The Influence of Sugar and Emulsifier Type During Microwave and Conventional Heating of a Lean Formula Cake Batter[1]

B. A. BAKER, E. A. DAVIS, and J. GORDON[2]

ABSTRACT

Cereal Chem. 67(5):451–457

A modified lean cake formulation was evaluated to compare the effects of sucrose added in its crystalline state versus sucrose solubilized in distilled water before incorporation into batters, and the effects of different types of emulsifiers (saturated or unsaturated monoglycerides) on the batter formulations heated by microwave and conventional heat sources. Temperature profiles during baking, cake quality characteristics, photographs of cross-sectioned cakes, and scanning electron micrographs were recorded for each experiment. The temperature profiles differed more based on the heating mode than on formulation variation. Overall weight loss and cross-sectional areas differed as a function of mode of heating. Also, cake structure appeared more variable for the thermally heated cakes than for the microwave-heated cakes as a function of formulation change. The unsaturated monoglyceride (*trans* form) increased air incorporation in cake batters. Also, unsaturated monoglyceride appeared to result in cross-sectional areas greater than those in cakes made with saturated monoglyceride. Solubilized versus crystalline sucrose influenced weight loss and cross-sectional area. All low-magnification scanning electron micrographs showed differences in air cell uniformity with the variously formulated and heated batters. At high magnification, starch granule swelling and matrix development appeared different with variation in formulation.

INTRODUCTION

Emulsifiers added to cake formulations have been examined by many researchers. Emulsifiers can increase air incorporation, decrease specific gravity, produce a finer fat dispersion, and as a result increase the final cake volume (Handelman et al 1961, Buddenmeyer et al 1962, Wootton et al 1967, Howard 1972, Guy and Vettel 1973, Del Vecchio 1975).

Carlin (1944), Del Vecchio (1975), and Cloke (1981) all stated that a certain level of emulsifier in oil produced an acceptable cake. Carlin (1944) noted that the cake volume decreased after the 5% level was reached. Cloke (1981) observed that the level of emulsifier also affected heat transfer properties and water loss rates, in addition to air incorporation and quality characteristics; optimum emulsifier level was found to be 4–5% based on fat weight.

Monoglycerides with straight-chain fatty acids can complex with amylose more readily than can *cis* unsaturated fatty acids, in which the aliphatic chain is bent at the double bond (Lagendijk and Pennings 1970; Birnbaum 1978; Krog 1971, 1977). Further studies have indicated that saturated monoglycerides are the most effective in complexing ability (Lagendijk and Pennings 1970; Krog 1971, 1981). The complexing, therefore, is influenced by the steric configuration of molecules such as amylose.

In the work by Cloke et al (1982, 1984a,b) glycerol monostearate and glycerol monooleate were incorporated into a lean cake formulation. Differences were noted between glycerol monostearate, the saturated monoglyceride (SMG), and glycerol monooleate, the unsaturated monoglyceride (USMG), when viewed by freeze-etch techniques (Cloke et al 1982). The SMG appeared to be composed of lamellar or layered sheets and as a result inhibited the starch from swelling. No crystalline mesophases were observed for the USMG, but it dispersed the oil droplets more finely than did the SMG.

Sugars also influence the development of cake structure and determine layer cake volume and contour by increasing the gelatinization temperature of starch (Hester et al 1956; Miller and Trimbo 1965; Osman 1975; Bean and Yamazaki 1978; Bean et al 1978; Donovan 1979; Mizukoshi et al 1979, 1980; Wootton

---

[1] Published as paper 17640 of the contribution series of the Minnesota Agricultural Experiment Station based on research conducted under projects 18-021 and 18-063.

[2] Department of Food Science and Nutrition University of Minnesota 1334 Eckles Avenue St. Paul, MN 55108; present address of first author, Quali Tech, 318 Lake Hazeltine Drive, Chaska, MN 55318.

and Bamunarachchi 1980; Davis and Gordon 1982; Spies and Hoseney 1982; Ghiasi et al 1983; Abboud and Hoseney 1984; Mizukoshi 1985a,b; Ngo and Taranto 1986).

For example, Bean and Yamazaki (1978) observed with the amylograph that wheat starch granules heated in 50 and 60% sucrose solutions gelatinized at 85 and 95°C, respectively. Gordon et al (1979) also found a similar trend in delaying starch gelatinization in cakes formulated with 42% sucrose. These cakes gelatinized in the range of 82–91°C instead of at 55–75°C, as expected for the same starch-water mixture without sucrose.

More recently, Spies and Hoseney (1982) hypothesized that the availability of water was not the sole factor influencing starch gelatinization. They hypothesized that sugars interact with starch molecule chains in the amorphous regions of the starch granules, thereby increasing the energy required for starch gelatinization.

Thus, both emulsifiers and sugar types influence starch swelling, water availability, and air cell stability during structural development of cake crumb. In addition, emulsifiers undergo phase changes with heating and water concentration, which may influence the absorption of microwave energy and/or heat transfer through a sample. This investigation examined the effects of crystalline versus solubilized sucrose and of two different emulsifiers in a batter formulation heated by microwave and conventional heat sources. Heat transfer characteristics, cake structure, and total water loss properties of the cakes were evaluated for each batter formulation.

MATERIALS AND METHODS

Batter Formulation

The modified lean cake formulation (Cloke et al 1982) used is shown in Table I.

USMG and SMG (see Table II for composition and properties) were used in the formulation at the 5% level based on the shortening weight, and the weight of oil was reduced accordingly. The emulsifiers were dispersed in oil (for USMG) or water (for SMG), heated to 60°C with stirring, and cooled to room temperature before being incorporated into the batter.

TABLE I
Modified Lean Cake Formulation

Ingredient	Quantity (g)	Percent by Weight	Percent Flour Basis
Cake flour[a]	150.0	25.3	100.0
Baking powder[b]	7.1	1.2	4.7
Shortening[c]	41.8	7.1	27.9
Sucrose[d]	167.4	28.2	111.6
Distilled water	226.5	38.2	151.0

[a] General Mills.

