CAKE STRUCTURE AND PALATABILITY AS AFFECTED BY EMULSIFYING AGENTS AND BAKING TEMPERATURES

by

MARTHA ELIZABETH JOOSTE

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APPROVED:

Associate Professor of Foods and Nutrition

In Charge of Major

Head of Department of Foods and Nutrition

Chairman of School Graduate Committee

Dean of Graduate School

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

CAKE STRUCTURE AND PALATABILITY AS AFFECTED BY EMULSIFYING AGENTS AND BAKING TEMPERATURES

INTRODUCTION

The physical character of a cake batter is established by the physico-chemical properties of the component parts, the mechanical treatment they have received and the activity of surface forces present.

The nature of a system resulting from the summation of so many influences lends itself to a great deal of speculation.

Microscopic studies of batters have shown that they are two-phase systems, one phase being the fat, and the second phase consisting of all the other ingredients of the mixture. Fat may be seen dispersed throughout the batter in the form of irregularly shaped particles. Within each particle of fat there are enclosed numerous small bubbles of air, incorporated during the mixing operation (2, p.276). Hence a cake batter containing fat and eggs has been referred to as a complex food emulsion (27, p.1196).

The recognition of the emulsion nature of cake batters has stimulated efforts to improve batter structure and hence cake quality through the use of emulsifying agents.

Reports in the literature indicate that when small percentages of certain emulsifying agents such as mono- and diglycerides of fatty acids are added to high sugar ratio cakes, a finer grain, improved effect on tactile senses and increased volume are obtained.

It has also been suggested that batters containing these glycerides show a marked resistance to variable conditions of baking and handling.

The purpose of this study was to determine the effect of monoglycerides on structure and palatability, when cakes were baked at various oven temperatures.

REVIEW OF LITERATURE

Cake Batters Classified as Emulsions

It has been suggested that a cake batter may exist as an oil-in-water emulsion (28, p.417) (2, p.284) (10), a water-in-oil emulsion (10), or as a foam structure of air in fat distributed in a medium of flour and liquid (24, p.51).

Carlin, after various studies of the behavior of fats in cake batters, was convinced that a continuous water-in-fat emulsion did not exist. He observed that the fat was distributed through the batter in the form of small clumps or lakelike areas. The clumps of fat held in suspension all of the air which the batter contained, while the continuous field was the aqueous phase with its dissolved sugar, salt, baking powder, and its suspended flour and eggs (5, p.191). He concluded that little, if any, liquid appeared to be emulsified in the fat, and that the air spaces were invariably surrounded by fat. "During baking, the fat quickly melts and releases its suspended air to the flour-water medium. Gas produced by baking powder finds its way into the air spaces already existing within the batter" (5, p.198).

It seems therefore acceptable to regard cake batters as oil-in-water emulsions.

Separation or Breaking of a Cake Batter

Various observations have been made on the breaking of the batter emulsion during mixing and its effect on the finished cake.

Kenny has stressed the fact that one of the essentials in the preparation of cake mixes should be to obtain a good emulsion--whether prepared by either the flour-batter or sugar-batter method (28, p.417). He said, "Sometimes this is not always achieved, as is illustrated by the phenomenon encountered when a batter curdles as a result of the addition of eggs either too quickly or at too low a temperature." Lowe noticed that with the modified conventional method, when egg, fat and sugar were creamed at the same time, the creamed mass was more likely to separate into fine curds than when the egg was added slowly as in the conventional method. Yet if the curds remained fine, cakes of excellent texture could be obtained (31, p.495).

Nason found that if a small amount of boiling water, one tablespoon per cup of flour in the formula, was added to the sugar and fat, the emulsion of water in fat formed more readily. This emulsion of water in fat broke when the amount of water was increased beyond a certain point. This breaking was characterized by a curdled appearance, and to prevent it some authorities recommended mixing in of some of the flour before the addition of any liquid. Nason commented, "It is believed by some that poorer cakes are made from batters in which the emulsion breaks. This belief has not been disputed to any extent and is worthy of proof," (34, p.166).

Grewe thought curdling was undesirable for it was a well established fact in the baking industry that cakes made from batters which break are less satisfactory than those made from batters which do not break (17, p.818).

When batters which were made with ordinary hydrogenated shortening had a water content greater than 110 per cent on the flour basis, a distinct tendency to "curdle" was noted. This occurred regardless of whether the batter was mixed by either the creaming or the single-stage method. Such batters yielded cakes of lower volume, coarser grain, and somewhat harsher, rubbery texture. If in the single-stage method enough water was kept out, so that a smooth batter could be first built up, the batter was sufficiently stable to tolerate the remaining liquid without excessive curdling, and excellent results were obtained (38, p.336-339).

Hunter (23, p.105-109) observed a slight separation (break or curdle) in batters containing margarine and lard as well as in those containing hydrogenated shortening (containing two per cent emulsifier). The most severe break was observed in margarine batters. In general, she observed that uniform distribution of the fat was associated with stable batters, while marked laking of the fat was associated with broken or curdled batters. This instability, as evidenced by curdling, was attributed to poor dispersion of the fat in the batter. It was not conspicuously reflected in cake grain, although the cakes had smaller volume than cakes from comparable non-broken batters. (23, p.150)

These observations lead to the conclusion that severe curdling of the batter has a detrimental effect, whereas slight curdling may have little effect on cake quality.

Emulsifying Agents to Promote Dispersion of Fat

The stability of cake batters can be improved by emulsifying agents. These promote a better dispersion of the shortening throughout the water phase of the batter (27, p.1196).

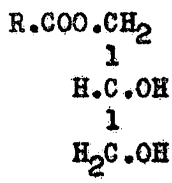
One of the functions of the egg used in cake batter is that of an emulsifying agent (2, p.284). This property of eggs is due to the lecitho-protein complex present in the yolk (40, p.1222). The fatty-acid groups in the lecithin molecule are fat-soluble, whereas the choline-phosphoric acid group is water-soluble (41, p.33). These groups are bound together as represented in the following formula:

```
CH2.OOC.R
l
CH.OOC.R
l
l        O
l        ll
CH2  O.P.O.C2H4N(CH3)3
         l        l
         OH       OH
```

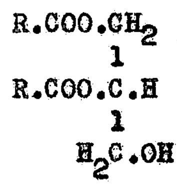
The importance of emulsifying agents in promoting dispersion of fat has led to the use of various surface-active agents to improve the yield and quality of commercially produced shortened cakes. Chemically, surface active agents are compounds in which one portion of each molecule is hydrophilic and another is lipophilic. Most commercially available food emulsifiers are compounds known chemically as esters. They are combinations of long-chain fatty acids, such as stearic, palmitic, or oleic, with one of the higher alcohols, such as glycerol or sorbitol. These esters differ from fats (triglycerides of fatty acids) in that not all of the available alcohol linkages are taken up by the fatty acids. Therefore, a compound is produced which has affinity for both fat and water, a property that promotes or improves an emulsion (37, p.2).

Synthetic emulsifiers can be classified in three general groups, as follows: (1) A mixture of monoglycerides and diglycerides; (2) esters of fatty acids and sorbitol, or higher alcohols; and (3) polyoxyalkylene derivatives of group 2 (37, p.2).

(1)

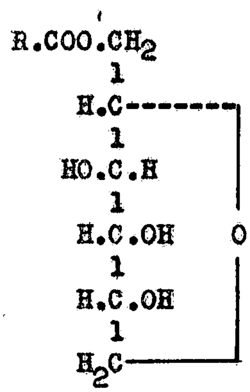


Monoglyceride



Diglyceride

(2)



Ester of fatty acid and sorbitol

(3)

```
              R.COO.CH2
                    1
                  H.C-------|
                    1       |
                 HO.C.H     |
                    1       |
H.(O.CH2.CH2)nO.C.H         O
                    1       |
H.(O.CH2.CH2)nO.C.H         |
                    1       |
                 H2C--------|
```

Ester of fatty acid and
polyoxyalkylene derivative of sorbitol

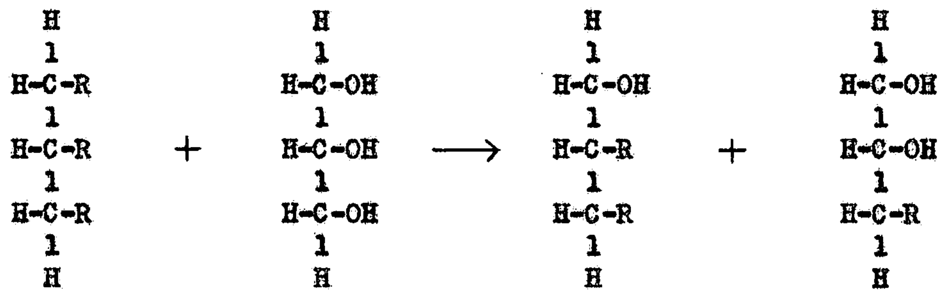
It is assumed that emulsifying agents act to lower the interfacial tension between two liquids by concentrating at the interface. If the surface tension at the interface water-emulsifier is less than at the interface oil-emulsifier, the film will tend to bend so as to become convex on the water side, thereby encouraging the formation of an oil in water emulsion. On the other hand, if the surface tension at the interface water-emulsifier is greater than at the interface oil-emulsifier, the film will be inclined to curve so as to become concave on the water side, thereby tending to give an emulsion of water in oil (43, p.337).

In ice cream mixes, emulsifying agents, through reducing the interfacial tension retard the clumping of the fat globules. It is also believed that, with the orientation of the emulsifiers at the fat surface and their affinity for water, a certain amount of water is combined with the emulsifier, thereby reducing the free water in the mix (37, p.3). Coughlin stated that special cake shortenings with particularly good emulsifying properties help in carrying the liquid in the cake mixture (12, p.2).

Superglycerinated Shortenings

Shortenings have lately been introduced which contain more powerful synthetic emulsifying agents than eggs which have heretofore been the chief agent used to promote dispersion of the fat in baked products. "These so called 'superglycerinated' shortenings contain mono- and diglycerides which are extremely effective in promoting and stabilizing emulsions of both the water-in-oil and oil-in-water types. While the effectiveness of mono- and diglycerides in cake doughs is explainable in terms of conventional theories of emulsification, on the basis of their content of hydrophilic (hydroxyl) and lipophilic (fatty acid) groups, it is nevertheless somewhat surprising that they are so much more efficient than a number of other emulsifying agents. There are other edible emulsifiers, such as soybean lecithin, which are very effective in lowering the interfacial tension of fat against water, but none of these is capable of conferring satisfactory emulsifying properties upon baking fats," (2, pp.285-286).

Mono- and diglycerides are easily prepared synthetically by the esterification of glycerol with higher fatty acids (20, p.17). In the simplest terms, the reaction between a triglyceride (fat) and glycerol may be represented as follows: (2, p.678)



Triglyceride Glycerol Diglyceride Monoglyceride

In the presence of an alkaline catalyst, the reaction product is a mixture of monoesters, diesters and triesters as well as free glycerol, free fatty acid and the catalyst in the form of metallic soaps (29, p.310).

Importance of Emulsifiers in High Ratio Cakes

A high ratio of soluble solids to water in cakes can give prolonged resistance to mold growth and inhibits staling (15, pp.771-772). That an increase in the ratio of sugar to flour, together with an increase in the water content, also resulted in a sweeter, moister, more tender cake was pointed out by Harris et al. (18, p.181). However, an increase in the sugar content, with the accompanying increase of moisture content, yielded a cake which would shrink or fall objectionably after being removed from the oven. When interface modifiers of the proper type, such as mono- or diglycerides or fatty acid esters of polyglycerols, were incorporated in the batter, the ratio of sugar to flour and the water content could be increased. A better cake was produced in all respects, particularly with regard to keeping quality and volume. The interface modifiers could be incorporated in the shortening, in the egg constituent, in prepared cake flours or in baking powder (18, p.181).

Daum et al. (13, p.39) pointed out that the role of emulsifiers in baked products for the most part appeared to be that of a stabilizer. Such "addition agents" produced an unusually smooth, well-combined batter, with a capacity for carrying relatively large amounts of sugar and moisture, and with a marked resistance to variable conditions of baking and handling. The main beneficial effect of such addition agents, according to Daum et al., was to decrease markedly the customary tendency of such cakes to shrink during baking and cooling. This was especially of interest for cakes made with high proportions of sugar and/or liquid to flour. These high ratio cakes were preferred by bakeries on account of their advantages over ordinary cakes in volume, color, texture, flavor, grain, keeping quality and cost. In testing glyceryl monostearate with different types of shortening, they found the most obvious distinguishing characteristic of the monostearate cakes as compared with the corresponding standard ones was their increased volume (13, p.41).

Carlin prepared cakes with hydrogenated shortening and similar shortening containing varying percentages of mono- and diglyceride emulsifying agent. "Macroscopically the batters appeared 'curdled' without the presence of emulsifying agent. Added quantities of emulsifying agent (up to 10 per cent of the total shortening) overcame this curdled appearance and developed a thin but smooth batter. The viscosity of the batter decreased with each added quantity of emulsifying agent; the batter specific gravity increased, the cake volume increased, and the fat lake areas became more finely dispersed," (5, p.191).

Bailey (2, pp.286-287) has stated that with ordinary fats it is not possible to produce a good cake dough if the combined amount of milk and sugar in the formula amounts to more than 40-45 per cent of the total ingredients; for the difficulty of maintaining the fat in sweet dough in a highly dispersed condition increases with increasing water and sugar content of the dough. With the use of high ratio shortenings it is possible to increase the milk and sugar to as much as 50-55 per cent of the total. In these batters the fat appears much more dispersed than in the batters made with ordinary all-hydrogenated shortening.

Fats are capable of absorbing and holding considerable quantities of water without benefit of an emulsifying agent, owing to their plasticity and more or less rigid structure. Compound-type shortenings consisting principally of unhydrogenated oil will absorb 20-50 per cent of water at 70°F., whereas high ratio shortenings will emulsify 400 per cent. The significance of the water holding capacity of a fat has not yet been demonstrated.

The Use of Glyceryl Monostearate as an Emulsifier

Glyceryl monostearate $C_{17}H_{35}COO.CH_2.CHOH.CH_2OH$ is an edible, white to cream colored, waxy solid, having a faint odor. The commercial product melts at 55-58°C. It is insoluble in water but is dispersible in hot water. It is slightly soluble in cold and very soluble in hot alcohol, and hot vegetable oils. Chemically pure glyceryl monostearate has a specific gravity of 0.984 and melts at 81°C. (25, p.253). It has been used widely in shortened cakes. One of the advantages in its use is that the ratio, sugar/flour, can be increased from 100/100 to 140/100, as a direct result of the increased dispersion of the fat to a very high degree, with a proportionate increase in the mechanical strength of the emulsion. Because of this additional emulsion strength, the aqueous liquid content, and consequently the sugar content, of the cake batter can be increased with no increased tendency for the cake to fall during baking (25, p.252).

The Glyco Products Co. Inc., Brooklyn, New York produces an edible glyceryl monostearate to be used with cake or bread under the trade name Aldo 33. It is distinguished by its fine granulated bead form which permits mixing with other ingredients with a minimum expenditure of processing effort and time. The manufacturers have pointed out the following advantages: the use of Aldo 33 by either bread or cake bakers assures the user of thorough distribution of all formula ingredients; makes possible extended retention of moisture and contributes to maximum cohesion of ingredients, thereby improving keeping quality; makes possible assured volume and fine cell structure without affecting flavors of basic allied ingredients. Aldo 33 is mixed with hot water in the proportion 3:7 to create a dispersion that is later used in conjunction with the shortening (16, p.2-3).

The manufacturers also state that biological tests have shown that glycoryl monostearate is formed in the human digestion of fats and oils. This formation takes place in the small intestine where it aids in the emulsification and assimilation of fats and oils by the body (16, p.2).

Microscopic Studies of the Fat Dispersal Pattern of Batters

The distribution of fat in a batter has been studied microscopically by several investigators. The photomicrographs produced by Bailey and McKinney showed the fat with occluded air distributed through the batter in clumps (3, p.121). In a later investigation, Bailey showed that if superglycerinated shortening is used instead of all-hydrogenated shortening a much better dispersion of fat is obtained (2, p.286).

Dispersion of hydrogenated shortening (containing 2 per cent monoglyceride) varied with the method of mixing, as demonstrated by Hunter et al. By the conventional method of mixing there was little tendency for aggregation, while with the pastry-blend method this tendency was apparent. The pattern of fat dispersion in margarine batters was characterized by aggregation of the fat resulting in distinct clustering of the air cells. This aggregation was more severe in batters prepared by the pastry-blend than by the conventional method of mixing. The clumping of the fat with the occluded air cells made it difficult to obtain thin smears. The dispersion pattern of lard batters differed radically from that of either hydrogenated-shortening or margarine batters. The lard was for the most part distributed in a continuous film. (24, p.36-37)

From their observations on the structure of the batters and on the quality of the corresponding cakes, Hunter et al. concluded that both a good foam structure and the dispersion of the fat in fairly fine lakes were important in the production of high-quality cakes. (24, p.51)

Carlin demonstrated with white layer cake batter that with each increase of emulsifying agent from 0.5 to 9 per cent the number of fat lakes increased per unit area and each fat clump decreased in size. The photomicrographs of the batters containing no emulsifier showed the fat distributed in the form of fat lakes or clumps, whereas those batters containing 9 per cent monoglyceride showed a very fine dispersal of fat. When these batters were baked the cake volume reached a maximum after the 5 per cent level was reached and at 8 to 9 per cent the cake volume began to decline, indicating a detrimental effect when fat is dispersed in too fine a pattern. He also noticed that lard dispersed throughout the cake batter in a much finer pattern than that of hydrogenated shortening. In fact the dispersal pattern of lard was somewhat similar to that obtained with hydrogenated fats containing emulsifying agents. There was one important difference: the quantity of air which was suspended in the fat lakes was reduced when lard was used as the shortening agent. The fine dispersion pattern explained to him why lard gave much better results on the richer type (140 per cent sugar) layer cakes than did regular hydrogenated shortening which contained no added emulsifier. Conversely, the ability of lard to suspend air cells was increased when the fat dispersal pattern became coarse. (5, p.195)

The Term "Emulsion" as Applied to Cake Batters

Although the term "emulsion" has been used by many people in their discussion of cake batters, the use of this term may be open to question. An emulsion has been defined as a dispersion of one liquid in a second liquid, a liquid/liquid system (21, p.123).

