APPLICATION OF MICROWAVE ENERGY FOR BAKING CAKES

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

Microwave energy with its unique heating ability offers many advantages, including those of savings in time and space for its application in the baking industry. A number of applications have been considered including those of proofing, baking, defrosting and pasteurization of certain baked products (17, 31). One of the most successful commercial applications is associated with the production of chemically-leavened and yeast-raised doughnuts (7, 20).

In the domestic market, the sales of microwave ovens have increased to the extent that by 1980, 20% of the homes in this country are estimated to have these types of ovens (11).

However limited information has been reported on the application of microwave energy for baking cakes. Therefore, this study was undertaken to investigate its application for baking high-ratio white layer cakes. This product was selected since layer cakes are one of the most popular large cakes available today (29).

The objectives of this study were to:

1. Determine the optimum conditions for baking this type of cake with microwave energy by considering the effect of the following processing conditions and ingredients:

    (a) baking time and oven power levels.

    (b) water level.

    (c) baking powder blend.

(d) emulsifiers.

2. Investigate the structure development in this type of cake baked with microwave energy as compared with that of a conventional cake by:

(a) batter flow studies.

(b) scanning electron microscopy.

LITERATURE REVIEW

Microwave heating

Microwaves are a form of electromagnetic radiation of 1m to 0.1 mm in wavelength and 300 megahertz (MHz) to 3,000 MHz in frequency (1). In the U.S.A. the Federal Communications Commission has provided four frequencies for industrial, scientific and medical uses. These four frequencies conform to the International Radio Regulations adopted in Geneva in 1959 (2). Two of these frequencies, 915 $\pm$ 25 MHz and 2450 $\pm$ 50 MHz are of practical importance in commercial and domestic food preparation and it is the latter which has been used the most in domestic and commercial ovens throughout the world (3).

Microwaves can interact with matter in three ways: reflection, transmission and absorption. Metals reflect microwaves. Because of this reflection of energy, metal is unsatisfactory for use as a material in food containers. Transmission of microwaves occurs when the energy passes through a material without the production of heat. Paper, glass, ceramics and plastics are examples of such materials (2). Different types of each of these materials vary in their transmittance properties and consequently in their suitability as materials for food containers (4, 8). Absorption of microwave energy produces heat within a material. Food constituents such as water and fat are examples of absorptive materials (7). Since the quantum energy of microwaves is too low to cause any change due to direct interaction with molecules and chemical bonds, microwaves and biological materials seem to be limited to thermal interactions (4).

Absorption of this energy occurs when a non-conducting material is placed in an electromagnetic field and the charged asymetric molecules within the material attempt to alternate at the applied frequency. In the case of most domestic microwave ovens the applied frequency is 2450 MHz which means that the electric field reverses 2450 million times per second. The molecules attempting to oscillate at this frequency generate intermolecular friction which quickly causes the food to heat (3).

Food molecules vary in the rate at which they oscillate in the alternating electric field. Particle vibration can be (i) restricted by mechanical forces contributed by the presence of materials such as ice and solid fats and (ii) influenced by differences in the extent of polarization between molecules within the electric field. The specific heat of a food is an important factor in influencing the effectiveness of microwave heating. For example water and fat have specific heat values of 1.0 and approximately 0.5 respectively which means that water requires twice as much heat as fat in order to obtain a temperature increase of $1^{o}C$ (1). Another important consideration is product geometry (9). Containers which satisfy the requirements of optimum product geometry are circular, shallow packages with round corners (8). However the most perfect shape has been suggested to be a container with the above specifications in addition to an elevated central region (8).

Microwave heating takes place directly within the food and within the limits of microwave penetration (3). Since the transfer of microwave energy to heat takes place within the heating food this form of heating is more efficient than conventional heating in which heat must pass through the transfer media. In microwave ovens the heating media has little radiation loss from the food surfacs while the interior temperature is rising because heat is developed to a greater extent beneath ths surface of the food (3). Therefore internal conduction is involved only as a secondary effect to modify the temperature distribution (7). Microwave heating does not result in surface browning since the surface tsmperature is lower and consequently the moisture content of the surface material is higher than in conventional heating. In order to achieve browning of food products in microwave ovens browning elements have been installed. Also work is being conducted on developing specially formulated browning mixes or glazes for surface application to various products (11).

A microwave oven is a metal cabinst containing as one of its main components a magnetron or microwave generator (10). The magnetron produces microwave energy by the interaction of strong electric and magnetic fields. The other components of the oven are responsible for transmitting and distributing this energy in a manner that ensures the best possible uniform energy density (2). Since the release of the first microwave oven in 1947 sales have increased to the extent that by 1980, 20% of homes in the U.S.A. are estimated to have these batch-type ovens (11). Also larger microwave ovens of a continuous-type are available for industrial applications (5).

The baking industry has considered the use of microwave energy for many applications including the proofing, baking, defrosting and pasteurization of certain baked products (17, 31). One of the first applications of microwave heating was in 1947 when Cathcart et al (15) suggested its use at 14 to 17 MHz for the pasteurization of packaged bread. More recently these results were confirmed at 2450 MHz (16).

Bread baking using combinations of microwave energy and conventional heat sources is technically feasible (12, 13, 14, 18). One of the advantages of this combination approach is the ability to use flour from a wheat grist of a lower protein content (13). However the most significant problem preventing its industrial application is the lack of a satisfactory alternative to the conventional baking tin (7, 14).

The production of doughnuts is an area of the food industry which has one of the most successful applications of microwave energy (7, 20). The microwave proofing of yeast raised doughnuts reduces production costs and proofing time from approximately 35 to 4 minutes. (21, 22, 24) Microwave energy is used also as an adjunct heat source for the frying of chemically leavened doughnuts to produce an improved product in a shorter frying time (24). Another successful commercial application of microwave energy is the drying of pasta products using a combination of microwave energy and hot air (7, 19, 20).

Food products are being formulated and packaged exclusively for microwave cooking (11, 30). An example of such a product is microwave pancakes (11, 30).

Limited work has been reported on the application of microwave energy for baking cakes. Neuzil and Baldwin (26) found that plain white and devils food cakes were less tender and less moist than conventional cakes though cell structure and flavor were not significantly different. Street and Surratt (25) studied the effect of liquid level, container shape and browning time on cake prepared from a yellow cake mix. The microwave baked cakes were more tender and less moist than conventionally baked while an increase in liquid level produced a cake similar in cell distribution, moisture content and volume to a conventionally baked cake. Also the effect of microwave energy on lipid changes in egg yolks and cakes was studied by Schiller et al (28). Their results were in accord with the review by Rosen (4) in that microwave energy was found not to interact strongly with lipid molecules to initiate hydrolysis or autoxidation in this food system.

Layer cake structure

Layer cakes are one of the most popular large cakes available today. While these cakes have been made by formulas which resemble modified pound cakes the so-called "high-ratio" cakes with sugar-flour ratios of 115 to 145 parts of sugar to 100 parts of flour are more tender, lighter-textured and softer (29).

The successful commercial production of these cakes has been dependent for some time on the chlorination of the flour although alternative procedures such as heat treatment of both wheat and flour have been suggested (32). However the detailed mechanisms operating during these "denaturation" processes remain to be elucidated (33). Chlorination of the flour has the advantage of preventing collapse of the cake surface, increasing volume and producing a more even product (34). An unimproved cake flour even at optimum liquid levels produces a layer cake with thick cell walls, soggy crumb and coarse appearance (35). Chlorination would seem to affect all of the components of wheat flour. A number of authors have shown that the primary effect of chlorine action is on the starch component of the flour (34, 36, 37), while other secondary effects involving the modifications of flour proteins (39) and lipids (40) have been reported. In a recent review Gough et al (41) concluded that chlorine appeared to be effective through its action upon the minor components (chiefly lipids but possibly some proteins) associated with the starch granules. These chemical changes altered the properties of the starch and thus its behavior in the cake batter during baking.

In the production of a high-ratio cake of a fine, even crumb structure and of good volume, the leavening gases (air incorporated mechanically, carbon dioxide chemically, and steam by evaporation) contained in discrete gas cells must be evenly distributed in the batter which therefore must itself be of such a nature as to allow expansion but yet minimize coalesence of the gas cells (41).

The correct formula balance is important in order to obtain a cake of maximum volume which does not collapse during baking (29). Flour and eggs provide the structure-building ingredients in layer cakes while sugar, shortening and water contribute to product tenderness and reduce batter viscosity (38). Empirical rules have been developed to assist the baker in achieving the correct balance between these opposing requirements.

It is well known that starch granules interact with water and undergo gelatinization when heated (41) although this process is moderated by the presence of other cake ingredients (43). Consequently water level in a cake batter has a critical effect on the extent of starch gelatinization which in turn determines the crumb structure of the layer cake (42). Sufficient liquid is necessary to dissolve the sugar and still provide adequate moisture for starch gelatinization. When insufficient liquid is present the starch would be at a disadvantage in competing for water against the strongly hydrophilic ingredients, sugar and protein. The result would be a coarse granular crumb (42). However if excess water was available for starch gelatinization the cake crumb would begin to assume a gel-like character.

A cake batter represents a complex emulsion and foam system (44). During baking the typical cake structure is formed which "sets" in the later stages of heating to produce a solid foam (46). According to Carlin (45) oil may be dispersed in a cake batter in several ways namely an oil-in-water emulsion, a water-in-oil emulsion, mono- or multimolecular layers at various interfaces or combinations of the above. In the initial stages of traditional methods of batter preparation the air in the batter is associated with the fat and the deficiency of water results in a water-in-oil emulsion. However as the full amount of water is added phase inversion occurs to produce an oil-in-water emulsion.

Howard and co-workers (47, 48) proposed that the mechanism of layer cake baking consists of at least three stages: (i) aeration of cake batter (ii) thermal stability of batter and (iii) thermal setting of batter. One of the most fundamental and initial means of leavening a cake batter is by mechanically entraining and subdividing bubbles of air and leavening gas during mixing (49). These bubbles provide the majority of sites for collecting leavening gas and water vapor as they are evolved. It is extremely unlikely that spontaneous nucleation of bubbles will occur in a continuous fluid since as bubbles become extremely small their internal pressure becomes very large (50). Therefore layer cake structure depends on the number and size of the individual air cells with an improved structure and volume resulting from a greater number of small bubbles (50).

The common chemical leavening system involves the reaction of sodium bicarbonate with an acid phosphate salt to produce carbon dioxide (51). The development of layer cake structure can be controlled by an appropriate blend of these acids since the rate of carbon dioxide release is governed by the solubility characteristics of the acids (51). This leavening system can influence the formation of cake structure through roles in addition to carbon dioxide generation, for example certain types of leavening acids are a source of polyvalent metal ions and can serve to stabilize oil-water interfaces (48). Also chemical leavening systems can affect crumb color (54), pH (53), grain (55) and textura (55) as well as batter viscosity (52).

The use of emulsifiers in cake either as components in the fat or as individual additives may be aimed at attaining one or more improvements in cake quality (44). Mono- and diglycerides of various forms are used widely as emulsifiers in hydrogenated shortenings. Generally these shortenings are used in cake formulations which require a creaming stage. In this type of batter the emulsifier is not as essential for air incorporation as are the physical properties of the plastic shortening (48). However the emulsified shortening does produce a smoother batter because a finer dispersion of fat is formed in the batter emulsion and if the batter is stable during baking a fine-grained cake is obtained. These emulsified shortenings were less successful for aeration of single stage cake batters (56). Many emulsifiers have been developed to improve air incorporation and fat dispersion in particular for single stage cake batters. Examples are lactoylated partial glycerides (57), and diol monoesters such as propylene glycol monostearate (56). The effect of these emulsifiers under the conditions of single stage mixing is thought to be due to the formation of a film encapsulating the oil droplet and preventing the fat phase from interfering with the foaming properties of the soluble proteins.

Even though these "aerating" emulsifiers have been used mostly in single stage cake batters they are used in multistage batter preparation methods (58). The selection of an emulsifier system for a particular use has become complex because of the many food-grade emulsifiers available today as illustrated in recent surveys by Petrowski (59, 60). Griffin (61) initiated a method to systematize the selection of nonionics based on hydrophile-lipophile balance (HLB). The HLB system is useful in the selection of emulsifiers in water-oil emulsions such as salad dressings however it is thought to have limited value in the complex systems found in most food products (58, 62). Various techniques have been used for arriving at optimal levels and combinations of emulsifiers in fluid shortening (63) and in plastic shortening (62).

Emulsifiers contribute substantially to batter development and consequently to cake structure through their control over factors which will influence cell size, namely size distribution, movement, film permeability and stability of gas bubbles. Also emulsifiers have been reported to have other functions in addition to aeration which include modification of the crystalline forms of fat and the extensibility of the protein and the ability to complex with starch (64).

When an aerated batter (oil-in-water emulsion) is placed in the oven a number of interactions begin as the temperature of the batter rises. As the fat crystals melt the air cells migrate from the fat to the aqueous phase and the cells expand slightly with the rise in temperature. Howard (48) observed batter instability as the temperature of the batter reached the melting point of the emulsifier film at the oil-water interface. At this stage soluble proteins, polyvalent cations and surface active lipids were shown to be necessary for stabilization of the batter (48). Also granular starch is considered important since the rate of swelling of the granule affects the viscosity and emulsion stability of the fluid batter (47).

In the final stages of baking the leavened emulsion coagulates to produce a solid foam. This thermal setting of the batter has been attributed to egg protein denaturation (33, 41) and starch gelatinization (41, 44) or to the effect of heat jointly upon the starch-protein complex (32).

Response surface methodology

Response surface methodology (RSM) was developed initially by Box and Wilson (27). Discussions of the theory and applications of RSM have been given by Davies (65), Myers (66), Hill and Hunter (67) and Box and Behnken (68).

RSM is an experimental technique using an incomplete factorial design to determine ths levels of various factors that will optimize a response. This approach has been applied successfully to mixture experiments in the chemical (69) and the food industry (62, 70, 71, 72, 73) since in many cases the use of complete factorial designs cannot be justified from an economic point of view.

In conventional response surface experimentation the response can be approximated over the experimental range by a second ordsr Taylor Series expansion:

$$Y = B_0 + B_1X_1 + B_2X_2 + \dots + B_kX_k + B_{12}X_1X_2 + \dots + B_{k-1,k}X_{k-1}X_k + B_{11}X_1^2 + B_{22}X_2^2 + \dots + B_{kk}X_k^2.$$

where $X_1, \dots, X_k$ are the independent factors and the coefficients B_0, ..., B_{kk} are the parameters to be astimated from the data (67). The response surface of the predicted values of Y can be constructed as a function of the independent factors X_1, ..., X_k using the estimated parameters B_0, ..., B_{kk}. The significance of this response surface can be appreciated by using graphical means such as contour plots or by employing search procedures when the number of independent variables is large. Interpretation of these results will permit the determination of the levels of the independent factors that give the optimum responses.

Scanning electron microscopy

The scanning electron microscope is a very useful investigative tool for the examination of sample surfaces (74). This technique offers several advantages over conventional microscopy, namely: (i) a depth of focus 500 times superior to the light microscope (ii) three-dimensional imaging due to the method in which the signal is generated, collected and processed (iii) simple and rapid sample preparation with little change of artifacts (iv) magnification range from 20X to 100,000X (44).

In the scanning electron microscope the sample surface is scanned by en electron beam and a sequential image is created by the secondary electrons emitted from the sample surface as a function of its structure. As the scanning beam of electrons is swept across the specimen, another beam of a standard cathode ray tube is operated in synchrony with it. The brightness of the cathode ray tube is modulated by the signal produced from the secondary electrons emitted from the sample surface and amplified by a scintillator-photomultiplier system. Electron micrographs of the viewed images can be taken instantly with a Polaroid camera (74).

In recent years the scanning electron microscope has been used for the examination of the surface structure of many products and processes involved with the utilization of cereal grains (75). Shepherd and Yoell (44) reported investigations with the scanning electron microscope on samples of madeira, and enriched and fatless sponge cake. However no references were found for the application of the scanning electron microscope for comparisons of the surface characteristics of samples of high-ratio white layer cakes baked conventionally and with microwave energy.

MATERIALS AND METHODS

Materials

The soft wheat flour used was obtained from International Multifoods, Minneapolis, Minnesota. This flour (brand name: Lite Maid high-ratio cake flour) was supplied in a bleached and non-enriched form. Analyses of the flour including farinograph data is contained in Table 1.

The leavening agents, shortenings and emulsifiers used are listed in Table 2. The ingredients contained in the commercial double-action baking powder and in the shortenings are outlined in the Appendix (Table 21).

Methods

Experimental procedures

Farinograph procedure. Farinographs were undertaken according to AACC Method 54-21 (76) using the constant Flour Weight procedure.

