THE INFLUENCE OF VARIOUS FAC-
TORS, INCLUDING ALTITUDE, IN
THE PRODUCTION OF ANGEL
FOOD CAKE

MARK A. BARMORE

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THE INFLUENCE OF VARIOUS FACTORS, INCLUDING ALTITUDE, IN THE PRODUCTION OF ANGEL FOOD CAKE

MARK A. BARMORE

The results of the study indicated in the title are a part of the project "The Baking of Flour Mixtures at High Altitudes." A bulletin giving the results of empirical studies, which constituted part I of the project, was published in 1930 (30). In this early work no attempt was made to explain the fundamental principles involved, nor were the recipes represented as the best of the range of the satisfactory combinations of ingredients. Until such interpretations and mathematical relationships were obtained, work on the project could not be considered as sufficiently complete to warrant final publication. Consequently part II, a more fundamental attack on the problem, was undertaken.

The first bulletin published, reporting on work under part II, appeared under the title "The Influence of Physical and Chemical Factors on Egg White Foams" (3). A second bulletin (51) gave the practical results of this study on angel food cake.

The equipment which makes possible the investigation of the effects of altitude has been previously described (30), but more recently changes and additions have been made. The altitude laboratory* as it now stands is shown schematically in figure I.

*Mr. J. Harry Scofield, associate professor in mechanical engineering at Colorado State College, designed and supervised the construction and installation of the laboratory and equipment.
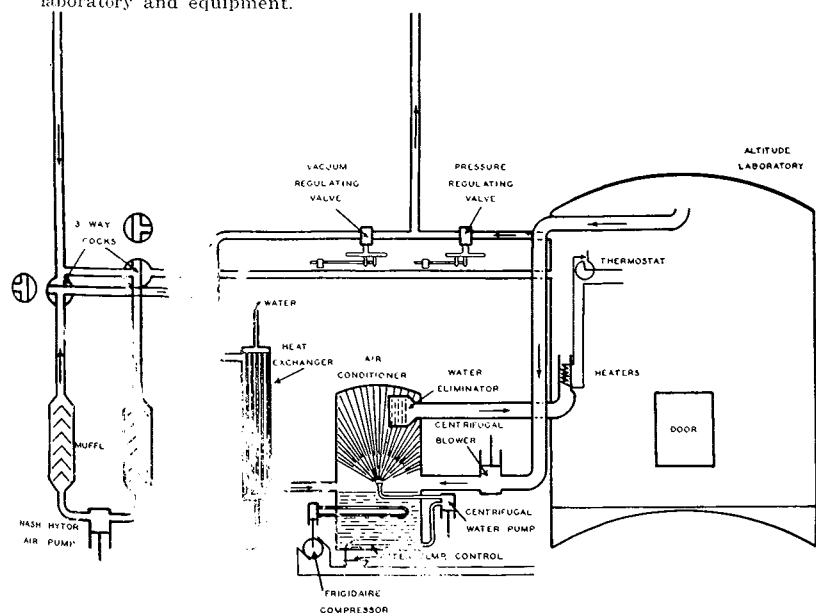

Figure 1.—Schematic drawing of altitude laboratory and equipment.

This consists of a steel cylinder, the altitude laboratory, in which air pressures can be produced that correspond to the standard atmospheric pressures encountered at elevations ranging from several thousand feet below to 18,000 feet above sea level. The laboratory is also equipped for temperature and humidity control and adequate ventilation, i. e., about 2.2 pounds of air per minute.

Angel food cake was chosen as the first type of flour mixture for investigation, because it contains the fewest ingredients.

LITERATURE REVIEW

Although considerable work has been reported on cake making, very few publications of real value have appeared. Quite generally the results reported are based merely on personal judgment and personal standards.

Hunt and St. John (1) hold that slightly better cakes can be made from the "thin" than from the "thick" egg white. Grewe and Child (2) found that the favorable effect produced by the addition of potassium acid tartrate was due chiefly to the resulting hydrogen ion concentration, and that maleic, citric, and tartaric acids produced equivalent effects for an equal pH. In the absence of the acid, or in the presence of sodium potassium tartrate, the cake was yellow, the cell walls thick, and the texture coarse.

