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PREPARING AND BAKING YELLOW SPONGE CAKE AT DIFFERENT ALTITUDES

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Since 1926 the Home Economics Section of the Colorado Experiment Station has been studying the relation of atmospheric pressure to the baking of flour mixtures. The early empirical studies published in bulletin form in 1930 met with such extensive demand that widespread interest in the solution of baking problems at the higher altitudes seemed evident. Since that time, various publications of this Section have given information on phases of this problem. Technical Bulletins 13* (1935) and 15* (1936) presented the results of a study of angel food cake. The present bulletin reports certain results obtained in the study of yellow sponge cake. The more technical phases of this investigation will appear as a separate publication.

During the period in which this Section has been concerned with the solution of problems arising from the effect of altitude upon the baking of batters, a noteworthy change has been taking place in many of the nation's kitchens. They have become more highly mechanized through the introduction of labor-saving devices. It seemed essential to develop sponge cake batters which could be prepared readily through the use of modern mixing equipment. A further requirement was that these batters be capable of reproduction by hand mixing methods and equipment without too great effort.

Bakers and housewives generally have experienced difficulty in consistently duplicating results when sponge cakes are made. Moreover, the conventional type of sponge cake is exceedingly difficult to produce when large-type mixing equipment is used. Because of this, a modified form of sponge cake containing baking powder has come into prominence both in the home and in industry.

The effect of altitude upon sponge cake has been very troublesome. Especially at high altitudes, production of a desirable sponge cake has been rare indeed. Altitude corrections for this type of cake have taken the form of removal of sugar from the batter as altitude increases. When corrections are made in this way, the product is so lacking in sugar at the higher altitudes that it can scarcely be called a cake.

Because glass and mortar are more easily fractured than other materials in a building during an earthquake, it does not follow that

*Out of print.

these materials should be practically omitted from structures in an area where severe earth shocks are common. Rather, with the continued use of these desirable materials, the structure should be so modified that it will satisfactorily withstand the stresses to which it may be subjected. When the various ingredients that build a cake structure are considered, it is apparent that some contribute greater strength than others to this structure. A proper balance between these building materials will produce a structure of desirable strength for each altitude.

Therefore, a further objective of this study was to maintain this structural balance throughout the practical altitude range and at the same time produce cakes of comparable volume, texture, and eating quality.

A review of the literature of cake baking to 1936 is given by Barmore (1)* in Colorado Experiment Station Technical Bulletin 15. He called attention to the general lack of objective measurements in most experimental work conducted on this subject. Since that time several publications (2, 3, 4, 5, 6, 7, 8, 9, 10, 11) giving some measurements upon cakes have appeared. Notable among these because of its relationship to our present work is the report of King, Morris, and Whiteman (11), who used sponge cakes as a measure in egg quality determinations. The sponge cake equations suggested by Barmore (12) were predicated upon control of the altitude effect by removal of sugar from the cake formula. While this method of approach was fairly satisfactory at lower altitudes, he indicated that difficulties arose at higher altitudes which rendered this method of adjustment impractical. The effect produced by the variation of this single variable was not sufficient to accomplish the desired results. Moreover, at lower sugar concentrations cake characteristics have vanished.

Ingredients used in the present study were brought to constant temperature (22-23° C.) in controlled storage cabinets in the laboratory. Measurements were made by weight except in the case of water and flavoring, which were measured volumetrically. A commercial-type electric mixer, a home-type electric mixer, and hand mixing equipment were used. Baking was carried on in thermostatically controlled electric ovens. The MacMichael viscosimeter was used to follow changes in batter consistency. High grade cake flour was used throughout the study. The eggs used were newly laid and of high quality. Their quality corresponded to egg scores of less than 3 by the Van Wagenen-Wilgus scoring method (16), unless otherwise mentioned in the text. After amounts of materials and the conditions of

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*Numbers in parentheses refer to bibliography, p. 21.

their usage had been established, the findings were adapted to the housewife's recipes by usual volume measurements.

A Study of Meringue and Batter Stability

When the conventional method of mixing sponge cakes was tested to learn the tolerance of sponge cake meringue and batter for *mechanical* abuse, it became apparent that the batter prepared in the conventional manner was exceedingly unstable. This method of mixing had been used by Barmore in the preliminary experiments upon sponge cake and is essentially that described by Peterson (13) and later by King, Morris, and Whiteman (11). When the meringue was tested for stability by a method similar to that described by Barmore (15) it was found to be surprisingly stable.

The white meringue used for angel food batters prepared according to the directions given by Barmore (1) was found by this same method to be quite stable. Like the conventional sponge cake batter, the angel cake batter will stand little mechanical abuse without serious alteration or destruction of its structure. Apparently in both types of cakes just mentioned the fine flour particles are folded into and entrapped in small pockets between the bubbles of foam. Only enough flour may be used to pick up the liquid in these spaces. If sufficient flour is added to pull liquid away from the foam bubbles at a more rapid rate than the slow drainage rate, the foam collapses and angel cake and conventional sponge cake structures are destroyed. Mechanical abuse makes the liquid of the foam structure of the slow-draining meringues momentarily more readily available to flour particles which take up this liquid as fast as it becomes available. The result is destruction of the foam structure. This theory of the structures of these two cakes suggested that a moderately stable meringue which drained rather rapidly because of more rapidly released liquid and relatively lower foam stability might rearrange itself somewhat in the presence of flour to form a stable foam-type structure in which the flour was included in the framework. A structure containing the flour as a strengthening material should be more stable than one in which the flour is extraneous and competing with the egg substance for the available water.