Baking procedure. Batters for the preparation of high-ratio white layer cakes were made according to AACC Method 10-90 (76). Baking pans were Pyrex (Corning Glass Works, New York) 8 inch round cake dishes. Conventional cakes were baked in an electrically fired rotary type oven for 25 minutes at 375^{o}F. The cakes were cooled for 30 minutes, depanned and cooled for an additional 30 minutes prior to being stored in sealed polyethylene bags. Microwave baking was undertaken in a Sharp Carousel Household Microwave oven (Model R-8200) operating with

Table 1. Flour analyses and farinograph data.[a]

Protein (Nx5.7) (%)	Ash (%)	pH	Farinograph		
			Absorption (%)	Dough Development Time (min)	Tolerance Index (B.U.)
8.7	0.35	4.6	56.8	3.25	90

[a]Results reported on 14% M.B.

Table 2. Leavening agents, shortenings and emulsifiers used in these studies

Ingredient	Manufacturer/Supplier
Leavening agents	
Double-action baking powder (Red Star)	Universal Foods Corp., Dist., Milwaukee, Wisconsin
Sodium bicarbonate	Fisher Scientific Co., Fair Lawn, New Jersey
Monocalcium phosphate monohydrate (MCP)	ITT Paniplus, Olathe, Kansas
Sodium aluminum phosphate (SALP)	ITT Paniplus, Olathe, Kansas
Shortenings	
Hydrogenated emulsified shortening (Super Quick Blend)	Hunt-Wesson Foods, Inc., Fullerton, California
Hydrogenated non-emulsified shortening (Primex)	Procter and Gamble, Co., Cincinnatti, Ohio
Emulsifiers	
Mono- and diglycerides (Panalite 50 SVK)	ITT Paniplus, Olathe, Kansas
Polysorbate 60	ITT Paniplus, Olathe, Kansas
Propylene glycol monostearate (Promodan SP)	Grindsted Products, Inc., Overland Park, Kansas
Glycerol-lacto-palmitate (Lactodan F 15)	Grindsted Products, Inc. Overland Park, Kansas

a frequency of 2450 MHz and with an output power (microwave) of 650 W. In the microwave oven, baking was undertaken in some cases at two power settings, full power (approximately 100% of microwave power) and roast (approximately 70% of microwave power) for two minimum baking times of 5.5 minutes and 8.0 minutes respectively. These cakes were cooled for five minutes, depanned and cooled for a further 30 minutes prior to being stored in sealed polyethylene bags.

Preparation of baking powder blends. Ten grams of the commercial double-action baking powder were used in all conventionally baked cakes and in the microwave baked cake prepared with this baking powder blend. The other blends were prepared for use in microwave baked cakes and were based on a mixture of a slow acting acidulent, sodium aluminum phosphate (SALP) and a fast acting acidulent, monocalcium phosphate monohydrate (MCP). These blends were formulated according to the following expression: amount of acidulent = (amount of sodium bicarbonate x 100)/ neutralizing value (52). In order to enable comparisons of cake quality between these blends and the commercial double-action baking powder three grams of sodium bicarbonate were used in each blend. This amount of sodium bicarbonate wes selected since most commercial double-action baking powders contain 30% sodium bicarbonate (52).

Determination of batter flow. A comparison of batter flow in microwave and conventionally baked cakes was investigated by noting differences in internal flow end surface flow using batters dyed red and black respectively. The dyed batters were prepared by incorporating 0.05 g of red (FD and C Red No. 3) and black dyes (Warner-Jenkinson Man. Co., St. Louis, Missouri) into each of 10 g of batter.

The red batter was transferred internally to the cake batter prior to baking by pulling a cotton thread through and out of the tip of a cut-off pipet which contained the dyed batter and up through the tip of a similar pipet. These two pipets were placed diagonally opposite each other and against the inner wall of the cake pan. The tips of each pair of pipets were placed at similar depths beneath the batter surface, namely 8 mm below the surface for the lower flow pattern and 4 mm for the upper flow pattern.

The black batter was applied to the surface of the cake batter in parallel strips (approximately 25 mm apart) which were perpendicular to the line between the transfer and receiving points for the cotton thread associated with the measurement of the internal flow patterns. A 50 ml syringe with a No. 18 needle was used for dispensing the black batter to the surface of the cake batter and the red batter to the appropriate cut-off pipet.

Scanning electron microscopy of cake surfaces. Cake samples from two experiments were examined by SEM. The experiments involved the comparisons between conventionally and microwave baked cakes for differences in (i) cell structure (ii) the effect of increasing baking time on cell structure. In these experiments microwave baked cakes were prepared using the commercial emulsified shortening and the optimum acidulent level for this shortening system of 61.4% SALP and 38.6% MCP. This acidulent level was determined in the experiment considering the combined effects of acidulent level and baking time. In the second experiment the baking times for conventionally and microwave baked cakes were increased 18%, from 25 to 29.5 minutes and 5.5 to 6.5 minutes respectivsly.

Samples of cake crumb (approximately 7 mm cubed) from two positions of each caks were studied. These positions were the middle of the center slice and a similar position in a slice one inch removed from the center of the cake. These pieces of cake were identical to those described in the crumb compression test.

The samples were prepared for examination by quenching in 2-methyl butane and cooling to liquid nitrogen temperatures. Then the samples were freeze dried at -60°C for 48 hours in an Edwards Freeze Drier (Sussex, England). A silver conducting paste obtained from Pelco Co., Tustin, California was used to mount the samples on circular (9 mm diameter) stubs. Prior to examination the samples were coated in vacuo with carbon and gold-palladium to a combined thickness of approximately 200 Å. An ETEC Autoscan scanning electron microscope, Model U-1 (Hayward, California) operating at 5 kV was used to view the samples. Images were photographed on Polaroid film (type 55 P/N).

<u>Incorporation of emulsifiers into shortening</u>. The requisite quantities of Panalite 50 SVK and Polysorbate 60 were blended with 95% of the non-emulsified shortening (Primex) by direct mixing at slow speed for 10 seconds in the bowl of the Hobart mixer (Model N-50). This mixer and bowl were the same as those used for batter preparation. The bowl contents were scraped and mixed at slow speed for a further 5 seconds.

The solid emulsifiers, Promodan SP and Lactodan F15 were blended into this mixture after melting the appropriate amounts with the remaining 5% of the shortening at 50° to $55^{\circ}C$. After addition of this liquid mixture, the bowl contents were mixed at slow speed for 10 seconds, scraped and finally mixed at slow speed for 15 seconds.

Quality assessment

Volume and weight were measured approximately 20 hours after baking. The volume was determined by rape seed displacement. Weight loss as a result of baking was the difference between batter and cake weights expressed as a percentage of batter weight.

Specific gravity of the batter was determined by dividing the weight of a given volume of batter by the weight of an equal volume of water.

Internal score and crumb pH were determined approximately 24 hours after baking according to AACC Methods (76) 10-90 and 02-52.

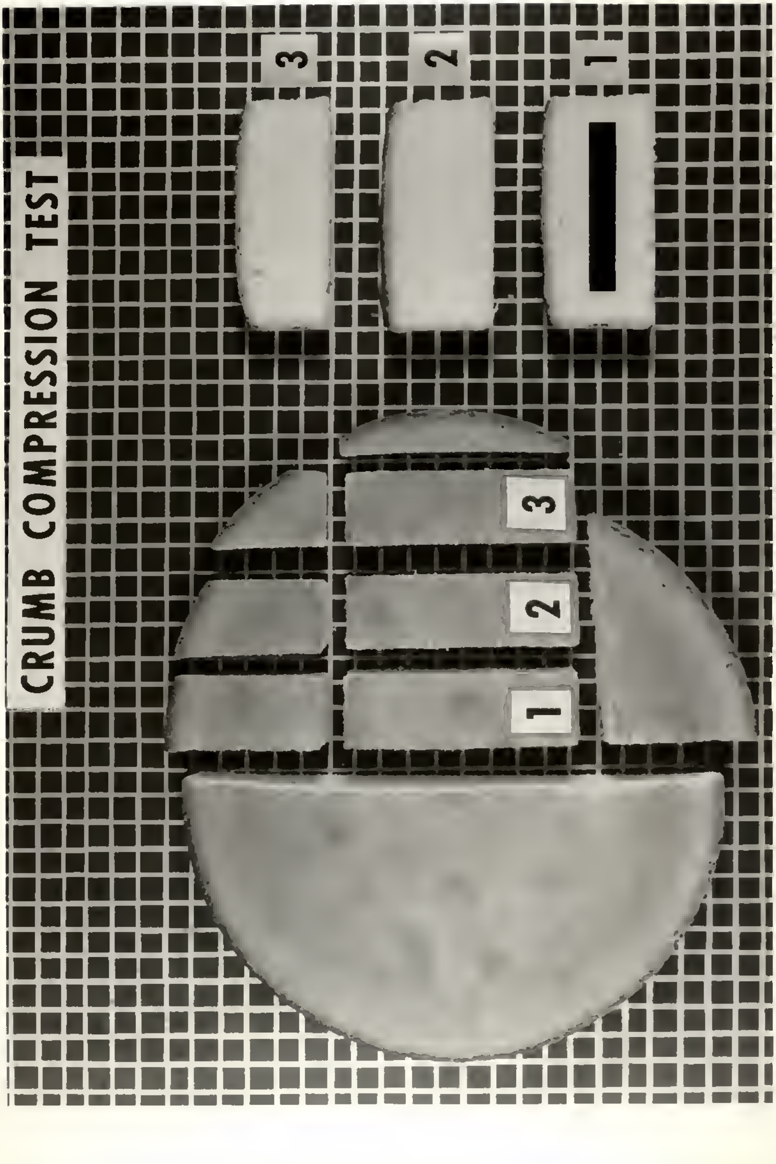
Crumb color was measured approximately 24 hours after baking with the Agtron Multichrometic Abridged Reflectance Spectrophotometer (Model M-300) using the monochromatic spectral line of the blue mode (436 nm). The scale was standardized using standard discs 56 and 81 to read 0.0 and 100.0 respectively. Measurements were carried out on a central portion of the cake obtained by cutting horizontally through the center of the cake. Black paper with a rectangular hole of 50 cm^2 in its center was used to block the escaping light at the edges of the cake sample and to standardize the reflectance area prior to undertaking the measurements.

With the exception of the last experiment crumb compression was measured approximately 24 hours after baking. In the last experiment which compared the effectiveness of different emulsifier blends, crumb compression was measured one day and four days after baking. In the crumb compression test three samples approximately 8 cm long and 2.5 cm thick were tested from each cake and the mean of these results was expressed in grams. However in the experiment comparing the effect of increasing baking time, crumb compression for each segment was calculated. As shown in Plate 1 the test surface of the first sample was from the center of the cake and each subsequent sample was approximately 2.5 cm from the preceding test surface. The measurement of crumb compression was undartaken by placing one of these samples on a load cell with the surface of the cake to be tested facing upwards and touching the base of a fixed perspex plate (6.0 cm x 1.0 cm). The black region on the cake sample in Plate 1 shows the relative area of this perspex plate in comparison to the size of the samples. When the instrument was switched on, the assembly containing the load cell and the cake sample was raised 0.5 cm in four seconds and the resistance exerted by the cake crumb to compression was recorded through a dual strain gauge amplifier and a strip chart recorder.

Experimental design

Effect of water level. Water level was varied between 115% and 160% (flour basis) for the preparation of cake batters which were baked conventionally and by microwave energy at the

Plate 1. Samples of cake arranged to show the three pieces of cake involved in the determination of crumb compression.


CRUMB COMPRESSION TEST
3
2
1
3
2
1

70% and 100% power levels. In the conventional series seven water levels were studied over this range while in the microwave series eleven water levels were considered. The batters for the microwave baked cakes were prepared using the commercial emulsified shortening and an acidulent level of 50% SALP/50% MCP. The following quality characteristics; volume, specific volume, crumb compression and internal score were determined for each of the two observations per treatment.

Effect of baking powder blends. Baking powder blends of different acidulent levels were prepared as described above to enable cakes to be baked by microwave energy at the 100% power level. Eight different blends from 100% SALP/0% MCP to 0% SALP/100% MCP were considered. Cake batters were prepared using the commercial emulsified shortening. The following quality measurements; volume, specific volume, crumb compression and internal score were determined for each observation. In this experiment there were a minimum of two observations per treatment. These results were compared with those obtained using the commercial double-action powder for the preparation of cakes baked conventionally and using microwave energy (100% power level).

Combined effect of baking time and acidulent level. A technique of response surface methodology (RSM) was used to study the effect of these two processing conditions on the following quality characteristics; volume, specific volume, crumb compression, internal score, crumb color, and crumb pH. This technique involved taking certain data points from a factorial design and solving for a response surface containing the desired response of dependent variables such as volume or crumb compression as a function of the independent variables of baking time and acidulent level. The regression coefficients for this surface were computed by the following Taylor expansion equation:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_{12}X_1X_2 + B_{11}X_1^2 + B_{22}X_2^2.$$

Table 3 shows the levels for the two processing conditions in this study while Table 4 indicates the experimental design. The cake batters were prepared using the commercial emulsified shortening. Baking time was considered over the range from the minimum of 5.5 minutes to 6.5 minutes at the 100% power level. Previous studies indicated that the range considered for the acidulent level was close to the optimum for these conditions.

Effect of increased baking time on cell structure and crumb compression. The effect on cell structure of increased baking time for conventionally and microwave baked cakes was investigated using scanning electron microscopy. The procedure for obtaining and examining the samples for the SEM studies was described above.

An experiment with a randomized complete block design was used to determine the effect of increasing baking time on crumb compression. The experiment involved 12 treatments with 4 observations for each treatment. These treetments consisted of two methods of baking cake, conventionel and microwave (100% power); two beking times for each method namely 25 and 29.5 minutes and 5.5 and 6.5 minutes for conventionally and microwave baked cakes respectively and three cake segments per cake for the determination of crumb compression. The locetion

Table 3. Processing conditions and their levels for RSM study

Processing Condition	Symbol	Code -3	-1	0	1	3
Baking time (min)	X_1	-	5.5	6.0	6.5	-
Acidulent level - SALP/MCP (%)	X_2	40/60	50/50	-	60/40	70/30

Table 4. RSM design for effect of different processing conditions

Number	Variable	
	X_1	X_2
1	-1	3
2	-1	1
3	-1	-1
4	-1	-3
5	0	3
6	0	1
7	0	-1
8	0	-3
9	1	3
10	1	1
11	1	-1
12	1	-3

of these three cake segments in a cake was outlined above in the description of the crumb compression test.

Effect of different emulsifiers. The general technique of RSM as described previously was used in the initial part of this experiment to determine the optimum blend of four emulsifiers. The emulsifiers studied were mono- and diglycerides, polysorbate 60, propylene glycol monostearate and glycerol lacto-palmitate. Table 5 shows the variables and their levels considered in this study. The cake batters were prepared with (i) the non-emulsified shortening and appropriate amounts of these emulsifiers incorporated in the manner described above and (ii) an acidulent level of 100% MCP. The cakes were baked at the 100% power level. The following quality characteristics; volume, specific volume, crumb compression and internal score were determined for the cakes prepared using each combination.

The experimental design for the study of the effects of four veriables at three levels is described in Table 6. This design was used by Mac Donald and Bly (62) and was proposed originally by Box and Behnken (68). The Taylor expansion equation for the response surface of this experiment is:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{14}X_1X_4 + B_{23}X_2X_3 + B_{24}X_2X_4 + B_{34}X_3X_4 + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2 + B_{44}X_4^2.$$

The initial part of this experiment enabled the selection of seven different combinations of these emulsifiers which were predicted to offer near optimum responses for the four quelity

Table 5. Emulsifiers and their levels* for RSM study

Emulsifier	Symbol	Code		
		-1	0	1
Mono- and diglycerides	X_1	1.0	4.5	8.0
Polysorbate 60	X_2	0.2	1.0	1.8
Propylene glycol monostearate (PGMS)	X_3	0.5	1.5	2.5
Glycerol-lacto-palmitate (GLP)	X_4	0.5	1.5	2.5

* % on a shortening basis

Table 6. RSM design for effect of different emulsifiers

Number	Variable			
	X_1	X_2	X_3	X_4
1	-1	-1	0	0
2	1	-1	0	0
3	-1	1	0	0
4	1	1	0	0
5	0	0	-1	-1
6	0	0	1	-1
7	0	0	-1	1
8	0	0	1	1
9	0	0	0	0
10	-1	0	-1	0
11	1	0	-1	0
12	-1	0	1	0
13	1	0	1	0
14	0	-1	-1	0
15	0	1	-1	0
16	0	-1	1	0
17	0	1	1	0
18	0	0	0	0
19	-1	0	0	-1
20	1	0	0	-1
21	-1	0	0	1
22	1	0	0	1
23	0	-1	0	-1
24	0	1	0	-1
25	0	-1	0	1
26	0	1	0	1
27	0	0	0	0

characteristics. In the final part of the experiment comparisons were made between cakes prepared with these seven different combinations of emulsifiers and with (i) non-emulsified shortening without any added emulsifiers (acidulent level of 100% MCP) (ii) emulsified shortening and the optimum acidulent level for this shortening of 61.4% SALP/38.6% MCP and (iii) conventionally baked cakes.