Hartman explained that, "An emulsion has been classified as a lyophobic colloidal system wherein the particles making up the internal phase consist of globules of a liquid which is immiscible with the liquid external phase. In general, however, the internal-phase particles of emulsions exceed in size the usually accepted limits of the colloidal range and are visible with an ordinary microscope" (19, p.326).

Since most cakes are prepared with semi-solid fats, Hunter felt that this involves a rather free interpretation of the term emulsion, when applied to cake batters (23, p.28).

Sutheim also raised the question whether such systems as milk and oleomargarine could be classified as emulsions, as they were not made up of two liquids in the true sense of the word.

Milk, for instance, has a liquid external phase, but the internal phase, the butter fat, is a solid rather than a liquid. In the case of oleomargarine the external phase consists of more or less solid fats, whereas the internal phase is a liquid. The difficulty in deciding whether to classify systems like those mentioned above as emulsions or suspensions arises from an inadequate definition of a liquid. Whereas the transition from gas to liquid is fairly sharp, there are innumerable intermediates between the liquid and the solid state. Highly viscous liquids, pastes, gels and plastic solids belong in this group (7, p.290).

If the term liquid were understood to include such borderline states as plastic solids, this may justify the classification of cake batters made with plastic fats as emulsions.

Importance of a Good Foam in Producing Good Quality Cakes

Of the two batter characteristics which appeared to be associated with cake quality, namely, good foam structure and fairly uniform pattern of ingredient dispersion, Hunter thought the foam structure was of greater importance (23, p.167).

Other investigators have also realized the importance of a foam or air in shortened cake batters. Dunn and White illustrated the importance of air in a pound cake batter by evacuating the air present in the batter. When there were no air cells into which the moisture could evaporate, the volume increase during baking was zero (14, p.99). That air should be present before the water vapor can function as a leavening gas in shortened cakes, was substantiated by Hood and Lowe (22, p.253). Dunn and White further observed that the incorporation of air in commercial shortenings improved the texture and volume of cakes, and reduced the time required for proper creaming (14, p.100).

"Creaming" in cake making indicates the formation of an air-in-fat foam and a water-in-fat emulsion (17, p.802). Since air cannot be incorporated into oils or melted fats, Lowe concluded that the plastic fats were preferable for cake making. She believed that "creaming quality" was important and was closely related to velvety texture and high cake scores (31, p.490). Her photomicrographs showed that the batters of cakes of excellent texture had small gas bubbles with even distribution, whereas batters of coarser textured cakes had irregular grouping of the gas bubbles of different sizes (31, pp.492-493).

Bailey and McKinney (3, p.120) recognized the ability of a fat to cream, or incorporate air, as a highly important factor in determining its quality as a cake shortening. The rationalization of the matter of air incorporation, according to them, rests upon a comparatively simple discovery; viz., "that the only ingredient in a cake mix, exclusive of the foam-type cakes, sponge and angel food, that is active in entrapping air is the shortening." Their photomicrographs of shortened batters show that the incorporated air appears in the form of numerous small, round bubbles, and that these appear exclusively in the fat.

The writers found good shortenings to incorporate a maximum of about 270 per cent air when creamed with granulated sugar in the most favorable proportions (about two parts by weight of shortening to three parts of sugar). The air is usually carried to 150-200 per cent in the first mix of sugar and shortening, and the remainder of the air beaten in after the addition of the eggs. The presence of eggs increases the ability of the shortening to absorb air; after they are added the air-content will rise to 300-375 per cent. Some air is always lost when the milk and flour are added, so that finished yellow-cake doughs usually contain 275-350 per cent of air on the basis of the shortening.

When cakes were made with oil, a stiff, stable sponge of egg and sugar stirred in at the end of the mixing process was the most important factor in determining cake quality (35, p.215). Ohlrogge and Sunderlin further noticed that in the batters of high-scoring cakes, the oil appeared to be in the form of many very small globules, and numerous vary small gas bubbles were present. The batters of low-scoring cakes had more large oil globules and fewer gas bubbles (35, p.215).

The importance of a good foam therefore has been amply demonstrated.

The Effect of Baking Temperature on Shortened Cake

A baking temperature of 185°C. was found to produce the best plain cake. Coarse-grained cakes were obtained at 155 and

165°C., and finer-grained, close-textured cakes resulted when cakes were baked at 185° and 195°C. (45, pp.25, 28).

For chocolate cakes an increase in cake volume with increase in baking temperature was obtained, for temperatures ranging from 175 to 225°C., though there was little difference in the mean volumes for cakes baked at 215 and 225°C. Palatability scores were also directly proportional to baking temperature.

Angel food cake baked at 180°C. was more tender than cakes baked at 149°C., and Barmore (4, p.14) believed that this might be due to increased cake volume and was not caused by any effect on the material itself.

Lowe concluded, from work done on cake in her laboratory, that with higher sugar contents, improved texture and palatability resulted from baking at temperatures higher than 185°C. (31, p.488).

It seems therefore that a baking temperature above 185°C. is to be recommended, especially for high sugar ratio cakes. No work has been published to show whether this also holds for a cake batter containing emulsifying agents.

PROCEDURE

Two types of fat, butter and a hydrogenated vegetable oil, with and without added emulsifier were tested in cakes baked at four different temperatures. The emulsifier, glyceryl monostearate, was prepared for use as a water dispersion and as a fat dispersion, each being used at two levels.

Six cake batters were mixed each day, following a randomized order of preparation. Five were experimental cakes and the sixth one was a control to be used as a standard during scoring by the judges.

Immediately after a batter was made, two cakes were weighed and baked. While cakes were baking, specific gravity determinations were made on the batter remaining in the mixing bowl, and slides were prepared for microscopic study of batter structure.

Data were collected on baked cakes as follows: weight loss during baking, cross section areas as an index to volume, subjective scores, and microscopic structure.

Formula and Method of Mixing

The formula and method of mixing employed had been developed for studies of fat behavior in cake (36).

Basic Cake Formula

Ingredient	Weight grams	Directions
Fat	45.0	Save 25 ml. water, to be added to creamed fat plus sugar and vanilla.
Milk, dried whole	13.0	
Water, distilled	80.0	Save baking powder out to be added near the end of the mixing.
Flour, cake	100.0	
Sugar	120.0	Dry ingredients: sifted flour, dry milk and salt.
Baking powder, tartrate	3.75	
Egg yolk	12.0	Liquid ingredients: egg yolk plus water, 55 ml.
Egg white	20.0	Whip egg white until stiff, add near the end of the mixing.
Salt	0.7	
Vanilla, 1 teaspoon		

Method of Mixing

Steps	Ingredient	Speed	Time
1	Sugar, fat and vanilla. Scrape bowl after each two minutes.	6 (410 rpm)	8 min.
2	Add 25 ml. water.	1 (137 rpm)	1 min.
3	Scrape, add $\frac{1}{2}$ dry and $\frac{1}{2}$ liquid ingredients. Scrape bowl after each 25 seconds.	1	50 sec.
4	Add remaining dry and liquid ingredients.	1	25 sec.
5	Scrape bowl, add baking powder.	1	25 sec.
6	Scrape, add beaten egg white, scrape bowl after each 15 seconds.	1	1 min.

When an emulsifier was used, adjustments were made in both liquid and fat. The weight of fat was reduced by the weight of emulsifier added. In the case of the water-dispersed emulsifier, the water added during mixing was decreased by the amount of water present in the emulsifier. Thus, fat plus emulsifier and liquid were kept at the same level as fat and liquid in the original formula.

TABLE I

Formula Adjustments for Addition of Emulsifier

Emulsifier Name	Emulsifier (fat basis)	Formula Changes			
		Decrease in fat	Total fat used	Decrease in water	Water added during mixing of batter
	%	grams	grams	ml.	ml.
Aldo 33	3	1.35	43.65	3.15	76.85
Glyceryl monostearate "S"	3	1.35	43.65	----	80.00
Aldo 33	6	2.70	42.30	6.30	73.70
Glyceryl monostearate "S"	6	2.70	42.30	----	80.00

During the preparation of the batters, the temperature of the room was maintained at 25°C. During the test period the barometric pressure varied between 29.29 and 30.06 inches. Mixing times given in the formula were controlled by using a stopwatch.

Baking

120 grams of batter were weighed into each of two pans and the weights recorded. The two batters were baked simultaneously. After

baking, which required different lengths of time for the various oven temperatures, the cakes were allowed to cool in the pans, weighed, and the loss in weight recorded. A small impression was made on the side of the cake that had been closest to the oven door, so that like sections of cake could be matched for comparative studies. The tins were then covered with tight fitting lids until all the cakes for one day were baked and the objective and organoleptic tests could be made.

The baking temperatures used were: 425°F. (218.3°C.), 375°F. (190.6°C.), 325°F. (163.2°C.) and 300°F. (148.9°C.).

Establishment of Baking Time

For the basic formula employed and 120 grams of batter in an eight ounce pan the optimum baking temperature and time were found to be 375°F. (190.6°C.) and 19 minutes (36). (Altitude: approximately 150 ft.) A thermocouple placed in the center of such a cake registered a maximum internal temperature of 230°F. (110°C.). When cakes were baked at 425°F. (218.3°C.) an internal temperature of 230°F. (110°C.) was reached after 13½ minutes. The amount of shrinkage and degree of caramelization of the crust indicated that this baking time was optimum at this temperature.

With a baking temperature of 325°F. (163.2°C.) an internal temperature of 221°F. (105°C.) was reached after 26 minutes, with no change in temperature during further baking. When baked 26 minutes the crust did not show any sign of caramelization. To acquire this it was desirable to leave the cakes in the oven for seven more minutes. Thirty-three minutes were therefore considered to be an optimum baking time for cakes baked at 325°F. (163.2°C.).

The cakes that were baked at 300°F. (148.9°C.) reached an internal temperature of 221°F. (105°C.) after 45 minutes, after which the temperature remained almost constant. To develop a better crust color and reduce stickiness, another 17 minutes were allowed. These cakes were therefore baked for 62 minutes.

TABLE II

Maximum Internal Temperature and Time Required to Bake Cakes at Four Oven Temperatures

Baking Temperature	Maximum Internal Temperature	Baking Time minutes
425°F. (218.3°C.)	230°F. (110°C.)	13.5
375°F. (190.6°C.)	230°F. (110°C.)	19.0
325°F. (163.2°C.)	221°F. (105°C.)	33.0
300°F. (148.9°C.)	221°F. (105°C.)	62.0

The difference in maximum internal temperature has also been mentioned by Barmore who worked with angel food cake. He found that an increase in oven temperature of 40°C. produced an increase in internal temperature of 2°C., and that an increase in baking period of 15 minutes raised the temperature no more than 1°C. (4, pp.14-15).

Ingredients

All ingredients except the eggs, which were obtained fresh weekly, were secured in quantities sufficient to last throughout the study. These included: cake flour,[1] table salt, cream of tartar baking powder, vanilla extract, granulated cane sugar, butter, hydrogenated vegetable shortening which contained no added emulsifier,[2] and powdered whole milk.

All were stored at room temperature except the butter and powdered milk, which were stored in a freezer at -15°F., and the eggs which were stored at refrigerator temperature.

All ingredients except the vanilla, water and eggs were weighed, then incubated in a thermostatically controlled box at a temperature of 25°C. for approximately twelve hours before mixing. Distilled water was kept in the incubator, and was measured when needed in a graduated cylinder. Eggs were prepared in quantities sufficient for one day's tests. The whites and yolks were blended separately by slow turns of a rotary egg beater.

The emulsifying agents used were commercially manufactured glyceryl monostearates. One was a flaked product, designated as "Glyceryl monostearate S", the other was in a fine bead form, and was called "Aldo 33". The latter had a melting point of 138-140°F.,

1. Swans Down
2. Primex, Procter and Gamble Company

and formed a stable water dispersion in relatively high (about 25%) concentrations.

In order to distinguish between the two emulsifying agents, the Glyceryl monostearate "S" will henceforth be abbreviated, GMS, and glyceryl monostearate (Aldo 33) dispersed in water will be designated, Aldo.

The water dispersion was obtained by heating seven parts of water to 200°F. and gradually mixing in three parts of Aldo 33. Stirring was continued until the temperature of the mixture fell to 100°F. or lower. The resultant product, which resembled soft shortening, was stored in a jar in the refrigerator and weighed out as required.

A fat dispersion of GMS was obtained by stirring over gentle heat, the weighed glyceryl monostearate with one-fourth of the weighed fat. When dissolved, the fat plus emulsifier was quickly mixed with the remaining fat in a KitchenAid mixer at speed 2. As soon as the mixture was well blended it was transferred to jars and stored in a freezer at -15°F.

Equipment

The batters were mixed in a Hobart model K4-B KitchenAid household-size electric food mixer. A four quart heavily tinned steel bowl of 8 inches diameter and flat beater 4-3/4 by 4½ inches were used. The cakes were baked in round lacquered tin pans 1¼ inches in depth and 4-7/8 inches in diameter. The pans were fitted with lids. This was an advantage in preventing drying out of the cakes which were baked first during the day. The bottom of each pan was lined with one thickness of waxed paper.

The cakes were baked in a heavily insulated despatch electric oven having controls for both top and bottom elements. The oven was equipped with a double glass window in the door through which cakes could be observed during the baking process. It also had two slots in the roof, which could be opened when necessary for oven temperature control.

Tests

Objective

Batters: Specific gravity

The specific gravity was determined for each batter that was mixed. For this purpose an aluminum pyonometer designed for the determination of the specific gravity of semi-fluid materials was used. The pyonometer consisted of three parts: a cup, a lid with a hole 3 mm. in diameter, and a threaded rim for screwing the lid onto the cup. The batter was placed carefully in the cup by means of a small spatula and the lid screwed down tightly. Excess batter was forced out through the hole in the lid and removed. Specific gravity was found by comparing the weight of the fixed volume of batter with that of the same volume of water, both weighed at 25°C.

$$\text{Specific gravity of batter} = \frac{\text{wt. of pyc. plus batter} - \text{wt. of pyc.}}{\text{wt. of pyc. plus water} - \text{wt. of pyc.}}$$

Cakes: Cross section area

One cake of each treatment and each replication was cut across the center and tracings were made of the cross sections of both halves. The areas of these cross sections were measured by means of a compensating polar planimeter. The readings were averaged to obtain the index to volume.

Subjective

Batters: Microscopic

A minute portion of a batter was transferred to a glass slide by means of a pointed glass rod or dissecting needle. A cover glass was placed on the small speck of batter and was pressed down with a forceps until the batter was extended sufficiently for microscopic study.

Low magnification (x120) photomicrographs of the batters were made.

Slides were also made of cake batters stained red with Sudan IV, a fat soluble dye. This was done by two methods: (a) 1.2 grams of Sudan IV were added to the formula when creaming was started, or (b) a few grains of dye were mixed in with a small amount (about 10 grams) of batter. Both methods proved to be successful in studying the fat distribution. Colored photomicrographs were made of the stained batters using an Ansco color tungsten type film, a light yellow filter (UV 16) and a carbon arc lamp.

Cakes: Microscopic

One cake of each treatment was used for microscopic studies of cake crumb. The procedure followed for fixing and staining fat was adapted from the method described by Lowe and Nelson (32, pp.164-165) and by Morr (33).

Small blocks, approximately $\frac{1}{2}$ x $\frac{1}{2}$ x 1 cm. were cut. Ten to twelve blocks were placed on glass wool and arranged in a small circle around a 5 ml. beaker containing 1$\frac{1}{2}$ ml. of a 5 per cent, freshly made, aqueous solution of osmic acid (OsO_4).[3] The whole was covered with a small bell jar, 4$\frac{1}{2}$ inches in diameter and 2 inches in height, and the edge well sealed with stopcock grease. This was kept in the dark for seven hours, after which time the osmic acid had penetrated practically to the center of each block of cake, as shown by the black stain. In the presence of osmic acid the fat is oxidized at the double bonds and the OsO_4 is reduced to OsO_2 and metallic osmium.

$$\begin{array}{c} H\ H \\ |\ \ | \\ -C=C- \end{array} + OsO_4 \longrightarrow \begin{array}{c} H\ H \\ |\ \ | \\ -C-C- \\ |\ \ | \\ O-O \end{array} + OsO_2 + Os$$

The osmium being a very heavy metal is adsorbed by the fat and protects the fat from being dissolved by the usual solvents like xylol, cedar oil and absolute alcohol (39, p.248).

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3. Osmic acid is highly corrosive, and care must be exercised in its preparation and use. Refer to Johansen (26, pp. 7, 37).

In order to make cake sections of 20 microns in thickness, the little blocks were dehydrated, evacuated, cleared and embedded in wax. This included the following steps:

1. The blocks were placed in three changes of absolute alcohol for three hours each time.
2. The air was evacuated by placing the vials in a vacuum oven for two hours at 42°C. under 15 inches of vacuum.
3. The blocks were transferred to a solution of half absolute alcohol and half tertiary butyl alcohol, and left for four hours.
4. The blocks were transferred to three changes of tertiary butyl alcohol, leaving the blocks four hours in each change of alcohol and in one change overnight.
5. The samples were infiltrated with paraffin[4] by adding paraffin chips to the last change of alcohol and placing in an oven kept at 60°C. until the paraffin melted.
6. The blocks were transferred to pure melted paraffin and the paraffin replaced three or four times, every twelve hours. The vials were kept at 60°C.
7. After the last infiltration the contents of the vials were poured into suitable glycerine lined mold, then submerged in ice water to ensure even textured paraffin through rapid chilling.