Figure 1 shows the rate of draining of meringues prepared in different ways. For comparison, egg-white meringues are included in the study. For convenience, these meringues have been divided into groups I and II. Group I includes stable, slow-draining meringues; and group II includes less stable, rapid-draining meringues. In all meringues, the sugar, salt, and cream of tartar were practically

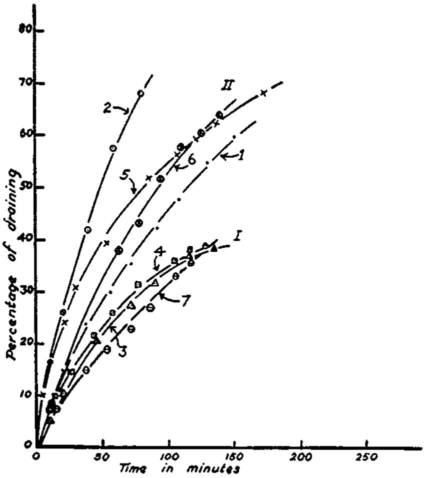

Figure 1.—Rate of draining of meringues. Curve 1 shows the rate for yolk meringue, hot method; curve 2, for yolk meringue, cold method; curve 3, for white meringue, cold method; curve 4, for white meringue, hot method; curve 5, for whole-egg meringue, hot method; curve 6, whole-egg meringue, cold method; and curve 7, for conventional mixed meringues.

in solution in the egg magma before beating commenced. Before the addition of these ingredients, the egg magma had been thoroughly mixed by beating for a few seconds at high speed. Cold-method meringues were prepared by whipping the mixture at high speed at room temperature with the commercial type mixer. The hot-method meringues were prepared in the same manner except that the 3-quart bowl of the commercial type mixer was immersed in a hot bath containing water at 80° C. during the beating. After beating, the bowl containing the hot meringue was immersed in cold water and the meringue was quickly cooled with occasional stirring until it was below 30° C. Curve number 6 in figure 2 shows the displacement of the origin obtained when the egg meringue is not cooled before the addition of the flour. This indicates that the meringue must be cooled in order that the proper specific gravity be obtained at the lower altitudes. The reason for this condition is that the meringue loses air too rapidly if the flour is added while the temperature of the meringue is above 30° C.

All meringue samples for draining experiments were 36 grams of the completed meringue weighed upon filter paper in funnels and allowed to drain into Erlenmeyer flasks. Each egg-white meringue contained 150 grams of sugar, 1 gram of salt, and 4 grams of cream of tartar to 210 grams of egg-white. Each whole-egg meringue contained 134 grams of sugar, 1 gram of salt, 1 gram of cream of tartar, and 30 cc of water to 192 grams of whole egg (120 grams of white and 72 grams of yolk). For the conventional meringue, one-half the sugar was added to the white, and one-half the sugar and all the water was added to the yolk before beating. The two resulting meringues were folded together at slow speed; then the sample was taken. Each yolk meringue contained 150 grams of yolk, 130 grams of sugar, 75 cc of water, and 1 gram each of salt and cream of tartar.

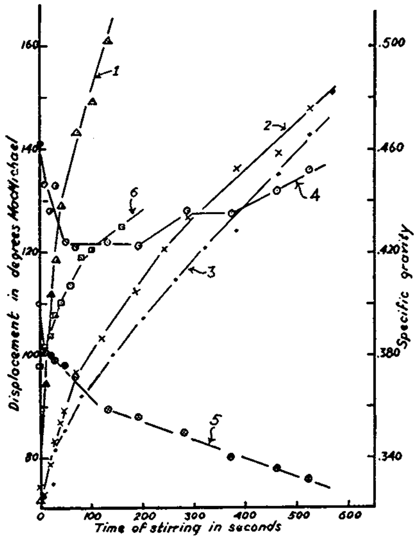

Figure 2.—Effect of stirring at slow speed upon properties of sponge cake batters. Curve 1 shows the change in specific gravity of conventional batter, flour folded in by hand in 3 minutes time; curve 2, the change in specific gravity of cold method, single meringue batter, flour added in 6½ minutes with machine stirring at slow speed; curve 3, the change in specific gravity of hot method, single meringue batter, flour added in 6½ minutes with machine stirring at slow speed; curve 4 shows the change in viscosity with stirring of the hot method, single meringue batter; curve 5 shows the change in viscosity with stirring of the cold method, single meringue batter; and curve 6 shows the change in specific gravity of hot method, single meringue batter to which flour was added while the meringue was hot (shrink has been too great).

The stability of some of the sponge cake batters resulting from these meringues is indicated in figure 2. Zero time occurs after the flour has been added. In the conventional method, the flour was hand-folded into the meringue during 3½ minutes. The same type of curve was obtained for this method when mechanical folding was used instead of hand folding. Only the point of origin would be altered. For all other batters, the flour was added in 6½ minutes with continued stirring by the commercial type mixer at slow speed. When such a procedure was tried upon conventional batters, so much air was lost that the batter was worthless as a straight sponge cake batter. The mechanical manipulation of these batters consisted of stirring with the whip of the commercial type mixer at slow speed. At intervals the machine was stopped and the specific gravity of the batter determined by the method used by this laboratory (1). The batter used for the determination was returned to the mixing bowl, and the stirring continued. The batters obtained from the yolk meringue were so stable that this type of mechanical treatment had practically no effect upon their lightness. It was necessary to tear them apart by beating about 1 minute at high speed to bring them to the specific gravity necessary for proper leavening at 5,000 feet altitude. It is evident that the batters formed from the high-draining-rate meringues of group II of figure 1 are much more stable to mechanical abuse than the sponge cake batter prepared by the conventional method. The equipment for the various mixing methods used throughout this investigation is shown in figure 3.