Work previously reported from this laboratory (3) shows that acid, when added to egg white, produces a more stable foam. This was apparently due to some change in the physical properties of the coagulated protein film formed at the air/liquid interface, caused by increased acidity. The small air cells in angel food cake in the presence of acid are the result of this increased foam stability. The suggested explanation is that the improved stability of the foam merely allows coagulation to take place before the bubbles have collapsed sufficiently to produce large cells.

The presence of acid improves the color of angel food cake, because flour pigments are yellow in slightly alkaline solution but colorless in slightly acid solution (4-8).

Platt (9) and Platt and Kratz (10) were the first to use measuring devices that were independent of personal opinion to test the characteristics of cakes. They measured the compressibility, the toughness or tensile strength, and made use of photography to record the characteristics of cell size. These methods they found to be fairly reliable. Reed (11), independently, attempted to measure toughness in a similar manner but without much success.

For several years, penetration and compressibility have been used in testing the ripeness or tenderness of fruits and other products (12-20).

Investigators have measured the temperature in bakery products during baking. Dack, Woolpert, Noble, and Halliday (21), in a study of bacterial survival, found that the temperature within the cake during baking, measured by means of thermocouples, rose rapidly at first and then gradually approached a maximum temperature, which varied between 95° and 105° C., depending on the size of the container and the cake mixture. For angel food cake they found a maximum temperature varying from 100° to 102° C. and a maximum rate of temperature change of about 4° per minute at an oven temperature of 150° C. Hall (22), using a maximum indicating thermometer, found a maximum temperature of 98.3° C. for an oven temperature of 182° C. Others (9, 23-28) report maximum temperatures ranging from 97° to 103° C. for various kinds of bread. Although none of these workers state the altitude at which they worked, the temperatures given indicate that it was very near to sea level.

Halliday and Noble (29) state that the most important item in the making of angel food cake is to incorporate the ingredients with the beaten egg whites in such a way as to mix them thoroughly but without losing the air held by the egg foam. This, they say, requires gentle movements. They also recommend the addition of one half the sugar to the egg white foam, and then the addition of the remainder of the sugar with the flour. Peterson (30) found that there were several possible ways of successfully combining the ingredients but adopted a method similar to that of Halliday and Noble.

Some work on the effects of altitude on the baking of cakes has been done other than that reported by Peterson (30), but none except her reported on angel food cake. She reduced the sugar and increased the amount of flour for increases in altitude.

Books on cookery (29, 8) state that eggs coagulating at low temperatures are more tender than those coagulated at high temperatures. No actual measurements have been reported. Halliday and Noble (29) state that angel food cakes baked at low temperatures are more tender because of this fact.

MATERIALS AND METHODS

The eggs used in the work herein reported were obtained the morning after the day laid and were immediately stored until used, in an ice refrigerator. The flour and sugar were obtained in large quantities, that the variations in different batches might be eliminated as nearly as possible. The cream of tartar and salt were of the customary C. P. grade.

Some egg whites were separated for one day's use and then stirred minutes in order to insure uniformity in egg white for each day's work.

The desired amount of egg white for a single test was weighed out into a 3-quart bowl and beaten for ½ minute by an electric mixer running at maximum speed. Without stopping, the acid and the salt were added, and the beating continued until the necessary volume was obtained. This required from 1 to 2 minutes' beating and was gauged by watching the height of the foam on the beater. The specific gravity of the foam was then measured in a 40 by 80 mm. crystallizing dish of known volume, and recorded as *specific gravity of the eggs*. After weighing, it was returned to the bowl, and the beating started again. Part of the sugar was immediately added, and the beating continued for 30 seconds. Again the specific gravity was measured and called the *meringue specific gravity*. The beater was now set for minimum speed, and the mixture of the flour and the remainder of the sugar, which had been sifted together three times, was added slowly. The mixer was assisted continuously by hand-stirring to insure complete mixing, since the beater did not reach all portions of the bowl. After a total time of 2 or 2½ minutes, depending on the amount of flour, the mixing was stopped and the specific gravity measured and this time recorded as the *specific gravity of the batter*.