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4. Fisher Tissuemat Embedding Wax, m.p. 50-52°C.

8. The hardened blocks of paraffin-embedded cake were trimmed down to be mounted in the carrying disc of a microtome.

The sections were cut 20 and 30 microns thick. When the protein was to be stained, the ribbons were mounted on slides with water, and no fixative was used. When protein was not to be stained Mayer's egg albumin fixative (26, p.21) was used. The slides were then dried on an electrically heated slide warmer for one hour, then at room temperature for at least 36 hours. To remove the wax the slides were immersed in xylene for at least five minutes. When slides were not to be stained a drop of thin balsam was placed on the section at this point and a cover glass mounted. The slides were placed in an incubator at 60°C. for the balsam to dry.

Staining the protein: A dilute solution of aqueous eosin stains protein a bright pink. A 0.04 per cent solution proved to be satisfactory. A drop of glacial acetic acid added to 100 ml. of stain helps to give a better adsorption of the dye by the protein. After the wax had been dissolved by the xylene, the slides were passed through a series of ethyl alcohol dilutions of 95, 70, 50, and 30 per cent. The slides were kept for five minutes in each alcohol solution. From the 30 per cent alcohol they were transferred to distilled water, then stained with eosin for one hour. To dehydrate before mounting the slides were again passed through the different alcohol solutions, starting with the most dilute and ending with absolute alcohol. They were then placed in xylene, 100 parts, plus absolute alcohol, one part, and finally transferred to undiluted xylene. Dehydration was accomplished in approximately seven minutes. Excess xylene was wiped from the slide, care being taken to avoid touching the sections. A drop of thin balsam was placed on the section and a cover glass mounted. The slides were left to dry for a few days when they were ready for microscopical examination.[5]

Cakes: Scoring

The cakes were scored the same day they were baked, by three experienced judges. A control cake was prepared each day to supply a standard with which the experimental cakes could be compared. For the control, the formula for the basic cake was used, with butter as fat and 3 per cent Aldo 33. In this case the butter was decreased by the total weight of incorporated Aldo (i.e., 4.5 grams). No adjustment was made for the water used in dispersing the Aldo. This procedure conformed with the directions given by the manufacturers for the use of Aldo in plain cake. The judges were asked to score ten different characteristics with reference to those of the control cake which were assigned a score of 5. When a characteristic appeared to be better in a test cake than in the control, a score higher than 5 was given, and when the

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5. For detailed information on embedding and staining refer to Chamberlain (6), Cole (9), and Johansen (26).

characteristic was poorer, the scores went down. The range of scoring was from 1 to 10.

Score Card Used by Judges

Cake number:
Date:
Judge:

	Rating
1. Thickness of cell walls	....
2. Cell distribution	....
3. Cell size	....
4. Springiness	....
5. Compactness	....
6. Tenderness	....
7. Moistness	....
8. Velvetiness	....
9. Flavor	....
10. Overall desirability	....

Statistical Analysis

Analyses of variance were used for batter specific gravity, cake scores and cake volumes in testing the significance of differences among emulsifying agents and baking temperatures in order to determine the merit of the different treatments. The 5 per cent significance level was used throughout.

RESULTS AND DISCUSSION

Batters

Glyceryl Monostearate and Foam Formation During Creaming

"Creaming" was the first step in the mixing of the cakes. Lowe (31, p.489) described creaming in cake making as the formation of an air-in-fat foam by stirring or beating. Bailey (2, p.280) expressed the same idea as follows: "The absorption of air by fats during mixing operations in the bakery is termed 'creaming'." By their mechanical action the fine, angular shaped sugar crystals promote the formation of the foam.

Both butter and Primex exhibited good creaming properties as shown by the development of lightness during mixing of the fat and sugar.

In addition to taking up large quantities of air, both fats were capable of absorbing and holding a considerable quantity of water without the benefit of an emulsifying agent.

This could easily be seen in smears made of the creamed mixture after the 25 ml. of water had been added at step 2 in the mixing process (see page 22). At low magnification (100X), minute water drops distributed in the creamed fat could be distinguished, indicating that the emulsion type was water-in-oil. All the water, however, was not emulsified since free water adhering to the mixture could easily be seen macroscopically. When the emulsifier was present in the mixture, practically no free water could be seen, the water apparently being emulsified in the fat. This was obvious for both fats used and for both emulsifiers. Tests of emulsion-type were made by placing a drop of water next to smears of creamed mixture plus water in which the fat was stained with Sudan IV. Though a water-in-oil emulsion predominated, the presence of an oil-in-water emulsion was demonstrated in the mix containing no emulsifier, by the floating of red fat globules out of the mix. This indicated that an oil-in-water emulsion was in the process of forming. In the creamed mixture containing an emulsifier, no fat globules separated from the mass. Since the emulsifier was more soluble in the fat than in the water, it lowered the surface tension at the interface oil-emulsifier to a greater extent than that of the interface water-emulsifier, and thereby assisted in the formation of a water-in-oil emulsion.

Colored photomicrographs were made to illustrate this phenomenon. In Figure 1 air bubbles can be recognized occluded in the spheres of red-stained fat. Spheres of fat carrying air bubbles could not be observed when an emulsifier was present. The fat appeared to be the continuous phase with water droplets dispersed throughout (Fig. 2).

Another observation made on batters containing emulsifying agent, was that the creaming property of the fat decreased. This was true both for butter and Primex. In the presence of an emulsifier the fat remained pastelike in texture, whereas without the emulsifier both butter and Primex creamed to a light and fluffy

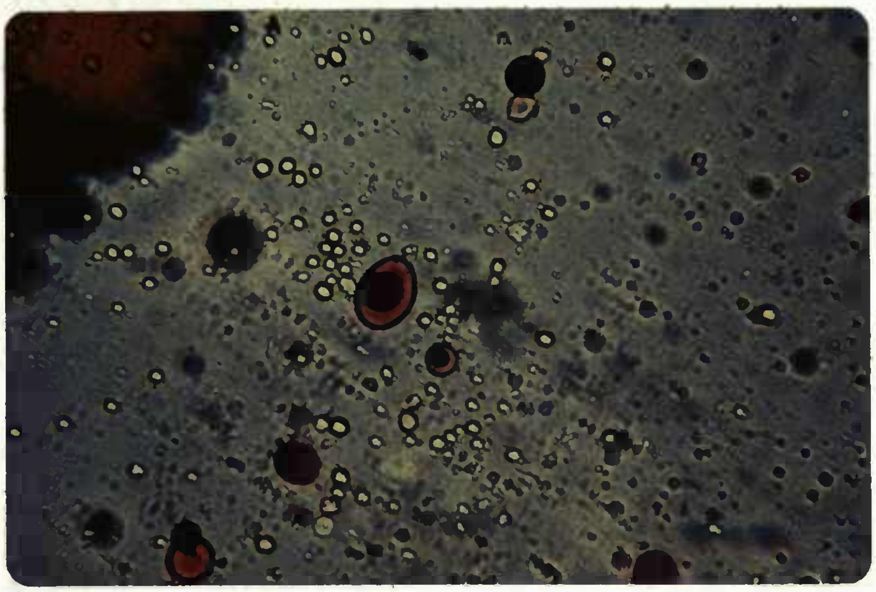


Fig. 1 Photomicrograph (100X) of a creamed mixture of butter, sugar and water without an emulsifier. Butter is stained red. A sphere of butter carrying an air bubble may be seen in the center of the picture.

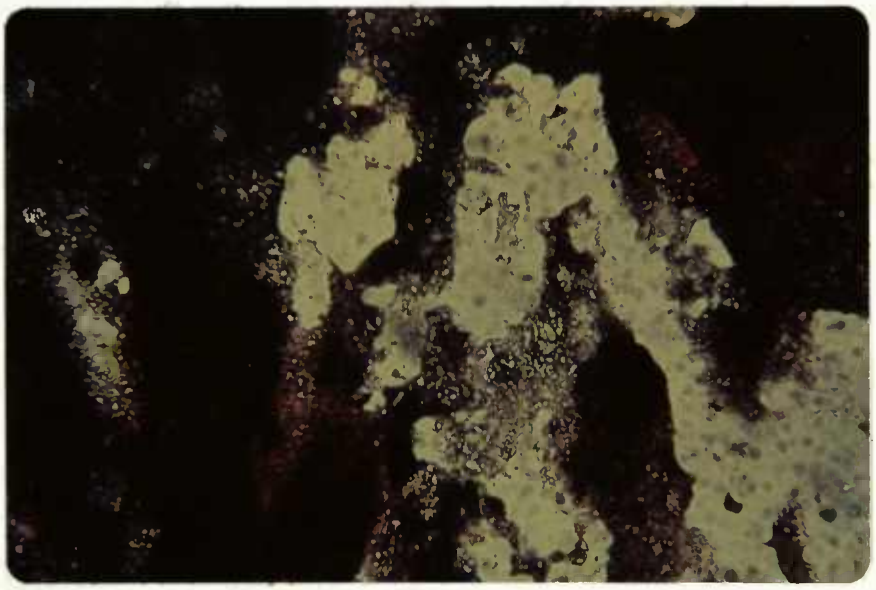


Fig. 2 Photomicrograph (100X) of a creamed mixture of butter plus emulsifier, sugar and water. Emulsified water droplets may be seen as gray spots in the fat (red).

consistency. This apparent difference was substantiated by specific gravity tests. The specific gravity of the creamed mixture of butter without emulsifying agent was 1.013 and of butter plus 6 per cent glyceryl monostearate 1.305. Primex always incorporated more air than butter did, so that the specific gravity of the creamed mixture increased from 0.937 for Primex without emulsifier to 1.187 for Primex plus 6 per cent glyceryl monostearate.

The poorer incorporation of air in the creamed mixture containing emulsifier was actually caused by the emulsifier. This was demonstrated by adding an emulsifier (Aldo) to a mixture that had been creamed till light and foamy. As the creaming was continued the mixture immediately lost its lightness and became pasty, as was typical for a creamed mixture which had the emulsifier added to the fat. A plausible explanation is that the surface active agent acts as a spreading agent for the fat. The fat becomes dispersed, loses its coherence and less air is occluded. Also if the emulsifier is added half-way through the creaming process, it disperses the fat and air is lost from the creamed mixture.

The fact that glyceryl monostearate serves both as a dispersing agent for the fat and an emulsifier for the water-in-oil emulsion. is not contradictory, for this is true of many surface active agents, i.e., they may be effective in more than one application and may perform two or more functions at the same time (1, p.2). It is also known that the anti-foaming properties of substances are very unpredictable and many surface active agents are employed in foam reduction.

Glyceryl Monostearate and the Physical Structure of the Batter

Macroscopic Appearance

The batters made with butter and with Primex in the absence of an emulsifying agent were well aerated, light and thick, resembling whipped cream. The batters also stood up in the bowl, like properly whipped cream. Characteristically, the batters showed a tendency to break. When 6 per cent emulsifying agent was present, the batters were smooth, glossy, relatively thick and showed a slight tendency to flow, but no break or separation occurred. The batters lacked the lightness of batters without emulsifying agent and appeared more like medium thick white sauce than like whipped cream. Batters containing 3 per cent glyceryl monostearate were between these two extremes in smoothness and lightness.

These results were in accordance with Carlin's observations (5, p.191). He related that, macroscopically, his batters appeared curdled without the presence of emulsifying agent, whereas added emulsifying agent overcame this curdled appearance and developed a thin but smooth batter.

Microscopic Appearance

When the batters were studied microscopically, the most obvious difference between the batters made with and without emulsifier was in the fat distribution. In the Primex and butter cakes without emulsifying agent the fat appeared in clumps, whereas the fat became more finely dispersed as the percentage of emulsifier was increased.

This dispersal pattern of the fat is illustrated in the colored photomicrographs, Figures 3, 4, and 5. The fat was stained red with Sudan IV. The rest of the cake ingredients appear gray, and the heavily outlined spheres are the gas bubbles.

In Figure 3, which shows a cake batter made with butter but without emulsifier, the fat can be seen as fairly large lakes or clumps, carrying numerous air bubbles.

In Figure 4, which shows a cake batter made with butter and containing 6 per cent Aldo, the fat can be seen as small particles. These particles disperse the fat more uniformly through the batter than the clumps observed in Figure 3. This is characteristic of a batter containing an emulsifying agent.

Of the two emulsifying agents used, glyceryl monostearate "S" gave a better dispersal of fat than Aldo, Figure 5.

As the gas bubbles appeared for the most part in the fat, a better dispersal of fat also meant a more even distribution of gas. The distribution of gas in batters made with the two fats and the two emulsifiers is illustrated in the photomicrographs shown in Figures 6 to 9. The Primex batters with and without emulsifier always showed a greater number of gas bubbles than the corresponding butter batters. It will be recalled that Primex also produced lighter creamed mixes than butter. Butter plus emulsifier on the other hand, was more highly dispersed than Primex plus emulsifier. The fine pattern of fat dispersion may partly explain the smoothness of batters obtained when an emulsifier was present.

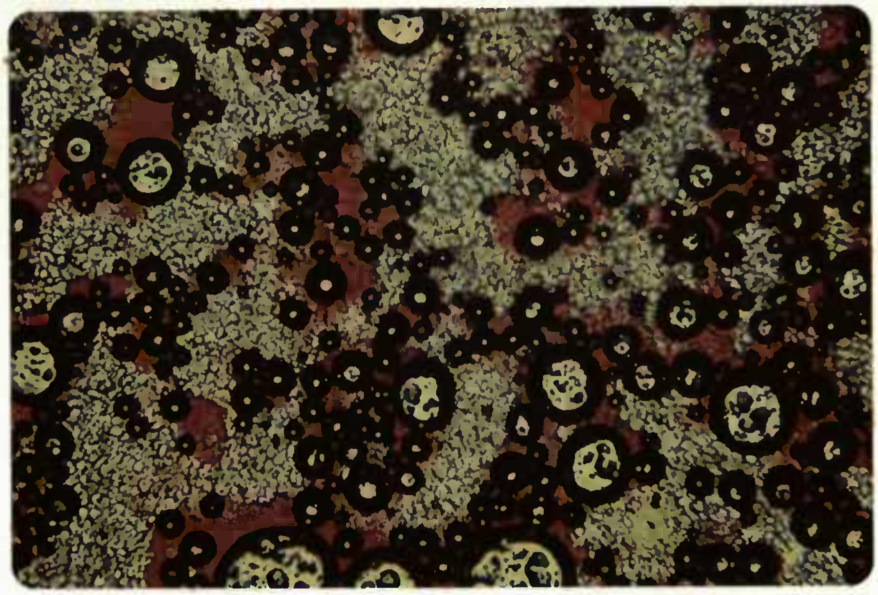


Fig. 3 Photomicrograph (100X) of cake batter made with butter, no emulsifier. The fat, stained red, appears in large patches. The heavily outlined spheres in the fat are the gas bubbles. The rest of the ingredients appear gray.

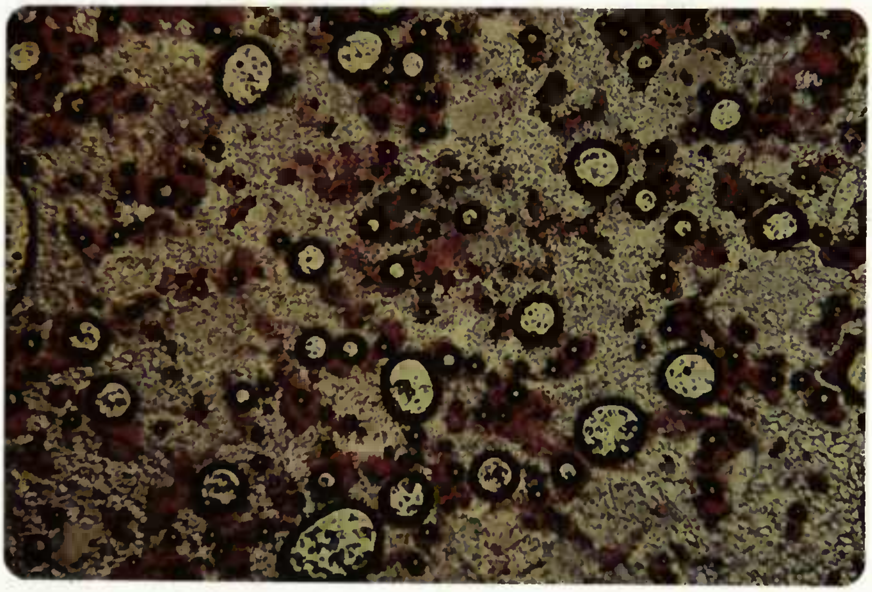


Fig. 4 Photomicrograph (100X) of a butter cake batter containing 6% Aldo 33. The fat, stained red, appears in small particles. The spheres are the gas bubbles, and the rest of the ingredients appear gray.