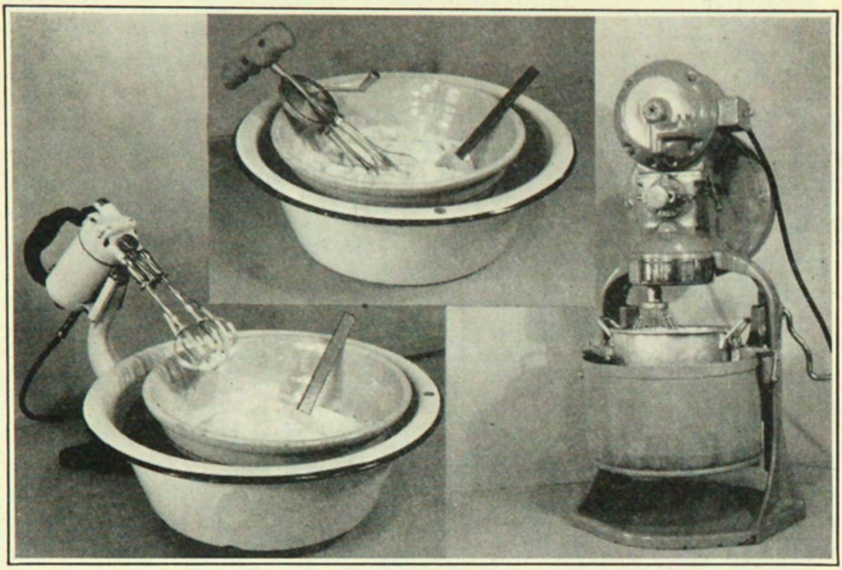

Figure 3.—Mixing equipment used in experiments. Left, small electric mixing equipment; center above, hand equipment; right, larger electric mixing equipment.

Leavening-Specific Gravity Variation with Altitude

Leavening in the true sponge cake is accomplished by the incorporation of air into the meringue during the mixing period. Since this air must be incorporated before the flour is added, it is essential to beat in enough air during the building of the meringue so that the finished batter (obtained by subsequent addition of the flour) will be of the proper lightness for the altitude at which the cake is to be baked. If the resulting batter is too light, this may be easily corrected by mechanically removing the excess air by stirring or beating for the required length of time. If the batter is too heavy, a heavy cake will result. It is true that a small amount of baking powder may be added to such a batter, but if under such conditions one obtained proper leavening and the desired texture it would be the result of a fortunate guess.

The specific gravity-altitude relationship which has been found satisfactory is shown in figure 4. For those who prefer to think in terms of specific volume (the reciprocal of specific gravity), these units have been included also. Batters of specific gravity in the zone indicated for each altitude will produce sponge cakes comparable in lightness, texture, and volume to those produced by batters whose specific gravity is in the zone indicated for any other altitude. It

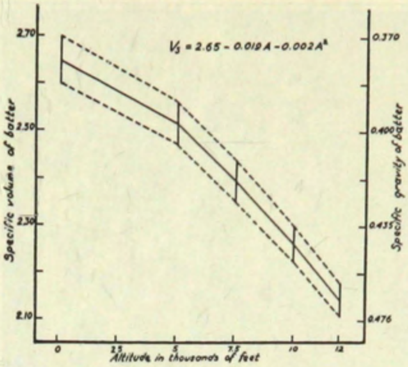

Figure 4.—Specific volume and specific gravity of batter versus altitude, indicating that as altitude increases specific gravity should increase.

would have been desirable for this zone curve to have represented the same cake formula over the entire altitude range. Unfortunately this is impossible. The objective has been to maintain the volume, sweetness, flavor, and quality as nearly constant as possible. If the sugar is held constant, the amount of water present in the batter must increase with altitude or neither egg nor starch will set properly during the baking process. If the liquid content of the batter is greatly increased, it may be desirable to increase slightly the flour used. This would be done to maintain a desirable viscosity. That these factors must be considered will be brought out later in the discussion. In figure 5, cakes from batters of three different specific gravities baked at 5,000 feet are compared. As the altitude increases, it becomes more and more important that sponge cake batters should not be too light.

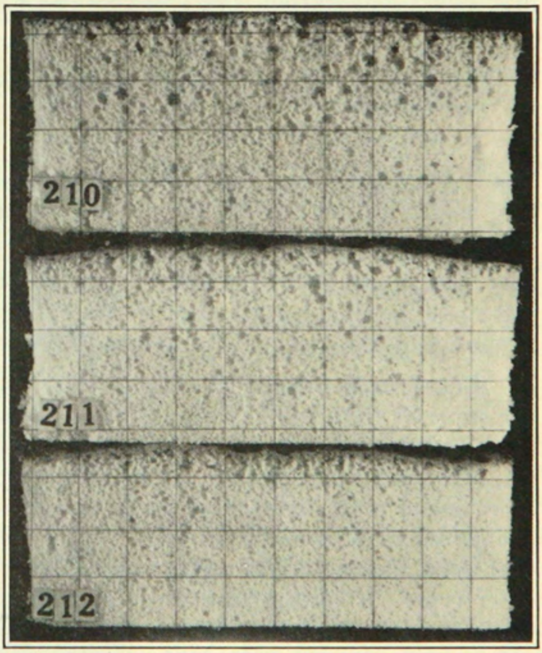

Figure 5.—Cakes from batters of three different specific gravities baked at 5,000 feet altitude. Specific gravity of cake 210 was 0.355; of cake 211 was 0.400; and of cake 212 was 0.440.

