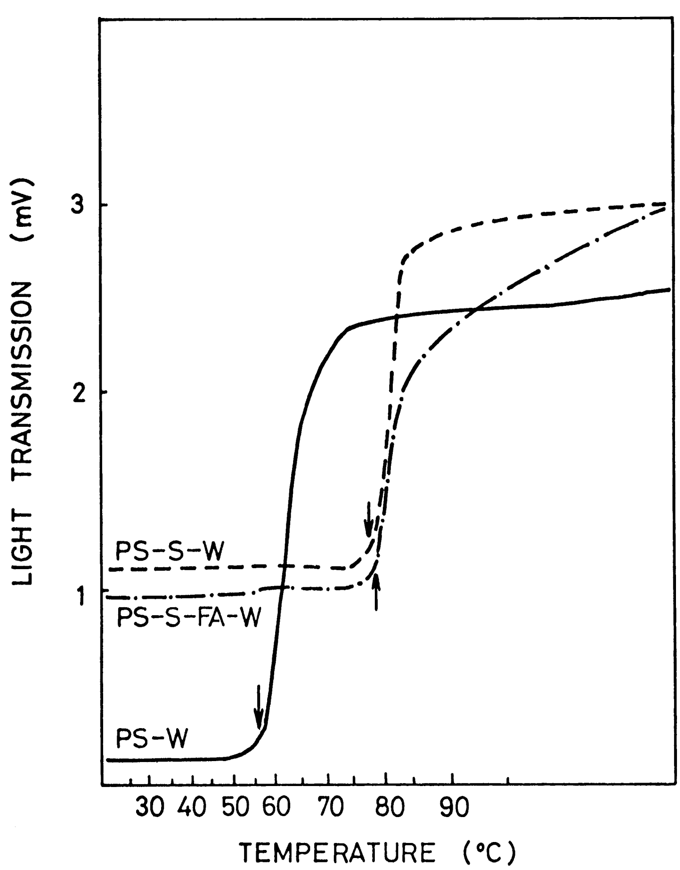

Fig. 7. Light transmission of prime starch-water system (PS-W), prime starch-sugar-water system (PS-S-W), and prime starch-sugar-foaming agent-water system (PS-S-FA-W). Arrows show points at which apparent viscosities began to rise abruptly.

Preparation for Measurement of Light Transmission and Viscosity

To investigate the effects of cake ingredients on light transmission, viscosity, and microscopic observation, the following model formulations were prepared: Flour-sugar-foaming agent-water, flour-water, whole egg-sugar-foaming agent-water, whole egg-sugar-water, whole egg, prime starch-sugar-foaming agent-water, prime starch-sugar-water, and prime starch-water systems (Table III). Each system was prepared by mixing the ingredients for 2 min at 150 rpm with the cake mixer. Light transmission and viscosity were measured by the same methods employed for cake batters.

RESULTS AND DISCUSSION

Temperature Profiles of Sponge Cake During Baking

Temperature changes at different locations in a sponge cake during baking are shown in Fig. 2, where observed temperatures are plotted against baking time. The temperature increase was most gradual at the center of the cake, and internal temperatures of the cake did not exceed the boiling temperature of water. These results are in good agreement with those obtained by Miller and Derby (1964).

Temperature Curve

The temperature profile of cake batter during baking is shown in Fig. 3. The temperature of the batter increased almost linearly with increasing baking time in the early and middle stages of the baking. After 25 min, the temperature was about 90°C, and increased gradually to 98°C after 35 min with no further change in temperature up to 40 min, the end of the baking period. We believe that temperatures of the model baking agree well with temperatures near the center in actual baking experiments.

Light Transmission and Apparent Viscosity

Results of light transmission and apparent viscosity for sponge cake batters plotted against temperature during model baking are presented in Fig. 4. The light transmission did not change until around 70°C. Above this temperature, there was a slight increase in light transmission, followed by an almost linear increase within the range from 79 to 88°C. At the final baking stage, inflection points were observed at 88 and 96°C. Light transmission decreased in the region between these two points, and increased slightly between 96°C and the end point. To determine the reason for these effects, we conducted the following experiments.