[b] Calumet.

[c] Corn oil (Mazola) and emulsifiers (none, saturated monoglyceride, or unsaturated monoglyceride) were used.

[d] Sucrose (C & H) solution or crystalline sucrose (C & H) were used.

TABLE II
Composition and Properties of the Emulsification Systems of Saturated and Unsaturated Monoglycerides

Property	Saturated Monoglyceride System (Dimodan PVK)	Unsaturated Monoglyceride System (Dimodan OK)
Monoester content	Min. 90%	Min. 90%
Fatty acid composition	85–90% stearic acid 10–15% palmitic acid	60–80% oleic acid 12–18% stearic acid 8–15% palmitic acid
Iodine value	Max. 5	Approx. 60
Free fatty acids	Max. 1.5%	Max. 1.5%
Free glycerol	Max. 1.0%	Max. 1.0%
Melting point	Approx. 72°C	Approx. 60°C[a]
Form	Beads	Block

[a] The melting point information indicates that the mainly unsaturated monoglyceride emulsifier may be mainly elaidic acid (*trans*), for which the melting point is 58.5°C. The melting point of oleic acid (*cis*) is 35.2°C.

Sucrose was added either as crystalline sucrose or a saturated sucrose solution (60:40, w/w) (Cloke et al 1984a).

The two-stage method of batter preparation was that of Cloke et al (1982). Batter (400 g) was added to glass baking pans (20.3 cm in diameter and 4.4 cm deep) and baked in a thermal-microwave oven (Litton Micro-Browner oven, model 1285). Maximum microwave power was 700 W at 2,450 MHz. Two resistant heating elements, one at the top and one at the bottom of the oven, supplied 2,000 W of thermal heat energy. Microwave cakes were baked for 8 min at 70% power (preliminary work showed this to be the best power level to use with this particular model of oven). Thermal cakes were baked for 30 min at 177°C.

Physical Measurements

Batter specific gravity was determined by the Fisher Grease pycnometer method.

Final weight loss after baking was determined by subtracting the weight taken immediately after removal from the oven from the initial weight.

Areas (mm^2) of cakes vertically bisected (cross-sectioned) after 1 hr of cooling were traced as an index to cake volume. The areas were computed as an average of triplicate measurements, using a digitizer (Hipad Houston Instruction).

Cake symmetry (mm) was determined from the cross-sectioned cake tracing by AACC Method-91 (AACC 1976).

Time-Temperature Profiles

Time-temperature profiles at center, midpoint, and edge positions of each cake were taken with a fiber optic probe (Luxtron model 1000A) as described in Baker et al (1990).

Photographs of Cross-Sectioned Cakes

Photographs of cross-sectioned cakes were taken to illustrate overall crumb, texture, height, and volume of the cakes. Cakes were also evaluated visually for crust color, shininess of crust, and presence of capillary pores.

Scanning Electron Microscopy of Cake Crumb

Cake crumb samples (10 × 5 × 2 mm) from the midpoint location were cut with a razor blade and placed on an aluminum-coated stub. The samples and stubs were placed in a desiccator containing solid OsO_4 crystals for 150 min, vacuum-coated with gold and palladium, and viewed in a scanning electron microscope (Philips 500) at 6 kV.

Statistical Design

The two modes of heat treatment (microwave and thermal), two types of sugar (crystalline sucrose and liquid sucrose), and three emulsification systems (no emulsifier, SMG, and USMG) were analyzed by a split-split plot design. Because the main objective was to study the effects of formulation, the experiment was designed with probe position as a whole-plot treatment, heat as a split-plot treatment, and formulations as a split-split-plot treatment.

The three temperature probe locations (center, midpoint, and edge) were randomly assigned to each block. Microwave and thermal heat treatments were then randomly assigned within each block, and finally the six formulations were again randomly assigned to each heat treatment.

Each block contained the formulations for microwave and thermal heating. The three blocks (probe position) resulted in 36 (12 × 3) cakes per replication. The experiment was replicated three times for a total of 108 cakes.

An analysis of variance was calculated using the Statistical Analysis System (Cary, NC) at the University of Minnesota, Saint Paul Computing Center.

The means for the main effects and for interactions of each dependent variable were analyzed by Tukey's test (Montgomery 1984) when the *F* test was significant at the 5% level.

TABLE III
Mean Square (MS) and *F*-Values for Specific Gravity, Final Weight Loss (%), Cross-Sectional Area, and Symmetry for the Modified Lean Cake Formulation[a]

Source	df[b]	Specific Gravity		Percent Final Weight Loss		Cross-Sectional Area (mm^2)		Symmetry (mm)	
		MS	*F*	MS	*F*	MS	*F*	MS	*F*
Replicate	2	0.001323	10.85*[c]	0.5079	8.19*	41,579.26	1.33	10.34	6.42
Probe	2	0.0005648	4.63	0.0695	1.12	74,622.70	2.39	8.39	5.21
Replicate × probe (error A)	4	0.0001219		0.062		31,171.77			1.61
Heat	1	0.00015647	1.2797	20.94	196.71*	2,390,754.75	72.01*	4.90	0.27
Probe × heat	2	0.0002843	2.32	0.0114	0.107	73,262.35	2.21	20.16	1.13
Replicate × heat (probe) (error B)	6	0.0001222		0.10645		33,200.45		17.80	
Sugar	1	0.00000833	0.01	0.88201481	20.47*	17,905,471.76	625.33*	313.48	30.22*
Emulsifier	2	0.0007676	9.59*	0.2048148	4.75*	5,061,540.50	176.77*	212.96	20.53*
Sugar × emulsifier	2	0.0000194	0.24	0.0700593	1.63	1,892,139.50	66.08*	149.25	14.39*
Probe × sugar	2	0.0000528	0.66	0.0170954	0.40	1,173.58	0.41	44.83	4.32*
Probe × emulsifier	4	0.0000704	0.88	0.0346134	0.80	22,375.99	0.78	3.78	0.36
Probe × sugar × emulsifier	4	0.0000056	0.07	0.0146606	0.34	45,457.10	1.59	14.65	1.41
Heat × sugar	1	0.00000093	0.01	0.61653333	14.31*	30,855.00	1.08	515.70	49.71*
Heat × emulsifier	2	0.0000287	0.36	0.2245815	5.21*	1,653,901.60	5.37*	26.61	2.57
Heat × sugar × emulsifier	2	0.0001176	1.47	0.2885444	6.70*	28,848.61	1.01	127.86	12.33*
Probe × heat × sugar	2	0.0000398	0.50	0.0174694	0.41	2,544.92	0.09	5.05	0.48
Probe × heat × emulsifier	4	0.0000898	1.12	0.0108634	0.25	21,875.56	0.76	9.04	0.87
Probe × heat × sugar × emulsifier	4	0.000065	0.08	0.0228847	0.53	11,536.94	0.40	7.37	0.71
Error C	60	0.0000800		0.04309556		28,633.63		10.37	