The design for this experiment was a randomized complete-block design with 10 treatments and three observations for each treatment. The following quality characteristics were determined for each observation; volume, specific volume, crumb compression, internal score, crumb color, crumb pH, batter specific gravity, weight loss, and crumb compression one day and four days after baking. In accordance with AACC Method 10-90 (76) the cake batter was halved to enable the production of two cakes. Samples for the two tests of crumb compression were obtained by randomly assigning these two cakes for the two storage periods of either one day or four days. The cake used for the crumb compression test after a storage period of one day was used for the remaining quality measurements with the exception of batter specific gravity.

RESULTS AND DISCUSSION

Effect of water level

The mean results for four quality measurements of the effect of different water level on cakes baked by conventional meane and with microwave energy at the 70% and 100% power levels are listed in Tables 7 and 8 and expressed graphically in Figures 1 to 4. The results of the regression analyses including the analyses of variance of the forward multiple regression solution using the method of least squares are contained in Tables 9, 10 and 11.

In the conventional series, volume, specific volume and internal score increased to a maximum and then decreased with the maximum values being obtained over similar ranges in water level. The maximum volume of 1039 cc and maximum specific volume of 2.65 cc/g occurred for water levels from 133% to 137% and from 135% to 138% respectively. Internal score achieved its maximum of 100 from 132% to 139%. However the minimum crumb compression of 485 g was obtained at slightly higher water levels from 143% to 144%. These effects of water level on the quality of cakes baked by conventional means are well known and with the exception of the effect on crumb compression have been reported by Wilson and Donelson (42).

However for the cakes baked with microwave energy at the 100% power level a linear relationship with a negative slope was obtained for the effect of water level on volume.

Table 7. Effect of water level on the quality of cakes baked by conventional means

Water Level (%)	Volume (cc)	Specific Volume (cc/g)	Crumb Compression (g)	Internal Score (100)
115	1002	2.53	701	60
125	1024	2.59	586	92
135	1038	2.71	485	100
137.5	1048	2.67	495	100
140	1036	2.62	473	100
150	1005	2.57	511	94
160	964	2.46	520	94

Table 8. Effect of water level on the quality of cakes baked with microwave energy at 70% and 100% power levels

Water Level (%)	Volume (cc)		Specific Volume (cc/g)		Crumb Compression (g)		Internal Score (100)	
	Power Level (%)							
	70	100	70	100	70	100	70	100
115	833	990	2.17	2.58	1012	870	52	49
120	850	970	2.27	2.60	842	662	50	44
125	873	965	2.31	2.56	851	708	84	50
130	853	950	2.24	2.52	857	694	83	68
132.5	845	945	2.22	2.50	831	672	88	83
135	838	928	2.21	2.47	873	688	86	86
137.5	828	923	2.20	2.45	900	696	92	88
140	835	903	2.20	2.40	847	724	88	86
145	820	893	2.17	2.38	888	716	92	86
150	803	858	2.11	2.27	848	737	90	88
160	770	815	2.06	2.18	947	800	88	88

Figure 1. Effect of water level on volume for cakes baked by conventional means and with microwave energy at 70% and 100% power levels.

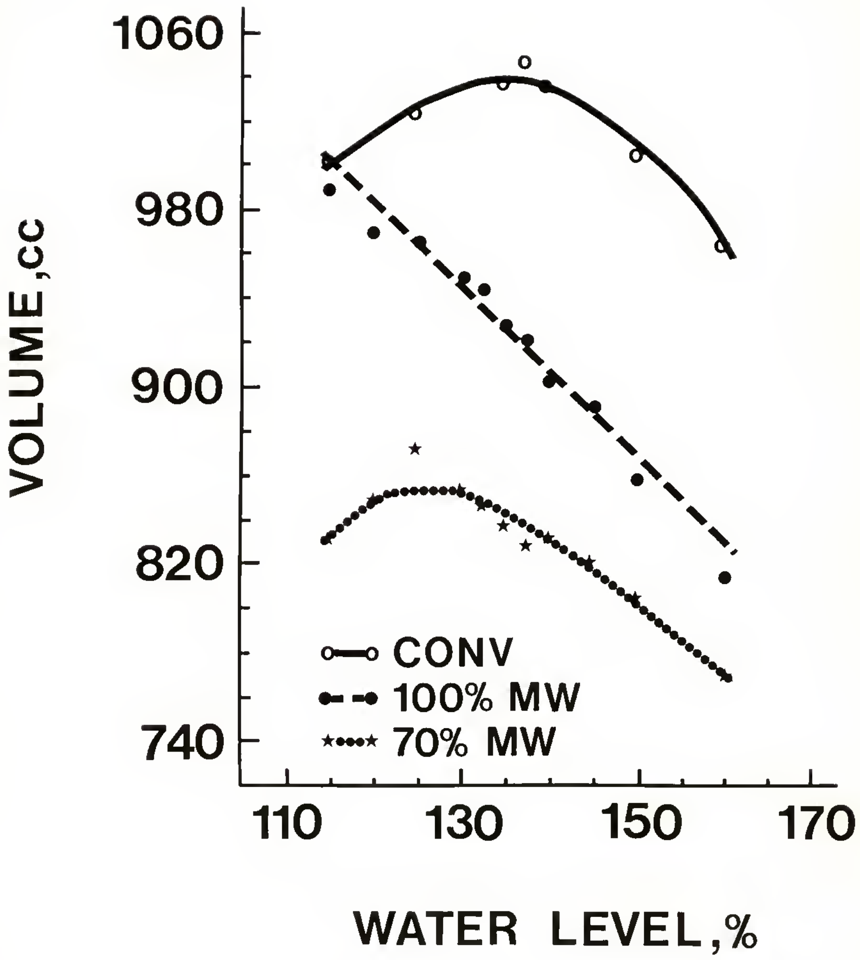

1060
980
900
820
740
VOLUME,cc
110
130
150
170
WATER LEVEL,%
CONV
100% MW
70% MW

Figure 2. Effect of water level on specific volume for cakes baked by conventional means and with microwave energy at 70% and 100% power levels.

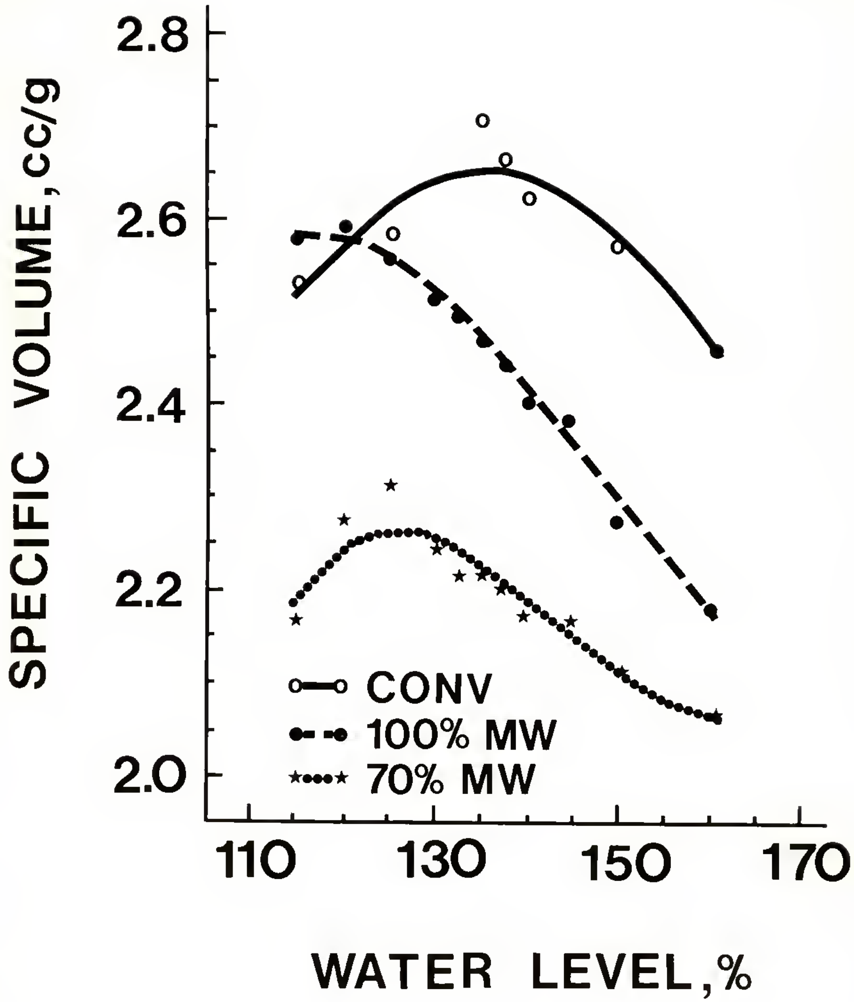

SPECIFIC VOLUME, cc/g
2.8
2.6
2.4
2.2
2.0
110
130
150
170
WATER LEVEL, %
CONV
100% MW
70% MW

Figure 3. Effect of water level on crumb compression for cakes baked by conventional means and with microwave energy at 70% and 100% power levels.

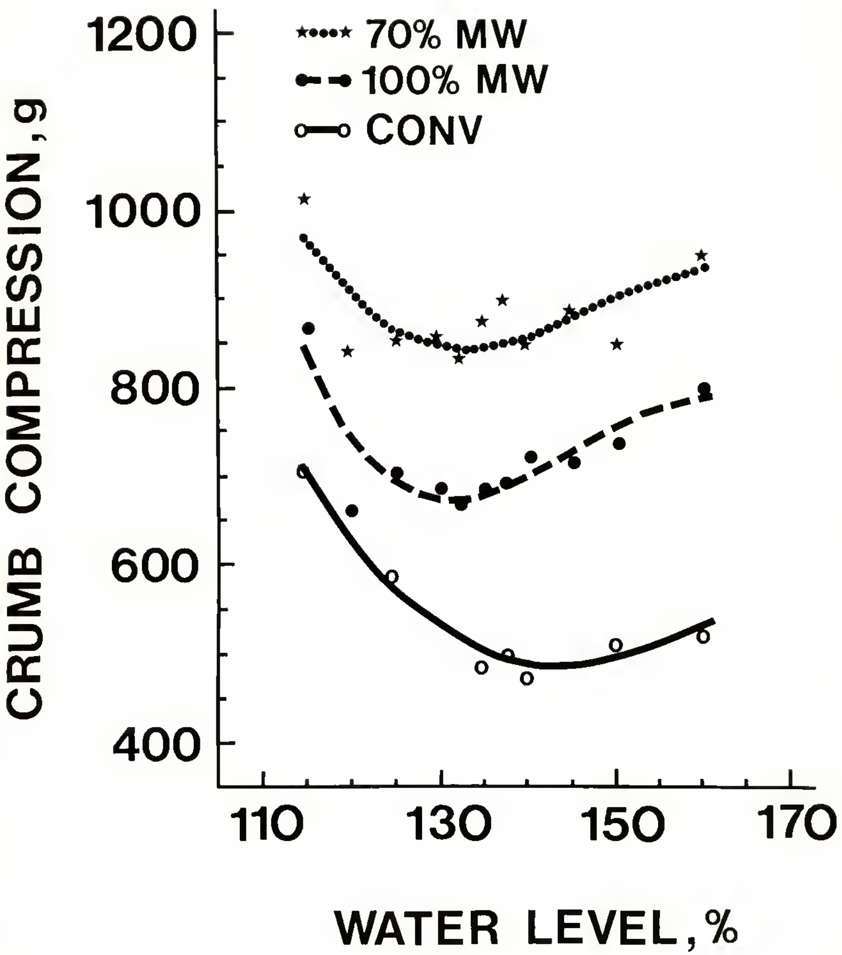

70% MW
100% MW
CONV
CRUMB COMPRESSION, g
1200
1000
800
600
400
110
130
150
170
WATER LEVEL, %

Figure 4. Effect of water level on internal score for cakes baked by conventional means and with microwave energy at 70% and 100% power levels.

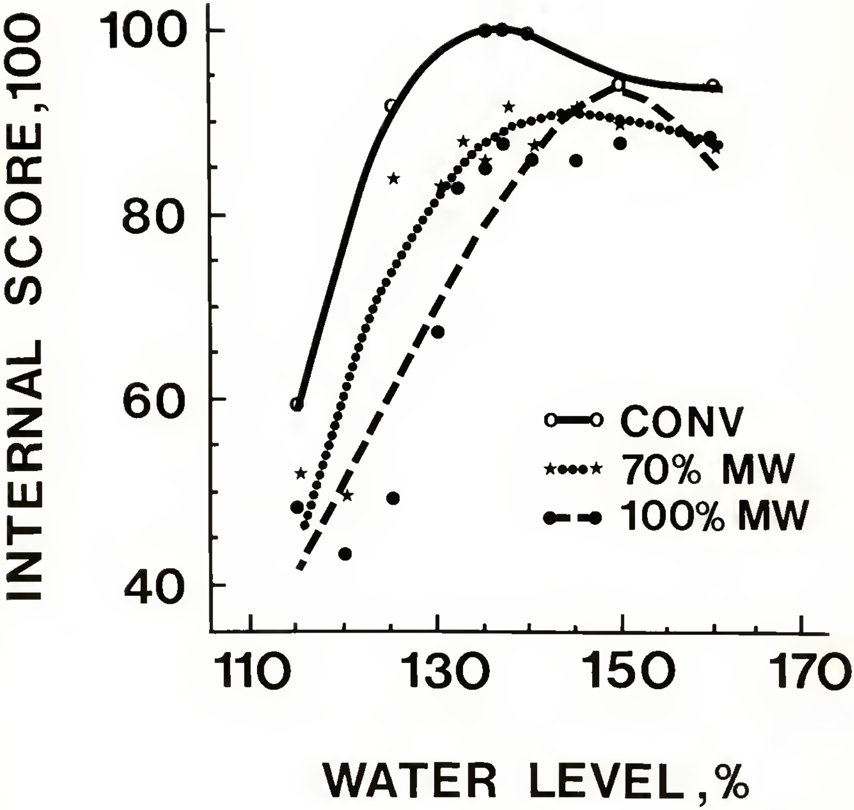

INTERNAL SCORE,100
100
80
60
40
110
130
150
170
WATER LEVEL,%
CONV
70% MW
100% MW

Table 9. Effect of water level on the quality of cakes baked by conventional means - Estimates, and R^2 and F values from analysis of variance of forward multiple regression solution

	Volume (cc)			Specific Volume (cc/g)		
	Estimate	F value	R^2	Estimate	F value	R^2
a	-72.2558	-	0.9627	-2.8367	-	0.8783
X	9.9937	14.11 *		0.0772	1.60 NS	
X^2	0.0357	63.29 **		-2.4086×10^{-4}	20.04 *	
X^3	-3.611×10^{-4}	0.07 NS		-2.2×10^{-7}	0.00 NS	
	Crumb Compression (g)			**Internal Score (100)**		
	Estimate	F value	R^2	Estimate	F value	R^2
a	13190.4149	-	0.9700	-5668.42	-	0.9996
X	-238.4116	49.32 **		119.9649	2663.4 **	
X^2	1.4712	46.88 **		-0.8281	3594.6 **	
X^3	-0.002974	0.72 NS		0.001896	638.6 **	

where a = intercept and X = water level (%)

Table 10. Effect of water level on the quality of cakes baked with microwave energy (70% power level) - Estimates, and R^2 and F values from analysis of variance of forward multiple regression solution

	Volume (cc)			Specific Volume (cc/g)		
	Estimate	F value	R^2	Estimate	F value	R^2
a	-6798.8936	-	0.9341	-28.1157	-	0.8854
X	162.8403	70.45 **		0.6563	34.58 **	
X^2	-1.1369	23.98 **		-0.004674	12.00 **	
X^3	0.002593	4.74 NS		1.094×10^{-5}	7.51 *	

	Crumb Compression (g)			Internal Score (100)		
	Estimate	F value	R^2	Estimate	F value	R^2
a	23587.1511	-	0.5931	-2857.6144	-	0.8691
X	-474.2977	0.04 NS		57.1945	28.78 **	
X^2	3.2708	8.56 *		-0.3679	16.98 **	
X^3	-0.007448	0.25 NS		7.842×10^{-4}	0.71 NS	

where a = intercept and X = water level (%)

Table 11. Effect of water level on the quality of cakes baked with microwave energy (100% power level) - Estimates, and R^2 and F values from analysis of variance of forward multiple regression solution

	Volume (cc)			Specific Volume (cc/g)		
	Estimate	F value	R^2	Estimate	F value	R^2
a	1446.7112	-	0.9696	-11.0591	-	0.9908
X	-3.8750	287.05 **		0.3008	721.96 **	
X^2	-	-		-0.002148	25.93 **	
X^3	-	-		4.91×10^{-6}	5.38 *	

	Crumb Compression (g)			Internal Score (100)		
	Estimate	F value	R^2	Estimate	F value	R^2
a	32161.9863	-	0.7292	1988.6422	-	0.8675
X	-663.7586	0.07 NS		-49.7104	36.52 **	
X^2	4.6137	14.88 **		0.4097	8.34 *	
X^3	-0.0106	3.90 NS		-0.001084	0.95 NS	

where a = intercept and X = water level (%)

The relationship for specific volume did not have any maximum or minimum but did have significant quadratic and cubic terms. In the microwave series at the 70% power level the volume and specific volume relationships increased to a maximum and then decreased and for a given water level these values were much lower than those of the microwave series at the 100% power level and the conventional series. The maximums associated with the volume and specific volume for the 70% series were 856 cc and 2.26 cc/g respectively which occurred in ranges of water level from 123% to 128% and from 124% to 128% respectively.