The effects of the flour and the whole egg in the model formulations are shown in Figs. 5 and 6. It was apparent that the flour component in a complete batter was a main factor in increases in light transmission and apparent viscosity around 79°C. To confirm that the wheat starch in the cake flour is responsible for increases in light transmission and apparent viscosity at 79°C, light transmission and apparent viscosity of a prime starch during baking were measured (Fig. 7). In the simple prime starch-water system, light transmission and apparent viscosity increased abruptly at 57°C,

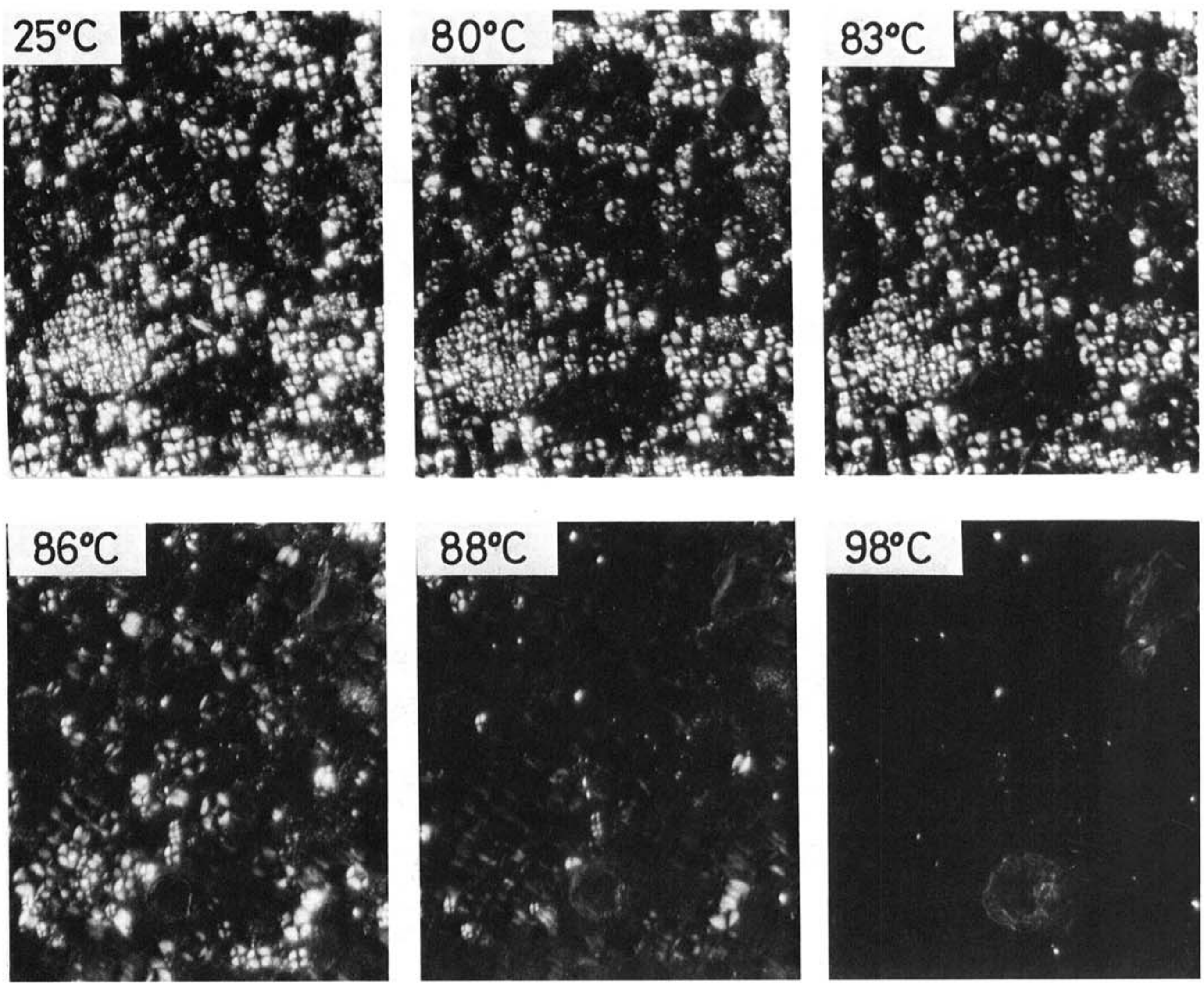

Fig. 8. Photomicrographs of starch granules taken from cake batter during model baking photographed under polarized light.

the same as with a cake flour-water system. Moreover, Fig. 7 shows the initial gelatinization temperature of the prime starch is 78°C in systems of prime starch-sugar-water and prime starch-sugar-foaming agent-water. These gelatinization temperatures were almost the same as gelatinization temperatures of the cake flour-sugar-water and the cake flour-sugar-foaming agent-water systems. Wheat proteins and other components of wheat flour did not affect the gelatinization temperature of the wheat starch. Retardation of starch gelatinization by addition of sugar has been reported by others (Bean and Yamazaki 1974, Miller and Trimbo 1965).