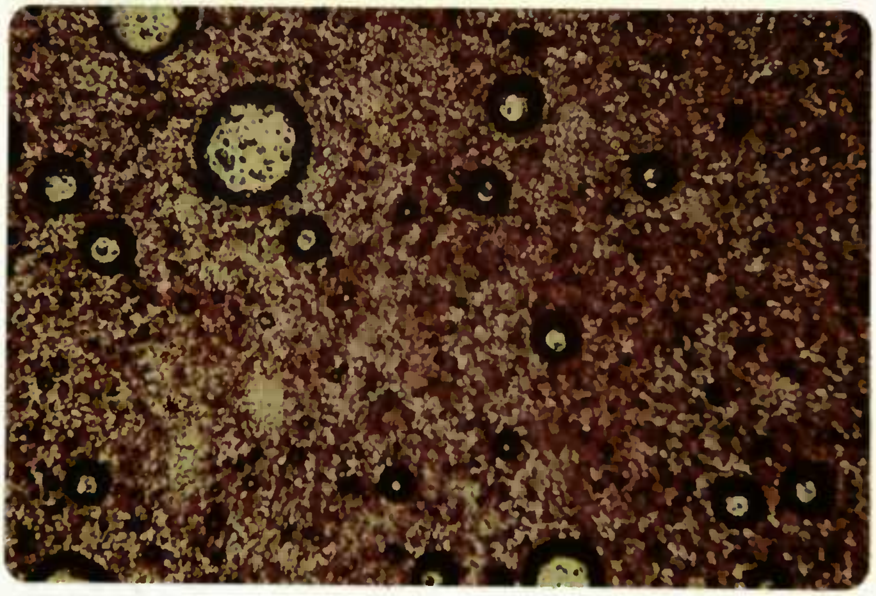
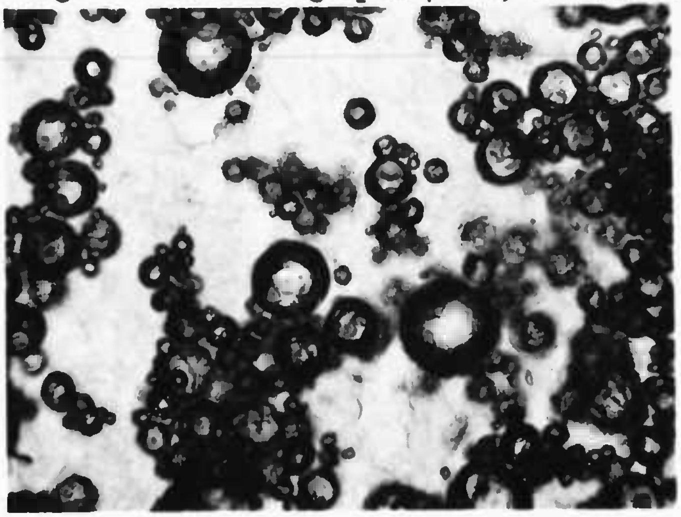
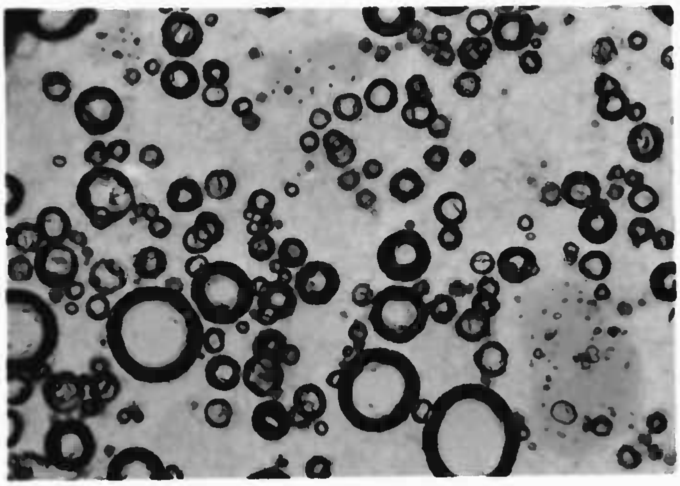


Fig. 5 Photomicrograph (100X) of a butter cake batter, containing 6% Glyceryl monostearate "S". The fat, stained red, appears highly dispersed throughout the batter.

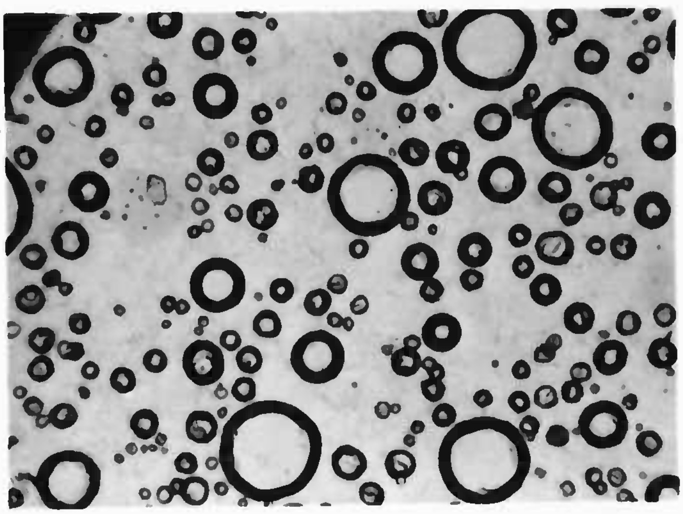
Fig. 6 Photomicrographs (120X) of cake batters



(1) Butter, no emulsifier. Fat appears in clumps as indicated by the irregular grouping of gas bubbles. The spheres with the black outlines are the gas bubbles. The rest of the ingredients appear white.

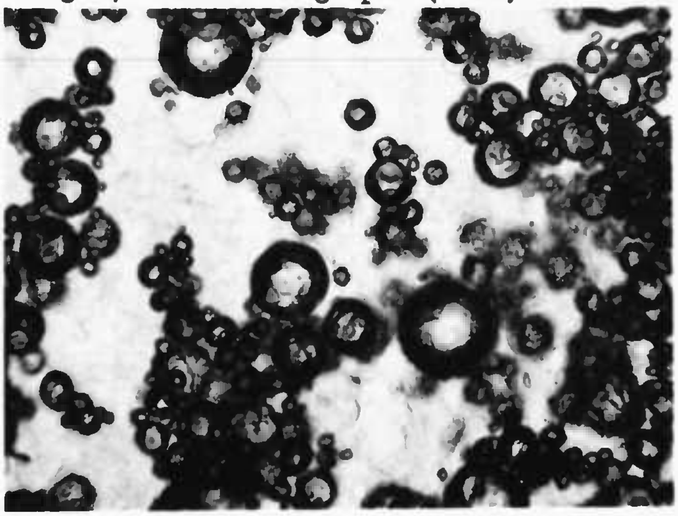


(2) Butter plus 3% Glyceryl monostearate "S". Fat (gray particles) appears finely dispersed, with gas bubbles spread fairly evenly throughout the batter.

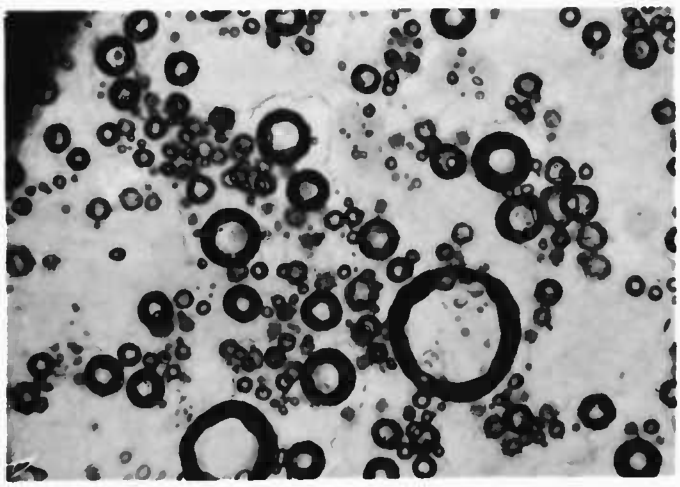


(3) Butter plus 6% Glyceryl monostearate "S". Fat is so well dispersed that there is little contrast between fat and the rest of the ingredients. Gas bubbles are evenly distributed.

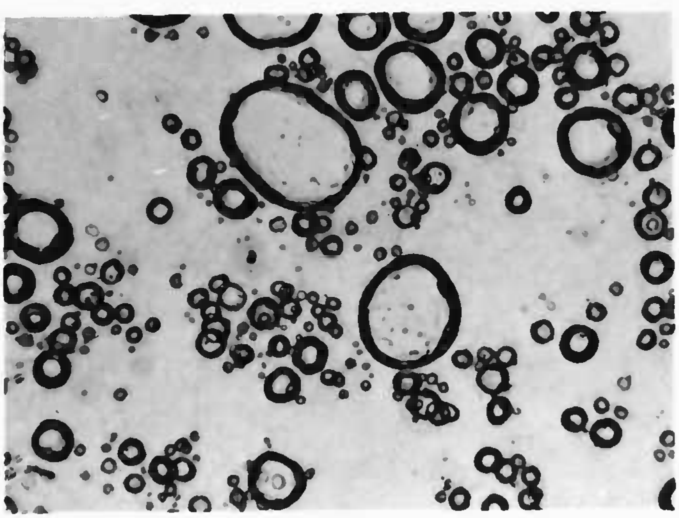
Fig. 7 Photomicrographs (120X) of cake batters



(1) Butter, no emulsifier. Fat appears in clumps as indicated by the irregular grouping of the gas bubbles. The gas bubbles are the spheres with the black outlines. The rest of the ingredients appear white.

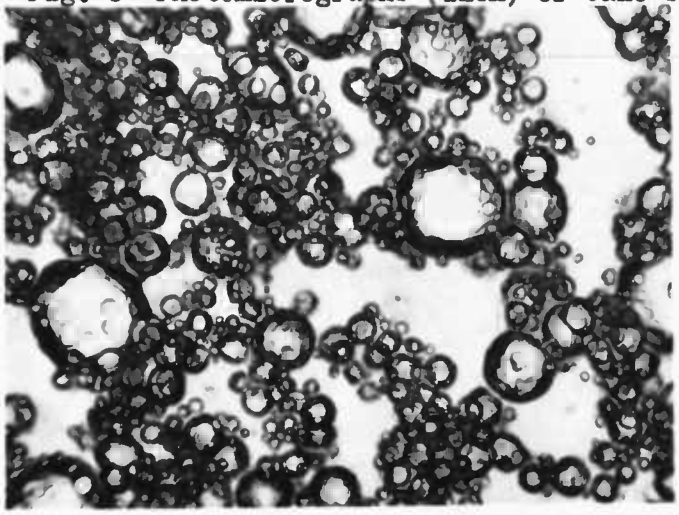


(4) Butter plus 3% Aldo 33. Fat appears finely dispersed, with gas bubbles spread fairly well through the batter.

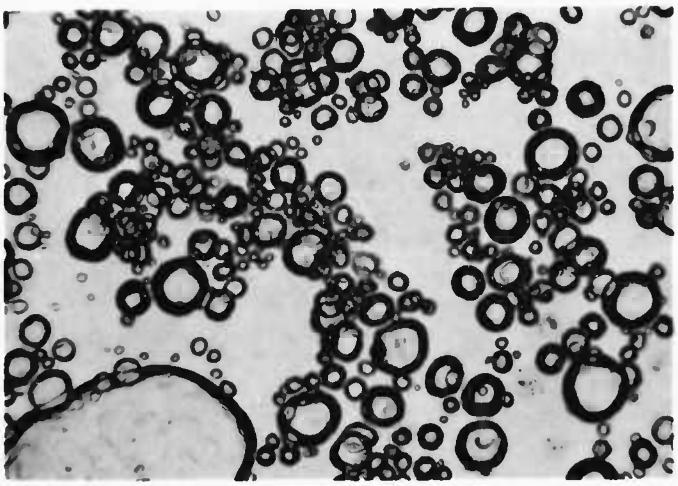


(5) Butter plus 6% Aldo 33. Fat appears more highly dispersed than with 3% emulsifier.

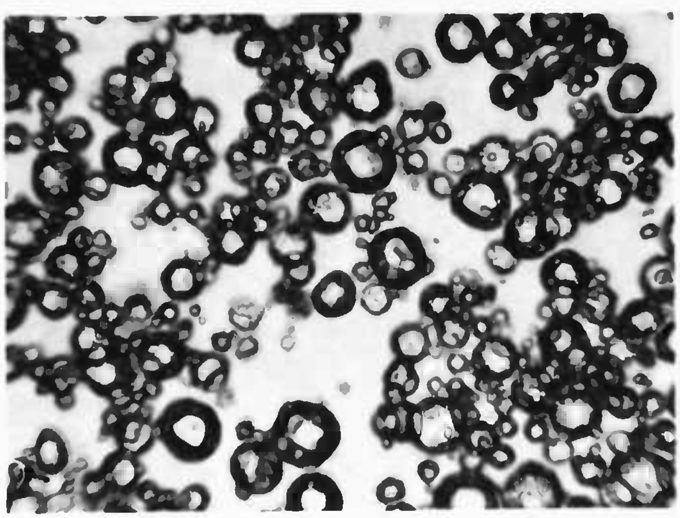
Fig. 8 Photomicrographs (120X) of cake batters



(6) Primex, no emulsifier. A well-aerated batter, with large numbers of gas bubbles crowded together in clumps of fat.

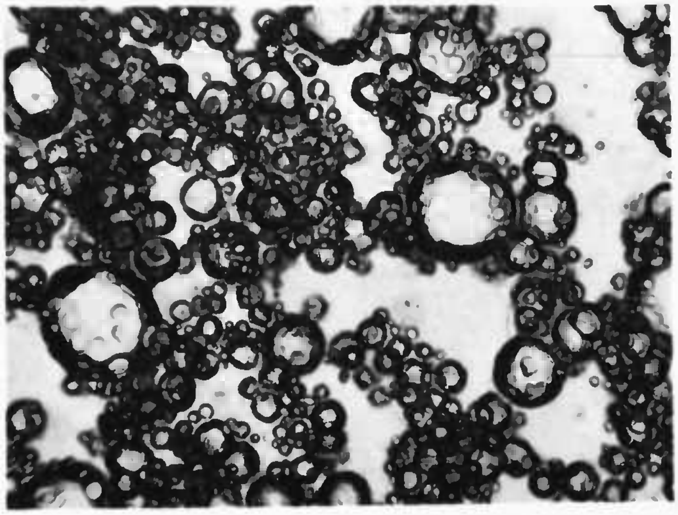


(7) Primex plus 3% Glyceryl monostearate "S". Fat and gas bubbles are more highly dispersed than when Primex was used without emulsifier.

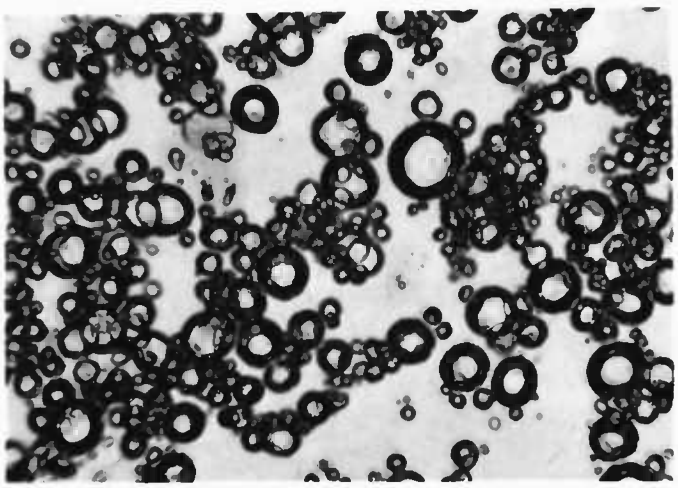


(8) Primex plus 6% Glyceryl monostearate "S". Fat and gas bubbles are well dispersed throughout the batter.

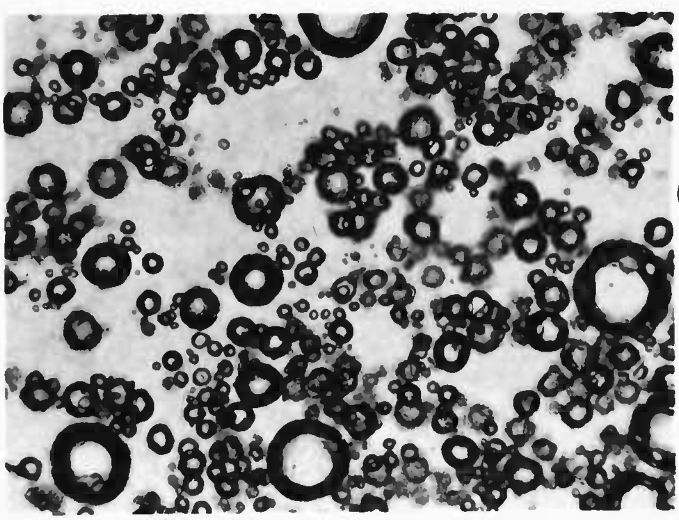
Fig. 9 Photomicrographs (120X) of cake batters



(6) Primex, no emulsifier. A well-aerated batter, with large numbers of gas bubbles crowded together in clumps of fat.



(9) Primex plus 3% Aldo 33. The fat and gas bubbles are better dispersed throughout the batter than when Primex was used without emulsifier.



(10) Primex plus 6% Aldo 33. Fat, light gray, may be seen in small particles fairly well dispersed throughout the batter.

Baked Cakes

Volume

Effect of Emulsifying Agent

As would be expected, the difference in batter structure was reflected in the cakes baked of these batters. When emulsifier was added, cake volume increased, but the size of cakes made with the two emulsifiers at the two levels were not significantly different.

The bigger volumes obtained indicated that more gas was retained in the batter at the time that coagulation of the protein occurred. The gas in the emulsifier-containing batters, being better distributed throughout the protein-starch suspension, produced an increased air/liquid interface which could have caused mechanical coagulation of the protein along with heat coagulation during baking. The fat on melting released its suspended air to the water phase (5, p.196). Weiser (43, p.305) explained that mechanical coagulation could be caused by the accumulation of dispersed phase in the surface as a result of the large development of surface by the many air bubbles. He refers to Ramsden[6] in explaining that it is possible to coagulate certain hydrophilic sols by bubbling gas through them, provided that the colloidal material is sufficiently surface-active to concentrate strongly in the surface film. When the bubbles rise and break, the excess material which they carry to the surface of the sol precipitates out. Egg albumin is highly surface-active and may be coagulated

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6. Ramsden, W. "Separation of Solids in the Surface-layers of Solutions and Suspensions - Preliminary Account." Proceedings Royal Society of London 72:156. 1904.

in this way.