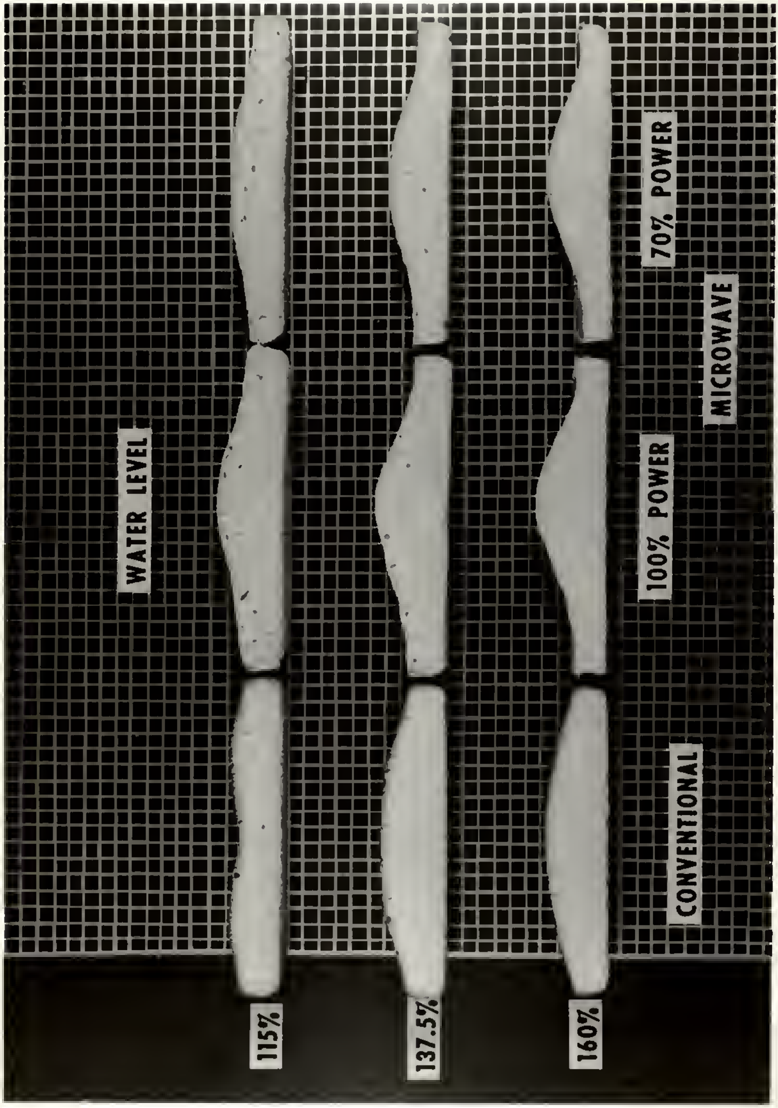
For the microwave series at 70% and 100% power levels the water levels corresponding to the maximum volume did not correspond to the maximum internal score nor to the minimum crumb compression. In these cases the relationships for internal score and crumb compression were similar to the conventional series except that the respective maximums and minimums were of different magnitudes and occurred over different ranges in water level. Internal score had a maximum of 91 from 140% to 150% water level in the 70% power series and 94 from 149% to 151% water level in the 100% power series. While crumb compression had a minimum of 843 g from 131% to 134% water level in 70% power series and a minimum of 674 g from 130% to 132% water level in the 100% power series.

Since the cakes baked with microwave energy at the 100% power level were superior to those prepared using the 70% power level in volume, specific volume and crumb compression the 100% power level was selected as the most satisfactory of the two levels for further studies. In each of the three series, conventional or the two microwave series there was no single water level which produced optimum results for each of the four quality measurements. For this reason a water level for further studies was selected which would result in near optimum results for the four quality measurements. The water level selected for baking by both conventional means and with microwave energy was 137.5%.

Cross-sectional views of representative samples of the end and mid-points of the range in water levels for the conventional and the two microwave series are shown in Plate 2. As expected the cake baked with the low water level in the conventional series showed a sunken contour. However for the cake baked at the same water level using microwave energy at either 70% or 100% power levels there was no evidence of any surface collapse.

As discussed by Wilson and Donelson (42) the water level in a cake formula has a critical effect on the extent of starch gelatinization during baking which in turn determines the type of crumb structure formed. In a limited water environment starch would be in an unfavorable position in competing for water against strongly hydrophilic ingredients such as sugar and protein. While when excess water is used extensive starch gelatinization occurs and the crumb begins to assume a gel-like character. The extent of starch gelatinization in relation to the degree of batter expansion has been proposed by Chamberlain (77) to be all-important. If the starch granules do not gelatinize and swell sufficiently, they are

Plate 2. Effect of water level on cakes baked by conventional means and with microwave energy at 70% and 100% power levels.


WATER LEVEL
115%
137.5%
160%
70% POWER
100% POWER
MICROWAVE
CONVENTIONAL

too far apart to make mutual contact before the batter sets and hence the cake structure will collapse. More recently Frazier (32) suggested that to prevent collapse, the baked cake structure must have sufficient strength to resist the stresses exerted upon it as a result of cooling. The cake crumb upon cooling has to support its own mass against gravity as well as counteract a difference in pressure between the atmosphere and the internal gas cells as watsr vapor within them condenses on cooling. Frazier (32) proposed that once the batter begins to solidify support of the cake crumb becomes dependent on the physical strength of starch-protein gel structure. Also other authors have attributed the setting of the cake batter to egg protein denaturation (41) and starch gelatinization (44).

The lack of any surface collapse in cakes baked with a low water level using microwave energy could be a result of microwave heating achieving modifications to the crumb structure which increase its strength. These modifications could be involved with the factors mentioned above as proposed to be associated with batter setting namely egg protein denaturation, starch gelatinization and the effect of heat on the starch-protein complex. Another possible explanation is that the lack of any crust formation with this heating process may make the occurrence of surface collapse less dependent on the factors affecting crumb strength.

Effect of baking powder blends

The effect of different baking powder blends on the results of four quality measurements for cakes baked with microwave energy are listed in Table 12 and expressed graphically in Figures 5 to 8. Also the results for cakes baked by conventional means were included to enable comparisons with the other treatments. Table 13 contains the results of the regression analyses including the analyses of variance of the forward multiple regression solution using the method of least squares.

As shown in Figures 5 and 6 a linear relationship with a negative slope existed for the effect of increasing amounts of MCP in the acidulent blend on volume and specific volume. The maximum volume attained at 100% SALP/0% MCP was similar to the cake prepared with the commercial double-action baking powder and baked with microwave energy (100% power level) but lower than the conventionally baked cake with this baking powder. However the specific volume at 100% SALP/0% MCP was similar to both the microwave and conventionally baked cakes using this commercial baking powder.

Equations with significant linear and quadratic terms were used to describe the relationships of acidulent level on crumb compression and internal score. As shown in Figure 7 crumb compression increased as the amount of MCP in the blend was increased with the minimum level having firmer crumb than the cakes prepared with the commercial baking powder and baked by conventional means and with microwave energy. As the amount of MCP in the blend was increased the internal score increased

Table 12. Effect of baking powder blend on cake quality

	Volume (cc)			Specific Volume (cc/g)			Crumb Compression (g)			Internal Score (100)		
Commercial Double-Action												
Conventional	1050	1045		2.66	2.65		479	475		100	100	
Microwave (100% power)	995	983		2.67	2.65		614	532		52	52	
Acidulent Level - SALP/MCP (%)												
100/0	975	970	970	2.62	2.62	2.61	682	735	689	52	52	
	970	970	970	2.60	2.59	2.59	697	726	758	52	52	
75/25	960	950	950	2.57	2.60	2.56	706	702	729	52	52	52
	950	940	940	2.56	2.51	2.52	771	685	776	52	56	56
68.8/31.2	930	940		2.47	2.52		715	808		70	70	
62.5/37.5	925	925		2.47	2.47		669	747		82	82	
50/50	920	910		2.45	2.45		737	778		88	88	
	915	915		2.45	2.45		706	726		88	88	
37.5/62.5	900	900		2.37	2.38		746	767		90	90	
25/75	870	875		2.34	2.34		804	804		96	96	
	870	870		2.33	2.33		770	805		96	96	
0/100	850	850		2.26	2.27		872	893		96	96	
	850	850		2.29	2.25		835	840		96	96	

Figure 5. Effect of different baking powder blends on volume for cakes baked by conventional means and with microwave energy.

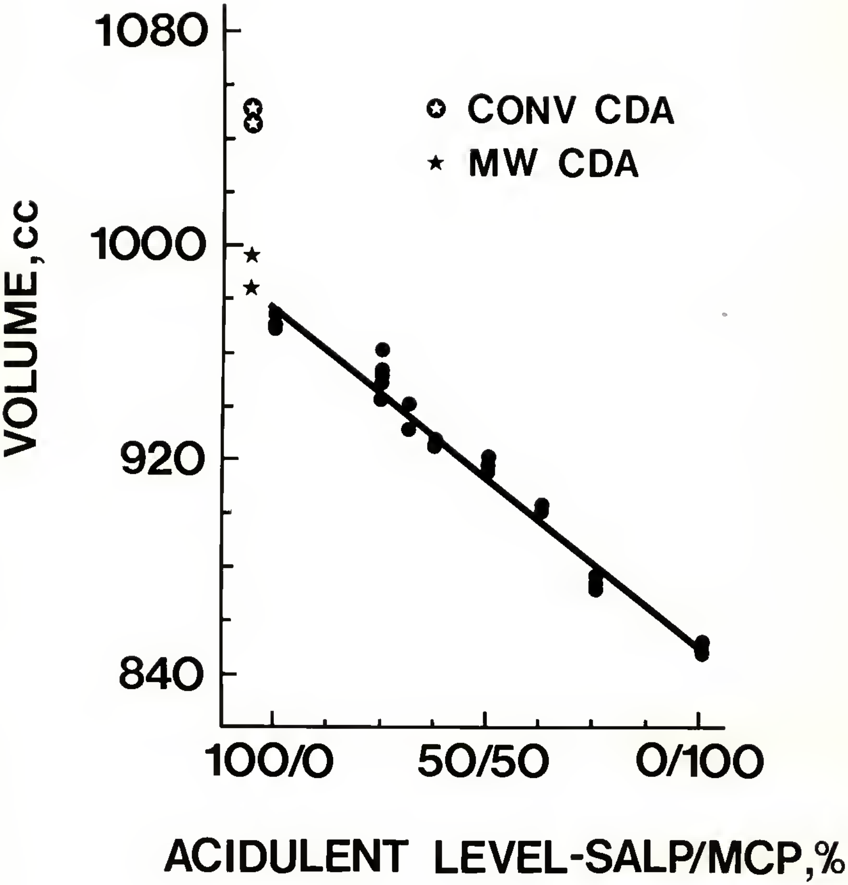

1080
1000
920
840
VOLUME, CC
CONV CDA
MW CDA
100/0
50/50
0/100
ACIDULENT LEVEL-SALP/MCP,%

Figure 6. Effect of different baking powder blends on specific volume for cakes baked by conventional means and with microwave energy.

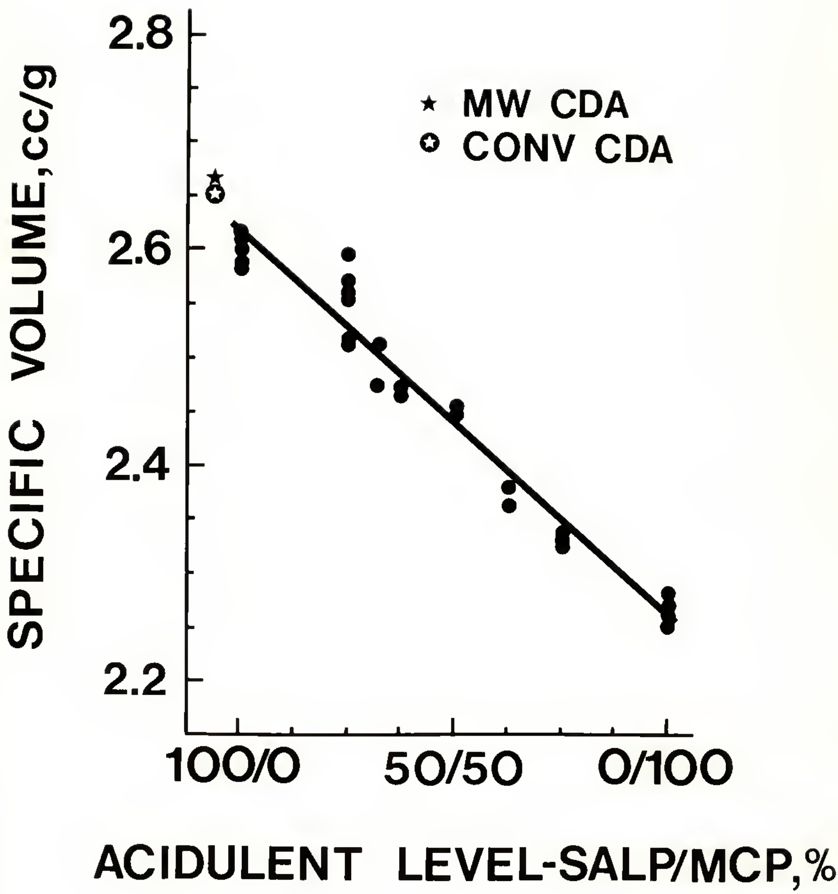
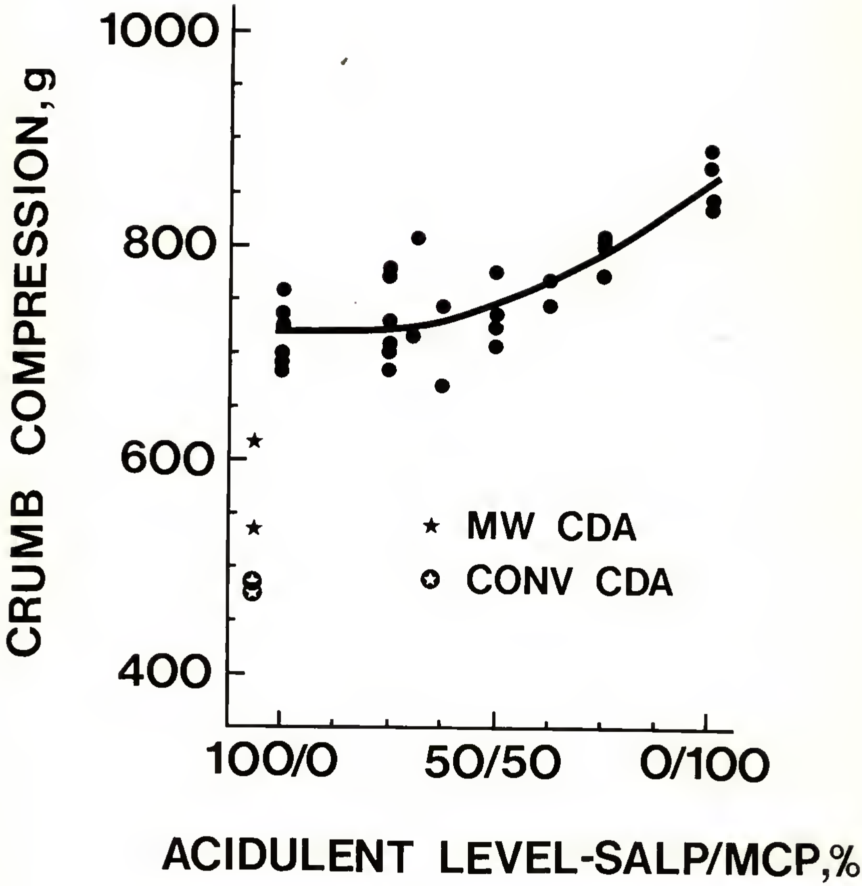

2.8
2.6
2.4
2.2
SPECIFIC VOLUME, cc/g
★ MW CDA
✪ CONV CDA
100/0
50/50
0/100
ACIDULENT LEVEL-SALP/MCP,%

Figure 7. Effect of different baking powder blends on crumb compression for cakes baked by conventional means and with microwave energy.



CRUMB COMPRESSION, g
1000
800
600
400
MW CDA
CONV CDA
100/0
50/50
0/100
ACIDULENT LEVEL-SALP/MCP,%

Figure 8. Effect of different baking powder blends on internal score for cakes baked by conventional means and with microwave energy.