[a] Total = 107.
[b] Degrees of freedom.
[c] * = $P < 0.05$.

RESULTS AND DISCUSSION

Physical Measurements

Table III shows the results of the analysis of variance for specific gravity, final weight loss, cross-sectional area, and symmetry for cakes baked by microwave and thermal heat using SMG or USMG (*trans* form) and sucrose solution or crystalline sucrose added to the batter during formulation.

The results (at the 5% level) showed no probe position effect in the randomization across all variables evaluated.

For batter specific gravity, the emulsifier effect was the only effect noted. The mean differences for specific gravity by Tukey's test indicated that the USMG gave a batter with lower specific gravity (1.214) than either no emulsifier (1.220) or SMG (1.224), indicating more air incorporation during batter formulation with USMG.

For percent final weight loss, a heat-sugar-emulsifier interaction was found. In Table IV, the means are given for final weight loss. The weight loss was not significantly affected during microwave heating as a function of sucrose type or type of emulsifier. Many people have the perception that products are drier after microwave heating. However, for thermally heated cakes, a higher percent of weight loss took place relative to microwave-heated cakes for those that gave similar temperature profiles. The temperature profiles are discussed later. Furthermore, thermally heated cakes made with sucrose solution and nonemulsified or emulsified with SMG resulted in even higher final weight loss.

The cross-sectional areas showed a sugar-emulsifier and heating mode-emulsifier interaction, although the overall heat-sugar-emulsifier interaction was not significantly different. USMG (*trans* form) resulted in the largest cross-sectional areas for both microwave and thermally heated cakes (Table V). Also, the difference between microwave and thermally heated cakes containing USMG was not significant. The cross-sectional area for the sugar-emulsifier interaction (Table V) showed that cakes baked with crystalline sucrose had significantly larger areas than those baked with sucrose solution except for the USMG-emulsified cake. The USMG-emulsified, crystalline sucrose cake had a greater cross-sectional area than its sucrose-solution counterpart; however, the cross-sectional area of the USMG sucrose solution cake was not significantly smaller than those of the nonemulsified or SMG-emulsified crystalline sucrose cakes.

Thus it was concluded from the cross-sectional area results that microwave-heated crystalline sucrose cakes with USMG (*trans*) emulsifier would have the largest areas. However, thermally heated cakes containing USMG would be the same or close in area when compared to microwave-heated cakes.

TABLE IV
Means[a] for Final Weight Loss (%) for Cakes Made with Different Heating, Emulsifier, and Sugar Systems

Emulsifier Type	Microwave-Heated		Thermally Heated	
	Crystalline Sucrose	Sucrose Solution	Crystalline Sucrose	Sucrose Solution
No emulsifier	10.53 a	10.32 a	11.05 b	11.50 c,d
Saturated monoglyceride	10.40 a	10.52 a	11.29 b,c	11.73 d
Unsaturated monoglyceride	10.40 a	10.57 a	11.18 b,c	11.28 b,c

[a] Means with the same letter are not significantly different as determined by Tukey's test at the $P < 0.05$ level of significance. Standard error = 0.098, $n = 9$.

TABLE V
Means[a] for Cross-Sectional Area (mm^2) of Cakes as Related to Heat × Emulsifier Interaction and Sugar × Emulsifier Interaction

Emulsifier Type	Heat Type		Sugar Type	
	Microwave	Thermal	Crystalline Sucrose	Sucrose Solution
No emulsifier	4,443 c	4,058 a	4,881 c	3,621 a
Saturated monoglyceride	4,633 d	4,272 b	4,872 c	4,033 b
Unsaturated monoglyceride	5,051 e	4,904 e	5,149 d	4,805 c

[a] Within each interaction, means with the same letter are not significantly different as determined by Tukey's test at the $P < 0.05$ level of significance. Standard error = 56; $n = 18$.

The lower specific gravity for the USMG batter formulations would show initially greater air incorporation that would aid in the greater cross-sectional areas for these cakes. Birnbaum (1978) reported that smaller, more numerous air bubbles were less buoyant and were retained in the cake batter to produce higher cake volumes and improved grain.

The *trans* USMG was solid at room temperature; therefore, the potential for incorporating and retaining more air cells and contributing to higher cross-sectional areas was greater for it than for the SMG. Shepherd and Yoell (1976) similarly reported that fats in the form of a block or solid incorporate more air. Batters prepared with liquid oil were also observed by Shepherd and Yoell (1976) to incorporate large amounts of air, but the air cells were not retained. This could explain why batters having lower or similar specific gravities result in cakes with small cross-sectional areas.

