Thermal Properties and Structural Characteristics of Model Cake Batters Containing Nonfat Dry Milk[1]

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Cereal Chem. 61(6): 549–554

ABSTRACT

Modified Kissell batter formulations were prepared with 0–27% nonfat dry milk (NFDM) on a flour basis. Influence of NFDM on batter characteristics was determined by specific gravity, water loss rates and temperature profiles of the batters during baking, and differential scanning calorimetry (DSC) of model systems and batters. Baked cakes were evaluated by photographing cross sections, computing cross-sectional areas, and observing crust and crumb characteristics visually and by scanning electron microscopy (SEM). No statistically significant differences were found among batter specific gravities or cake cross-sectional areas. Water loss rates decreased with differing amounts of NFDM. DSC data indicated the onset of starch molecular transformations occurred at higher temperatures in NFDM batters than in those without NFDM. Enthalpies of batters with and without NFDM were similar. Cross sections of baked cakes revealed layering with NFDM addition. Crust color was darker with increasing amounts of NFDM. SEM examination of cake crumb showed that as the level of NFDM increased, starch granules were less swollen and the matrix material, which contained lipid, was more finely dispersed.

Nonfat dry milk (NFDM) is a common ingredient in baked products and affects final product structure. Little data, however, are available characterizing the specific effects of NFDM in cake batter formulations.

The manner in which water is lost during baking relates to product composition and formulation (Cloke 1981, Davis and Gordon 1982, Hsu et al 1980, Gordon et al 1979). Studies of specific components supplement and support the studies of complete batters. Enthalpy requirements of individual components of a system, such as the starch granule, have been useful in evaluating whether the degree and type of starch transformations change with the amount and type of components added to the system (Donovan 1979, Eliasson 1980, Stevens and Elton 1971, Wootton and Bamunuarachchi 1979, Biliaderis et al 1980, Cloke et al 1983, Donovan 1977, Wootton and Bamunuarachchi 1980, Kugimiya et al 1980, Spies and Hoseney 1982). Electron microscopy techniques have yielded micrographs from which such features of a batter system as extent of starch granule swelling and dispersion of lipid-containing matrix can be examined (Hsieh et al 1981, Lineback and Wongsrikasem 1980, Hoseney et al 1978, Hoseney and Atwell 1977, Davis and Gordon 1982).

[1]Scientific Paper No. 13768, Minnesota Agricultural Experiment Station, St. Paul 55108.

In this study, effects of NFDM on batter formulations were investigated by measuring batter specific gravity, by determining water loss rates and temperature profiles during baking, and by differential scanning calorimetry (DSC) of both model systems and batter systems. Alterations in the final baked product due to different levels of NFDM were evaluated by examining crumb structure of cake cross sections visually and with scanning electron microscopy (SEM) and by measuring cake cross-sectional area as an index of volume.

MATERIALS AND METHODS

Batter Formulation, Specific Gravity, and Cross Section Evaluation

A lean batter formulation (Table I) based on that of Kissell (1959) was prepared incorporating 0, 10, 20, 30, or 40 g of NFDM. Initially, the cake flour, baking powder, corn oil, and sucrose solution were combined and mixed for 3 min with a Hobart Kitchen-Aid mixer (model K45). NFDM was hydrated with the additional distilled water during this mixing stage, then added to the batter, which was mixed for another 2 min. Batter specific gravity was determined with a 15-ml Fisher Grease Pycnometer.

Two hundred twenty grams of the batter were weighed into a greased, waxed paper-lined aluminum baking pan (15.2 cm diam, 3.2 cm deep) and baked for 25 min at 191 ± 1°C. Baked cakes were cooled at room temperature for 60 min, turned out of the pans, and cross-sectioned. Cross sections were evaluated for crust color, air cell size, and uniformity. Cross-sectional areas were computed as an index of volume with a Hewlett-Packard digitizer (model 9107 A). Statistical analysis of batter specific gravities and cross-sectional areas was by simple or one-way classification analysis of variance, with four replications of each batter formulation.