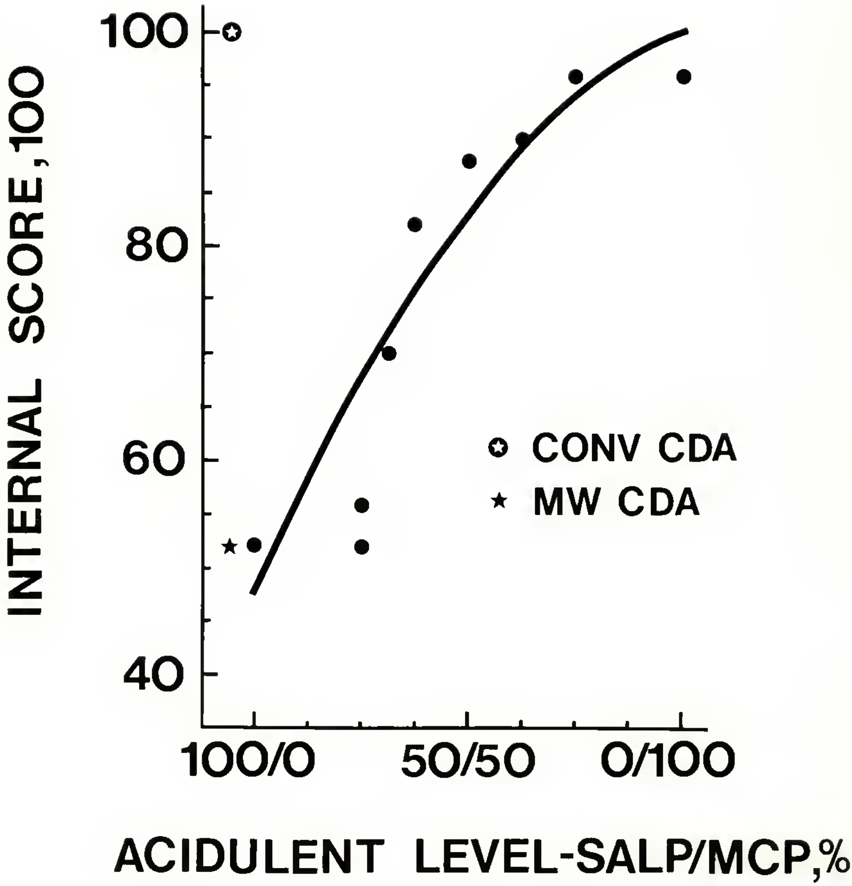

INTERNAL SCORE, 100
100
80
60
40
CONV CDA
MW CDA
100/0
50/50
0/100
ACIDULENT LEVEL-SALP/MCP,%

Table 13. Effect of baking powder blend on cake quality - Estimates, and R^2 of regression analyses and F values from analysis of variance of forward multiple regression solution.

	Volume (cc)		Specific Volume (cc/g)	
	Estimate	R^2	Estimate	R^2
a	848.2499	0.9788	2.2608	0.9605
X	1.2636		0.003564	

	Crumb Compression (g)			Internal Score (100)		
	Estimate	F value	R^2	Estimete	F value	R^2
a	858.5319	-	0.6900	99.8605	-	0.8449
X	-3.0905	52.01 **		-0.1511	130.10 **	
X^2	0.016919	8.09 **		-0.003676	6.05 *	

where a = intercept and X = SALP composition (%) of the acidulent blend of SALP/MCP.

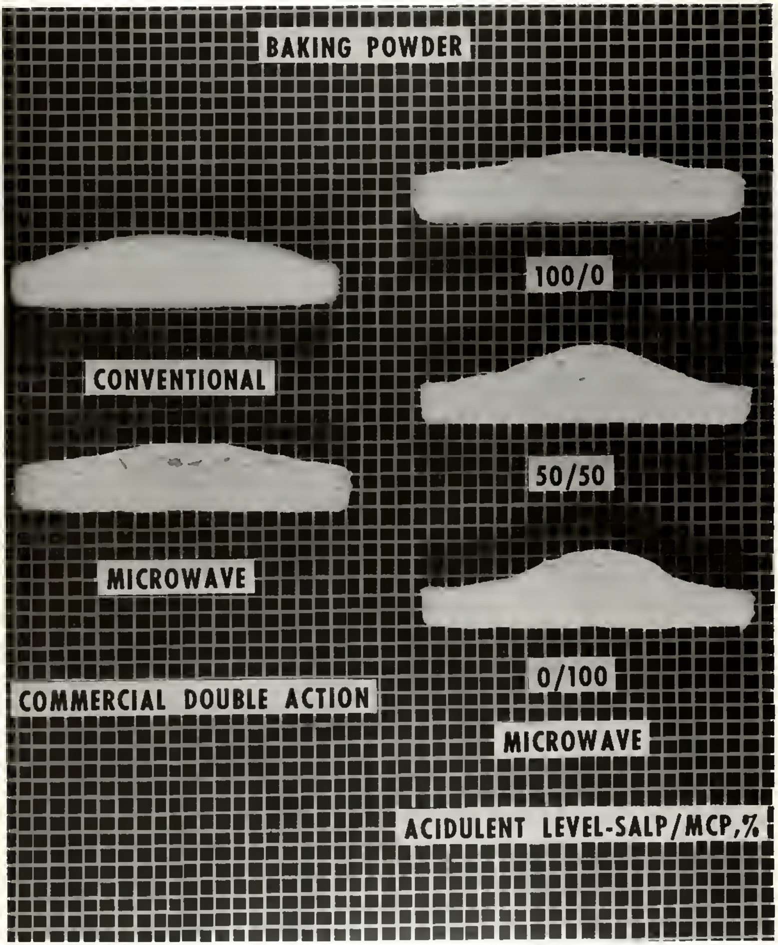
from a score similar to that obtained with the cake baked with microwave energy and prepared with the commercial baking powder to a score close to the conventionally baked cake with this baking powder. (Figure 8)

Since it is not possible from this experiment to select one blend of these two acidulents to optimize all four quality measurements a narrower range of these blends was selected for further study. The range selected was from 40% SALP/60% MCP to 70% SALP/30% MCP.

Cross-sectional views of representative samples of some of the treatments in this experiment are shown in Plate 3. It is apparent from the results of this study and the samples shown in Plate 3 that a commercial double-action baking powder is not suitable for baking cakes with microwave energy because of the resulting coarse and open grain. The explanation for this result would seem to involve the differences between the conventional and microwave heating processes and the required changes in formulation to optimize each process. In the conventional process the commercial double-action baking powder was designed to generate carbon-dioxide over a baking period five times longer than in the microwave process. In the microwave case the presence of slow acting acidulents in the commercial baking powder cause carbon dioxide to be generated in the later stages of heating which results in a coarse and open grain.

Explanations for the effects of different acidulent levels on volume and crumb structure would seem to involve mainly the differences between the two acidulents in terms of

Plate 3. Effect of baking powder blends on cakes baked by conventional means and with microwave energy.


BAKING POWDER
100/0
CONVENTIONAL
50/50
MICROWAVE
0/100
COMMERCIAL DOUBLE ACTION
MICROWAVE
ACIDULENT LEVEL-SALP/MCP,%

control of gas production. With increasing amounts of MCP in the blend of acidulents there would be less generation of carbon dioxide in the heating stage with a consequential decrease in internal pressure in the gas cells (51). This decrease in internal pressure would result in gas cells of reduced diameters which would be expressed as an improvement in crumb structure. Also it is possible that the different acidulent levels may have some effect on crumb structure by way of an anionic or cationic effect (54).

As shown in Plate 3 there is a change in the surface contour of the cake as the amount of MCP in these blends of acidulents is increased. This peaked contour of the cake with 100% MCP could result from the cake batter setting at the extremities of the cake after only a limited expansion. In the later stages of baking the concentration of the microwave energy in the cake's center and the conduction of heat to this region from other regions of the cake could cause the center of the cake to expand upwards and set to give a peaked contour. The initial limited expansion on the extremities of the cake could result from decreased gas production caused by the greater amounts of MCP in the blends of acidulents.

Combined effect of baking time and acidulent level

The mean results for the six quality measurements associated with this experiment are listed in Table 14. A technique of response surface methodology was used to study this combined effect. The equations for the response surfaces of the dependent variables such as volume or crumb compression

Table 14. Combined effect of baking time and acidulent level on the quality of cakes baked with microwave energy

Number*	Volume (cc)	Specific Volume (cc/g)	Internal Score (100)	Crumb Color	Crumb pH	Crumb Compression (g)
1	915	2.44	80	35.3	7.26	604
2	913	2.40	84	38.5	7.24	627
3	895	2.37	90	42.5	7.23	659
4	895	2.35	81	44.0	7.20	683
5	937	2.54	72	36.0	7.26	662
6	930	2.49	80	37.5	7.26	693
7	905	2.44	94	41.0	7.25	706
8	907	2.45	94	45.0	7.23	706
9	900	2.47	72	32.3	7.25	744
10	923	2.49	72	38.0	7.25	726
11	895	2.47	72	40.0	7.24	744
12	853	2.36	72	42.5	7.19	777

* Refer to Tables 3 and 4 for key to number sequence

were obtained as functions of the independent variables of baking time and acidulent level. The estimates and R^2 values for these equations are contained in Table 15. In order to enable easier interpretation of these relationships the response surfaces were expressed graphically as contour plots as shown in Figures 9 to 14.

Rising ridge systems (66) were fitted to the six response surfaces. The contour plots for volume, specific volume and crumb pH indicated, that as the amount of MCP in the acidulent blend was increased the values for these measurements decreased eventhough some of the differences involved may not have been significant.

Crumb color became whiter as the amount of MCP in the acidulent blend increased (Figure 13). This increased crumb whiteness can be attributed to the role of MCP in control of gas production. As the amount of MCP in the acidulent blend is increased there would be less generation of carbon dioxide in the heating stage with a consequential decrease in internal pressure in the gas cells. A decrease in internal pressure would result in cells of a reduced diameter. Cake crumb with such cells would reflect more light and so appear whiter.

Internal score improved as the amount of MCP in the acidulent blend increased and as the baking time decreased to the minimum of 5.5 minutes.(Figure 12) It is not possible to state which, if any, of the contour lines in Figure 12 are significantly different however it does seem that the maximum internal score is obtained with higher amounts of MCP in the

Table 15. Combined effect of baking time and acidulent level on the quality of cakes baked with microwave energy - Estimates and R^2 values for multiple regression equations of contour plots

	Volume (cc)	Specific Volume (cc/g)	Crumb Compression (g)	Internal Score (100)	Crumb Color	Crumb pH
a	-1948.317	-6.8187	1254.450	-875.233	-52.038	4.4487
X_1	952.20	2.970	-159.10	325.30	34.90	0.840
X_2	0.6967	0.00482	-12.815	1.0883	0.0593	0.0089
$X_1 X_2$	0.9100	0.0005	1.520	0.090	-0.025	0.0
X_1^2	-84.50	-0.245	15.00	-28.50	-2.950	-0.07
X_2^2	-0.045	-4.167×10^{-5}	0.0175	-0.0175	-0.002	-6.67×10^{-5}
R^2	0.7936	0.8595	0.9656	0.7030	0.9629	0.9000

where a = intercept (B_0), X_1 = baking time (min) and X_2 = acidulent level - SALP/MCP (%)

Figure 9. Contour plot of volume for different baking times and acidulent levels for cakes baked with microwave energy.

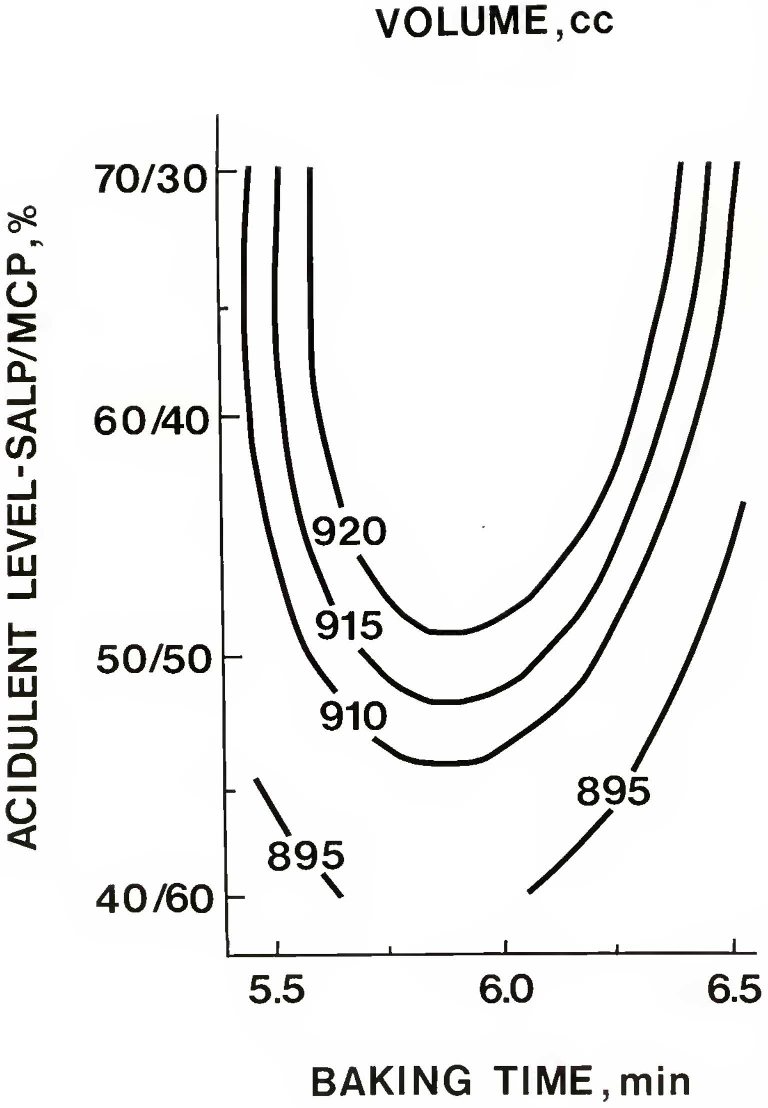

VOLUME, cc
ACIDULENT LEVEL-SALP/MCP, %
70/30
60/40
50/50
40/60
920
915
910
895
895
5.5
6.0
6.5
BAKING TIME, min

Figure 10. Contour plot of specific volume for different baking times and acidulent levels for cakes baked with microwave energy.

SPECIFIC VOLUME,cc/g

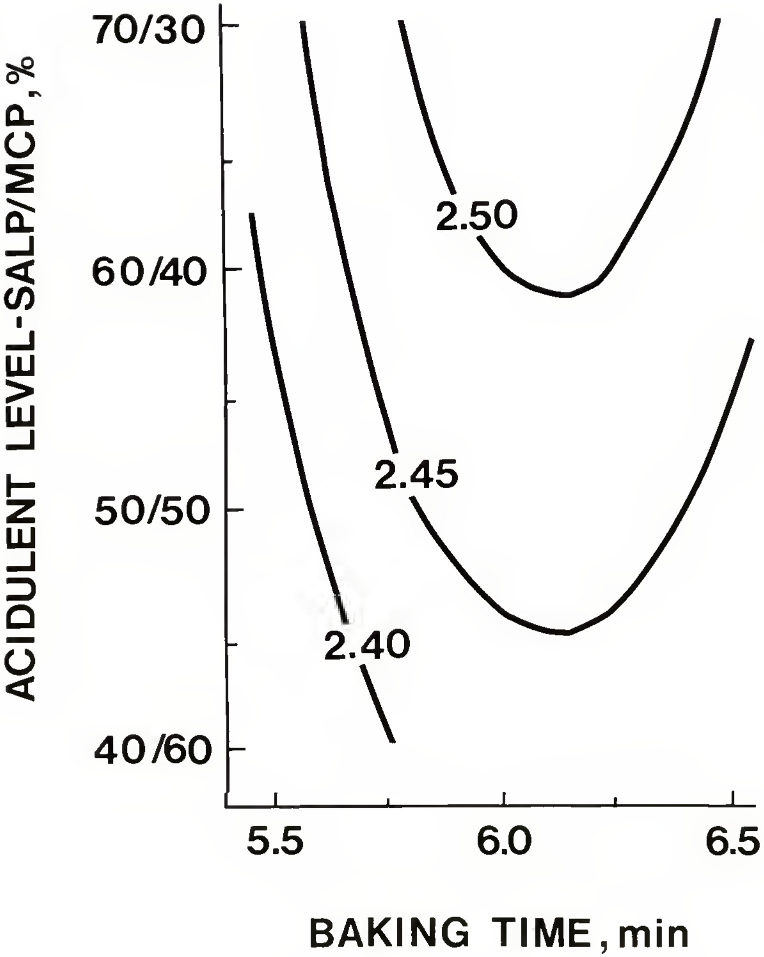


Figure 11. Contour plot of crumb compression for different baking times and acidulent levels for cakes baked with microwave energy.