TABLE VI
Means[a] for Index to Symmetry (mm) for Cakes Made with Different Heating and Sugar Systems

	Microwave-Heated		Thermally Heated	
Emulsifier Type	Crystalline Sucrose	Sucrose Solution	Crystalline Sucrose	Sucrose Solution
No emulsifier	14.883 b,c	16.444 b,c	21.778 d	6.338 a
Saturated monoglyceride	18.833 c,d	18.222 c,d	21.444 d	12.556 b
Unsaturated monoglyceride	18.111 c,d	20.000 d	20.388 d	20.833 d

[a] Means with the same letter are not significantly different as determined by Tukey's test at the $P < 0.05$ level of significance. Standard error = 1.518, $n = 9$.

The mesomorphic nature of emulsifiers is well documented in the literature (Krog 1971, Krog and Borup 1973, Krog and Lauridsen 1976). These emulsifier-water properties have implications in terms of dielectric coupling as well and will be the subject of other work from our laboratory.

For index to symmetry, a heat-sugar-emulsifier effect was seen. The specific mean differences are evaluated in Table VI. These results (lower numbers indicate flatter cakes) show the highest (and significantly similar) amount of peaking for all thermally heated crystalline sucrose cakes and for those that were emulsified, except for USMG, sucrose-solution cakes. Thus, USMG-emulsified cakes, regardless of mode of heating and type of sucrose used, gave the same symmetry. It was concluded that USMG cakes would give the most uniform symmetry across modes of heating and sucrose types.

Time-Temperature Profiles for Cake Batter Systems

A representative time-temperature profile for a microwave and a thermally heated formulation is shown in Fig. 1. For the microwave batters, the edge position is always the hottest and rises faster than the temperature at the midpoint and center position probes. At about 3.8 min, 100°C is reached. The temperature of the midpoint probe is between the edge and center temperatures but closer to the edge temperature, and 100°C is reached at about 4.5 min. The center temperature is coolest and considerably below 100°C for the major part of the baking time; for the center probe position, 100°C is reached at about 6.2 min.

For the thermally heated batters, the edge position probe generally registers the highest temperature and the center probe the lowest temperature during most of the baking period. The edge probe reaches 100°C at approximately 18 min, the midpoint

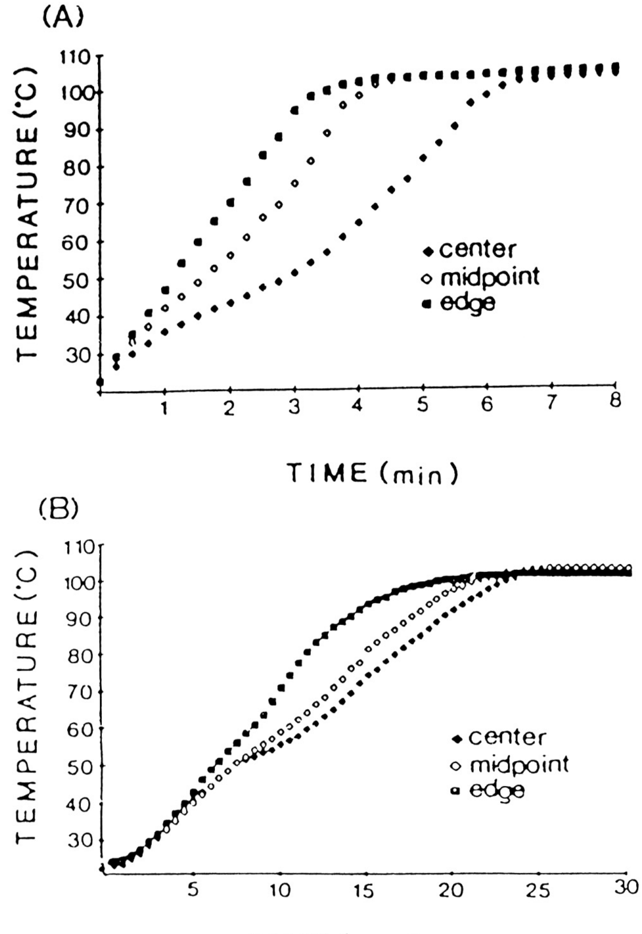

Fig. 1. Representative time-temperature profiles for microwave-heated (**A**) and thermally heated (**B**) cake batters.

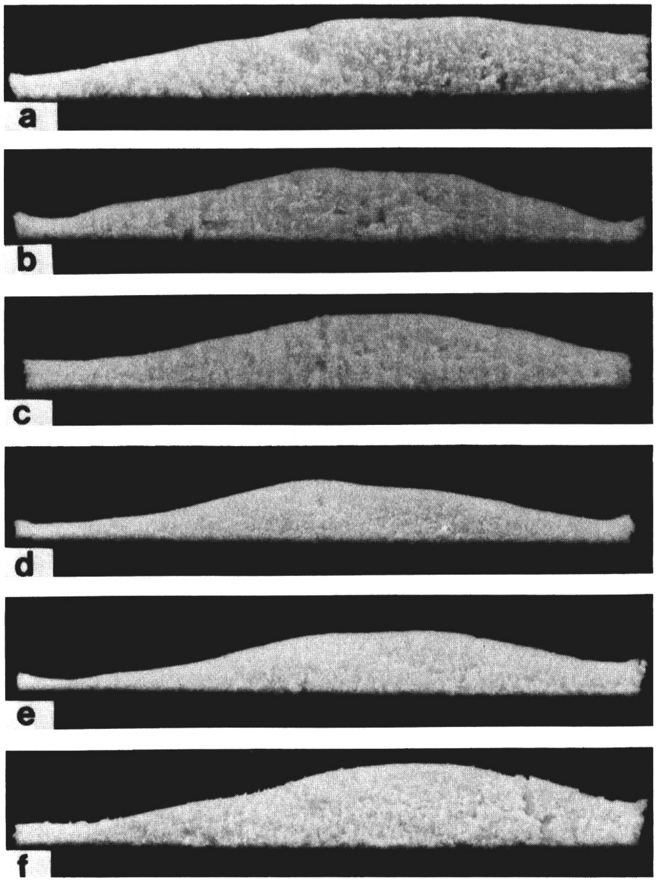

Fig. 2. Photographs of microwave-heated cross-sectioned cakes containing different types of sugars and emulsifiers: **a,** crystalline sucrose; **b,** crystalline sucrose with saturated monoglyceride (SMG); **c,** crystalline sucrose with unsaturated monoglyceride (USMG); **d,** sucrose solution; **e,** sucrose solution with SMG; **f,** sucrose solution with USMG.

at approximately 22 min, and the center probe at approximately 23–24 min.