Mixing Methods

It is of interest to compare in figure 6 the finished structure of cakes baked from a batter prepared by the conventional method (I) and by the improved single meringue method (II) described previously. These batters both were brought to the proper specific gravity to produce like volumes at 5,000

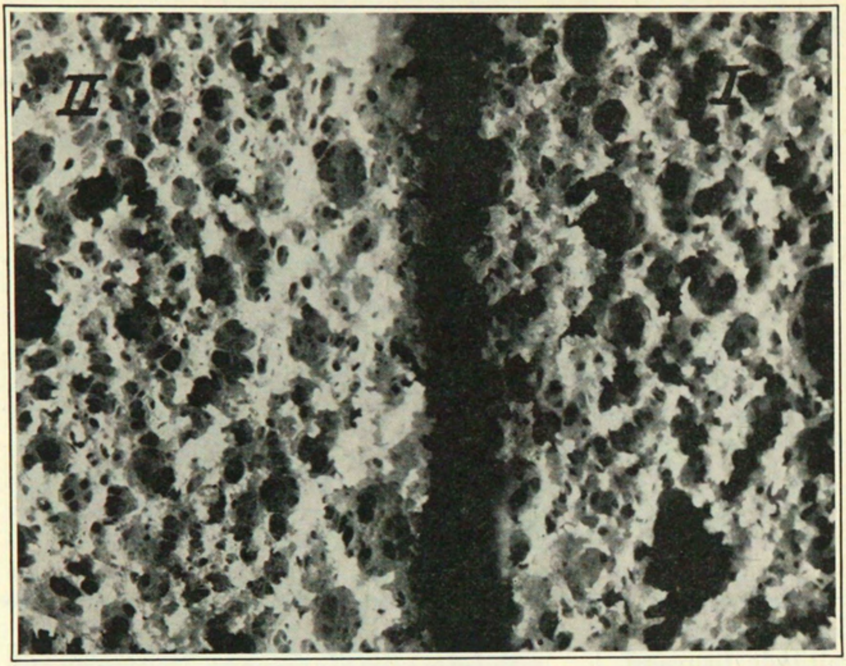

Figure 6.—Photomicrograph of cake samples baked at 5,000 feet altitude. Magnification is four diameters. Note the thick cell walls of sample I which was prepared by the conventional method of mixing. The thin, lacy cell walls of sample II are the result of the improved single meringue method of mixing.

feet. They contained identical quantities of the same ingredients. The magnification used in the photomicrographs is 4 diameters.*

It is evident that the cell walls are thinner in sample II than they are in sample I. Moreover, the lacy-type structure shown in the single meringue method of mixing (II) is never found in cakes prepared by the conventional method of mixing.

Cakes made through the use of this improved method of mixing are superior to those of the conventional type by every criterion used in comparing the quality of sponge cakes. They are more tender. They feel far more velvety to the tongue. When tasted, they seem more moist and, hence, give the impression of being sweeter than sponge cakes of the conventional type. Organoleptic tests indicate that these improved-type cakes retain their freshness longer than the older type. When the time and effort necessary for the preparation of each of these types of batter are compared, the improved-type

*The authors are indebted to Dr. Dudley P. Glick, Colorado State College Veterinary Division, for the donation of equipment and time necessary for preparation of this illustration.

batter is favored, provided a technique adapted to the mixing equipment to be used is followed. Cakes from the improved type of batter are *easily reproducible* with the usual equipment available to either the housewife or the baker, provided the same cake formula is followed and the specific gravity of the batter is controlled. Control of the specific gravity is easily obtained in this method of mixing. Such control is difficult to obtain when the conventional method of mixing is used.

Balancing the Sponge Cake Formula

The selected size of the batter in our basic sponge cake formula for 5,000 feet altitude was chosen because it produced a cake of medium size and it readily adapted itself to equipment already available. The pans used were rectangular, 4½ by 8 inches at top and bottom, and were 4 inches deep. The bottoms of the pans were removable. Behavior was also checked in the usual round tube pan. A rectangular pan of the dimensions given permitted the baking of 380 grams of batter to the cake and allowed ample room for cake volume determinations by the seed displacement method before removal of the cake from the pan. Each cake, after removal from the pan, permitted the cutting of four test pieces for tensile strength measurements. The tensile strength apparatus used by Barmore (1), similar to that used by Platt and Kratz (17), was modified to permit its use upon very tender test pieces with much less danger of accidental damage to the test piece. This apparatus is shown in figure 7.

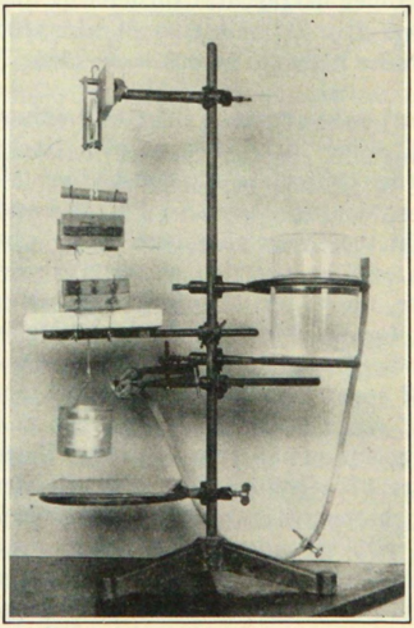

Figure 7. — Improved apparatus for testing tensile strength.