Water Loss Rates and Temperature Profiles

Cakes were baked in a controlled-environment oven designed to allow measurement of water loss rates and temperatures of the batter at 1-min intervals. To obtain temperature profiles, thermocouples were inserted in the batter 5 mm from the bottom base of the cake pan and at 0, 2.5, 5.1, and 6.9 cm radii. Godsalve et al (1977) give further details on design and operation of the environmental oven.

Enthalpy Measurements

DSC studies using a Perkin-Elmer DSC-II were done on model systems. Sample weights were determined with a Perkin-Elmer thermogravimetric system (TGS-II) and ranged from 9.00 to 20.55 mg. Samples were sealed in volatile DSC pans (Perkin-Elmer 219-0062) and heated from 20 to 110° C at a rate of 5° C/min and a sensitivity of 2 mcal/sec, utilizing an empty sample pan as a reference. A recorder sensitivity of 20 mV and a chart speed of 20 mm/min were used for all samples. Changes in enthalpies (ΔH) for thermograms were obtained from $\Delta H = A \times C/W$, where ΔH is enthalpy in calories per gram, A is area of the thermogram in square centimeters measured with a Hewlett-Packard digitizer (model 9107A), W is weight of the sample in milligrams, and C is the instrument constant at settings of 2 mcal/sec, 20 mV, and 20 mm/min. The instrument constant was determined from indium, which has a heat of melting of 6.80 cal/g. Transition onset temperatures were obtained from the endotherms by the method of Biliaderis et al (1980).

Model Systems

DSC of milk. Samples of pasteurized skim milk, NFDM hydrated in glass-distilled water, and NFDM hydrated in 42% sucrose solution were heated in the DSC to determine if any observable thermal transitions occurred.

DSC of starch. Model systems consisting of wheat starch/water, wheat starch/water/NFDM, wheat starch/42% sucrose solution, and wheat starch/42% sucrose solution/NFDM were heated in the DSC. For all samples, dry starch was transferred directly into a preweighed sample pan and weighed. Glass-distilled water or sucrose solution was then pipetted into the sample pan, the weight of the transferred water or sucrose solution was determined, and the sample pan was sealed. If NFDM was incorporated in the model system, 0.80 g was hydrated in 6 g of water or 10.34 g of sucrose solution, and the mixture was pipetted into the sample pan to achieve a starch-water ratio similar to that of the cakes. The sample pans were then sealed and weighed. Four samples of each model system were heated in the DSC. Concentration ranges of constituents are listed in Table II.

DSC of batters. Batters formulated with 0 or 40 g of NFDM were prepared and heated in the DSC. Immediately after preparation, batter was pipetted, weighed, and sealed in a preweighed DSC sample pan. Six samples were prepared from each batter preparation, with three replications each of 0 and 40 g of NFDM.

SEM of Cake Crumb Samples

Two cakes from each level of NFDM batters were baked, then cooled for 60 min before samples were prepared for SEM analysis. Wedges 5 × 3 × 2 mm were cut from the middle of the cake cross section. SEM stubs were coated with silver-conducting paint, and cake samples were placed on the stub. The samples were then placed in a desiccator, exposed to osmium tetroxide vapors for 120 min, double-coated in a vacuum evaporator with gold/palladium, and viewed on a Philips SEM 500 at 6 kv.

RESULTS AND DISCUSSION

Although many studies report that milk proteins have foaming functionality (Phillips 1981, Graham and Phillips 1976), the addition of NFDM to the batters in this study did not significantly alter the amount of air incorporation in the batter system as measured by specific gravity (mean value 1.03). Cake cross-sectional areas, an index to volume, were not significantly different at the 5% level of significance after NFDM was incorporated in batter formulations (mean value 26.12 cm^2). Lack of significance of cake cross-sectional areas further indicated that addition of NFDM did not result in greater air incorporation.