Comparing the two sets of temperature profile curves, the major differences in profile characteristics relate to a larger temperature spread due to probe position for microwave-heated cakes than for thermally heated cakes. Differences were therefore attributed to the mode of heating rather than to the formulations.

The heat transfer profiles influence weight loss measurements and are related to the overall structural properties of the cakes. The microwave-heated cakes had a significantly lower ($P < 0.05$) weight loss than the thermally heated cakes, irrespective of formulation. Since the microwave-heated batters maintained lower temperatures for longer periods of time, it was not surprising that the total weight loss was less for microwave- than thermally heated batters. This finding was in contrast to that of Evans (1982), who reported higher total losses for the microwave-heated cakes than for thermally heated cakes. In the study by Evans (1982), this discrepancy was accounted for by the different microwave power levels, type of oven for the thermal experiments, and the formulation used, as well as because of terminating heating at a different point of doneness. This is an important fact to consider in interpreting such data.

Photographs of Cake Cross Sections

Microwave-baked cakes that had been bisected were photographed after baking and are shown in Fig. 2a–f for crystalline sucrose cakes (nonemulsified, SMG, and USMG) and sucrose solution cakes (nonemulsified, SMG, and USMG), respectively. Similarly, thermally baked cakes are presented in Fig. 3a–f. The oven was not perfectly level, causing some asymmetry on one side. However, all cakes were bisected in the same location relative to cake oven placement.

All the microwave-heated cakes (Fig. 2) were peaked. From observations, those same cakes had pulled somewhat from the pan upon cooling. None of the cakes were brown on the crust, and all were dull in appearance. Crust surface capillary pores were present for all cake formulations, with the largest capillary pores in the crystalline-sucrose SMG formulation. The crumb structure was the most compact for the nonemulsified cake made with sucrose solution (Fig. 2d), with the SMG-containing cake made with sucrose solution (Fig. 2e) being the next most compact. The USMG cake made with sucrose solution (Fig. 2f) had a crumb structure that was coarse with some open cell structure, and the USMG-emulsified cake made with crystalline sucrose (Fig. 2c) had a coarse crumb.

In summary, for the microwave-heated batters, all cakes were peaked and similar in appearance. However, the crumb structure for the crystalline sucrose series and the sucrose-solution USMG cake were more similar in appearance than the sucrose-solution nonemulsified and SMG-emulsified cakes.

The thermally heated cakes in Fig. 3a–c, e, and f are very similarly contoured, but the cake in Fig. 3d (nonemulsified sucrose solution) is not peaked and most different in appearance from the cakes with other batter formulations. From observation, thermally baked cakes pulled completely from the sides of the pan upon cooling as did the microwave-heated cakes. The cakes had a light brown glossy appearance, and the surfaces had many capillary pores and small cracks. The capillary pores were somewhat larger for the crystalline sucrose SMG cakes (Fig. 3b), however. Crumb structure was most compact for the nonemulsified sucrose-solution cake (Fig. 3d), followed by the sucrose-solution SMG cake (Fig. 3e); the sucrose-solution SMG cake was also very uniform in cell structure. The USMG, sucrose-solution cake was coarse, crumbly, and fragile. All the crystalline sucrose cakes (Fig. 3a–c) had a coarse crumb structure with some open cell areas.

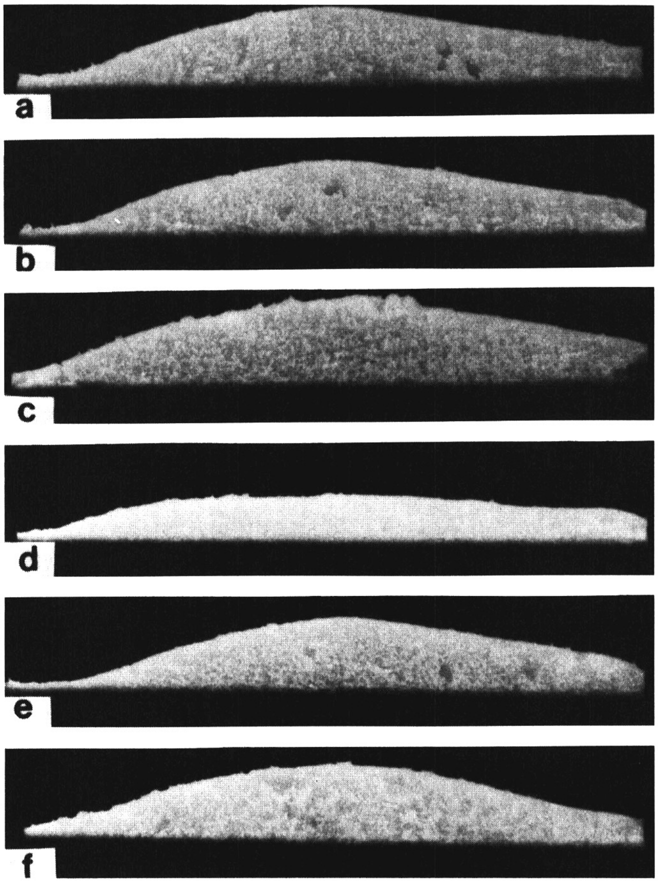

Fig. 3. Photographs of thermally heated cross-sectioned cakes containing different types of sugars and emulsifiers: **a,** crystalline sucrose; **b,** crystalline sucrose with saturated monoglyceride (SMG); **c,** crystalline sucrose with unsaturated monoglyceride (USMG); **d,** sucrose solution; **e,** sucrose solution with SMG; **f,** sucrose solution with USMG.