The completed batter was placed in a pan of known weight and volume and then weighed. The baking was done in the altitude laboratory in a heavily insulated electric oven, the temperature of which could be accurately reproduced but which varied uniformly during the cycle $\pm$ 4.5° C. from the average. The complete "off and on" cycle required about 15 minutes.

After the baking had been completed and the cake cooled in the pan, inverted over a cooling rack, for 45 minutes, it was weighed. The amount of loss in weight was considered to be entirely due to evaporation.

After cooling 2 hours, the surface of the cake was dusted with flour to prevent the sticking of the seeds used in the determination of the volume. The weight was noted again and the pan filled level with rape seeds, of known specific gravity, in a uniform manner. The volume and the specific gravity of the cake were calculated from the weight of the seeds, their specific gravity, the volume of the pan, and the weight of the cake.

The above procedure was worked out and used in order to study and control the manipulations required for the preparation of the cake batter. All cakes were baked at the pressure corresponding to an altitude of 5,000 feet, unless otherwise stated.

The method used for testing the toughness of the cake has yielded the most valuable information in this study. The apparatus was copied from Platt and Kratz (10), and the arrangement is shown in figure 2. The clamps were made from piano wire, with thin wooden strips fas-

tened inside the jaws. By using wooden strips the sample could be held tightly without cutting into the cake so badly as with the use of the bare wires. The samples were always cut 2 hours after the cake had been taken from the oven, since Platt and Kratz (10) have shown that toughness increases with the age of the cake. Most of the cakes to be used for tensile measurements were baked in rectangular tin pans of about 2,000 ml. capacity and with top dimensions of 24 by 14 cm., bottom dimensions of 21 by 11 cm. and a depth of 7.5 cm.
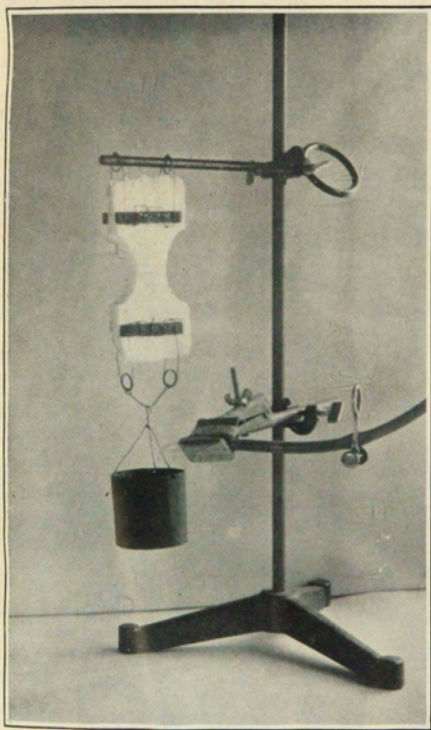

Figure 2.—Tensile strength measuring device.

The cakes were cut horizontally through the center, and two upper and two lower samples 2 cm. thick, were taken from these planes. These slices were trimmed to a uniform size with dimensions of 7 cm. by 12 cm. The center of the sample was cut out to a width of 3 cm. with a circular cutter mounted on a small sewing machine motor. The clamps were then carefully placed in position and water was run into the vessel, suspended from the lower clamp, at a constant rate of 200 grams per minute until the sample broke. The lower clamp and vessel weighed a total of 36.0 grams. The total weight below the point of separation, divided by the square centimeters of area at the point of separation, was used as the measure of tensile strength or toughness. Many samples *tore* in two, starting at some corner or side and gradually tearing across the neck; others had large holes at the point of separation. Only those samples which *broke* quickly over the whole neck and had uniform texture were included in the data. Usually two bottom samples and two top samples were tested from each cake and the results averaged. The following data is an example of the results obtained by means of the above described method on cakes of identical composition and manipulation:

TABLE 1.—DATA SHOWING THE REPRODUCIBILITY OF TENSILE
STRENGTH MEASUREMENTS

Top of cake gms./sq. cm.	Bottom of cake* gms./sq. cm.	Top of cake gms./sq. cm.	Bottom of cake* gms./sq. cm.
15.8	21.3	15.2	19.8
16.1	20.7	16.9	19.6
16.3	20.4	14.8	20.1
16.5	18.7	15.0	21.2

Formula: 210 gms. egg white, 4 gms. potassium acid tartrate, and 0.5 gms. salt, 57 gms. flour C; 160 gms. of sugar, baked at 165° C. for 45 minutes.
 * It will be noted that the samples were tougher near the bottom than the top. This was doubtless due to the fact that the bottom samples were always more dense.

RESULTS

VARIATION IN MIXING METHODS.—Peterson (30) found that there were several successful ways in which to add the flour and sugar to the beaten egg whites, and these were as follows:
1. All the sugar first and then the flour.
2. One half the sugar first and the remainder with the flour.
3. All the sugar and one third the flour first and then the remainder of the flour.
4. All the sugar added with the flour.

Halliday and Noble recommend the second method, because "the flour may be combined more easily with the egg white."

A number of cakes were baked* to test out the effect of various methods of mixing on the cake characteristics. The first portion of the sugar was added and incorporated at maximum beater speed, after the eggs had been beaten to a specific gravity as near 0.160 as possible. The remainder was added with the flour and stirred in with the beater at minimum speed. One sixteenth of the flour-sugar mixture was added every 10 seconds and stirred an additional minute after all of it had been added. The amount of sugar added with the flour was varied from zero to 100 percent.

It was found that the batter decreased in volume considerably more when the flour was added with the sugar than when it was added by itself after the sugar had been beaten into the egg foam. This decrease in batter volume, of course, resulted in a smaller cake. No other difference between the cakes produced by the various methods was detected.

The addition of sugar to the egg white foam seems to strengthen it, making it possible to add the flour and mix it in well with less decrease in the foam volume. The strengthening seemed to be progressive, i. e., the more sugar added to the foam, before the addition of any flour, the stronger the product.

The method of mixing used in the experiments reported in the remainder of this publication was not the one shown to give the largest cake. Since it was necessary to change the recipe constantly, the

*Formula: 210 gms. egg white, 4.0 gms. potassium acid tartrate, 0.5 gms. sodium chloride, 150 gms. sucrose, 50 gms. flour C. baked at 165° C. for 45 minutes.

method adopted was to add 100 grams of the sugar to the egg white foam and then to add the remainder with the flour. When there was less than 100 grams of sugar required in the recipe, all the sugar was added before any of the flour. This method was used because it was thought that the effect of variations in sugar content would be less when that variation was entirely confined to the amount of sugar added with the flour.

FOAM DRYNESS.—A series of cakes* was baked from eggs whipped to various specific gravities. In this case all the sugar was added and beaten into the egg white foam before the addition of any of the flour.

The results indicate that the maximum cake volume was obtained when the egg foam specific gravity was between 0.150 and 0.170. Above 0.170 the foam simply did not contain enough air to produce the lightest cake, and below 0.150 the stability was sufficiently reduced by the greater amount of beating so that the finished cake was smaller.

Figure 3 illustrates what happens to the cake structure because of the continued decrease in egg white foam specific gravity, i. e., the decrease in foam stability. These cakes were identical in ingredients and manipulation except that the specific gravity (indicated below each picture) of the egg-white—$KHC_4H_4O_6$—NaCl foam mixture was decreased progressively.