A study of sponge cake formulas available indicated the approximate ratio of ingredients to produce a conventional type cake. Reference to the literature and some of the preliminary work of Barmore indicated that this product was much tougher than would be desirable in this type of cake. A

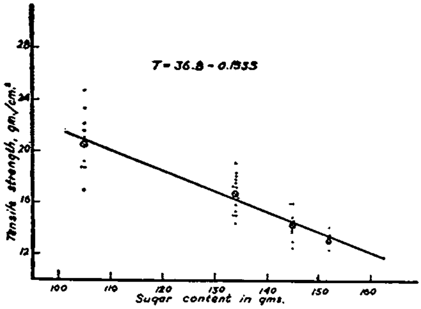

Figure 8.—Relation of sugar content to tensile strength of sponge cake, showing that as the sugar content increases, tensile strength decreases.

tensile strength study upon a 4-egg cake (120 grams of white and 72 grams of yolk) with varying sugar content indicated an acceptable formula for this cake with a tensile strength of approximately 17 grams per square centimeter at 5,000 feet altitude. The results of this study are shown in figure 8. The 5,000-feet-altitude basic formula adopted was:

Egg white	120 grams	Cream of Tartar	1 gram
Egg yolk	72 grams	Salt	1 gram
Cake flour	77 grams	Flavoring	2 cc
Sugar	134 grams	Water	30 cc

Ingredients

The sugar content of this basic batter represents about the average amount of sugar recommended in recipes used at sea level. The water added is necessary for the proper baking of a formula of this sweetness at 5,000 feet. For lower altitudes this amount of water should be decreased; at higher altitudes it should be increased (18).

Water in a cake batter serves several purposes. It is the medium in which the solids are suspended, either in solution or in a finely dispersed state. The proper moisture content in the finished crumb contributes much toward that velvety texture that is so desirable and plays no small part in bringing out the flavor characteristics of the various ingredients. Since the rate of evaporation of water varies with the temperature and pressure, the water content of the batter should vary with the altitude conditions under which the batter is to be baked. Moreover, studies now in progress at this laboratory have shown that it is the ratio of sugar to water that is most important in influencing the rate of coagulation of egg proteins and the gelatinization of starch as the cooking temperature varies. Since the maximum internal temperature of a baking cake approximates closely the boiling point of water, the temperature at which the batter ingredients are cooked varies with altitude. A change in oven temperature within the limits found suitable for baking only alters slightly the time necessary to reach this maximum internal temperature of the baking cake at any selected altitude. It does not change the magnitude of this maximum temperature to a significant extent.

The sugar concentration affects both the rate at which the baking process proceeds and the structural strength developed by various batter ingredients. This effect of sucrose is primarily that of a specific negative catalyst. It will be recalled that Barmore (1) successfully substituted fructose (levulose) for sucrose, gram for gram, in angel food cake. If the effect of the increase of sugar was primarily on the water activity, this substitution could not have been successful. Moreover, the authors confirmed this point by baking high-sugar-ratio cakes containing shortening at the upper limit for sucrose content and have added in addition a like equivalent in sweetness of invert sugar and large quantities of milk sugar (lactose) without causing the cake to fall. At 5,000 feet altitude an increase of the sucrose content by a slight amount or a decrease in the water content by a few cc caused this cake to fall. The same series of experiments showed that a considerable amount of the water in such cake batters could be replaced by glycerine without causing cake failure. These facts demonstrate that the effect of sucrose upon the baking characteristics of cake batters is, in a large measure at least, a specific one. A high concentration of sucrose will completely inhibit the gelatinization of starch and the coagulation of egg in the temperature range under consideration (85°-95° C.)

The amount of cake flour suitable for this batter varies somewhat from brand to brand. If the cake flour is ground to extreme fineness or has been blended with a stream of finely ground hard winter wheat in the manufacture, a slightly smaller amount of flour should be used. Such flour will yield a cake of lower volume and somewhat poorer quality. For special sponge to be used for jelly roll or shortcake, the amount of flour may be somewhat greater. The amount of flour recommended is for a typical high quality, low protein, all-soft-wheat cake flour containing 11 to 12 percent moisture. This type of flour yields the highest quality sponge cake. It will give a consistently greater volume than will a cake flour diluted with a stream of finely ground hard winter wheat. This increase in volume yield usually runs between 10 and 20 percent. While it is possible to bake fair sponge cakes when general purpose flour is used, such practice is not recommended. For the baker, it would prove uneconomical and would contribute toward the production of poor quality products lacking in uniformity. If the housewife decides to use hard wheat flour for cakes in an emergency, she should not be too disappointed with poor results. The basic formula given has not been balanced for use with hard wheat flour.

When the egg ingredients are not measured by weight, considerable variation in results may be expected. A variation of 20 percent may be realized in the weight of the contents of eggs that appear about the same size. High quality eggs make a different contribution to cake structure than do low quality eggs, regardless of age. Deterioration of eggs in storage produces an effect in the finished cake very similar to that of a higher altitude. Eggs stored for 1 month at 20° C. at Fort Collins (5,000 feet) required a formula correction which was equivalent to that necessary for baking a cake with fresh eggs at 9,000 feet. Correction of these eggs for loss in water by evaporation and change in pH did not materially alter their characteristics. High quality frozen eggs produced sponge cakes of excellent quality. If the yolk is frozen without sugar or glycerine, special mechanical methods are required to redisperse it to a sufficient extent so that a uniform, stable whole-egg meringue may be prepared. If frozen eggs contain sugar or glycerine, correction of the formula for these substances should be made. For practical purposes glycerine may be considered to replace water, volume for volume, when small amounts are used.

The other ingredients are important in their contribution of desirable characteristics to the cake even though they represent but a small fraction of the material. Cream of tartar adjusts the pH of the egg magma so that meringue production is relatively easy. If lemon juice and grated lemon peel are to be used for flavoring, they should *not* be added to the egg magma at this stage. Rather the cream of tartar should be added as recommended; then the lemon juice and gratings should be added during or at the end of the addition of the flour. Lemon juice impedes the formation of the whole-egg meringue. In sufficient quantity it may prevent meringue formation entirely. Salt and flavoring extract may be added to the egg magma before the eggs are beaten.