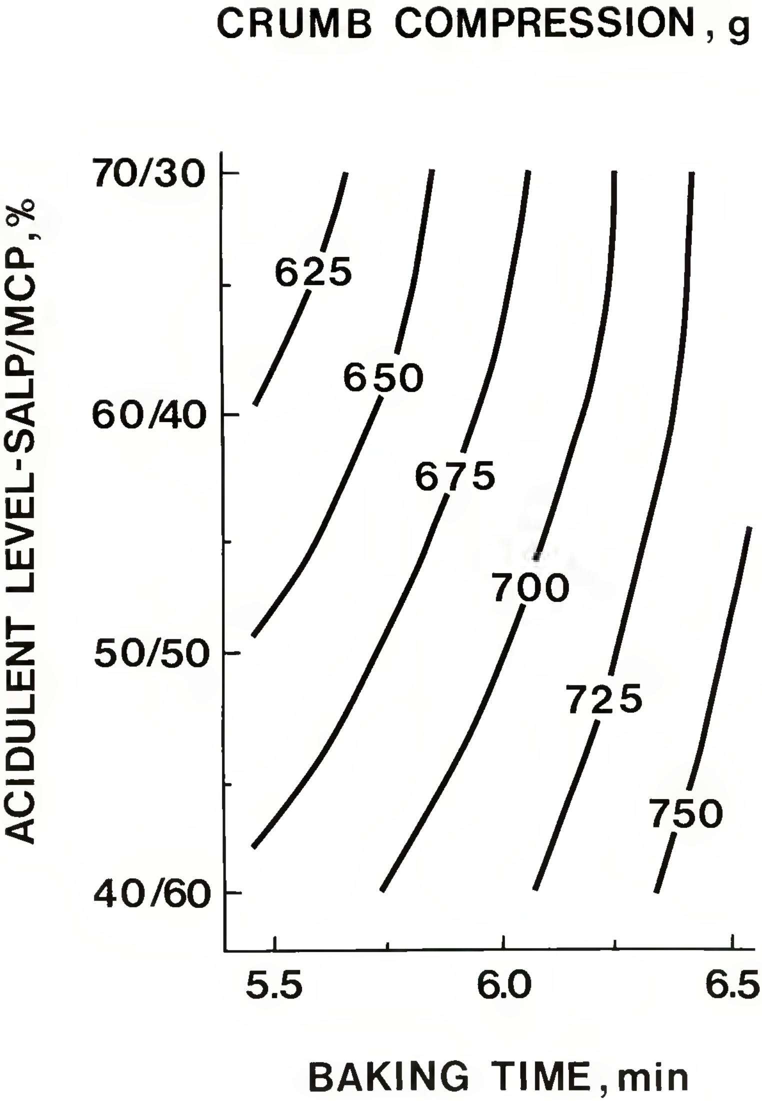

CRUMB COMPRESSION, g
ACIDULENT LEVEL-SALP/MCP, %
70/30
60/40
50/50
40/60
625
650
675
700
725
750
5.5
6.0
6.5
BAKING TIME, min

Figure 12. Contour plot of internal score for different baking times and acidulent levels for cakes baked with microwave energy.

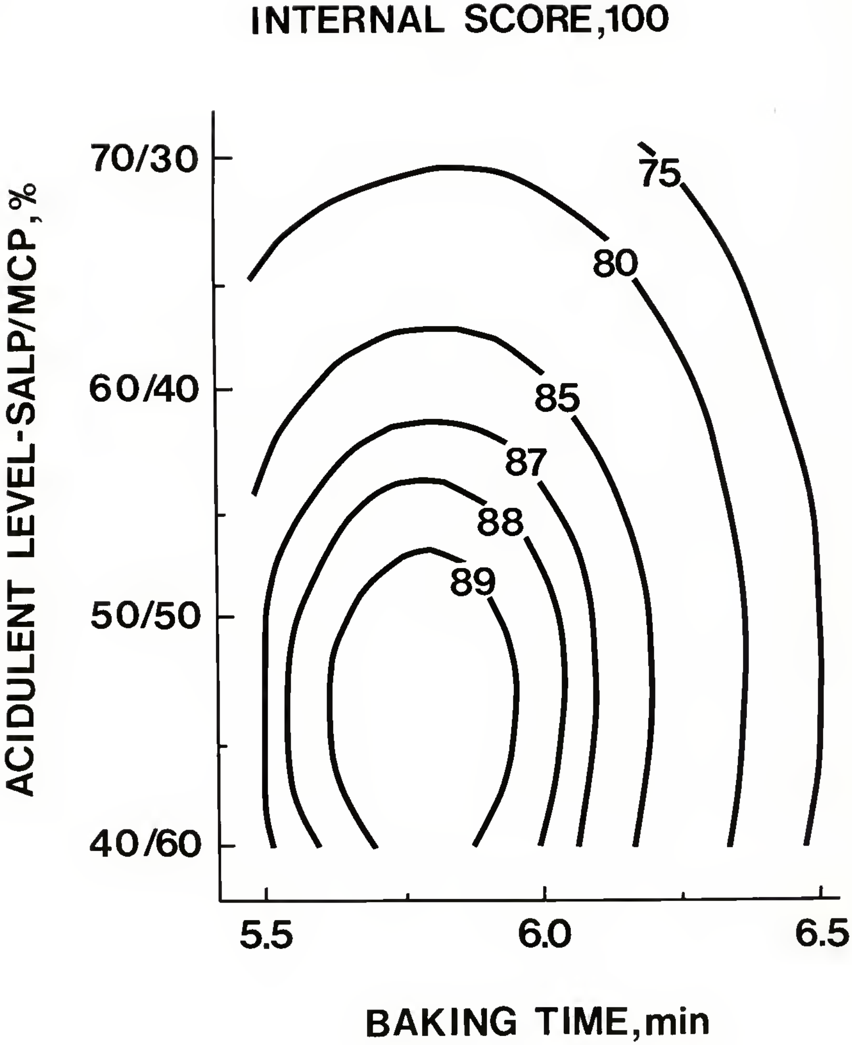

INTERNAL SCORE,100
ACIDULENT LEVEL-SALP/MCP, %
70/30
60/40
50/50
40/60
75
80
85
87
88
89
5.5
6.0
6.5
BAKING TIME, min

Figure 13. Contour plot of crumb color for different baking times and acidulent levels for cakes baked with microwave energy.

CRUMB COLOR

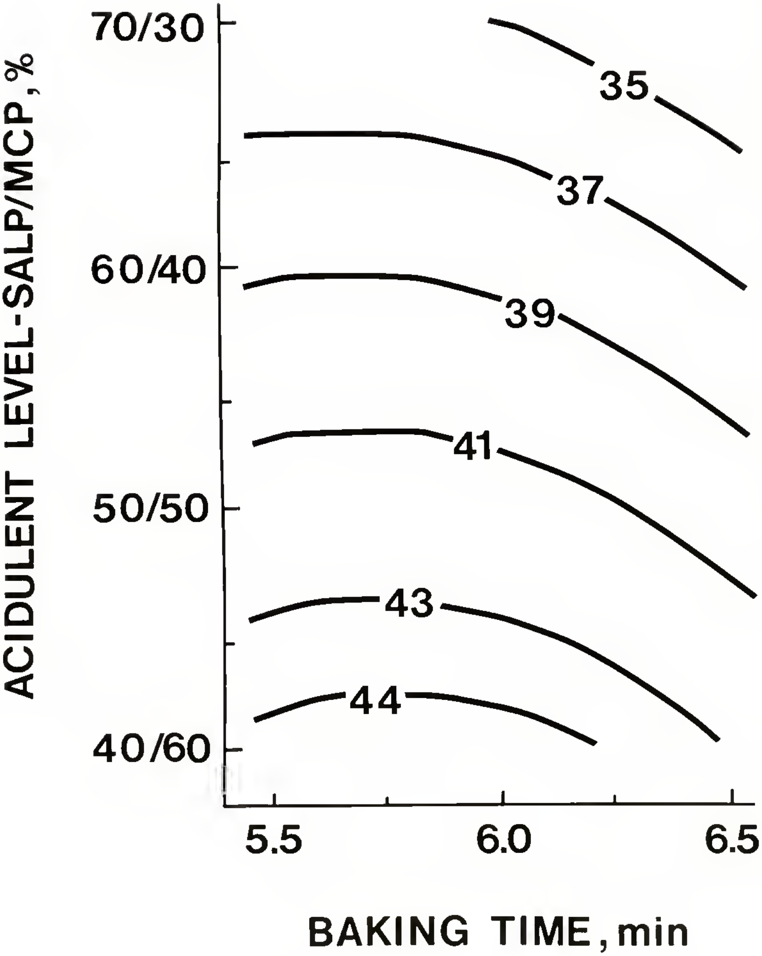
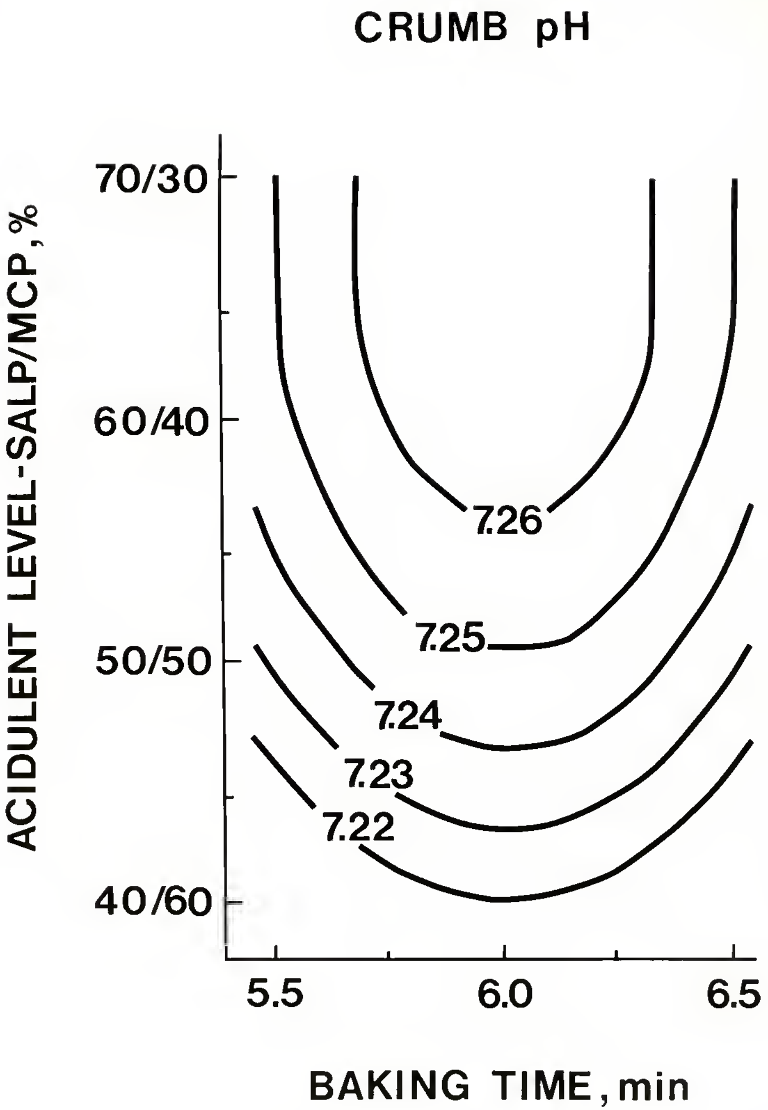

70/30
60/40
50/50
40/60
35
37
39
41
43
44
5.5
6.0
6.5
ACIDULENT LEVEL-SALP/MCP, %
BAKING TIME, min

Figure 14. Contour plot of crumb pH for different baking times and acidulent levels for cakes baked with microwave energy.


CRUMB pH
ACIDULENT LEVEL-SALP/MCP, %
70/30
60/40
50/50
40/60
7.26
7.25
7.24
7.23
7.22
5.5
6.0
6.5
BAKING TIME, min

acidulent blend and minimum baking times.

As shown in Figure 11 crumb compression is less at lower levels of MCP in the blend and becomes less dependent on acidulent level and more dependent on baking time as the baking time is increased. This increased dependence on baking time was indicated by the tendency for the contour lines to become more vertical as the baking time was increased from the minimum of 5.5 minutes to 6.5 minutes.

It is apparent from these contour plots that it is not possible to optimize the six quality measurements with a given combination of acidulent level and baking time. Therefore a combination was selected in order to achieve a compromise between the desired optimum regions of these quality measurements. This selected combination corresponded to the minimum baking time of 5.5 minutes and an acidulent level corresponding to the contour line of a crumb compression of 625 g which was 61.4% SALP/38.6% MCP. This combination resulted in a cake of a minimum crumb compression for acceptable results for the other five quality measurements. Also this experiment indicated the importance of baking time for cakes baked using microwave energy in terms of its influence on measurements of cake quality particularly crumb compression.

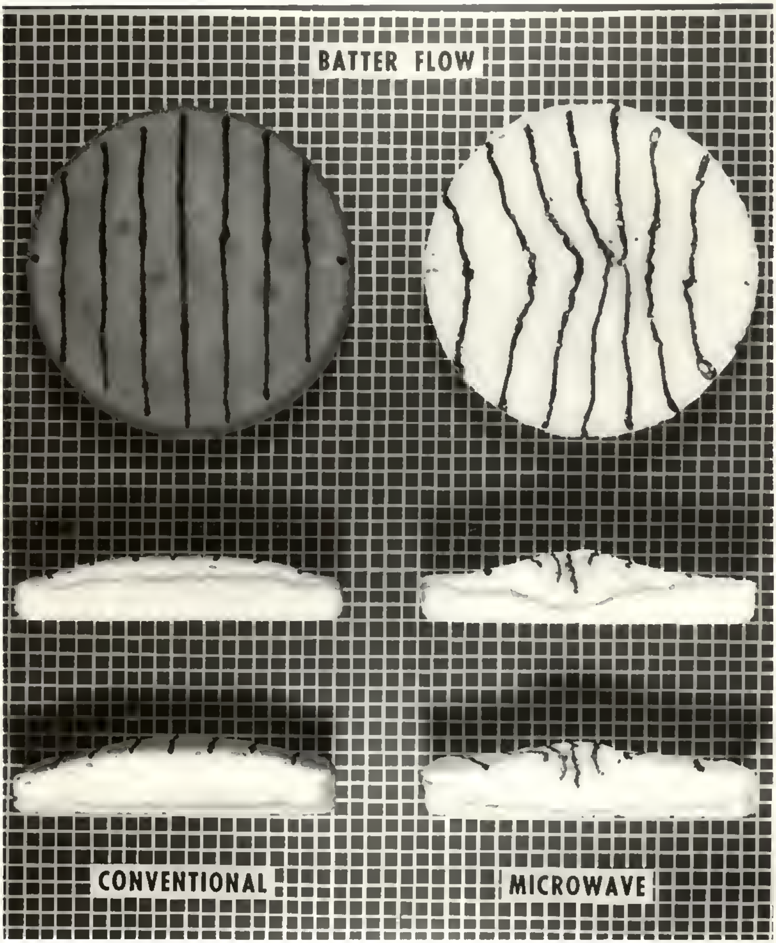
Structure development

Batter flow. Comparisons of batter flow within and on the surface of the cake were considered for cakes baked with microwave energy and by conventional means. The cake baked with microwave energy was prepared with the emulsified shortening and the ecidulent level for this shortening of 61.4% SALP/38.6% MCP with baking at the 100% power level for 5.5 minutes. Representative samples from this experiment are shown in Plate 4.

In the cakes baked by conventional means there was no evidence of any significant internal nor surface batter flow since the upper and lower internal regions of dyed batter remained approximately horizontal and the dyed batter applied to the surface appeared to be unaffected as a result of the baking process. Trimbo et al. (78) reported similar observations for cakes baked from mix-type cake batters. However in an attempt to explain a quality defect of surface rings in their white layer cakes they observed that this defect could be associated with internal batter flow patterns. Since the cakes prepared in this experiment did not have any undesirable surface rings the lack of any internal or surface better flow was in accord with the observations of Trimbo et al. (78).

The different patterns of dyed batter evident in the samples shown in Plate 4 indicate that there are differences in batter flow between the two methods of baking cake. These differences are prominent particularly on the cake surface and internally in the upper regions of the cake. In the cake baked with microwave energy there is a minimal amount of upward better flow of the red batter while the surface of the batter in the center of the ceke appears to have risen vertically during baking. It would seem that during the later

Plate 4. Batter flow in cakes baked by conventional means and with microwave energy.