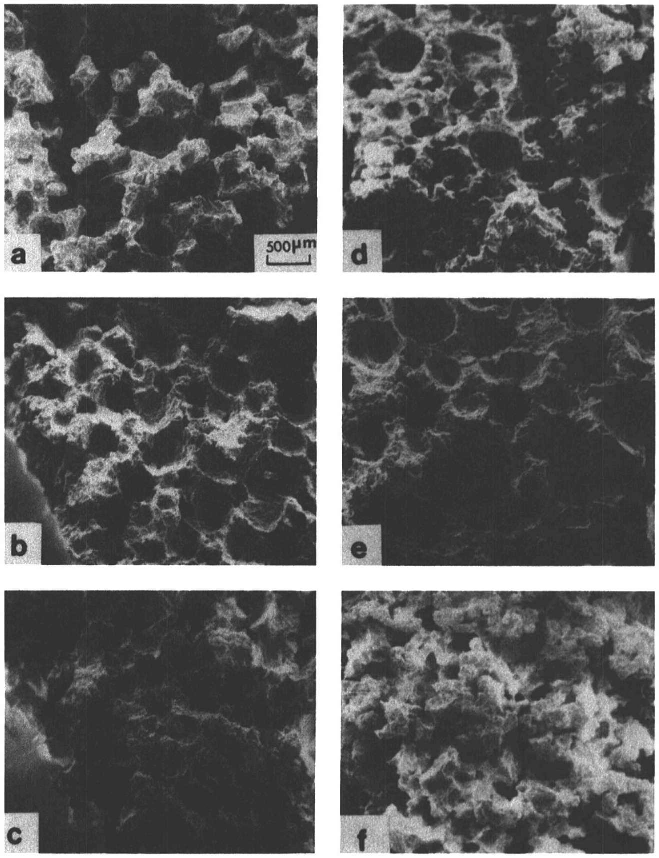

Fig. 4. Scanning electron micrographs of microwave-heated cake crumb made with different types of sugars and emulsifiers: **a,** crystalline sucrose; **b,** crystalline sucrose with saturated monoglyceride (SMG); **c,** crystalline sucrose with unsaturated monoglyceride (USMG); **d,** sucrose solution; **e,** sucrose solution with SMG, **f,** sucrose solution with USMG.

In summary, for the thermally heated batters, crystalline sucrose cakes were less variable in overall crust and crumb structure. The sucrose-solution cakes were more variable among emulsification systems, with the USMG cakes being closer to the cakes formulated from the three crystalline sucrose formulations. This could imply that sucrose solution is more interactive with other components in the batter formulation. For example, a saturated-sucrose solution can inhibit starch gelatinization. The microwave heating, under our experimental conditions, is rapid. In this way, crystalline sucrose may minimize the inhibition of some of these molecular changes.

Scanning Electron Microscopy

Figures 4 and 5 are scanning electron micrographs of microwave and thermally heated cakes, respectively, at low magnification.

Generally, the air cell structure was most uniform in microwave-heated cakes containing crystalline sucrose (Fig. 4a–c). The sucrose-solution cakes (Fig. 4d–f) that were microwave-heated appeared more variable among emulsifiers. However, the air cell structure was most variable with thermally heated cakes (Fig. 5), where larger, more irregular cell structure was seen (especially if cakes were made with sucrose solution). USMG resulted in fewer and smaller air cells within larger building blocks of starch-containing matrix for both modes of heating. From personal observation, the crumb structure was more fragile for cakes containing USMG for microwave and thermally heated cakes.

Starch granules from a crystalline sucrose formulation, thermally heated, center position (Fig. 6a) were more distinct than those from a sucrose solution formulation, microwave heated, edge position (Fig. 6b). These two micrographs at higher magnification are typical of the micrographs taken of the other formulations, showing starch granules that are distinct and granules that are embedded in a more fully developed matrix. However, as emulsifiers were introduced into the formulations, starch granules from the sucrose-solution formulations were more variable than those from the crystalline sucrose formulations; the non-emulsified sucrose-solution cakes had the least distinct starch granules, and the USMG sucrose-solution cakes had the most distinct starch granules. Fine differences were difficult to relate to these observations. Also, emulsifiers dispersed the fat more uniformally around the air cell. However, the largest cross sections appeared to be related to cakes that had the most distinct starch granules and therefore the least swelling.