Both evenness of crust color and crumb structure development were affected by NFDM additions. Lack of significance of cake cross-sectional areas further indicated that greater air incorporation was not achieved due to NFDM addition in test formulas. Crusts of control cakes were cream colored; as levels of NFDM increased, so did the degree of browning, owing to the Maillard browning reactions. Cross sections (Fig. 1) showed control cakes had a close, compact crumb structure with fairly uniform air cells except for larger cells in the middle of the top area. The higher the level of NFDM, the greater the area of larger, more variable air cell structure. At levels of 30 and 40 g of NFDM, almost the entire cross section consisted of large, nonuniform air cells, with close, compact crumb structure only at the outer edges. Although overall batter specific gravity and cake cross-sectional areas indicated little effect of NFDM on the amount of air initially incorporated and retained throughout baking in the batters, the layering and nonuniform air cells observed in cake cross sections were attributed to destabilization of the batter foam by air bubbles of different sizes initially incorporated in the batter. This was supported by the study of Handleman et al (1961), in which layering in crumb structure was due to foam destabilization.

The characteristic features of water loss rate curves, which were similar for all batter systems, and a typical temperature profile for a control batter during baking are shown in Fig. 2. Temperature profiles from each level of NFDM batter formulation were used to obtain batter temperatures throughout baking. Batter temperatures were then associated with regions of water loss rate curves. Five distinct regions, each characterized by a change in slope of the water loss rate, were found at all levels of NFDM. An initial period of gradually increasing water loss rates (region I) was followed by more rapidly increasing rates (region II). Region III, a period of relatively constant water loss rates, has been associated with solid, porous structure development and also is the temperature range at which starch transformations occur (Gordon et al 1979, Cloke et al 1984). Region IV was a period of very rapidly rising rates, and region V was the second period of relatively constant rates.

The composite average water loss rate vs. time curves for each level of NFDM batter formulations are shown in Fig. 3. Although the five regions of water loss rate curves were evident for all levels of NFDM, both the time of occurrence and the duration of the first three regions changed with the level of NFDM. Water loss rates were very similar for all formulations during the initial 5 min of baking, but as the level of NFDM increased, regions I and II occurred earlier and were shorter. Because region III also occurred

TABLE I
Cake Batter Formulation

Ingredient	Quantity (g)	Percent (Flour Basis)
Cake flour[a]	150.0	100
Baking powder[b]		
(sodium aluminum sulfate-phosphate)	7.1	4.7
Corn oil[c]	41.8	27.9
Sucrose solution		
Sucrose	167.4	111.6
Distilled water	107.0	151.0
Additional distilled water	19.5 + 100.0	···
Instant nonfat dry milk[d]	0–40	0–26.7

[a]Softasilk, General Mills, Inc.
[b]Calumet, General Foods Corporation.
[c]Mazola, Best Foods.
[d]Carnation Instant Nonfat Dry Milk, Carnation Company.

earlier and at lower water loss rates with increasing levels of NFDM (Table III), batter temperatures were lowered throughout this period.

Region IV, ie, the period of rapidly increasing water loss rates, commenced earlier as NFDM levels increased but was maintained until minute 16 or 17 in baking for all levels. Region V showed little variability in time of occurrence, but the extent of decrease in water loss rates was greater at higher levels of NFDM. Decreased water loss rates associated with increasing NFDM incorporation may result from the water absorption properties of caseins (Kinsella 1971) and the hydrophilic properties of the carbohydrate lactose (Wilson and Donelson 1963, Hester et al 1956, Howard et al 1968).

Measurements of enthalpy and onset temperature with DSC are summarized in Table II, and representative endotherms of starch model systems are shown in Fig. 4. No thermal transitions were observed in samples of pasteurized skim milk, NFDM hydrated in water, or NFDM hydrated in 42% sucrose solution. Enthalpy of the starch model systems averaged 2.4 cal/g and were within the 10–12% variability found by Cloke et al (1983) and Galletti et al (1980). Addition of NFDM did not affect enthalpy of the starch phase transition. The onset temperature for the starch phase transition, however, depended on whether distilled water, sucrose solution, or NFDM was incorporated in the system. The incorporation of 42% sucrose solution in starch/water systems elevated endotherm onset temperatures approximately 20° C with or without NFDM. These results support the delayed starch transformations in the presence of sugars reported by Wootton and Bamunuarachchi (1980) and Spies and Hoseney (1982). NFDM addition elevated the onset temperature 2–7° C in starch/water and starch/sucrose systems, possibly because of the high lactose content of NFDM. The combined effect of sucrose and NFDM was an elevation of 23–27° C in the onset temperature of the starch phase transition.