Effect of Altitude Upon the Basic Formula

The relation of the specific gravity to leavening has been discussed. As has been stated, it was desired to correct the basic formula for altitude in a manner that would permit the use of the same amount of sugar in the batter at all altitudes. The flavor characteristics of cakes at the various altitudes would then be approximately the same. From the standpoint of uniform quality and appearance, it is desirable to maintain the texture of the finished cakes reasonably constant at all altitudes. If these ends are achieved and specific gravity corrections on the batter produce cakes of like volume at the different altitudes, a workable solution has been found. Figure 9 shows cakes resulting from corrected and uncorrected formulas baked at different altitudes after mixing by the improved cold

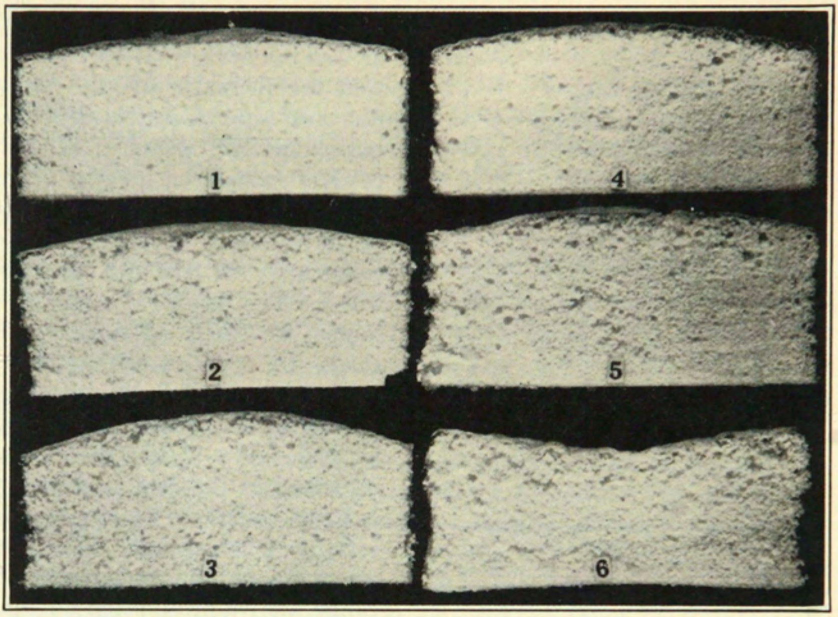

Figure 9.—Corrected and uncorrected sponge cake formulas baked at different altitudes. Samples 1, 2, and 3 were baked from corrected formulas at sea level, 5,000 feet, and 10,000 feet, respectively. Samples 4, 5, and 6 were baked from sea-level formulas at sea level, 5,000 feet, and 10,000 feet, respectively.

single meringue method. It is apparent that a change in batter specific gravity at a given altitude influences the volume and texture of the finished cake. If the conventional method of mixing had been used at 10,000 feet and no specific gravity correction whatsoever had been made, this cake would have been a complete failure. Egg meringues come up with exceeding rapidity at altitudes as high as 10,000 feet. As a result, a few minutes beating produces a very light foam structure. The folding of flour into such a meringue shrinks it to a specific gravity suitable for baking at a couple of thousand feet below sea level. If such a batter is baked at high altitudes, it swells up like a balloon, bursts, and falls completely. This explains why the opinion persists that the true sponge cake cannot be baked at high altitudes.

In figure 10 are presented the results of a study of the effect of altitude upon the tensile strength of sponge cakes. In this study the specific gravity of the batter was adjusted at each altitude so that cakes of like volume would be obtained throughout the study (see fig. 4). An exception was made of the data plotted for 5,000 feet altitude. After a series of cakes of approximately the correct specific gravity was obtained for this altitude, pairs were baked in which one

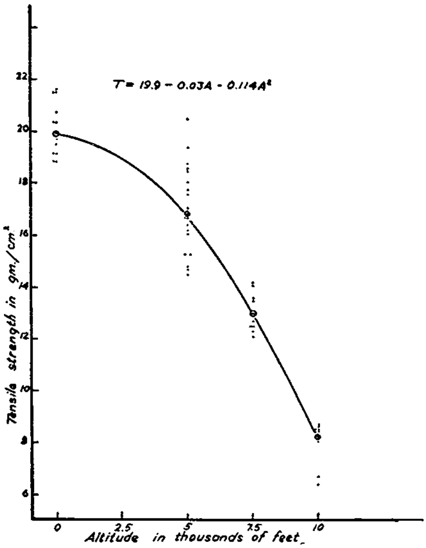

Figure 10.—Relation of altitude to tensile strength of sponge cake, showing that as altitude increases, tensile strength decreases.

was as much too light as the other was too heavy. It was found that the inclusion of such data did not alter significantly the mean specific gravity of the cakes obtained, as long as such observations were paired. The mean specific gravity of the cakes at 5,000 feet altitude was 0.168. The corrected cake formulas for each altitude yield cakes of a mean specific gravity of 0.168, provided the specific gravity of each batter of the series baked lies within the limits indicated in figure 4. Since it is inconvenient to obtain a specific gravity precisely in the midpoint of the recommended range, the values plotted on figure 10 have been corrected to a cake specific gravity of 0.168. These cakes were mixed by the cold single meringue method.