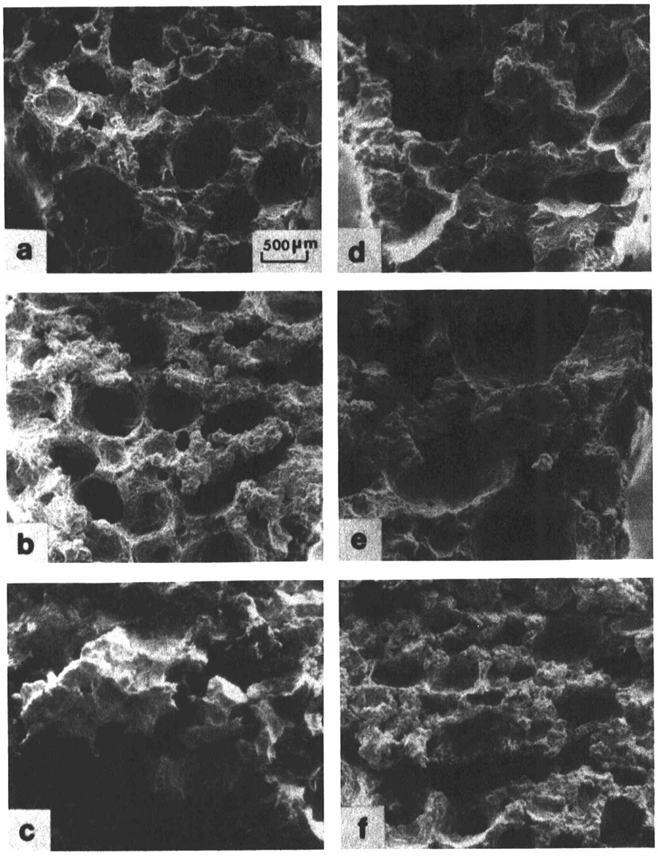

Fig. 5. Scanning electron micrographs of thermally heated cake crumb made with different types of sugars and emulsifiers: **a,** crystalline sucrose; **b,** crystalline sucrose with saturated monoglyceride (SMG); **c,** crystalline sucrose with unsaturated monoglyceride (USMG); **d,** sucrose solution; **e,** sucrose solution with SMG; **f,** sucrose solution with USMG.

CONCLUSIONS

The temperature profile results showed a larger temperature spread between probe locations for microwave-heated cakes than for thermally heated cakes under the experimental conditions used in this study.

The results on batter specific gravity, cross-sectional area, and symmetry showed that the USMG had the greatest effect on air incorporation during formulation; that microwave heating re-

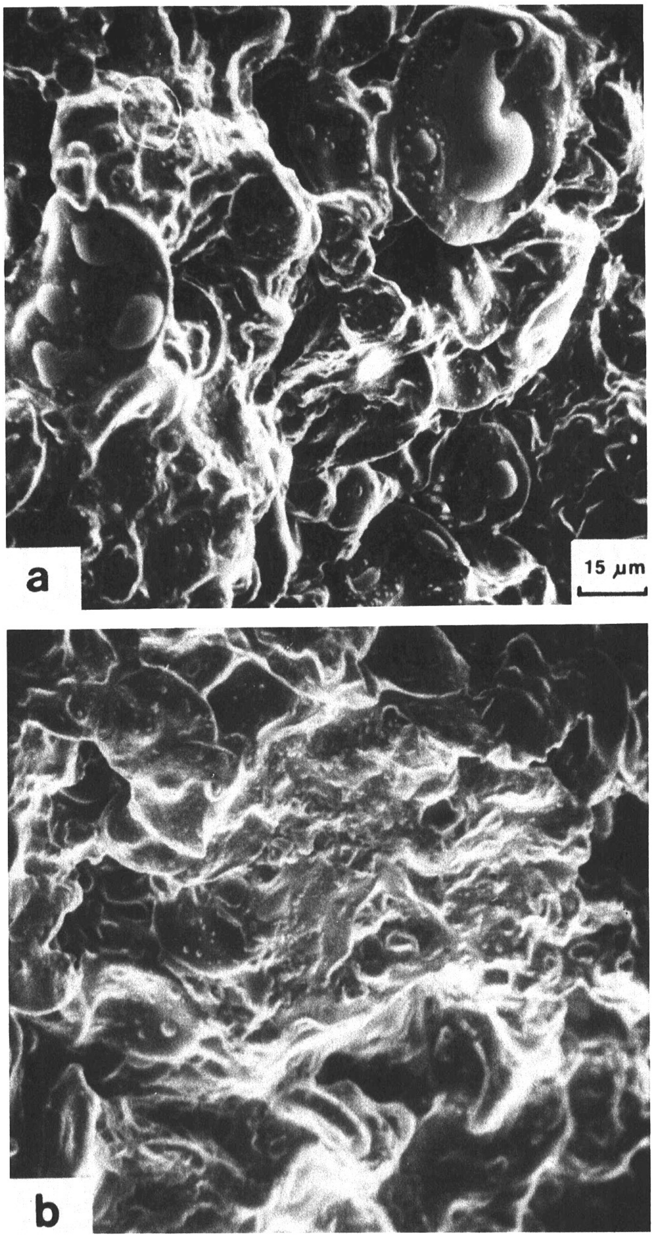

Fig. 6. Representative scanning electron micrographs of cake crumb for: **a,** distinctly delineated starch granules (thermally heated, containing crystalline sucrose, measured at center position) and **b,** starch granules that are not as distinct with a more fully developed matrix (microwave-heated, containing sucrose solution, measured at edge position).

sulted in lower final weight loss regardless of sucrose type or emulsifier used; that the cross-sectional area was greatest for microwave and thermally heated USMG-emulsified cakes, as well as for cakes containing crystalline sucrose regardless of emulsifier; and that USMG-emulsified cakes gave the most uniform cakes across heating and sucrose type, while SMG cakes gave the same results for all cakes except those heated thermally with sucrose solution.

Furthermore, the scanning electron micrographs showed that air cell structure was most uniform for crystalline sucrose cakes heated by microwave energy. The cakes formulated with sucrose solution appeared most variable between emulsifiers. Also, starch granules appear more swollen and the matrix is more fully developed for all sucrose-solution microwave-heated cakes. Also, cakes formulated with USMG (*trans*) gave the most distinct starch granules and the least differences between mode of heat and form of sucrose incorporation.

LITERATURE CITED

ABBOUD, A. M., and HOSENEY, R. C. 1984. Differential scanning calorimetry of sugar cookies and cookie doughs. Cereal Chem. 61:34-37.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS 1976. Approved Methods of the AACC. Method 10-91, approved April 1968. The Association, St. Paul, MN.

BAKER, B. A., DAVIS, E. A., and GORDON, J. 1990. Glass and metal pans for use in microwave- and conventionally heated cakes. Cereal Chem. 67:448-451.

BEAN, N. M., and YAMAZAKI, W. T. 1978. Wheat starch gelatinization in sugar solutions. I. Sucrose: Microscopy and viscosity effects. Cereal Chem. 55:936-944.

BEAN, M. M., YAMAZAKI, W. T., and DONELSON, D. H. 1978. Wheat starch gelatinization in sugar solutions. II. Fructose, glucose and sucrose: Cake performance. Cereal Chem. 55:945-952.