Phase transitions in batter systems (Table II and Fig. 5) were similar to those in the starch model systems. Enthalpies due to molecular starch transformations were similar with and without NFDM. Onset temperatures, however, were higher in batters with NFDM than in those without NFDM.

When data from water loss rate curves, temperature profiles, and DSC results for batter systems are integrated, it becomes apparent that the first constant rate period (region III) of water loss rate curves can be only partially attributed to starch transformations. DSC results indicated onset of starch transformations at 81–84° C for batters with 40 g of NFDM, whereas the temperature range for region III was 70–83.3° C. These results suggest that NFDM influenced batters and the resultant cakes not only by elevating starch transformation temperature requirements but also by other mechanisms, such as water binding due to proteins and lactose.

TABLE II
Enthalpies and Endotherm Onset Temperatures for Starch and Batter Model Systems With and Without Nonfat Dry Milk (NFDM)

Starch Systems				Batter Systems		
Starch (%)[a]	NFDM (%)[b]	Enthalpy (cal/g)	Onset Temperature (° C)	NFDM (g)	Enthalpy (cal/g)	Onset Temperature (° C)
14–32	0	2.2–2.5	52–56	0	2.5–2.9	76–81
28–35	17–21	2.0–2.2	58–59	40	2.3–3.2	81–84
28–30[c]	0	2.3–2.5	72–74			
25–29[c]	25–29	2.5–2.8	79			

[a] Based on total weight of starch and water.
[b] Based on total weight of starch and NFDM.
[c] Sample contained 42% sucrose solution.