A noticeable decrease of light transmission above 88°C in the cake flour-water and cake flour-sugar-foaming agent-water systems was attributed to the denaturation of the flour protein, but this was not confirmed.

In the whole egg-sugar-foaming agent-water system, coagulation of the whole egg took place from 82 to 96°C (Fig. 6). The foaming agent had almost no effect on coagulation temperature of the whole egg; however, sugar delayed the coagulation temperature of the whole egg in the cake batter from 74 to 82°C.

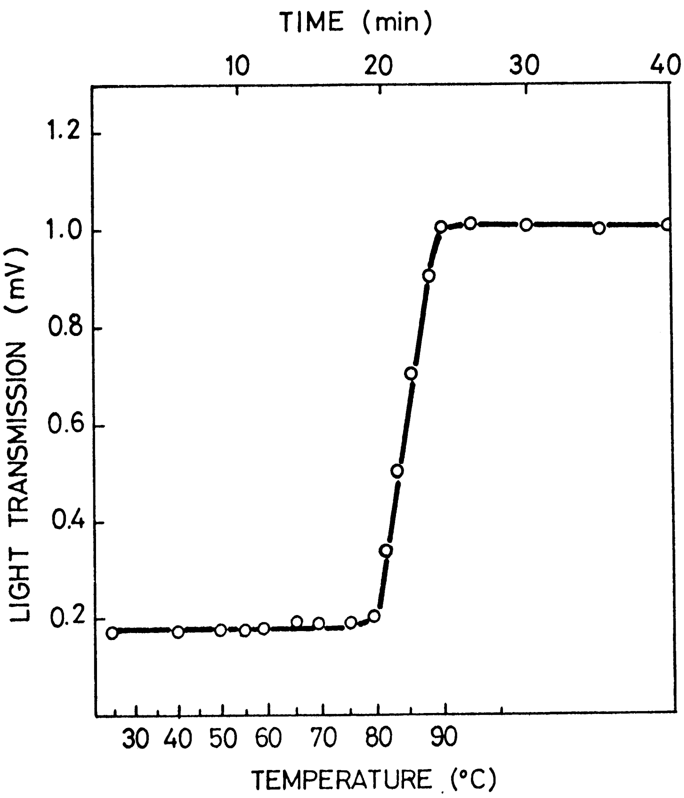

Fig. 9. Loss of birefringence of starch granules in cake batter during model baking.

The light transmission curve of the cake batter was estimated to be a composite of the transmission curves of the cake flour-sugar-foaming agent-water system and the whole egg-sugar-foaming agent-water system. The temperature at which light transmission in the cake batter decreased was 88°C, but it was 82°C in the whole egg-sugar-foaming agent-water system. This difference between two temperatures can be due to inability to detect the egg protein coagulation that occurred simultaneously with the starch gelatinization in the 82–88°C range. Thus the light transmission decrease caused by the egg protein was masked by the light transmission increase caused by starch gelatinization. Therefore, we presumed that the egg protein coagulation started at about 82°C in the cake batter.

Microscopic Observation on Starch Gelatinization

The loss of birefringence under polarized light attributed to gelatinization of starch granules in the cake batter during baking is shown in Figs. 8 and 9. The birefringence of the starch granules began to decrease at about 79°C and was completely lost at about 90°C. The process of birefringence loss is in good agreement with the light transmission change under normal light in the 79–88°C range (Fig. 5).

The foregoing results lead to the conclusion that the component that causes the sudden changes in light transmission and apparent viscosity about 79°C is the wheat starch in the cake batter.

The model baking system described in this study has been shown to be useful for monitoring starch gelatinization and protein coagulation in cakes during baking. The system should be applicable to the study of the heating process in other baked goods, as well as in cereal foods and protein foods.

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