To get the effect of altitude upon the tensile strength of cakes from the basic formula, many were baked at altitudes ranging from 10,000 to 7,500 feet and at 5,000 feet using the 10,000-foot corrected formula. The tensile strength of these cakes was measured, using the apparatus shown in figure 7. These values were compared with tensile strength determinations upon cakes from the basic formula baked at 5,000 feet. It was assumed that the difference found between cakes from the basic formula and cakes baked from the 10,000-foot and 7,500-foot corrected formulas at 5,000 feet represented the difference in tensile strength due to the formula correction. These corrections, applied to the tensile strength determinations made upon the corrected formulas baked at 7,500 and 10,000 feet, permitted calculation of the effect of altitude upon the basic formula at these altitudes. The points at 5,000 feet and sea level are actual points, not calculated. However, all points, actual and calculated, have been corrected to a cake specific gravity of 0.168 for purposes of comparison upon this curve. Thus this curve represents the effect of altitude upon the ingredients of the batter.

If an attempt had been made to maintain the same specific gravity of the batter throughout the study, over-expansion would have occurred at high altitudes, followed by a partial collapse of the cake.

A soggy streak develops after this collapse (see fig. 9). Samples for tensile strength measurements from such fallen cakes include variables which have been eliminated in figure 10. A check of the basic formula baked at 7,500 feet indicated that the assumption upon which the calculations were based could not be far wrong for this altitude. At 10,000 feet the tenderizing effect of altitude upon the baked ingredients might actually give somewhat lower values than the calculated ones shown on the curve. Cakes baked by the hot single meringue method using the basic formula for 5,000 feet had a tensile strength of between 8 and 9 grams per square centimeter when baked at 10,000 feet. These were the expected values.

It will be noted that the equation: $T=19.9 - 0.03\,A - 0.114\,A^2$ indicates that at sea level the tensile strength of this sponge cake is approximately 20 grams per square centimeter. This cake is much more tender than those which have previously been recommended. It is superior in quality and keeping characteristics to those heavier, tougher cakes. At the higher altitudes, sponge cakes are as tender as butter-type cakes. They are very desirable and economical.

While it is possible to balance the sponge cake formulas for altitudes 5,000 feet and above so that an approximately constant tensile strength may be maintained, this approach to the problem does not seem advisable. Uniformity in texture, flavor, eating quality, and volume could not be approximated under such conditions. Below 5,000 feet the characteristics of the ingredients permitted in the true sponge cake and the demands that nature places upon their use in cake baking require that we should be content to accept a tougher sponge cake at these lower altitudes.

The formula recommended for sea level produces a cake much more tender than do those usually recommended. In fact its tensile strength is only about 75 percent of that yielded by most recipes. It represents about the limit of tenderness that one can obtain with the ingredients permitted. The reasons for this lie in the effect of the higher internal temperature attained in the cake at sea level. When egg substance is cooked at 100° C., it becomes much tougher and more elastic than when cooked at 95° or 90° C. The same is true with flour paste. This more highly developed elasticity brings about a greater shrinkage upon cooling. An increase in sugar in the sea-level formula within certain limits will permit somewhat greater expansion during baking, but the shrinkage due to the developed elasticity and somewhat decreased strength of these structures does not result in a more tender cake. At 5,000 feet and above, the shrinkage due to elastic egg substance becomes much smaller. The shrinkage due to developed flour-substance elasticity becomes very small at 10,000 feet and above, so that cakes at high altitudes tolerate relatively much more flour without becoming dry and tough. In fact the formulas for 10,000 and 12,000 feet if baked at sea level would produce cakes resembling sponge rubber. When baked at their proper altitudes, these cakes are only about one-half as tough as the cake from the sea-level recipe baked at sea level.

Whole-Egg Sponge Cake

Ingredients	Altitude	Metric formula	Commercial formula		Housewife's formula (volume measure)		
	Feet	Grams weight	Pounds	Ounces	Cups	Table-spoons	Tea-spoons
Cake flour sifted once before measuring	0 to 5,000	77	2	0	¾+**	1+	2
	7,500	85	2	4	1-**	1-	2
	10,000	95	2	8	1+	1+	0
	12,000	105	2	12	1+	2+	2
Water*	0	20	0	8	....	1+	1
	2,500	25	0	10	....	1+	2
	5,000	30	0	12½	....	2+	0
	7,500	30	0	12½	....	2+	0
	10,000	35	0	14	....	2+	1
	12,000	40	1	0	....	2+	2
Egg white	any	120	5 pounds whole eggs			4 each medium-sized eggs	
Egg yolk	any	72					
Sugar	any	134	3	8	⅔+	0+	0
Salt	any	1	0	½	0+	0+	¼
Cream of tartar	any	1	0	½	0+	0+	¼
Vanilla*	any	2cc	0	1	0+	0+	½
		Grams		Ounces			
Correct weight of 1 cup (net) of batter for proper leavening	0	87 to 91		3 to 3 1/5			
	2,500	90 to 93		3 1/6 to 3 1/4			
	5,000	92 to 96		3 1/4 to 3 3/8			
	7,500	97 to 100		3 7/16 to 3 1/2			
	10,000	103 to 106		3 5/8 to 3 3/4			
	12,000	109 to 112		3 13/16 to 3 15/16			

*It is often desirable to include lemon juice and grated lemon peel as a flavor in sponge cake in addition to the small amount of vanilla advised. The amount of water to be added should be corrected for the amount of lemon juice to be added. Five cc. or 1 teaspoon, of juice and 1 tablespoon of freshly grated peel should be added at the end of the mixing period for the metric and housewife's formula. For the commercial formula 2½ ounces of juice and 1 ounce of grated peel should be used.