BIRNBAUM, H. 1978. Surfactants and shortenings in cake making. Baker's Dig. 52:28-38.

BUDDENMEYER, B. D., MONEYMAKER, J. R., and MEYER, N. C. 1962. Single and multiple emulsifier systems in a fluid shortening. Cereal Sci. Today 7:266-270, 284.

CARLIN, G. T. 1944. A microscopic study of the behavior of fats in cakes. Cereal Chem 21:189-199.

CLOKE, J. D. 1981. The role of monoglycerides in cakes. Ph.D. thesis, University of Minnesota, St. Paul, MN.

CLOKE, J. D., GORDON, J., and DAVIS, E. A. 1982. Freeze-etch of emulsified cake batters during baking. Food Microstruct. 1:177-187.

CLOKE, J. D., DAVIS, E. A., and GORDON, J. 1984a. Relationship of heat transfer and water-loss rates to crumb-structure development as influenced by monoglycerides. Cereal Chem. 61:363-371.

CLOKE, J. D., DAVIS, E. A., and GORDON, J. 1984b. Water loss during reheating of fresh and stored cakes made with saturated and unsaturated monoglycerides. Cereal Chem. 61:371-374.

DAVIS, E. A., and GORDON, J. 1982. Food microstructure: An integrative approach. Food Microstruct. 1:1-12.

DEL VECCHIO, A. J. 1975. Emulsifiers and their use in soft wheat products. Baker's Dig. 49:28-35, 52.

DONOVAN, J. W. 1979. Phase transitions of the starch-water system. Biopolymers 18:263-275.

EVANS, J. E. 1982. Quality characteristics of cakes baked in a convection microwave oven. M.S. thesis, University of Minnesota, St. Paul, MN.

GHIASI, K., HOSENEY, R. C., and VARRIANO-MARSTON, E. 1983. Effects of flour components and dough ingredients in starch gelatinization. Cereal Chem. 60:58-61.

GORDON, J., DAVIS, E. A., and TIMMS, E. M. 1979. Water loss rates and temperature profiles of cakes of different starch content baked in a controlled environmental oven. Cereal Chem. 56:50-57.

GUY, E. J., and VETTEL, H. E. 1973. Effects of mixing time and emulsifier on yellow cakes containing butter. Baker's Dig. 47:43-48.

HANDELMAN, A. R., CONN, J. F., and LYONS, J. W. 1961. Bubble mechanics in thick foams and their effects on cake quality. Cereal Chem. 38:294-305.

HESTER, E. E., BRIANT, A. M., and PERSONIUS, C. J. 1956. The effect of sucrose on the properties of some starches and flours. Cereal Chem. 33:91-101.

HOWARD, N. B. 1972. The role of some essential ingredients in the formation of layer cake structures. Baker's Dig. 46:28-37, 64.

KROG, N. 1971. Amylose complexing effect of food grade emulsifiers. Starch/Staerke 23:206-210.

KROG, N. 1977. Functions of emulsifiers in food systems. J. Am. Oil Chem. Soc. 54:124-131.

KROG, N. 1981. Theoretical aspects of surfactants in relation to their use in breadmaking. Cereal Chem. 58:158-164.

KROG, N., and BORUP, A. P. 1973. Swelling behavior of lamellar phases of saturated monoglycerides in aqueous systems. J. Sci. Food Agric. 24:691-701.

KROG, N., and LAURIDSEN, J. B. 1976. Food emulsifiers and their associations with water. Pages 67-139 in: Food Emulsions. S. Friberg, ed. Marcel Dekker, Inc., New York.

LAGENDIJK, J., and PENNINGS, H. J. 1970. Relation between complex formation of starch with monoglycerides and the firmness of bread. Cereal Sci. Today 15:354-356, 365.

MILLER, B. S., and TRIMBO, H. B. 1965. Gelatinization of starch and white layer cake quality. Food Technol. 19:208-216.

MIZUKOSHI, M. 1985a. Model studies of cake baking. V. Cake shrinkage and shear modulus of cake batter during baking. Cereal Chem. 62:242-246.

MIZUKOSHI, M. 1985b. Model studies of cake baking. VI. Effects of cake ingredients and cake formula on shear modulus of cake. Cereal Chem. 62:247-251.

MIZUKOSHI, M., KAWADA, T., and MATSUI, N. 1979. Model studies of cake baking. I. Continuous observations of starch gelatinization and protein coagulation during baking. Cereal Chem. 56:305-309.

MIZUKOSHI, M., MAEDA, H., and AMANO, H. 1980. Model studies of cake baking. II. Expansion and heat set of cake batter during baking. Cereal Chem. 57:352-355.

MONTGOMERY, D. C. 1984. Design and Analysis of Experiments. John Wiley & Sons, Inc., New York.

NGO, W. H., and TARANTO, M. V. 1986. Effect of sucrose level on the rheological properties of cake batters. Cereal Foods World 31:317-322.

OSMAN, E. M. 1975. Interaction of starch with other components of food systems. Food Technol. 29:30-35, 44.

SHEPHERD, I. S., and YOELL, R. W. 1976. Cake emulsions. Pages 215-275 in: Food Emulsions. S. Friberg, ed. Marcel Dekker, Inc., New York.

SPIES, R. D., and HOSENEY, R. C. 1982. Effect of sugars on starch gelatinization. Cereal Chem. 59:128-131.

WOOTTON, J. C., HOWARD, N. B., MARTIN, J. B., McOSKER, D. E., and HOLME, J. 1967. The role of emulsifiers in the incorporation of air into layer cake batter systems. Cereal Chem. 44:333-343.

WOOTTON, M., and BAMUNARACHCHI, A. 1980. Application of differential scanning calorimetry to starch gelatinization. III. Effect of sucrose and sodium chloride. Starch/Staerke 32:126-129.

[Received August 8, 1989. Accepted March 29, 1990.]