BATTER FLOW
CONVENTIONAL
MICROWAVE

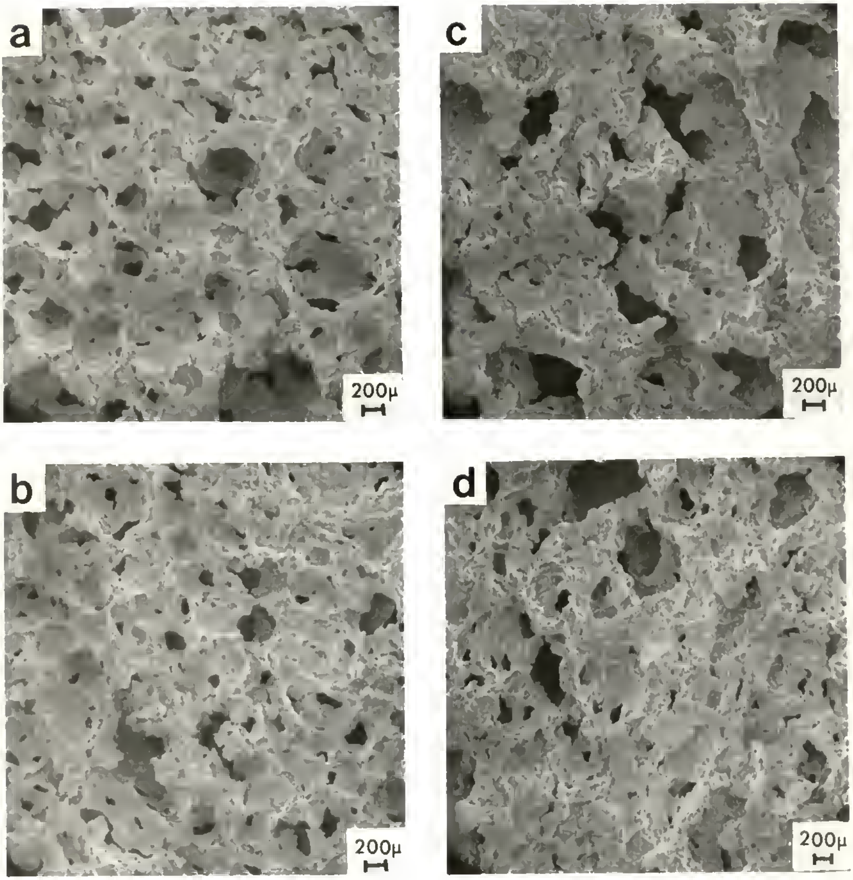
stages of the baking process the central regions of the cake batter would have sustained the combined effect of a concentration of microwave energy in the center of the cake as well as a conduction of heat to this region from other parts of the cake. This concentration of energy and accumulation of heat would result conceivably in large temperature differentials causing differences in batter density. Such differences in batter density would be expressed as batter flow patterns. In this case it seemed as though the lower central region of the cake remained stationary while the outer regions increased in volume and appeared to fold in towards the center of the cake. As this central region may have been affected by large temperature differentials the cake batter was forced to expand upwards rapidly as shown by the presence of black batter in the internal regions of the cake.

A possible explanation for the significant involvement of the surface in batter flow was that there was a lack of surface browning and significant crust formation in the cakes baked with microwave energy.

Scanning electron microscopy. Comparisons of cell structure for cakes baked by conventional means and using microwave energy were made using scanning electron microscopy. As described above, samples from two positions of both types of cake were scanned and images of representative areas were photographed. The scanning electron micrographs of these samples are shown in Plate 5.

For position 1 which corresponds to the center of the

Plate 5. Scanning electron micrographs of samples of cake crumb from two positions in cakes baked by conventional means and with microwave energy (a - conventional, position 1; b - conventional, position 2; c - microwave, position 1; d - microwave, position 2).


a
200μ
c
200μ
b
200μ
d
200μ

cake the cell structure for the cake baked with microwave energy was much coarser than the cake baked by conventional means. The cells in the microwave cake were of a more irregular size and had thicker cell walls than the conventional cake. The cell structure for the samples from both positions of the conventional cake were similar however in the microwave case position 2 had more regular and finer cells than position 1. Eventhough the cells of position 2 showed an improvement in structure they were slightly coarser than in the conventional cake.

The possible concentration of microwave energy in the cake's center and the conduction of heat to this region from other parts of the cake may be responsible for the greater cell distortion observed for samples of position 1 compared to position 2. This cell distortion could be due to the cell membrane being unable to withstand the pressure exerted by the leavening gases as they are influenced by these increasing temperatures.

Effect of increased baking time on cell structure and crumb compression

The effect of increased baking time on cell structure for cakes baked by conventional means and with microwave energy was studied using scanning electron microscopy. As described above samples from two positions of both types of cake each baked at two baking times were scanned, and representative areas were photographed. The scanning electron micrographs of these samples are shown in Plates 6 and 7.

Plate 6. Scanning electron micrographs of samples of cake crumb from position 1 in cakes baked by conventional means and with microwave energy at increased baking times (B.T.) (a - conventional, 25 min. B.T.; b - conventional, 29.5 min. B.T.; c - microwave, 5.5 min. B.T.; d - microwave, 6.5 min. B.T.)

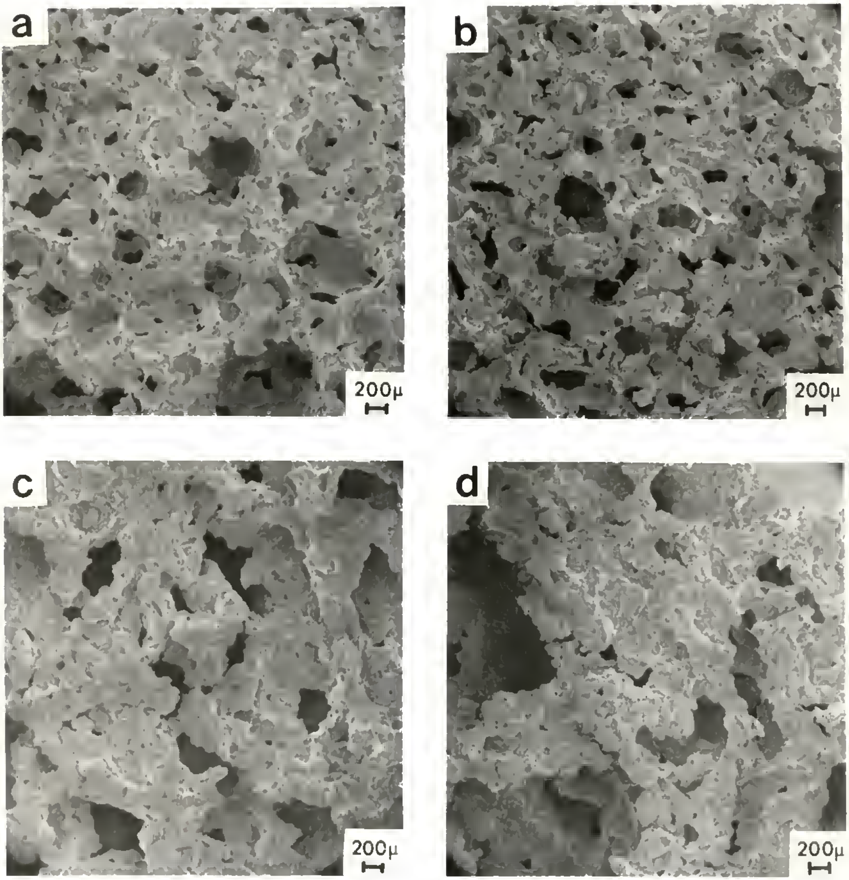
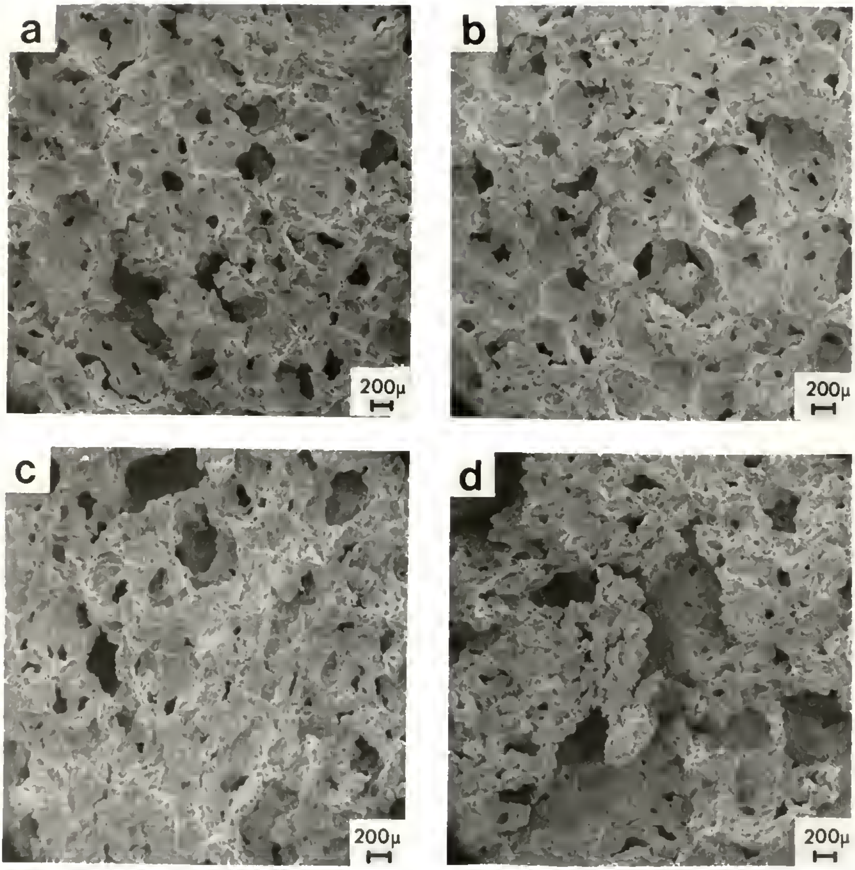

a
200μ
b
200μ
c
200μ
d
200μ

Plate 7. Scanning electron micrographs of samples of cake crumb from position 2 in cakes baked by conventional means and with microwave energy at increased baking times (B.T.) (a - conventional, 25 min. B.T.; b - conventional, 29.5 min. B.T.; c - microwave, 5.5 min. B.T.; d - microwave, 6.5 min. B.T.).


a
200μ
b
200μ
c
200μ
d
200μ

For both positions in the conventional cake, increased baking time did not appear to affect the cell structure. However in the microwave case the 18% increase in baking time caused the cells to become more open and consequently have much thicker cell walls.

An experiment with a randomized complete-block design was used to determine the effect of increased baking time on crumb compression. The ranked mean results and the results of the one-way analyses of variance are listed in Table 16, and expressed graphically in Figure 15.

The treatment with the firmest crumb was position 1 for the cake baked with microwave energy at the increased baking time. The softest crumb was obtained for position 3 of the conventional cake at both the minimum and the increased baking time. Comparisons of the crumb compression at the minimum and the increased baking times for cakes baked with microwave energy showed that the crumb was firmer for positions 1 and 3 and similar for position 2. However for the conventional case the crumb compression was similar at the minimum and increased baking times for each position in the cake.

The significant increase in crumb compression with an increased baking time for position 1 of the microwave cake could be a result of the observed increase in size and wall thickness for the cells of this position with an increased baking time. An explanation for this effect might be that the increased baking time could result in a rapid increase in gas pressure within the cells, particularly in the center of the cake which could cause some severe cell distortion giving rise

Table 16. Effect of increased baking time on crumb compression - Ranked mean results, mean comparisons, F value and LSD for analysis of variance

Treatment[y]			Crumb Compression (g)
Cake Type[x]	Baking Time (min)	Position	
MW	6.5	1	956 a
MW	6.5	3	822 b
MW	5.5	1	808 b
MW	6.5	2	720 c
MW	5.5	2	643 cd
MW	5.5	3	627 d
CONV	29.5	1	621 d
CONV	25.0	1	598 de
CONV	29.5	2	578 def
CONV	25.0	2	534 ef
CONV	29.5	3	507 fg
CONV	25.0	3	452 g

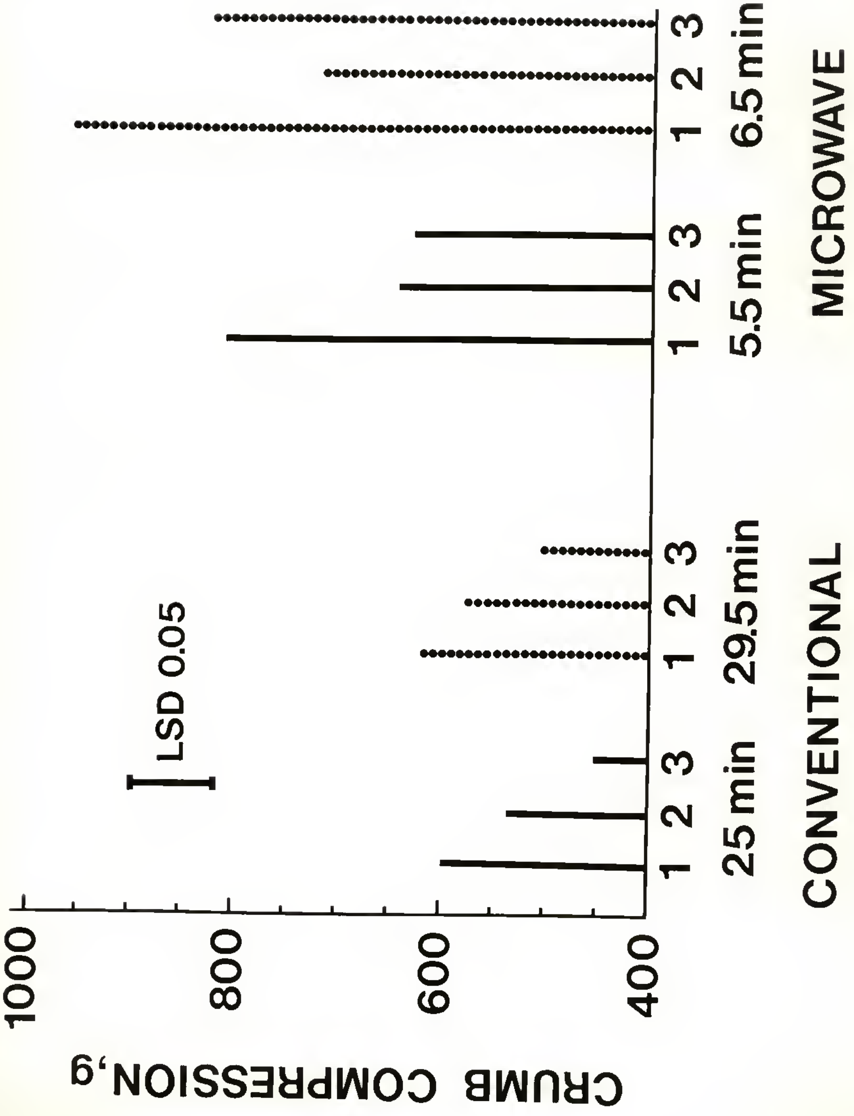
F value : 26.83**

LSD 0.05: 80.6

[x]MW = microwave and CONV = conventional

[y]Means having any letters in common are not significantly different at the 0.05 level of probability

Figure 15. Effect of increased baking time on crumb compression for cakes baked by conventional means and with microwave energy.


CRUMB COMPRESSION,g
1000
800
600
400
LSD 0.05
1 2 3
25 min
1 2 3
29.5 min
CONVENTIONAL
1 2 3
5.5 min
1 2 3
6.5 min
MICROWAVE

to the more open cells with the thicker cell walls.

Effect of different emulsifiers

In the initial part of this experiment a technique of response surface methodology was used to determine the optimum blend of four emulsifiers. The mean results for the four quality measurements associated with this experiment are listed in Table 17. The equations for the response surfaces of the dependent variables such as volume or internal score were obtained as functions of the independent variables of the four level quadratic expansion equation. The equation is as follows:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{14}X_1X_4 + B_{23}X_2X_3 + B_{24}X_2X_4 + B_{34}X_3X_4 + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2 + B_{44}X_4^2.$$

The final equations for each of the response surfaces were obtained using a stepwise multiple regression procedure (method of least squares) with a backward elimination step until all variables in the model were significant at least, at the 0.1 level of probability. The estimates and R^2 values for these equations are contained in Table 18. A search procedure was used to determine combinations of these four variables which gave near optimum responses for all four quality measurements. In the selection of these combinations the predicted responses for all four quality measurements had to be considered since in some cases the optimum for one particular quality measurement gave unacceptable poor quality

Table 17. Effect of emulsifiers on the quality of cakes baked using microwave energy

Number*	Volume (cc)	Specific Volume (cc/g)	Crumb Compression (g)	Internal Score (100)
1	1005	2.70	477	90
2	990	2.66	626	86
3	1030	2.78	424	48
4	1000	2.66	466	42
5	1070	2.86	425	84
6	1073	2.86	382	84
7	1063	2.86	415	78
8	1063	2.84	368	50
9	1075	2.88	443	84
10	1050	2.81	421	84
11	1023	2.74	493	86
12	1045	2.81	390	90
13	1058	2.84	401	54
14	983	2.63	630	86
15	1065	2.84	405	54
16	1075	2.87	483	84
17	1025	2.76	428	48
18	1080	2.90	358	78
19	1040	2.79	401	84
20	1010	2.69	549	84
21	1058	2.83	403	90
22	1053	2.83	434	60
23	923	2.45	743	94
24	1060	2.84	425	54
25	1070	2.85	501	84
26	975	2.66	378	42
27	1063	2.85	489	84

*Refer to Tables 5 and 6 for key to number sequence

Table 18. Effect of emulsifiers on the quality of cakes baked with microwave energy - Estimates and R^2 values for multiple regression equations of response surfaces

	Volume (cc)	Specific Volume (cc/g)	Crumb Compression (g)	Internal Score (100)
a^y	1076.370	2.881	424.800	78.267
X_1	-7.833	-0.026	37.750	-6.167
X_2	9.083	0.031	-77.833	-19.667
X_3	7.083	*	-28.083	-5.167
X_4	8.833	0.031	-35.500	-6.667
X_1^2	-26.097	-0.067	*	*
X_2^2	-46.222	-0.121	74.033	-10.600
X_3^2	*	*	*	*
X_4^2	-14.097	-0.038	*	*
X_1X_2	*	*	*	*
X_1X_3	*	*	*	-9.500
X_1X_4	*	*	*	-7.500
X_2X_3	-33.000	-0.081	42.500	*
X_2X_4	-58.000	-0.145	48.750	*
X_3X_4	*	*	*	-7.000
R^2	0.9184	0.8767	0.8065	0.9473

^{y}a = intercept

*indicates that the term was deleted as nonsignificant in the stepwise regression procedure in terms of some of the other quality measurements. From this search procedure seven out of 625 combinations tested were selected fcr further study in the final part of this experiment.