Along with this timely coagulation of the protein, the glyceryl monostearate could assist in stabilizing the foam in the batter during baking. Foams and emulsions admit of somewhat similar considerations, adsorption being effected at both kinds of interface (8, p.1). The emulsifier could orient itself at the air/liquid interface causing a variation in the surface forces of the liquid in relation to the gas. It could therefore assist in stabilizing the foam in the cake batter. Weiser (43, pp.350-353) has explained that foams resemble emulsions in that adsorption films surround the dispersed phase in both systems,--the difference being that the dispersed phase is a gas in foams and a liquid in emulsions, and the gas bubbles in foams are, in general, much larger than the dispersed droplets in emulsions. He found that aqueous solutions (alcohols and acids) exhibit an optimum concentration for giving the most stable foam or bubble and that the solutions with the lowest surface tension tend to give the most durable foams.

In the previous paragraphs it has been assumed that the increased cake volume could be ascribed to a better gas retention. Two other possible explanations for the increased volume were however considered and experimentally disproved: (1) Whether increased volume could have been due to increased moisture retention, as the emulsifier has an affinity for water; (2) Whether volume increase could be accounted for by the presence of more air in the mixed batter, since Bailey (2, p.277) concluded that cake doughs containing large amounts of air entrapped within the fat produced cakes larger in volume than those doughs containing relatively little air.

Moisture loss was determined by the weight of the batter minus the weight of the baked cake. The loss in weight during baking may be considered entirely due to evaporation (4, p.8). 240 cakes were weighed before and after baking. The losses in weight for cakes baked at a specific temperature were found to be independent of kind or percentage of emulsifier present. With an increase in baking time which accompanied a decrease in baking temperature, moisture losses increased. But at each temperature these losses were approximately the same for emulsifier and non-emulsifier cakes. These results therefore rule out the suggestion that a greater moisture retention in the emulsifier-containing cakes may be the explanation of the increased volumes obtained. Table III.

The second possibility, namely, that increased volume may be due to increased aeration of the batters was investigated through specific gravity measurements on the batters. Specific gravity was determined on 120 different batters. The average specific gravity for each treatment is given in Table IV, and is compared with cake volume obtained when these batters were baked at 425° F.

If the supposition is correct that better aerated batters produce bigger cake volume, the biggest cake should have been obtained when Primex without emulsifier was used. Instead it was found that the heavier batters when baked at the two higher temperatures (425 and 375° F.) yielded the largest cakes. This was

TABLE III

Average Baking Losses of Cakes Made With Two Fats, With and Without Emulsifiers, and Baked at Four Temperatures. (Baking losses in grams)

Baking Temperature	Butter					Primex				
	No Emulsifier	GMS		Aldo		No Emulsifier	GMS		Aldo	
		3%	6%	3%	6%		3%	6%	3%	6%
425°F. (218.3°C.)	11.3	11.2	10.8	11.8	11.7	10.5	10.0	10.5	11.2	10.7
375°F. (190.6°C.)	11.7	11.9	11.7	11.9	11.6	11.4	12.2	12.0	11.5	12.4
325°F. (163.2°C.)	14.1	14.7	14.0	14.8	14.9	13.8	14.3	14.2	14.4	14.4
300°F. (148.9°C.)	21.3	21.0	20.7	20.1	20.4	20.6	20.9	20.6	20.3	20.7

also the tendency when the cakes were baked at 325°F., although the increase in volume was not so evident as at the higher temperatures. When cakes were baked at 300°F. no beneficial effect on cake volume could be observed through the use of an emulsifier. Hence, a high degree of aeration was not the explanation for the larger cake volumes obtained when emulsifiers were used.

Similar results with emulsifying agents were obtained by Pyke and Johnson (38, p.339) and by Carlin (5, p.191). Cook (11) also found with chocolate cakes, when no emulsifiers were added, that batters of greatest volume, i.e. lowest specific gravity, produced smaller cakes, and Merr (33) observed that there was a tendency for cake volume to decrease as creaming volume increased.

Since the increased volume could not be correlated with the incorporation of air or moisture retention, the postulation that a better gas retention during baking was responsible for the volume obtained seemed most tenable. Even though less air was present in the batter containing an emulsifier, the air could have been used to better advantage.

Effect of Fat and Baking Temperature

The analysis of variance of cake volumes, Table VI, showed a significant difference due not only to the addition of emulsifier, but also to fat and to baking temperature used. Butter cakes which contained emulsifier were larger than corresponding Primex cakes. This may be accounted for by the greater dispersion of butter accompanied with a more uniform distribution of gas bubbles through

TABLE IV

Average Specific Gravity of Batters and Average Cross Section Areas of Cakes Made With Two Fats, With and Without Emulsifiers

Measurement	Butter					Primex				
	No Emulsifier	GMS		Aldo		No Emulsifier	GMS		Aldo	
		3%	6%	3%	6%		3%	6%	3%	6%
Specific gravity of batter	0.780	0.840	0.827	0.856	0.856	0.709	0.775	0.820	0.813	0.841
Cross section area in square inches. Cakes baked at 425°F.	4.30	5.40	5.68	5.46	5.63	4.57	4.79	5.32	5.37	5.61

the batter.

The volumes of emulsifier cakes increased with each increase in baking temperature. When no emulsifier was added, cake volumes were approximately the same regardless of the temperature at which they were baked, Table V.

The small volumes of cakes baked at low temperatures may be due to excessive loss of gas because of delayed coagulation of egg and flour proteins (31, pp.486-487). That this was probably the case is suggested by the fact that the internal temperature of cakes baked at 300° F. and 325° F. rose more slowly and reached a lower maximum than did the internal temperature of cakes baked in hotter ovens, Table II (p.25).

External Appearance

The appearance of the cakes was influenced by the shape of the top and by the crust characteristics.

Shape of the Top

The cakes baked at 375° F. developed a well-rounded top when an emulsifying agent was present, but the top flattened when the emulsifier was omitted. This is apparent from Figure 11, in which B1 represents a butter cake without an emulsifying agent, B2 a butter cake with 3% Glyceryl monostearate "S", and B3 a butter cake with 6% Glyceryl monostearate "S".

The flattened top of the cake without emulsifier in comparison with the rounded tops when an emulsifier was present, may also be seen

TABLE V

Average Cross Section Areas of Cakes Prepared With Two Fats, With and Without Emulsifiers, and Baked at Four Temperatures.
(Cross section area in square inches)

Baking Temperature	Butter					Primex				
	No Emulsifier	GMS		Aldo		No Emulsifier	GMS		Aldo	
		3%	6%	3%	6%		3%	6%	3%	6%
425°F. (218.3°C.)	4.30	5.40	5.68	5.46	5.63	4.57	4.79	5.32	5.37	5.61
375°F. (190.6°C.)	4.33	4.93	5.48	5.09	5.34	4.44	4.57	4.76	4.84	5.09
325°F. (163.2°C.)	4.63	4.74	4.89	4.82	4.71	4.20	4.57	4.61	4.59	4.69
300°F. (148.9°C.)	4.11	3.92	4.18	4.09	4.25	4.09	3.78	3.95	4.09	3.83

in the cross sections of those cakes as presented in Figure 10.

When cakes were baked at 425°F. they tended to peak, and occasionally a small center crack appeared. The tops of the cakes baked at 325°F. became level in the absence of an emulsifier and slightly rounded when an emulsifier was present. When baked at 300°F. the tops of cakes tended to sink. Again a survey of the cross sections of the cakes presented in Figure 17 will reveal these differences obtained at the various baking temperatures.

But for the occasional center crack when cakes were baked at 425°F., cracks never appeared in the crust of cakes.

The kind of fat did not produce significant differences in the shape of the top. A comparison may be made between butter and Primex cakes pictured in Figures 12 and 13.

Crust Characteristics

The appearance of the crust was influenced by the degree of brownness, adherence of the crust to the sides of the pan, the presence of white dots, gumminess and smoothness of crust.

Degree of Brownness: This depended for the most part on the baking temperature and was not affected by the kind of fat or the presence of an emulsifying agent. Cakes baked at 425°F. tended to become too brown. When the baking temperature was lowered to 375°F. a rich golden brown color was obtained. At 325°F. the color was changed to a deep straw color and an undesirable pale crust was produced when cakes were baked at 300°F.

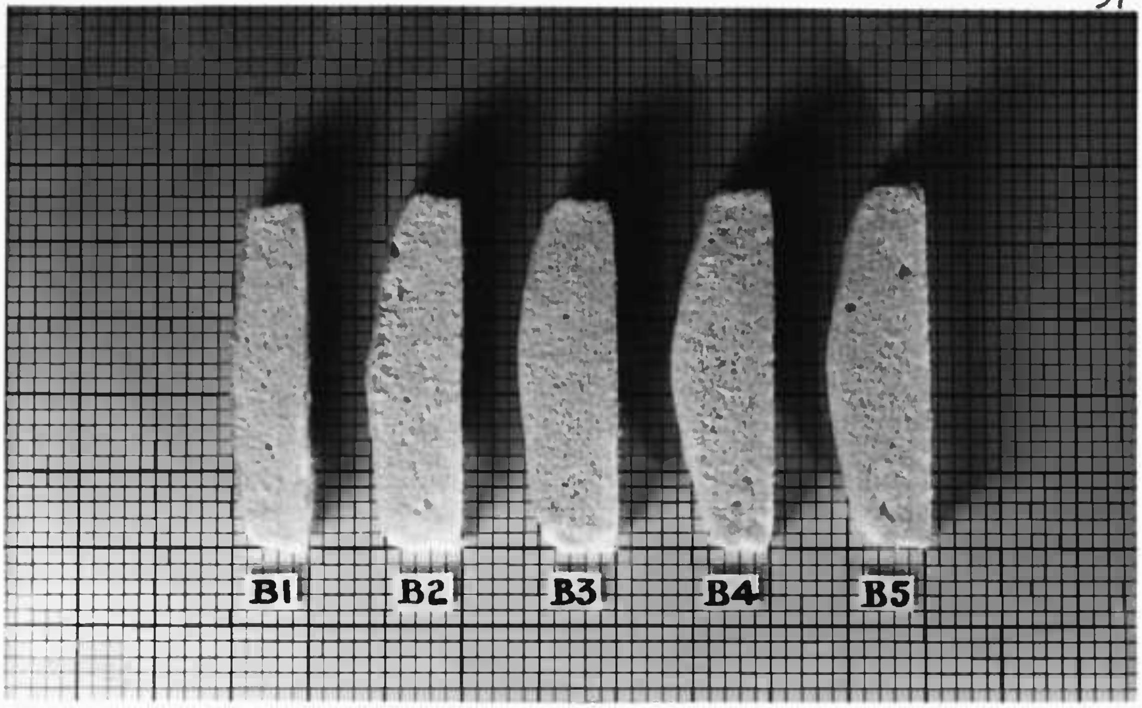


Fig. 10 Butter cakes baked at 375°F.
B1 No emulsifier
B2 3% GMS
B3 6% GMS
B4 3% Aldo
B5 6% Aldo

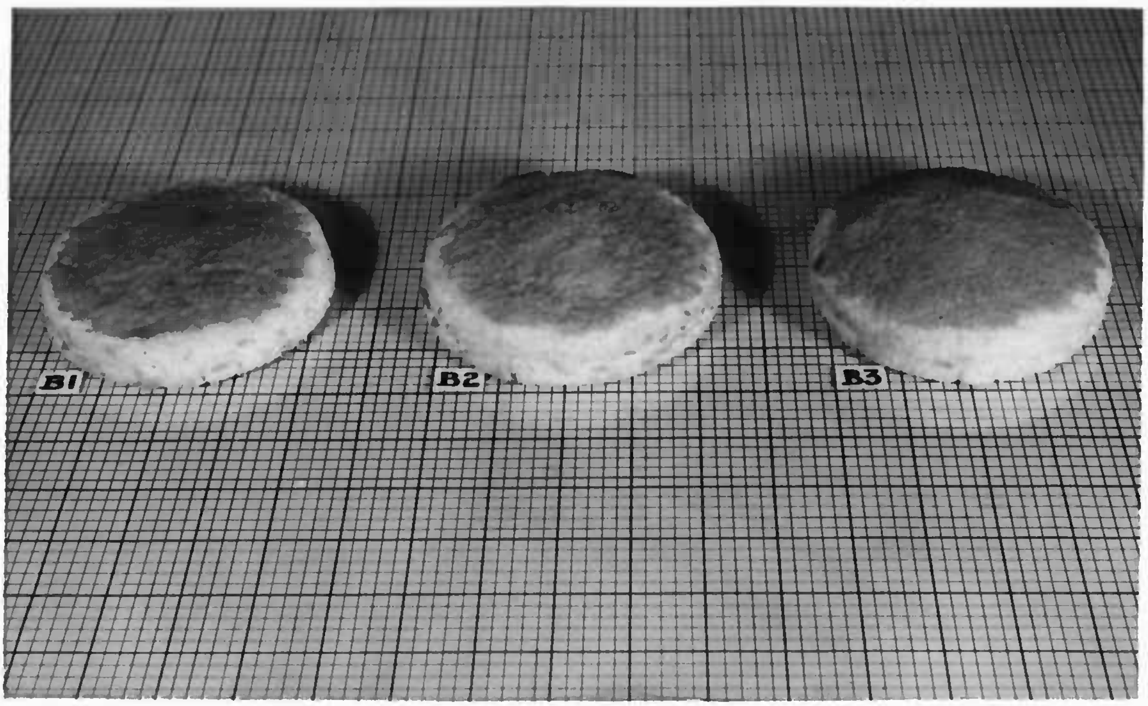


Fig. 11 Butter cakes baked at 375°F.
B1 No emulsifier
B2 3% GMS
B3 6% GMS

Adherence of Crust to Sides of Pan: Only those cakes that were baked at 425°F. would pull away from the sides of the pan without crust adhering to the pan. As the baking temperature was decreased more of the crust adhered to the pan, so that cakes baked at 300°F. would leave quite a collar of crust adhering to the pan. Compare A1 with D1 and A3 with D3 in Figures 14 and 15. This was true for both fats and for all emulsifier treatments.

Presence of White Dots in the Crust: White dots appeared in the crust of cakes baked at the lower temperatures. When these dots were observed at 36 magnifications, they appeared to be sections of the crust that had been raised by gas or steam escaping from the cake. At these points the crust was dehydrated and had lost its gelatinous consistency. Such spots were more pronounced for Primex cakes. A few may be recognized in Figure 14, D1.

Gumminess: Thin tender crusts were obtained when cakes were baked at 375°F. and 425°F. The crust appeared glossy but was not sticky. When the cakes were baked at 325°F. the crust tended to become gummy and at 300°F. all crusts were sticky. Gumminess was not affected by the presence of an emulsifier but was influenced to a slight degree by the kind of fat used. The crusts of Primex cakes baked at 300°F. were more gummy than those of butter cakes baked at this temperature.

Smoothness of Crust: Smoothness was the only crust characteristic that appeared to be affected by the presence of an emulsifier. The crust of cakes without an emulsifier baked at 375°F. and 425°F.

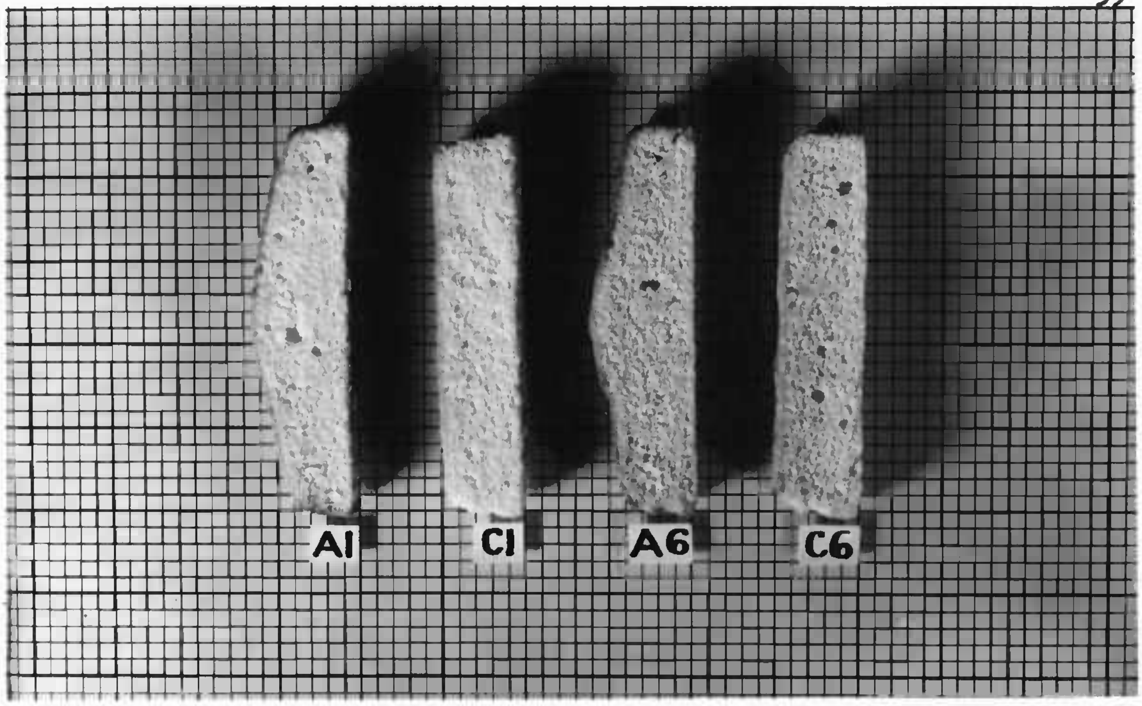


Fig. 12 No emulsifier added.
A1 Butter cake baked at 425°F. A6 Primex cake baked at 425°F.
C1 Butter cake baked at 325°F. C6 Primex cake baked at 325°F.