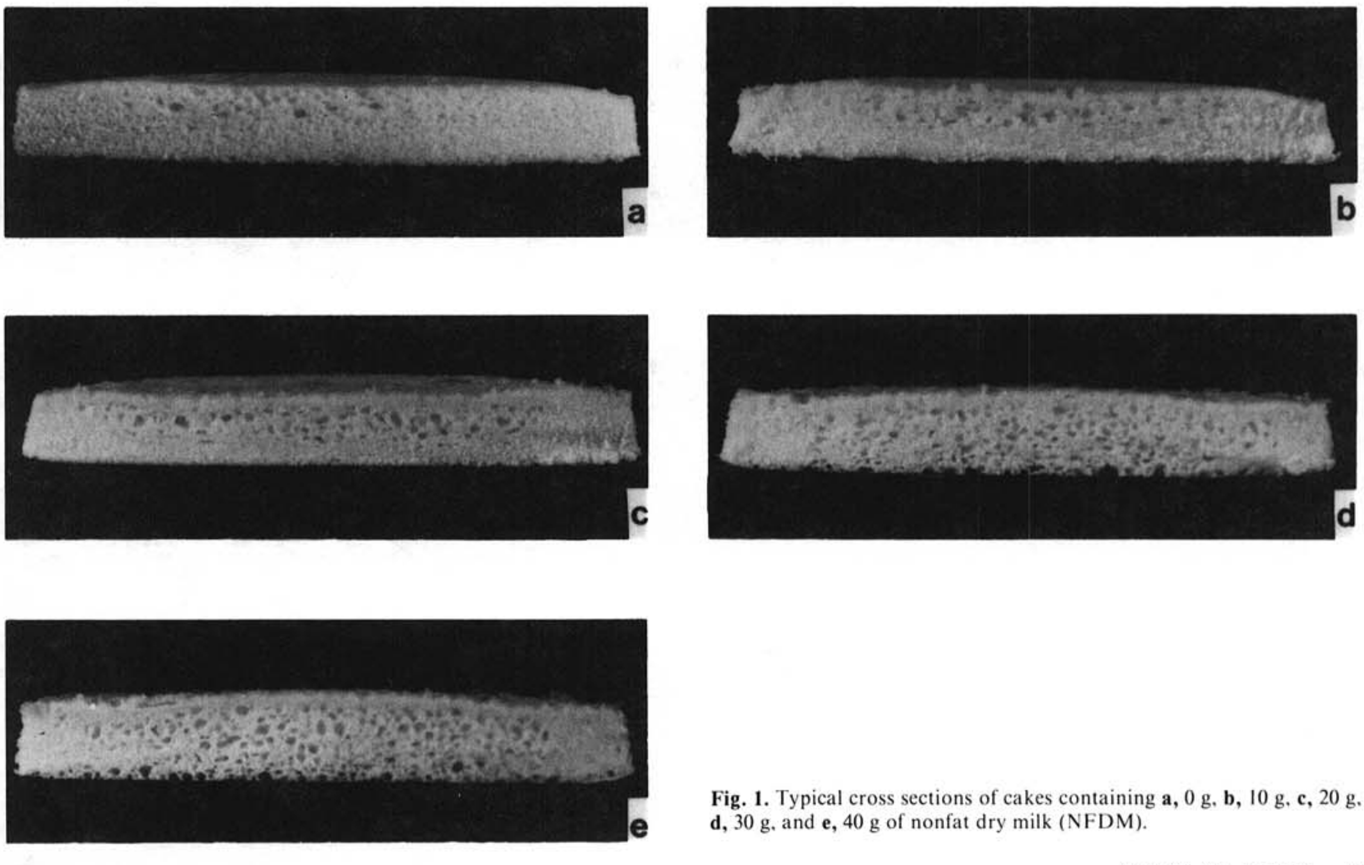

Fig. 1. Typical cross sections of cakes containing **a,** 0 g, **b,** 10 g, **c,** 20 g, **d,** 30 g, and **e,** 40 g of nonfat dry milk (NFDM).

SEM micrographs of cake crumb samples from each batter formulation showed differences in both the appearance of starch granules and the dispersion of the lipid-containing matrix material (Fig. 6). Starch granules in control cakes were very swollen, and granule integrity appeared almost lost in some cases. Lipid-containing matrix material was dispersed throughout the sample in both large pools and small droplets. With increasing levels of NFDM, starch granules appeared less swollen and retained more integrity. Micrographs from the 40-g NFDM formulation showed starch granules that were less swollen and easily distinguished from each other. The decreased starch granule swelling combined with the decreased water loss rates suggest that constituents of NFDM altered the water-binding properties of the cake batter system, resulting in less water available for evaporative loss and starch granule swelling.

The distribution of lipid-containing matrix material was also altered by NFDM incorporation in batters, with fewer large pools as NFDM levels increased. In the 40-g NFDM formulation, the lipid-containing matrix dispersed in very small and medium-sized droplets; large pools were not observed. The finer dispersion of matrix material in NFDM cakes was attributed to the emulsification properties of milk proteins, ie, the amphoteric nature and surface-active properties that have been observed to

TABLE III
Time of Occurrence, Center Batter Temperature, and Water Loss Rate During First Constant Loss Rate Period

Nonfat Dry Milk Content of Batter (g)	Time of Occurrence (min)	Center Temperature (° C)	Water Loss Rate (g/min)
0	10–12	90.0–97.2	0.56–0.58
10	8–9	79.4–83.9	0.40–0.41
20	8–10	82.8–88.3	0.35–0.36
30	7–9	74.4–83.3	0.27–0.29
40	6–9	70.0–83.3	0.30–0.32