** + = plus; - = minus.

Procedures

A. SINGLE MERINGUE METHOD OF MIXING

1. Cold Method.—Equipment recommended for this method of mixing is an efficient mechanical mixer with a wire whip. The egg whites, yolk, and water required are cut together with the beater to mix them thoroughly. The sugar, salt, cream of tartar, and vanilla

are dissolved in the egg, and the mixture is beaten until the meringue is very light and just fails to stand in a peak. The mixer is changed to slow speed and the cake flour added slowly over a period of 6 minutes. The bowl is thoroughly scraped down, the lemon juice and grated peel added if desired, and mixing continued one-half minute at slow speed. The batter is then weighed in a standard tared cup. If necessary (this is always the case at high altitudes), stirring is continued at slow speed until a cup of batter gives the required net weight. Baking should be in an unlined, ungreased tube pan with removable bottom. Cakes should be inverted to cool. For jelly roll the heavier of the recommended weights should be used for each altitude. The jelly roll batter should be baked in a large, flat, lined pan.

2. Hot Method.—The hot method is recommended for hand equipment with double Dover beater, small mixing equipment, and large commercial equipment. This method is the same as the cold method except that the bowl containing the egg mixture after the solids have dissolved is placed in a pan of hot water (80° C. or 175° F. for the greatest effect) during the beating period. The meringue comes up much more rapidly by the hot method. When the meringue forms a soft peak, the bowl is placed in cold water and the contents cooled with occasional stirring. The cake flour is added as directed under the cold method. The batter gives a larger volume by the hot method than by the cold method. The heavier of the net weights for a cup of batter is to be preferred for each altitude.

B. CONVENTIONAL METHOD OF MIXING

Equipment recommended is either hand equipment or a combination of hand and mechanical equipment. The whites and yolks are beaten up separately. The water required, the salt, and the vanilla are added to the yolks and mixed by a few seconds beating. One-half of the sugar required for the formula is added and stirred until mostly dissolved. This mixture is beaten until it forms a soft-peaked meringue. The whites with the cream of tartar and one-half the sugar are beaten to a meringue that just peaks but is not too stiff. The two meringues are folded together. The flour is then folded into the mixed meringue. If lemon juice and peel are desired they are also folded in. Folding and mixing the batter are continued until the required leavening density is reached as determined by the weight of a cup of batter. This method of mixing does not give as desirable a cake as is obtainable by procedure A. The mixed meringues and the finished batter are very sensitive to mechanical abuse. Baking directions are the same as for the cake mixed by the single meringue method.

Baking Time and Temperatures

Altitude	Degrees Centigrade	Degrees Fahrenheit	Time in Minutes*
0 and 2,500	165	330	50 - 55
5,000 and 7,500	171	340	55 - 60
10,000 and 12,000	177	350	63 - 65

*Baking time depends upon shape of pan and its size. The time recommended is for a batter of 380 grams or 13⅜ ounces (the 4-egg cake) in a pan permitting the height of the cake to approximate the distance from the tube to the side of the pan, measured at the top of the cake. A flat sheet for jelly roll or smaller batches should be baked for shorter periods of time. In a controlled oven, the top heat should be low and the bottom heat high.

Yolk Sponge Cake**

Ingredients	Altitude	Metric formula	Commercial formula		Housewife's formula (volume measure)		
	Feet	Grams weight	Pounds	Ounces	Cups	Table-spoons	Tea-spoons
Cake flour sifted once before measuring	0 to 5,000	100	2	0	1+	2+	0
	7,500	110	2	3	1¼+	0+	2
	10,000	130	2	6	1½−	0−	2
	12,000	130	2	9	1½+	2+	0
Water*	0	70	1	6	¼+	0+	2
	2,500	75	1	8	¼+	1+	0
	5,000	85	1	11	¼+	1+	2
	7,500	90	1	12⅔	¼+	2+	0
	10,000	100	2	0	¼+	2+	2
	12,000	110	2	3	¼+	3+	1
Egg yolk	any	150	3	0	8 egg yolks		
Sugar	any	134	2	11	⅔+	0+	0
Salt	any	1	0	½	0+	0+	¼
Cream of tartar	any	1	0	⅓	0+	0+	¼
Vanilla*	any	2cc	0	1	0+	0+	½

		Grams	Ounces
Correct weight of 1 cup (net) of batter for proper leavening	0	91 to 93	3 1/5 to 3 1/4
	2,500	93 to 95	3 1/4 to 3 1/3
	5,000	98 to 100	3 7/16 to 3 1/2
	7,500	103 to 106	3 5/8 to 3 3/4
	10,000	112 to 115	3 15/16 to 4 1/16
	12,000	118 to 120	4 1/8 to 4 1/4

*See note at end of whole-egg sponge cake formula.

This cake is far more tender than the usual sponge cake. It requires more careful handling, but its high quality recommends it. The baking temperature for the yolk sponge cake is the same as for the whole-egg sponge cake. The baking time should be increased by 10 minutes. **Top heat should not be used.

Summary

1. New methods of mixing have been investigated and described. These are readily adaptable to various types of equipment. The new methods give products which are superior to the old, conventional type of sponge cake.
2. It is possible to bake cakes of the same sweetness at any altitude in the United States provided the cake formulas have been balanced to respond properly to the changing effects of altitude.
3. The only accurate manner by which the amount of air incorporated for leavening may be controlled as altitude varies is by the weight measurement of the batter specific gravity. The weights of the contents of a standard cupful of batter have been given for different altitudes as a means of controlling this variable. More sponge cake failures at high altitude are due to too light a batter than to any other cause.
4. Formulas for the preparation of yellow sponge cakes at various altitudes have been presented. Interpellation between the intervals of 2,500 feet is permissible.
5. Yolk-sponge-cake formulas, adjusted for use at various altitudes and containing no leavening agent but air have been given. These cakes are of exceedingly high quality and are very tender. These formulas will yield the most desirable sponge cake at low altitudes, where sponge cakes tend to be tough. At high altitudes they are equally desirable.

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— Notes —

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