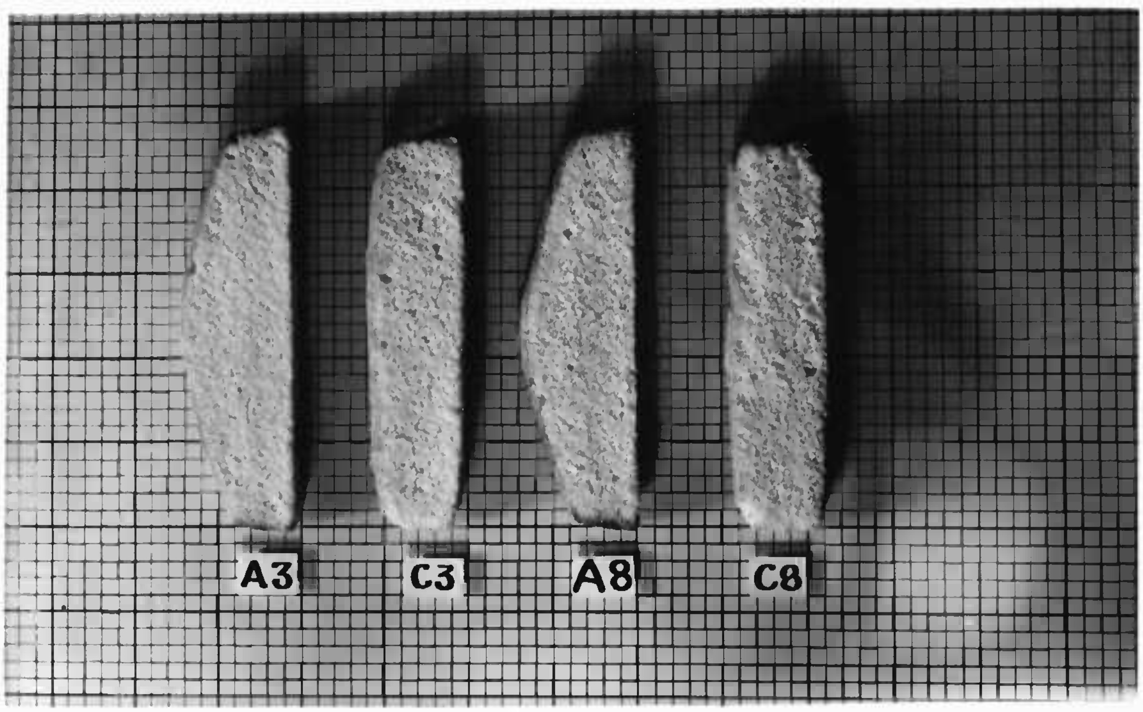


Fig. 13 6% Glyceryl monostearate added.
A3 Butter cake baked at 425°F. A8 Primex cake baked at 425°F.
C3 Butter cake baked at 325°F. C8 Primex cake baked at 325°F.

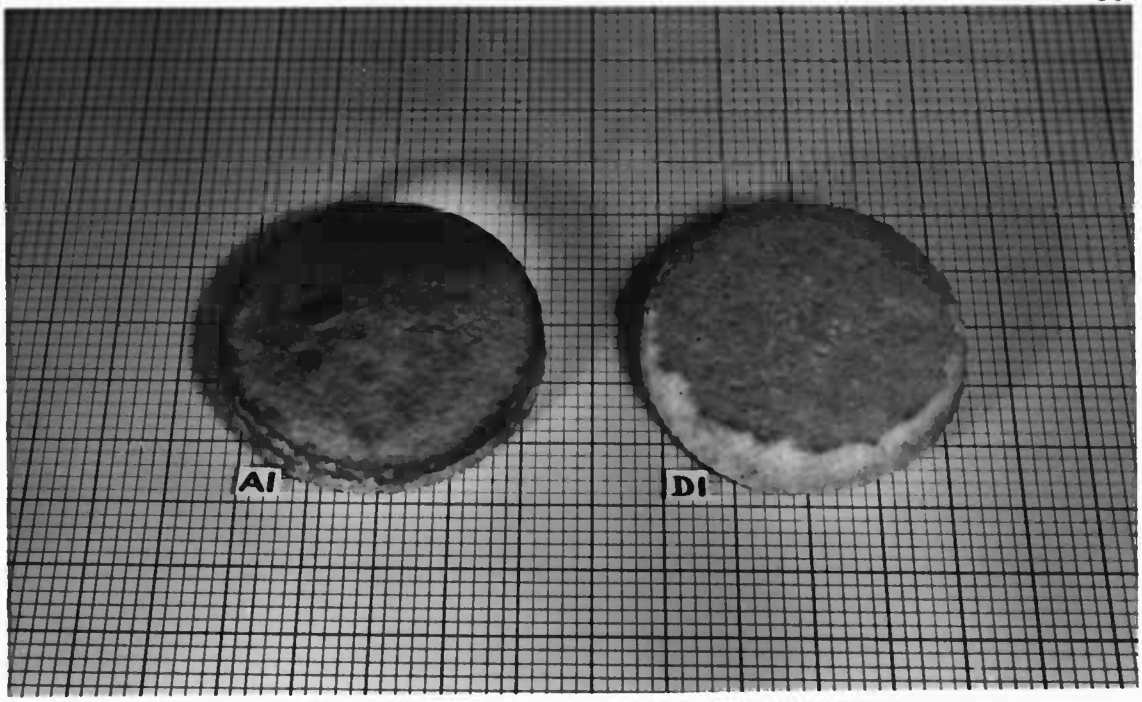


Fig. 14 Butter cakes, no emulsifier added.

A1 Baked at 425°F. D1 Baked at 300°F.

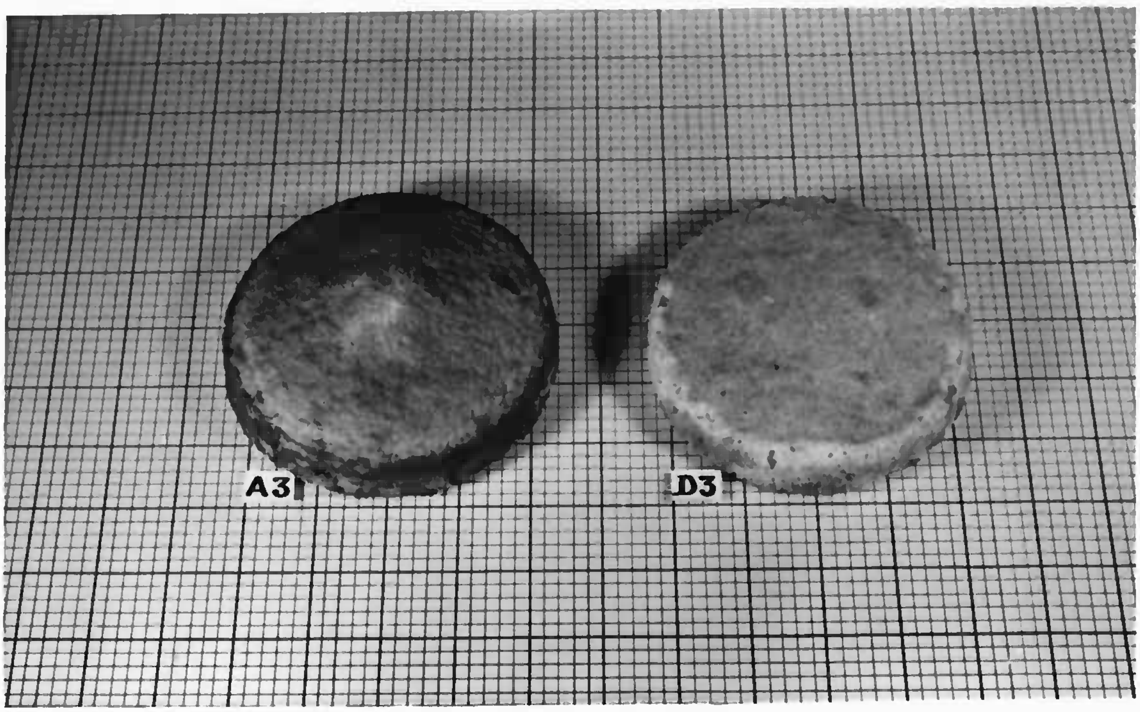


Fig. 15 Butter cakes, 6% Glyceryl monostearate added.

A3 Baked at 425°F. D3 Baked at 300°F.

were blistered, whereas the crusts of cakes containing emulsifier were smooth, and velvety in appearance. Blisters disappeared at the lower baking temperatures of 300°F. and 325°F.

From the above observations it may be concluded that cakes baked at 375°F. had the best external appearance.

Cake Crumb

Palatability Scores

The scores given by the three judges agreed surprisingly well, both among judges and for the three replications. This was undoubtedly due to the experience of the judges in cake scoring, and the use of a control cake as a reference standard.

Of the ten characteristics scored, three were concerned with cell structure: thickness of cell walls, cell distribution, and cell size; three to other aspects of texture, namely: springiness, compactness and tenderness; three were judged primarily by tasting: moistness, velvetiness and flavor; and lastly the judges were asked to give a score for overall desirability.

The scores for each characteristic were analyzed separately by means of the analysis of variance, Table VII. Several characteristics were affected in a similar way by the variables under study and are classified accordingly.

Overall Desirability: This characteristic will be discussed first for it practically predicts the scores for certain of the other characteristics. As this score was based on general preference, it was a reflection of the characteristics which weighed most heavily in determining the acceptability of a cake. The scores indicated that butter was superior to Primex when used as a cake shortening, and that cakes with emulsifier were preferred to those without, but cakes made with the two emulsifiers at the different levels were not distinguished from each other. Desirability increased with each increase in baking temperature.

Cell Structure (thickness of cell walls, cell distribution and cell size): The addition of emulsifier improved cell structure, but no difference was found between the kinds or amounts of emulsifier used. The type of fat did not produce any difference in the grain. Better cell structure was obtained with each increase in baking temperature. The difference in grain between cakes made with and without emulsifier when baked at different temperatures may be seen in Figures 12, 13, 16 and 17.

Compactness and Tenderness: Cakes without emulsifier were scored lower than those containing emulsifier, but there was no significant difference among cakes prepared with the two emulsifiers at two levels. Butter cakes were scored higher than Primex cakes. No significant difference was found among cakes baked at the three higher temperatures, but those baked at 300°F. received lower scores. The cakes baked at this temperature were compact, gummy, and excessively tender.

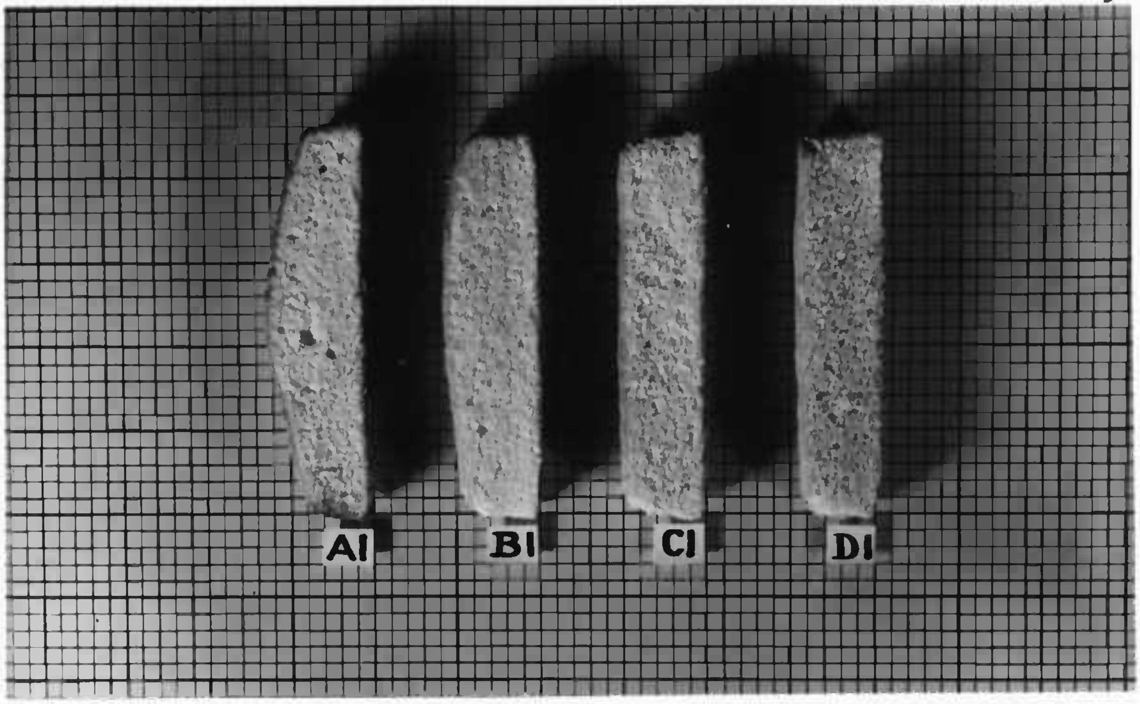


Fig. 16 Butter cakes, no emulsifier.
A1 Baked at 425°F. C1 Baked at 325°F.
B1 Baked at 375°F. D1 Baked at 300°F.

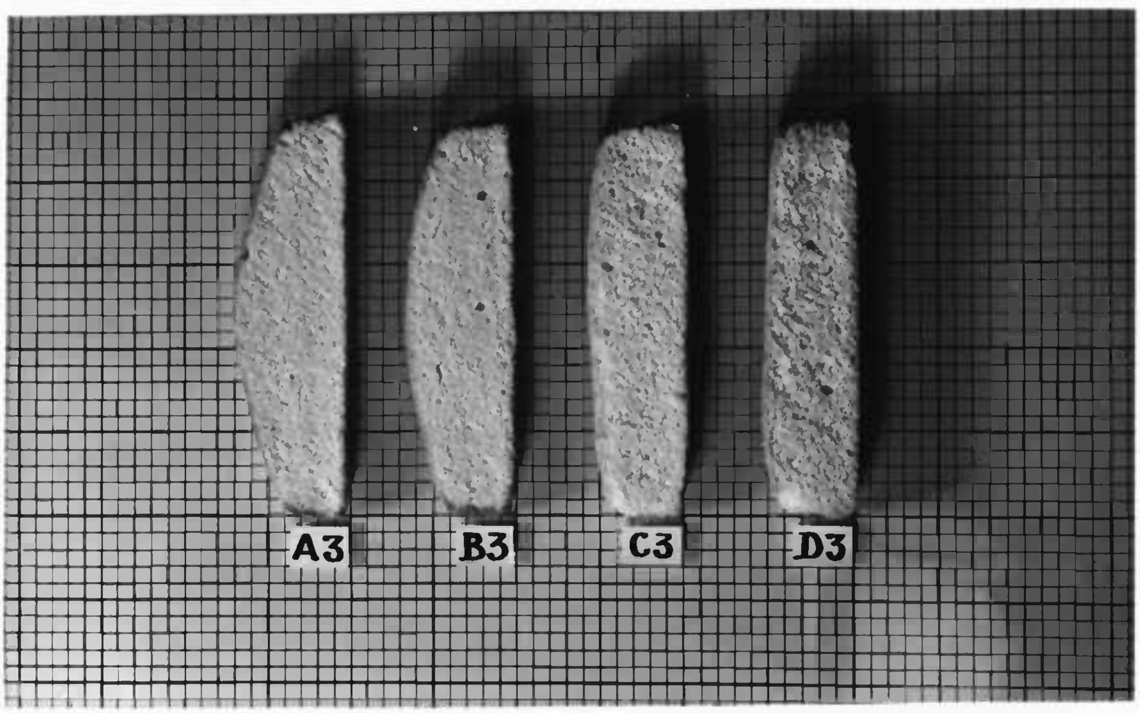


Fig. 17 Butter cakes, 6% Glyceryl monostearate "S" added.
A3 Baked at 425°F. C3 Baked at 325°F.
B3 Baked at 375°F. D3 Baked at 300°F.

Springiness, Moistness, Velvetiness and Flavor: For these characteristics butter cakes were rated higher than Primex cakes. This may be accounted for by the distinctive flavor of butter and the fact that butter dispersed better throughout the crumb. The presence of an emulsifier did not produce significant differences in cake scores for any of these characteristics. Each increase in baking temperature resulted in improved palatability.

Microscopic Appearance of Cake Crumb

Good color contrasts were obtained when cake crumb was treated with osmic acid and the sections stained either with aqueous iodine or eosin. The fat stained black with osmic acid, the starch blue with iodine and the protein a bright pink with eosin.

Microscopic observations revealed that the protein formed the framework of the cake crumb, for the gluten could be seen spreading in filaments in a fine threadlike structure to form the cell walls. Starch granules were embedded in the filamentous protein structure. When the sections were viewed between crossed polaroids, the presence of a few raw starch grains could be recognized. The fat appeared for the most part as a coating on the protein framework. Starch grains could also be seen in the fat border and appeared to be only partially covered with fat.

Photomicrographs were made of sections stained with osmic acid and eosin, illustrating the relationship between the fat and the protein. Figure 18 represents a photomicrograph of a section of the crumb of a Primex cake with no emulsifier added. The branched red

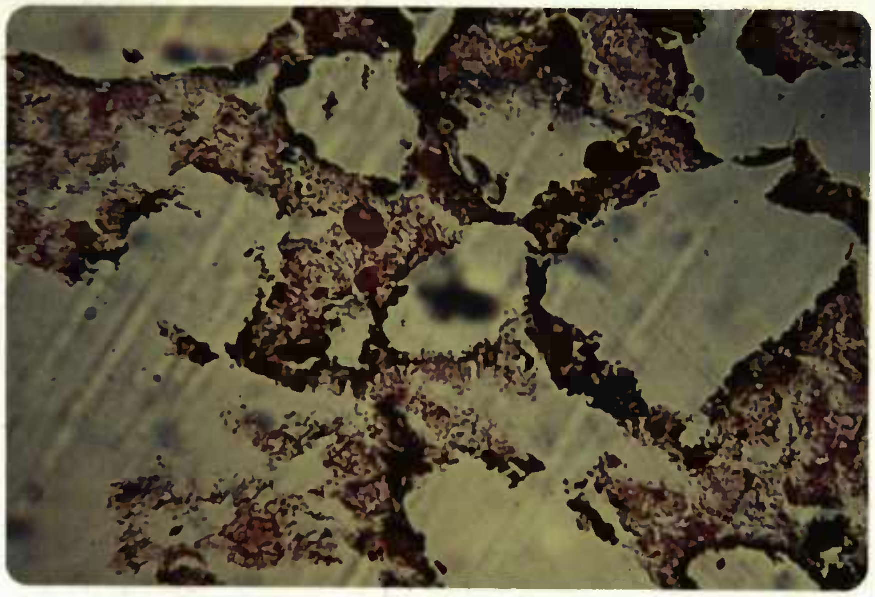


Fig. 18 Photomicrograph (100X) of a cake section, 20μ. Gluten (red) may be seen as a filamentous structure forming the cell walls. Fat (Primex), stained black, appears in heavy beads edging the protein structure. The open spaces are the air cells. Baking temperature, 375°F.