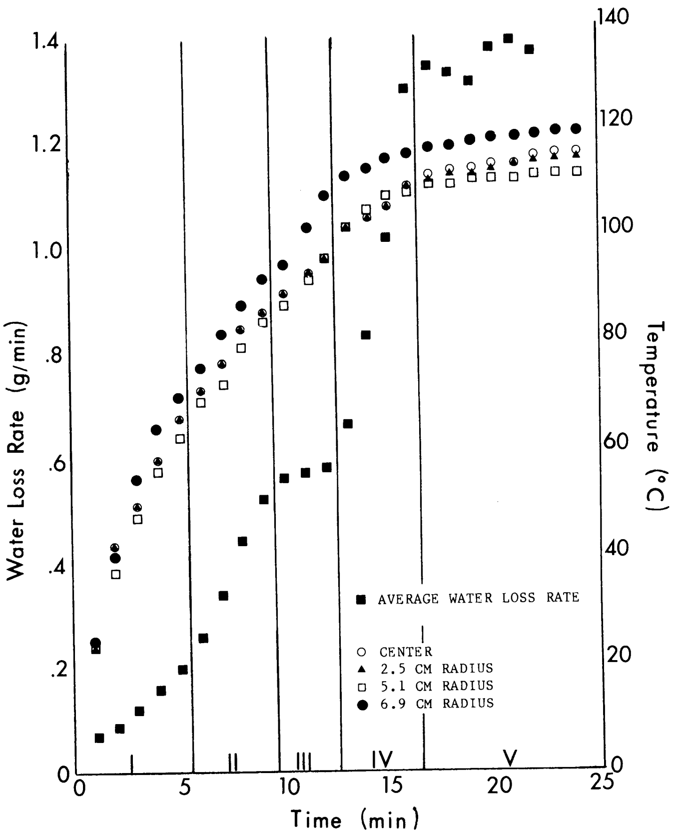

Fig. 2. Representative water loss rate curve and temperature profile for a cake containing no NFDM. I, II, III, IV, and V denote regions associated with water loss rate curves.

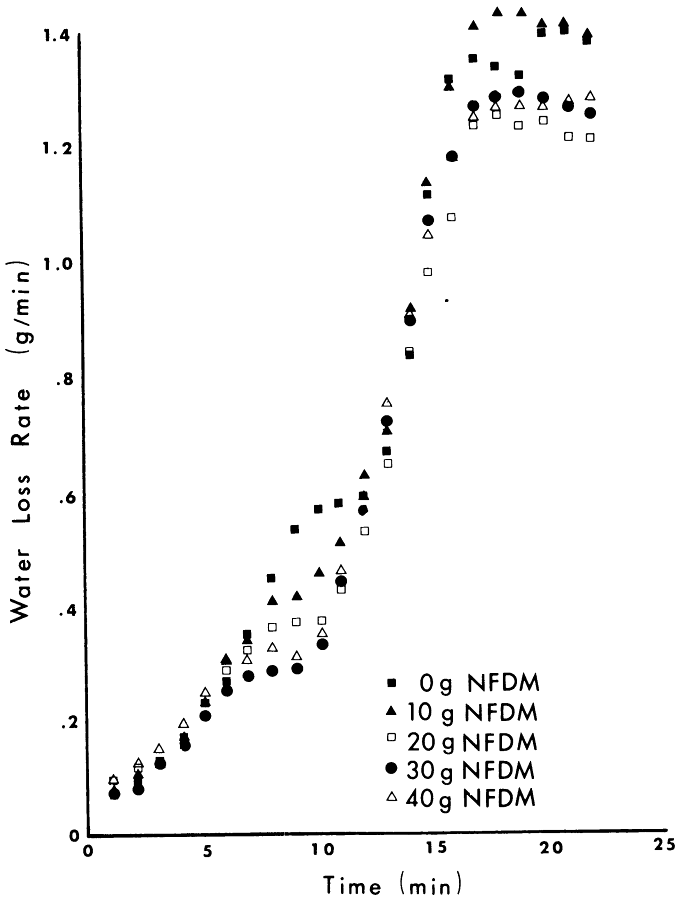

Fig. 3. Average water loss rate curves for cakes containing 0, 10, 20, 30, and 40 g of NFDM.