This final experiment involved comparisons between cakes prepared with these seven different combinations of emulsifiers and with other cakes baked by conventional means and using microwave energy. A description of and key for the 10 treatments involved in this experiment are listed in Table 19. The ranked mean results, mean comparisons, F values and LSD's from the one-way analyses of variance for the 9 quality measurements in this experiment are presented in Table 20. Cross-sectional views of representative samples of some of the treatments in this experiment are shown in Plate 8.

The volumes for all seven combinations of the four emulsifiere were similar to the conventional cake and superior to the other two cakes baked with microwave energy. For specific volume the seven combinations of emulsifiers were similar and superior to the other treatments including the conventional cake. The cake prepared with the non-emulsified shortening and baked with microwave energy was similar in specific volume to the conventional cake. The treatment with the lowest volume and specific volume was the cake prepared with the commercial emulsified shortening.

The cake batters using these combinatione of emulsifiers had lower specific gravities than the batters prepared with either the non-emulsified shortening or the commercial emulsified shortening. Cake batters from the two treatments using the commercial emulsified shortening had the

Table 19. Effect of emulsifiers on the quality of cakes baked with microwave energy - Description of treatments in comparative study

Treatment Code	Treatment			
A	Conventional; Commercial double-action baking powder; Quick blend shortening			
B	Microwave; Acidulent level - 61.4% SALP/38.6% MCP; Quick blend shortening			
C	Microweve; Acidulent level - 100% MCP; Primex shortening			
	Microwave; Acidulent level - 100% MCP; Primex shortening with the following blends (%[a]) of emulsifiers:-			
	MD[b]	Poly. 60[c]	PGMS[d]	GLP[e]
D	1.0	0.6	1.0	2.5
E	1.0	0.6	1.5	2.0
F	1.0	0.6	2.5	1.0
G	1.0	0.6	2.0	2.0
H	1.0	0.6	2.0	2.5
I	1.0	0.6	2.5	2.0
J	1.0	0.6	2.5	2.5

[a]% based on a shortening basis

[b]MD = Mono- end Diglycerides (Panalite 50 5VK)

[c]Poly. 60 = Polyeorbate 60

[d]PGMS = Propylene glycol monostearate (Promodan 5P)

[e]GLP = Glycerol-lacto-palmitete (Lactodan F 15)

Table 20. Effect of emulsifiers on the quality of cakes baked with microwave energy - Ranked mean results, mean comparisons[x], F values and LSD's for analyses of variance of comparative experiment

Trt.[y]	Volume (cc)	Trt.	Specific Volume (cc/g)	Trt.	Batter Specific Gravity	Trt.	Weight Loss (%)	Trt.	Internal Score (100)
I	1050 a	I	2.84 a	A	0.98 a	F	13.2 a	A	100 a
J	1050 a	J	2.83 a	B	0.96 a	I	13.0 a	D	86 b
D	1043 a	G	2.82 a	C	0.68 b	G	12.9 a	E	86 b
G	1043 a	F	2.82 a	G	0.64 c	C	12.9 a	G	86 b
H	1040 a	D	2.81 a	H	0.64 c	J	12.7 a	H	86 b
E	1038 a	H	2.80 a	I	0.64 c	D	12.7 a	I	86 b
F	1038 a	E	2.79 a	J	0.64 c	E	12.5 a	J	86 b
A	1028 a	C	2.64 b	D	0.63 c	H	12.5 a	F	84 c
C	978 b	A	2.63 b	E	0.63 c	B	12.4 a	B	80 d
B	937 c	B	2.51 c	F	0.63 c	A	8.0 b	C	56 e
F value:	23.03**		33.30**		494.21**		28.89**		299.56
LSD 0.05:	22.9		0.06		0.02		0.84		1.9

[x]Means having any letters in common are not significantly different at the 0.05 level of probability

[y]Trt. = Treatments defined in Table 19.

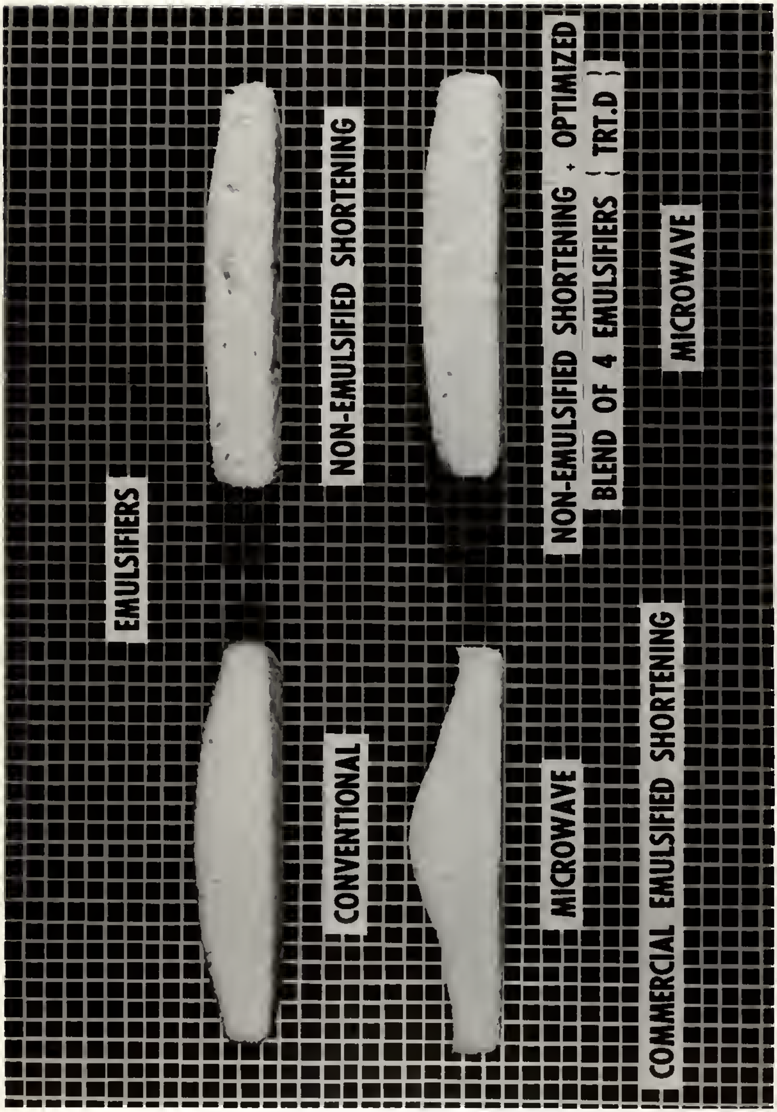
Table 20 (cont). Effect of emulsifiers on the quality of cakes baked with microwave energy - Ranked mean results, mean comparisons[x], F values and LSD's for analyses of variance of comparative experiment

Trt.[y]	Crumb Color	Trt.	Crumb pH	Trt.	Crumb Compression (g) (Day 1)	Trt.	Crumb Compression (g) (Day 4)
A	39 a	A	7.26 a	B	794 a	B	866 a
H	35 b	B	7.21 a	A	577 b	A	599 b
D	33 bc	H	7.10 b	I	521 bc	C	553 bc
B	33 bc	G	7.10 b	H	520 bc	H	532 bc
J	33 bc	E	7.09 b	F	513 bc	J	529 c
I	32 bc	F	7.09 b	G	511 bc	I	527 c
F	30 c	J	7.09 b	J	498 bc	G	514 c
E	30 c	D	7.08 b	C	495 c	E	508 c
G	30 c	I	7.08 b	E	469 c	F	505 c
C	21 d	C	7.07 b	D	465 c	D	491 c
F value:	12.42**		12.49**		12.38**		23.59**
LSD 0.05:	3.8		0.05		80.2		67.4

[x]Means having any latters in common are not significantly different at the 0.05 level of probability

[y]Trt. = Treatments defined in Table 19.

Plate 8. Effect of emulsifiers on cakes baked by conventional means and with microwave energy.


EMULSIFIERS
NON-EMULSIFIED SHORTENING
CONVENTIONAL
NON-EMULSIFIED SHORTENING + OPTIMIZED
BLEND OF 4 EMULSIFIERS (TRT.D)
MICROWAVE
MICROWAVE
COMMERCIAL EMULSIFIED SHORTENING

highest specific gravity. The low specific gravities obtained with these combinations of emulsifiers can be attributed to the use of the aerating emulsifiers (48) such as propylene glycol monostearate and glycerol-lacto-palmitate. However these low specific gravities were above the minimum specific gravity of 0.60 recommended by one emulsifier supplier[1] for the preparation of cake batters using aerating emulsifiers.

Weight loss on baking for the cakes baked with microwave energy was greater than those baked by conventional means. Similar results were reported by Street and Surratt (25) and Neuzil and Baldwin (26). Presumably the penetrating heating ability and the lack of crust formation with microwave heating results in this greater weight loss upon baking.

The internal score for all of the emulsifier blends except treatment F were similar however less than the conventional cake. Treatment F was slightly less than these six blends however it was greater than the cake made with the commercial emulsified shortening. The lowest score of 52 was obtained with the cake made with the commercial emulsified shortening. The lower scores for the cakes prepared from the emulsifier blends can be attributed to the greater number of tunnels found in these cakes compared to the conventional cakes. Tunneling in cakes has been attributed to pockets of water vapor being entrapped in the batter during

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[1]Personal communication with L. Davis, Eastman Chemical Products, Inc., Kingsport, Tennessee, February, 1979

the thermal setting period (79). Miller and Trimbo (79) reported that tunnels occur more frequently when the batter density is substantially less than 1.0 which is in accord with the observations of this experiment. Presumably the increased air incorporation in the batter associated with the lower batter density results in a greater frequency for tunnelling. Unfortunately no specific methods have been reported for the prevention of tunnels in cakes (79).

The crumb color of the cakes from these seven combinations of the emulsifiers was not as white as the conventional cake but similar to the cake prepared with the commercial emulsified shortening. The cakes associated with the above treatments had crumb colors which were whiter than the cake prepared with the non-emulsified shortening. The lower readings for the cakes prepared from these blends of emulsifiers compared to the conventional cake could be caused by the greater number of tunnels found in these cakes.

Crumb pH was similar for those cakes prepared using 100% MCP and lower than for those cakes made using the commercial double-action baking powder and the acidulent level of 61.4% SALP/38.6% MCP. It would appear that differences in the baking powder blends contributed to these differences in crumb pH. However the values obtained for all the treatments were within the general range of acceptable pH for cake crumb of 6.5 to 7.5 (53).

The crumb for the cake made with the commercial emulsified shortening and baked with microwave energy was firmer than for all the other treatments for tests after storage periods of one day and four days. However the other treatments including the seven combinations of the four emulsifiers were either similar to or softer than the conventional cake after both storage periods. After storage for one day, treatments C, D and E were softer than the conventional cake while after the four day storage period treatments D, E, F, G, I and J were softer than the conventional cake.

In summarizing the comparisons with the conventional cake the cakes with these seven different blends of emulsifiers were similar in volume, superior in specific volume and inferior in internal score, crumb color and weight loss. All seven blends produced cake crumb either similar to or softer than the conventional cake after storage periods of one day and four days. After a storage period of one day the cake crumb from treatments D and E was softer than the conventional cake while after the storage period of four days treatments D, E, F, G, I and J produced cake crumb softer than the conventional cake.

The mechanisms by which these emulsifiers achieved the above improvements in cake quality could be complicated because of the complex nature of the cake batter system and since some of these emulsifiers in particular the aerating emulsifiers such as PGMS and GLP contain a mixture of molecular species (56). Improvements in crumb structure by using emulsifiers has been attributed to the incorporation of a greater number of air cells of smaller size. In the baked cake this rssults in an improvement in volume and crumb structure and a greater surface area for the absorption of water vapor which condenses as the baked cake cools resulting in an improvement in the eating quality (44).

Generally the function of emulsifiers can be divided into three main groups: (i) reductions of surface tension at the oil-water interfaces (80) (ii) interactions with starch and protein components (80) and (iii) modification of the crystallization of fats and oils (80) and the surface charge of the fat droplets (44). Wootton et al. (56) proposed that the aerating emulsifiers affect air incorporation through an indirect mechanism. The emulsifiers were thought to form a film incapsulating the oil droplets and preventing the fat phase from interfering with the foaming properties of the soluble protein. While Greethead (81) proposed that emulsifiers achieved stabilization of the foam by causing an acceleration of protein denaturation at the oil-water interface.

In conclusion there appears to be no comprehensive theory but rather a number of possible mechanisms to account for the functions of emulsifiers in cake batters and for the effects observed in this experiment.

SUMMARY

The application of microwave energy for baking high-ratio white layer cakes was investigated. Different processing conditions and ingredient levels were optimized and the structure development was considered using batter flow studies and scanning electron microscopy.

The study of the processing conditions, baking time and oven power levels indicated that baking performance was superior at the 100% power level with the minimum baking time of 5.5 minutes.

The effects of water level on the quality of cakes baked by conventional means and with microwave energy were generally similar except that in the microwave series there was a lack of any surface collapse regardless of the water level. This observation is in contrast to conventional baking which is characterized by surfece collapse at low water levels.

Baking performance was affected by the levels of the acidulents, monocalcium phosphate monohydrate (MCP) and sodium aluminum phosphate (SALP) in the baking powder blends. As the amount of MCP was increased volume decreased and crumb firmness and internal score increased.

In comparison with the conventional cake, cakes prepared using seven different blends of four emulsifiers and baked with microwave energy were similar in volume, superior

in specific volume and inferior in internal score, crumb color and weight loss. All seven blends produced cake crumb either similar to or softer then the conventional cake after storage periods of one day and four days. These blends of emulsifiers consisted of 1.0% mono- and diglycerides, 0.6% polysorbate 60 and different levels from 1.0% to 2.5% of propylene glycol monostearete and glycerol-lacto-palmitate.

Comperisons of the structure development indicated different batter flow patterns in cakes baked by conventional means and with microwave energy. In the conventional cake there was no evidence of any significant internal nor surface batter flow while in the microwave case considerable batter flow was observed on the surface and internally in the upper central regions of the cake. Scanning electron microscopy showed differences in cell structure between both types of cake. The cells in the center of the cake baked with microwave energy were more irregular and had thicker cell wells than the conventional cake. Also in the microwave case an increase in baking time wes found to increase cell size and wall thickness.

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APPENDIX

Table 21. Composition of specific ingredients

Ingredient	Composition*
Double-action baking powder (Red Star)	Sodium acid pyrophosphate, sodium bicarbonate, monocalcium phosphate and corn starch.
Hydrogenated emulsified shortening (Super Quick Blend)	Partially hydrogenated soybean and palm oils, mono- and diglycerides and polysorbate 60.
Hydrogenated non-emulsified shortening (Primex)	Partially hydrogenated soybean and palm oils and methyl silicone.

*Source: Ingredient declaration on product.

APPLICATION OF MICROWAVE ENERGY FOR BAKING CAKES

by

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ABSTRACT

Microwave energy was evaluated for its application for baking high-ratio white layer cakes. Different processing conditions and ingredient levels were optimized and the structure development was considered using batter flow studies and scanning electron microscopy.

Baking performance was superior at the 100% power level with the minimum baking time of 5.5 minutes. The effects of water level on the quality of cakes in the microwave and conventional series were generally similar except that in the microwave case there was no evidence of any surface collapse regardless of the water level. Baking performance was affected by the level of the acidulents, monocalcium phosphate monohydrate (MCP) and sodium aluminum phosphate (SALP) in the baking powder blends. As the amount of MCP was increased, volume decreased and crumb firmness and internal score increased.

In comparison with the conventional cake, cakes prepared using seven different blends of four emulsifiers and baked with microwave energy were similar in volume, superior in specific volume and inferior in internal score, crumb color and weight loss. All seven blends produced cake crumb either similar to or softer than the conventional cake after storage periods of one day and four days. These blends consisted of 1.0% mono- and diglycerides, 0.6% polysorbate 60 and different

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Comparisons of the structure development indicated different batter flow patterns in cakes baked by conventional means and with microwave energy. In the microwave case considerable batter flow was observed on the surface and internally in the upper central regions of the cake while there was a lack of any such flow patterns in the conventional cake. Differences in cell structure were shown using scanning electron microscopy. The cells in the center of the cake baked with microwave energy were more irregular and had thicker cell walls.