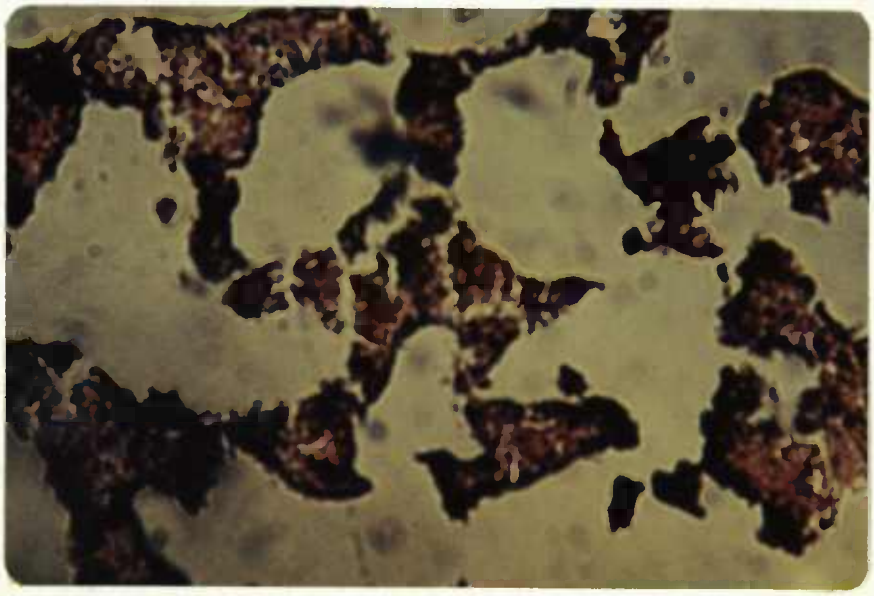


Fig. 19 Photomicrograph (100X) of a cake section, 20μ. The fat (Primex plus 6% glyceryl monostearate), stained black, is spread throughout the protein (red) structure. Open spaces are the air cells. Baking temperature, 375°F.

protein structure may be seen, and the fat as a beaded outline following the contours of red protein. The large open spaces are the Air cells. The shadows in the air spaces were caused by the type of lighting used in taking the photomicrographs and did not appear in the slides.

<u>Effect of Emulsifier:</u> In sections of cakes containing an emulsifier more fat appeared to be spread throughout the protein structure than when no emulsifier was present. When staining, it was more difficult to obtain a good eosin stain in sections which were made from cakes containing emulsifier. This resistance to staining with a water-soluble dye was probably due to the repelling action of fat dispersed throughout the crumb. The photomicrograph presented in Figure 19 shows the red-stained protein being obscured by the black-stained fat. The fat distribution in the cake crumb was not visibly affected by the kind or amount of emulsifier.

<u>Effect of Kind of Fat:</u> When cake sections were studied microscopically, the distribution of butter appeared different from that of Primex, which is a hydrogenated vegetable fat. The butter covered the protein walls in a thin film which penetrated the cell wall structure following the gluten fibers. Primex on the other hand gathered in heavy beads along the protein walls. These beads can be differentiated in Figure 18 edging the protein structure in a discontinuous row. Although butter clumps could be noticed at the points of contact between cell walls, it was not typical of this

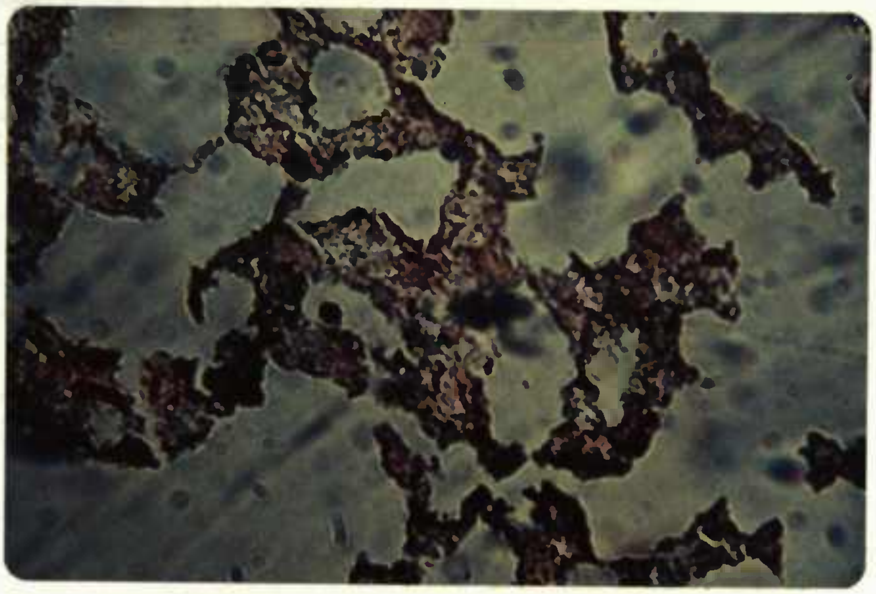


Fig. 20 Photomicrograph (100X) of a cake section, 30μ. The fat (butter) is stained black and the protein red. The open spaces are the air cells. Cake was baked at 425°F.

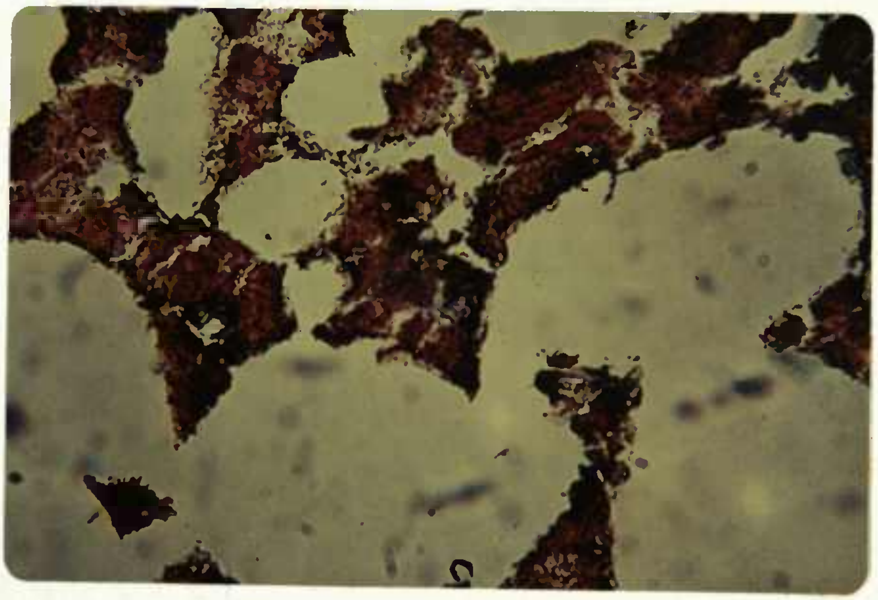


Fig. 21 Photomicrograph (100X) of a cake section, 30μ, from a cake baked at 300°F. The same cake formula as above. Thick cell walls and large air cells are apparent.

fat to gather in drops or beads (Fig. 20). Morr (33) also noticed heavy clumps of fat and a heavy coating around the cake/air interface with some fat within the crumb when hydrogenated vegetable oil was used as fat in shortened cakes, whereas butter appeared within the crumb with a few fat areas at the cake/air interface.

Tenderness in cakes is usually associated with fat. Coughlin (12, p.2) stated that the chief functions of the shortening are to give eating quality, keeping quality, and tenderness to the cake. The higher scores obtained for tenderness when an emulsifier was added may therefore be related to the fat being spread throughout the crumb.

Effect of Baking Temperature: Microscopic sections of butter cakes baked at 425°F. and 300°F. are pictured in Figures 20 and 21. Thin cell walls and small air cells may be seen in the cakes which were baked at a high temperature as contrasted with thick cell walls and large air cells in cakes baked at a low temperature. No emulsifier was used in these cakes.

The differences in cell structure of cakes baked at different temperatures were even more pronounced in cakes containing emulsifying agents. Figure 22 is a photomicrograph of a butter cake containing 6% GMS which was baked at 425°F., and Figure 23 represents the same batter baked at 300°F.

The thicker cell walls and larger air cells observed in microscopic sections of cakes baked at the lower temperatures were

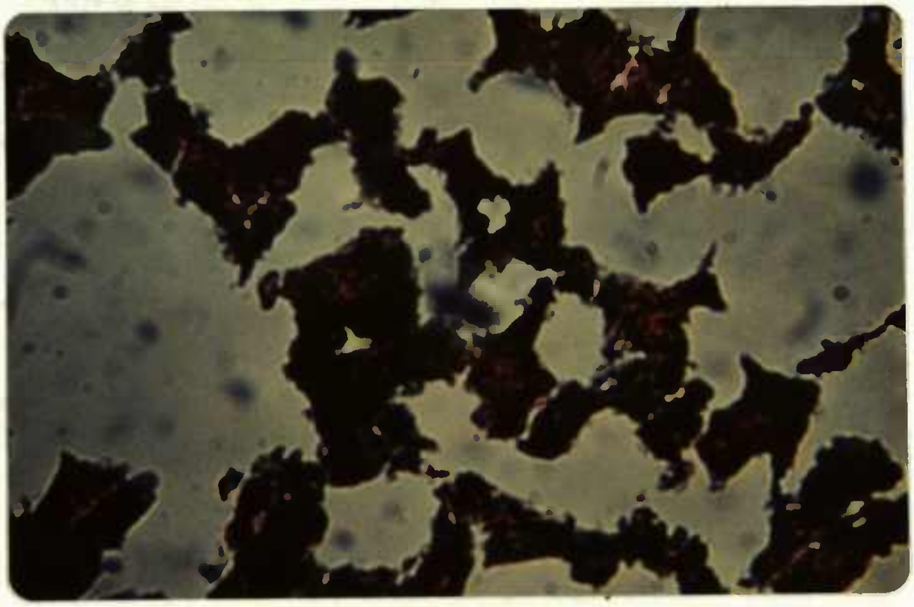


Fig. 22 Photomicrograph (100X) of a cake section, 30μ
6% Glyceryl monostearate was added to the butter.
Thin cell walls and small air cells may be noted.
Cake was baked at 425°F.

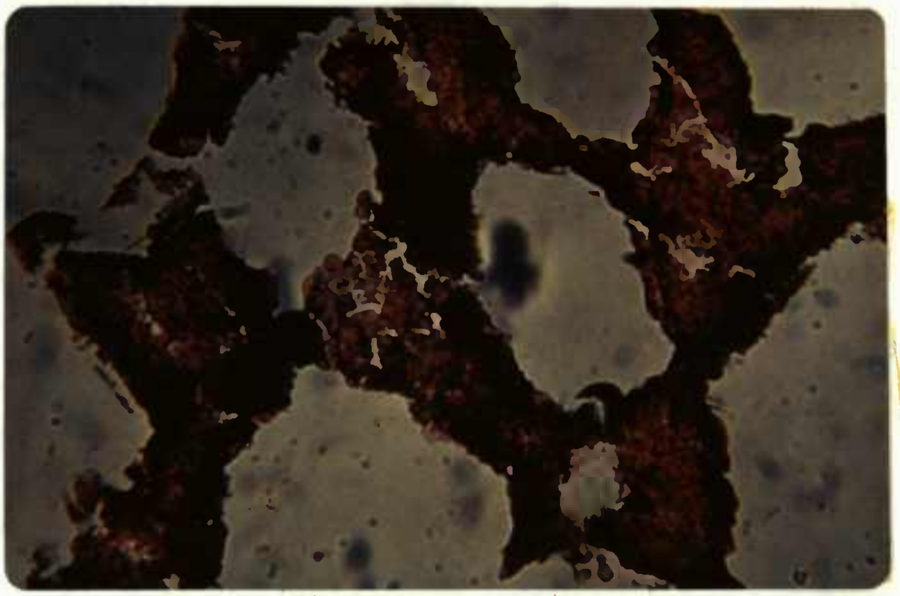
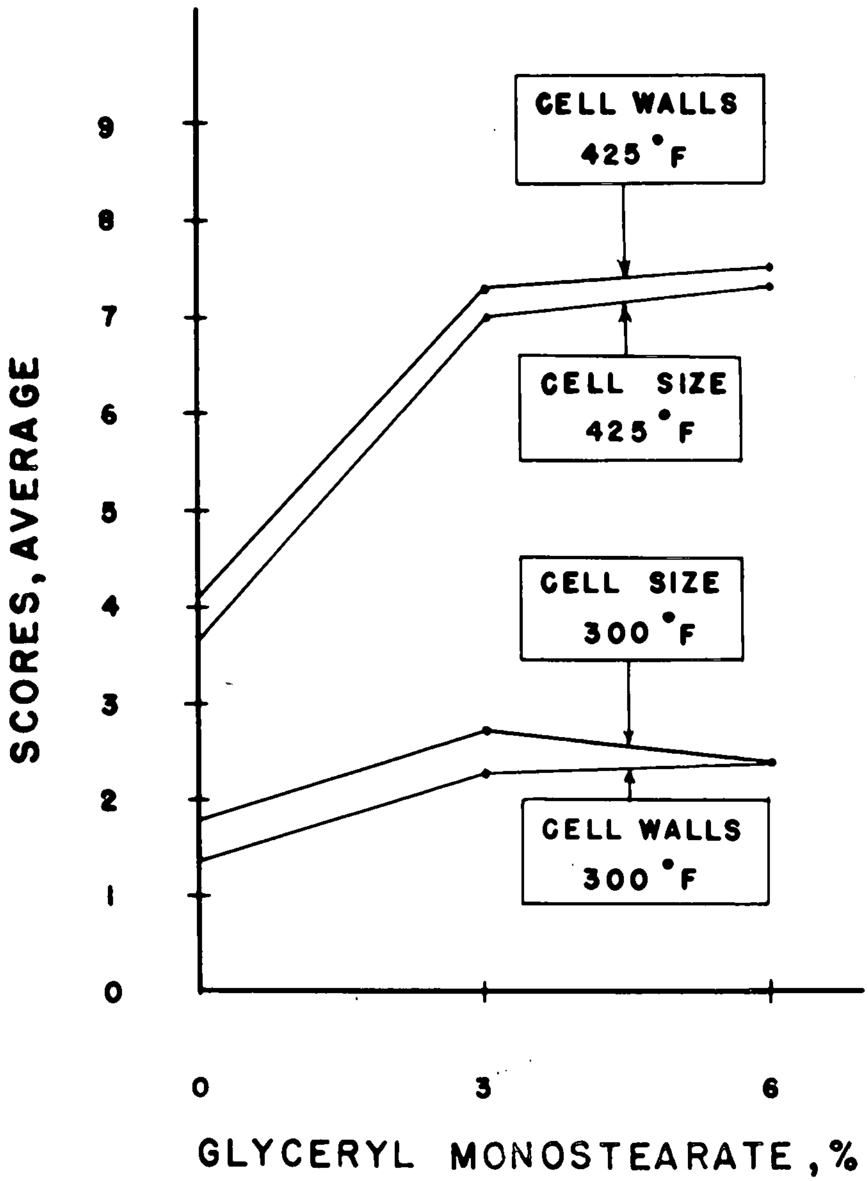


Fig. 23 Photomicrograph (100X) of a section, 30μ, from a cake
baked at 300°F. The same cake formula as above.
Thick cell walls and large air cells are apparent.

also detected by the judges during their evaluation of cake structure. They agreed that thin cell walls and small air cells, as well as more uniform cell distribution, were found in cakes baked at higher temperatures, and that these differences were more pronounced in cakes containing emulsifiers, Figure 24.

Figure 24 Subjective Scores for Cell Structure of Butter Cakes Made With and Without Glyceryl Monostearate "S", and Baked at Different Temperatures



SUMMARY AND CONCLUSIONS

The effectiveness of emulsifying agents in improving the quality of cakes made with different fats and baked at various temperatures has been studied. Two commercial preparations of glyceryl monostearate were tested at 3 per cent and 6 per cent levels (fat basis), one as a fat dispersion and the other as a water dispersion. Butter and hydrogenated vegetable shortening were used. Cakes were baked at four temperatures, 300°F., 325°F., 375°F., and 425°F.

Permanent records were obtained of the physical structure of cakes and batters. These included photographs of cakes, and photomicrographs of creamed mixes, batters and cake sections. Specific gravity of batters, baking losses and cross section areas of cakes were determined.

Scores for palatability of cakes were secured through a panel of judges. A control cake was used as a reference standard.

Microscopic observations indicated that when glyceryl monostearate is added to a cake formula the fat becomes more highly dispersed. Improved fat dispersion in the presence of emulsifier could be observed at each stage of preparation: during creaming, in the batters and in the baked cakes. This dispersal pattern is brought about by the emulsifier concentrating at the fat/liquid interface thereby reducing the interfacial tension.

The emulsifier further causes a variation in the surface forces of the gas in relation to the aqueous phase. Hence the gas is stabilized in the batter during baking. This property of the emulsifier is made effective by an early coagulation of the protein, when cakes are baked at a high temperature. With an increase in oven temperature the time for protein coagulation is decreased, and cake structure is established before a considerable amount of gas can escape from the batter.