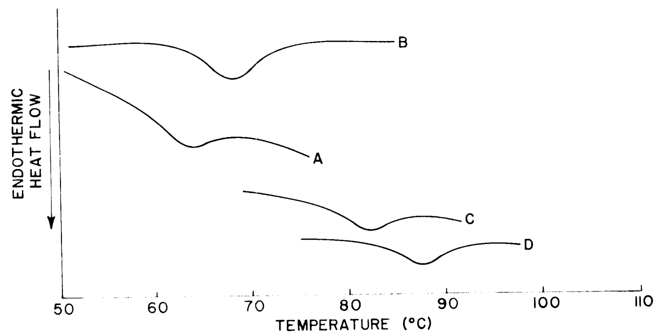

Fig. 4. Representative endotherms of model systems containing starch/water (A), starch/water/NFDM (B), starch/sucrose solution (C), and starch/sucrose solution/NFDM (D).

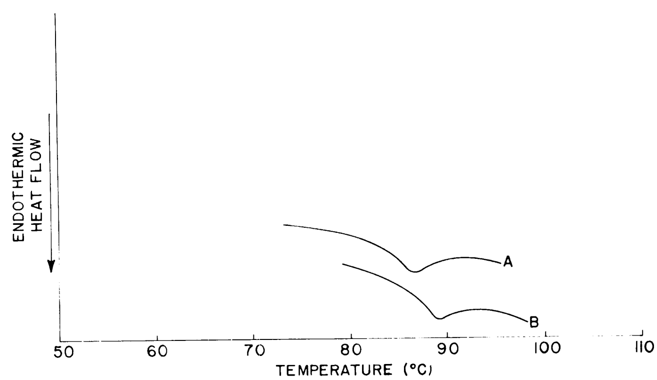

Fig. 5. Representative endotherms of batter systems containing no NFDM (A) and 40 g of NFDM (B).

stabilize minimum dispersions of oil in model system emulsions (Phillips 1981, Graf and Bauer 1976). It is possible that the altered lipid dispersion affected batter viscosity prior to heating, thus also affecting and limiting starch granule swelling. Altered lipid dispersion perhaps influenced not only the extent of starch granule swelling but also the extent of water loss from the system, thereby influencing the physical transformation of the batter to a solid porous medium.

CONCLUSIONS

The addition of NFDM to a modified Kissell batter formulation affected the structural characteristics of the baked cake but not the initial batter specific gravity or the final cake volume. Addition of NFDM to batters produced layering in the final cake structure, indicating destabilization of the batter foam, and enhanced the development of a golden crust color, owing to browning reactions.

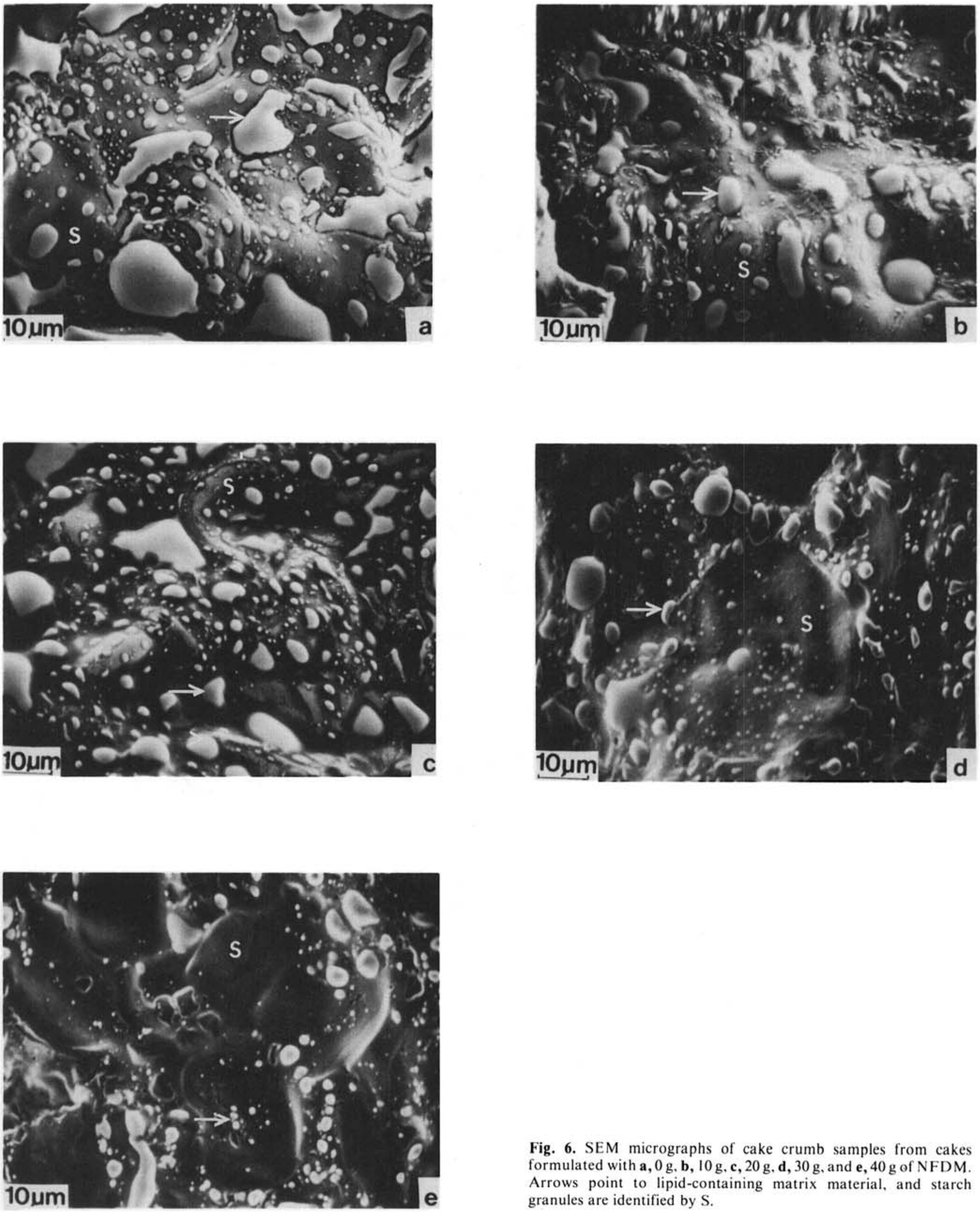

Fig. 6. SEM micrographs of cake crumb samples from cakes formulated with **a,** 0 g, **b,** 10 g, **c,** 20 g, **d,** 30 g, and **e,** 40 g of NFDM. Arrows point to lipid-containing matrix material, and starch granules are identified by S.

Water loss rates and temperature profiles of batters during baking showed that water loss rates decreased with increasing NFDM content. Water loss rate patterns were also altered by NFDM incorporation, with the first constant loss rate period in baking occurring earlier and at lower temperatures than in batters without NFDM.

DSC studies of model systems and batters showed starch transformation onset temperatures to be elevated by incorporation of sucrose and/or NFDM. Enthalpies of starch transformations were not influenced by sucrose or NFDM. SEM micrographs of cake crumb samples showed decreased starch granule swelling and finer dispersion of lipid-containing matrix material with increasing levels of NFDM.

These results suggest that addition of NFDM to cake batter formulations influences such batter properties as air cell size, foam stability, and lipid emulsification. Batters with NFDM absorbed more water earlier during baking than batters without NFDM, as indicated by region III water loss rate curves. Therefore, a solid porous structure developed earlier during baking in batters with NFDM; in batters without NFDM, a solid porous structure developed at the same time as starch swelling. NFDM inhibited starch swelling and therefore influenced when and how much swelling occurred during the baking process.

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[Received March 1, 1984. Accepted July 26, 1984]