As a result of the increased fat dispersion and gas retention when batters containing emulsifying agents are baked at higher temperatures, i.e. 375°F. and 425°F., light full-volumed, tender cakes of fine cell structure are obtained.

Specific gravity measurements on the creamed mixes and on the batters showed that less air was incorporated when an emulsifier was present. Yet the batters containing emulsifier yielded bigger and lighter cakes when baked at 325°F., 375°F., or 425°F. Batters prepared with butter plus emulsifier had the highest specific gravity, and cakes baked from these batters had largest volume. The increase in cake volume and fine cell structure obtained when an emulsifier was present could therefore not be ascribed to increased aeration.

Palatability scores were influenced by the baking temperature employed, by the addition of emulsifier and by the type of fat used. Cake quality as indicated by scores was poorest for cakes baked at 300°F., regardless of whether an emulsifier was added. Beyond this temperature, the addition of emulsifier produced lighter, finer grained and more tender cakes, its effect on grain becoming more noticeable with each increase in baking temperature. Cakes made with butter were scored higher than those made with hydrogenated vegetable oil, for flavor, moistness, velvetiness, lightness and tenderness. With each increase in baking temperature cakes were scored higher for all characteristics except tenderness and lightness. These two texture qualities improved with the first increase in baking temperature, but not after that.

The external appearance of cakes made with emulsifier baked at 325°F., 375°F. and 425°F., was always better than that of cakes made without emulsifier.

Glyceryl monostearate proved to be equally effective whether it was dispersed in fat or in water. Three per cent of emulsifying agent, based on the fat, was as efficient as six per cent in improving cake quality, except that at high baking temperatures, the use of six per cent emulsifier resulted in bigger volumes.

BIBLIOGRAPHY

1. Atlas powder company. Atlas surface active agents. Their characteristics. The HLB system of selection. Wilmington, 1950. 34p.

2. Bailey, Alton E. Industrial oil and fat products. N.Y., Interscience, 1945. 735p.

3. ________ and R. H. McKinney. A rational method for evaluating the creaming qualities of a shortening. Oil and soap 18:120-122. 1941.

4. Barmore, Mark A. The influence of various factors including altitude, in the production of angel food cake. Colorado experimental station technical bulletin. 1936. 55p.

5. Carlin, George T. A microscopic study of the behavior of fats in cake batters. Cereal chemistry 21:189-199. 1944.

6. Chamberlain, charles J. Methods in plant histology. 5th ed. Chicago, University of Chicago press, 1932. 416p.

7. Chemical Publishing Company. Emulsion technology. 2d ed. Brooklyn, Chemical publishing company, 1946. 360p.

8. Clayton, William. The theory of emulsions and their technical treatment. 4th ed. Philadelphia, Blakiston, 1943. 492p.

9. Cole, Elbert C. Comparative histology. Philadelphia, Blakiston, 1941. 396p.

10. Collins, Opal Dewey. The viscosity of cake batter as related to batter structure. M.S. thesis, Purdue university, 1940.

11. Cook, F. E. Chocolate Cake I. Optimum baking temperature. M.S. thesis, Iowa state college, 1938. 50p.

12. Coughlin, F. J. The evolution of a cake formula balance. Cincinnati, Procter and Gamble Bakery research department. Presented at the American institute of baking wholesale cake course. Jan. 5-17, 1941; Jan. 4-17, 1942. 48p.

13. Daum, Ruth, Evelyn G. Halliday and W. F. Hinman. The effect of glyceryl monostearate on the baking properties of cakes. Oil and soap 19:39-41. 1942.

14. Dunn, J. A. and J. R. White. Leavening action of air included in cake batter. Cereal chemistry 16:93-100. 1939.

15. Fuller, C. H. F. Cakes as food. Chemistry and industry Nov. 5, 1949, pp.771-772.

16. Glyco products company, inc. Use aldo 33. Brooklyn, Glyco products company, inc. 7p.

17. Grewe, Emily. The emulsion-foam produced by agitating butter, sugar and egg: A method for testing the stability of the emulsion and the effect of the conditioning temperature of the fat. Cereal chemistry 14:802-818. 1937.

18. Harris, B. R., A. K. Epstein and F. J. Cahn. Fatty interface modifiers. Composition, properties and uses in the food industries. Oil and soap 18:179-182. 1941.

19. Hartman, Robert J. Colloid chemistry. Boston, Houghton, 1939. 556p.

20. Harvey, A. Technical aspects of emulsions. 2d ed. London, A Harvey, 1935. 150p.

21. Hauser, Ernst A. and J. Edward Lynn. Experiments in colloid chemistry. N.Y., McGraw, 1940. 178p.

22. Hood, Maude Pye and Belle Lowe. Air, watervapor and carbon dioxide as leavening gases in cakes made with different types of fats. Cereal chemistry 25:244-254. 1948.

23. Hunter, Mildred Pixton Bowers. The effect of formula, temperature of ingredients, kind of fat, and method of mixing on batter structure and cake quality. Ph.D. thesis, Cornell university, 1949. 175p.

24. ________, Alice M. Briant and Catherine J. Personius. Cake quality and batter structure. Effect of formula, temperature of ingredients, kind of fat and method of mixing. Cornell university agricultural experimental station Bulletin 860. 1950. 59p.

25. Jacobs, Morris B. Synthetic food adjuncts. N.Y., Van Nostrand, 1947. 335p.

26. Johansen, Donald Alexander. Plant microtechnique. N.Y., McGraw, 1940. 523p.

27. Johnston, N. F. and H. H. Favor. New emulsifiers for foods. Food industries 19:1196-1197. 1947.

28. Kenny, R. L. Emulsions and their application in the bakery. Food manufacture 22:415-418, 420. 1947.

29. Kuhrt, N. H., E. A. Welch and F. J. Kovarik. Molecularly distilled monoglycerides, I: Preparation and properties. Journal of American oil chemist's society 27:310-313. 1950.

30. ________. Molecularly distilled monoglycerides, II: Cake baking experiments. Journal of American oil chemist's society 27: 344-346. 1950.

31. Lowe, Belle. Experimental cookery. 3d ed. N.Y., Wiley, 1943. 611p.

32. ________ and P. Mabel Nelson. The physical and chemical characteristics of lards and other fats in relation to their culinary value, II: Use in plain cake. Iowa state college research Bulletin 255, 1939. 66p.

33. Morr, M. L. Plain cake XI. Distribution of fat as affected by kind of fat and method of combining ingredients. M.S. thesis, Iowa state college, 1939.

34. Nason, Edith Holloway. Introduction to experimental cookery. N.Y., McGraw, 1939. 317p.

35. Ohlrogge, Harriet Beyer and Gertrude Sunderlin. Factors affecting the quality of cakes made with oil. Journal of the American dietetic association 24:213-216. 1948.

36. Overman, Andrea C. Cake formula and method of mixing for cakes made with different types of fat. (Unpublished data) available at Dept. of home economics, Oregon state college, Corvallis.

37. Potter, F. E. and D. H. Williams. Stabilizers and emulsifiers in ice cream. U.S. Dept. of agriculture. Bureau of dairy industry, Washington, 1950. 4p.

38. Pyke, W. E. and Gestur Johnson. Relation of mixing methods and balanced formula to quality and economy in high sugar ratio cakes. Food research 5:335-359. 1940.

39. Romeis, B. Mikroskopische Technik. 15th ed. Munchen, Leibniz, 1948. 695p.

40. Sell, H. M., A. G. Olson and R. E. Kremers. Lecitho-protein. The emulsifying ingredient in egg yolk. Industrial and engineering chemistry 27:1222. 1935.

41. Snyder, Walter E. Emulsifiers are useful. Milk plant monthly 38:30-33, 43-44. June 1949.

42. Stone, Alice Mae. Plain cakes VII. The determination of the optimum baking temperature for three types of baking powders. M.S. thesis, Iowa state college, 1934. 68p.

43. Weiser, Harry Boyer. Colloid chemistry. 2d ed. N.Y., Wiley, 1949. 444p.

APPENDIX

TABLE VI

Analysis of Variance of Cake Volumes

Source of Variation	Degrees of Freedom		Mean Squares
Temperatures	3		45.1237*
Fats	1		8.0412*
Cakes	4		7.8611*
No emulsifier vs. emulsifier		1	23.3388*
Among emulsifiers		3	8.1057
Temperatures X Fats	3		0.1928
Temperatures X Cakes	12		1.7544*
Fats X Cakes	4		0.7966
Temperatures X Fats X Cakes	12		0.4952*
Experimental error	80		0.1268
Sampling error	600		0.0033
Total	719		----

* Indicates significance

TABLE VII

Analysis of Variance of Scores for Cake Palatability

Source of Variance	Degrees Freedom	MEAN SQUARES									
		Thickness Cell Walls	Cell Distribution	Cell Size	Springiness	Compactness	Tenderness	Moistness	Velvetiness	Flavor	Overall Desirability
Replication	2	6.55	20.04	6.30	1.12	0.31	4.34	0.93	0.34	0.63	0.78
Cakes (C)	4	22.33	23.78	18.18	0.48	20.24	10.82	1.92	2.57	0.45	12.03
No emulsifier vs. emulsifier	1	71.56*	64.60*	52.14*	---	64.60*	43.06*	---	---	---	35.16*
Among emulsifiers	3	17.76	30.54	20.57	---	5.46	0.07	---	---	---	4.32
Fats (F)	1	5.38	0.47	1.00	16.90*	26.14*	14.80*	18.23*	29.47*	98.18*	51.38*
Temperatures (T)	3	304.61*	203.33*	250.01*	177.13*	91.00	90.88	145.81*	235.05*	44.76*	178.56*
300°F. vs. others	1					259.11*	255.21*				
Among others	2					6.95	8.71				
Judges (J)	2	0.84	2.74	0.92	7.94	0.76	3.47	2.63	4.02	4.36	1.68
Cakes X Fat	4	2.16	0.40	2.98*	1.98	2.82	3.93	0.51	2.90*	1.92*	4.67
Cakes X Temperature	12	3.64*	3.04*	2.83*	4.49*	4.51	6.06	0.89*	1.66*	1.69*	4.72
Cakes X Judge	8	0.91	0.07	0.43	0.54	0.16	1.37	0.81	1.02	0.72	0.87
Fats X Temperature	3	3.46*	1.87	2.34	0.11	1.43	0.41	0.91	2.79*	0.54	1.65
Fats X Judge	2	0.42	0.88	0.17	0.56	2.69	1.55	0.63	0.47	0.85	3.10
Temperature X Judge	6	2.71*	1.06	2.22*	1.24	5.89	1.78	2.15*	1.65*	2.55*	0.32
F X T X J	6	0.69	0.56	0.21	0.49	0.34	0.24	0.14	0.07	0.14	0.47
C X T X J	24	0.94	0.76	0.83	0.53	0.82	0.89	0.71	0.52	0.54	0.49
C X F X T	12	1.56	1.71	1.65	1.25	3.16*	1.89*	0.47	0.70	0.47	1.82*
C X F X J	8	0.35	0.70	0.36	0.51	0.53	0.62	0.42	0.33	0.54	0.67
C X F X T X J	24	0.85	0.58	0.53	0.59	0.58	0.81	0.28	0.64	0.52	0.49
Error	238	0.92	1.04	1.04	0.96	0.99	0.99	0.50	0.68	0.63	0.60
Total	359										

* Indicates significance

TABLE VIII

Average Scores for Characteristics of Cakes Made With Two Fats, With And Without Emulsifiers and Baked at 425°F. (218.3°C.)
(Cakes compared with a reference standard having a score of 5)

Cake Characteristics	Butter					Primex				
	No Emulsifier	GMS		Aldo		No Emulsifier	GMS		Aldo	
		3%	6%	3%	6%		3%	6%	3%	6%
Thickness of cell walls	4.1	7.3	7.5	6.5	5.7	4.6	6.1	6.6	6.0	6.5
Cell distribution	3.9	6.2	7.1	6.1	5.1	4.4	6.0	6.9	5.8	6.2
Cell size	3.7	7.0	7.3	6.3	5.4	5.4	6.0	7.2	6.1	6.2
Springiness	3.8	6.1	6.3	5.0	3.9	3.9	4.7	5.2	5.2	5.3
Compactness	3.1	6.0	6.6	5.2	5.3	3.8	4.0	5.9	5.8	5.6
Tenderness	3.8	6.8	6.9	5.2	5.2	3.9	4.9	6.0	5.3	6.3
Moistness	5.3	5.7	5.0	4.8	4.7	4.4	4.4	4.3	4.6	4.1
Velvetiness	5.2	6.8	7.0	5.1	5.4	4.6	5.0	5.1	4.8	5.1
Flavor	4.4	5.8	5.3	5.0	4.6	3.8	4.0	4.0	4.0	3.9
Overall desirability	3.4	6.9	7.3	5.7	5.6	3.9	4.4	5.6	5.1	5.0

TABLE IX

Average Scores for Characteristics of Cakes Made With Two Fats, With and Without Emulsifiers and Baked at 375°F. (190.6°C.) (Cakes compared with a reference standard having a score of 5)

Cake Characteristics	Butter					Primex				
	No Emulsifier	GMS		Aldo		No Emulsifier	GMS		Aldo	
		3%	6%	3%	6%		3%	6%	3%	6%
Thickness of cell walls	3.9	4.9	6.7	5.7	5.3	3.8	4.7	5.3	4.7	4.3
Cell distribution	4.4	4.9	6.3	5.5	5.3	4.6	4.7	5.8	5.6	4.3
Cell size	4.2	5.3	6.5	5.4	5.2	4.8	4.9	5.8	5.3	4.3
Springiness	4.3	4.7	5.0	4.7	5.2	4.4	4.2	4.1	4.2	4.1
Compactness	3.6	4.6	6.3	5.3	5.4	3.7	5.0	4.9	5.0	4.7
Tenderness	4.1	5.0	6.2	5.3	5.9	3.8	5.3	5.1	5.1	5.2
Moistness	4.7	5.0	4.3	4.8	4.4	4.1	4.4	4.0	4.3	4.2
Velvetiness	4.4	5.3	5.7	4.8	4.9	4.0	4.4	4.2	4.4	4.4
Flavor	4.8	4.9	5.0	4.7	4.8	3.4	4.0	3.9	4.2	4.0
Overall desirability	3.9	4.7	6.3	5.0	5.2	3.2	4.4	4.1	4.4	3.9

TABLE X

Average Scores for Characteristics of Cakes Made With Two Fats, With and Without Emulsifiers and Baked at 325°F. (163.2°C.) (Cakes compared with a reference standard having a score of 5)

Cake Characteristics	Butter					Primex				
	No Emulsifier	GMS		Aldo		No Emulsifier	GMS		Aldo	
		3%	6%	3%	6%		3%	6%	3%	6%
Thickness of cell walls	2.9	2.8	3.3	3.5	3.2	2.7	3.7	3.7	3.2	3.6
Cell distribution	3.1	3.3	3.5	4.3	3.5	3.0	4.4	4.2	4.2	3.7
Cell size	3.0	3.1	3.3	3.7	3.6	3.2	4.0	4.2	3.8	3.9
Springiness	4.3	3.6	3.2	3.4	4.0	3.4	3.1	2.6	3.7	3.3
Compactness	5.9	5.7	5.7	5.8	5.7	3.8	5.1	4.9	5.9	5.6
Tenderness	4.7	5.2	5.0	5.3	5.3	4.6	4.7	3.8	5.2	4.3
Moistness	3.7	3.3	3.6	3.6	3.4	3.6	3.5	3.0	3.5	3.1
Velvetiness	3.3	3.3	3.6	3.7	3.3	3.2	3.3	3.2	3.1	3.2
Flavor	4.0	4.6	4.4	4.2	4.2	3.2	3.6	2.8	3.6	3.7
Overall desirability	3.6	3.7	3.9	3.8	3.8	3.1	3.4	3.1	3.2	3.3

TABLE XI

Average Scores for Characteristics of Cakes Made With Two Fats, With and Without Emulsifiers and Baked at 300°F. (148.9°C.)
(Cakes compared with a reference standard having a score of 5)

Cake Characteristics	Butter					Primex				
	No Emulsifier	GMS		Aldo		No Emulsifier	GMS		Aldo	
		3%	6%	3%	6%		3%	6%	3%	6%
Thickness of cell walls	1.4	2.3	2.4	1.8	1.8	1.9	1.6	1.8	2.1	2.2
Cell distribution	1.6	2.7	2.5	2.3	2.3	2.3	2.1	2.8	3.0	2.0
Cell size	1.8	2.7	2.4	2.3	2.2	2.3	2.2	2.3	2.8	2.2
Springiness	2.4	2.1	2.0	2.1	1.6	2.0	1.3	1.3	2.1	1.4
Compactness	3.7	3.2	4.0	3.7	3.2	2.8	2.6	2.7	3.4	2.3
Tenderness	3.3	3.6	3.4	3.2	3.2	3.4	2.9	2.3	3.4	2.9
Moistness	2.4	2.1	2.3	1.8	1.8	2.6	1.2	1.7	1.7	1.3
Velvetiness	1.9	1.8	2.2	1.7	1.9	2.2	1.2	1.3	1.6	1.4
Flavor	4.3	4.0	3.8	3.3	3.3	3.1	1.8	2.0	2.7	2.0
Overall desirability	2.2	2.3	2.8	2.1	2.1	2.3	1.3	1.7	2.0	1.4

TABLE XII

Analysis of Variance of Specific Gravities of Batters

Source of Variation	Degrees of Freedom	Mean Squares
Fats	1	0.04800*
Cakes	4	0.09287
No emulsifier vs. emulsifier	1	0.13571*
Among emulsifiers	3	0.02641
Fat-Cake interaction	4	0.00497
Error	110	0.00048
Total	119	

* Indicates significance