*Formula: 52.5 gms. egg white, 1.0 gm. potassium acid tartrate, 0.12 gm. sodium chloride, 37.5 gms. sucrose, 12.5 gms. flour C, baked at 159° C. for 40 minutes.
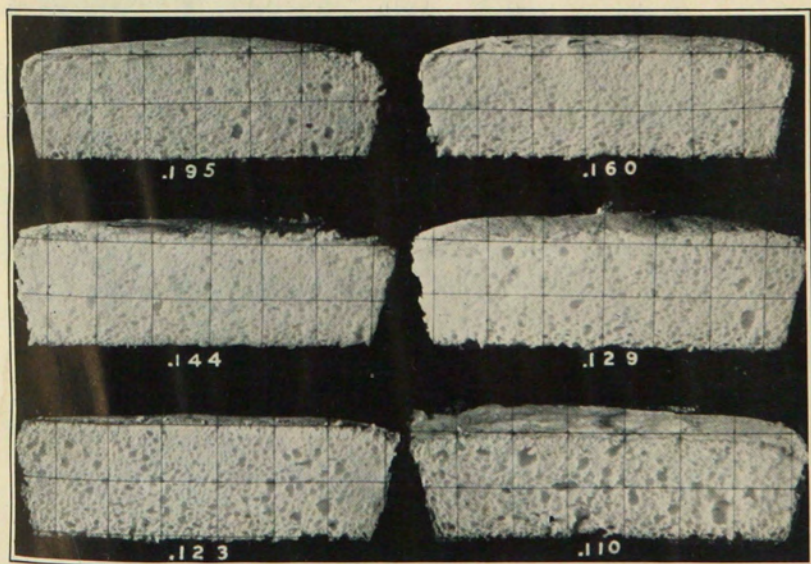

Figure 3.—The influence of foam specific gravity (as given) on cake texture. (All cake pictures were taken with a 2 cm. mesh screen on top of the cake to give the scale in all cases.)

The situation then is that, as the beating of egg whites progresses, two opposing effects are operating. One is the tendency to increase the cake volume because of the increasing amount of air incorporated; the second, the tendency to decrease the cake volume because of the decreased foam stability. This latter effect is shown in a previous bulletin (3). When the egg white foam specific gravity is between 0.170 and 0.150, these two effects are approximately balanced.

It was found that as the specific gravity of the egg foam decreased the volume shrinkage caused by the addition of the flour to the meringue increased. This effect is shown in figure 4. The true volume decrease, however, was some value negatively greater than that indicated, because no allowance was made for the volume occupied by the flour.
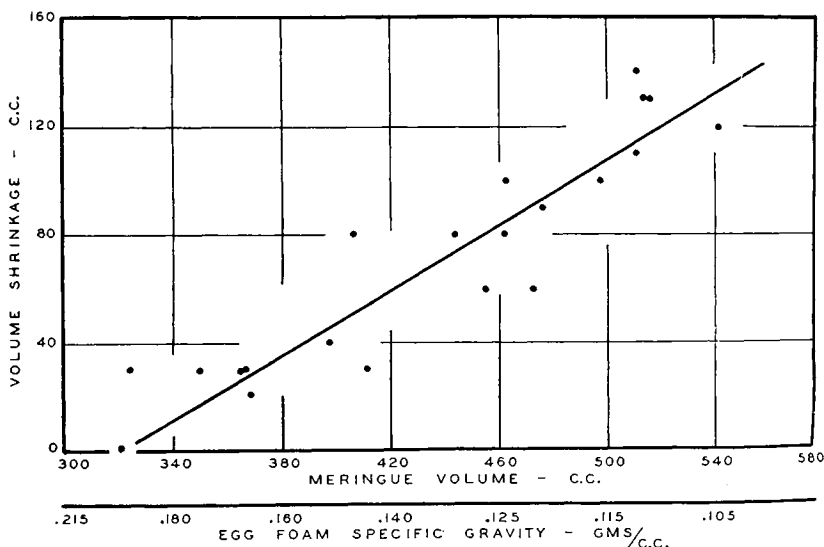

Figure 4.—The relation of shrinkage in meringue volume to meringue volume or egg foam specific gravity.

ACID CONTENT.—It has been shown by Grewe and Child (2) that a small amount of acid is a necessary ingredient for the production of angel food cake, and that with increases in acid the color becomes whiter and the grain finer. In this study the above results have been substantiated, but other characteristics have also been found to change with changes in the acid content.

From the findings in the study of egg white foam (3) it was predicted that the entire favorable effect of the acid on the finished cake was the result of its action on the protein exposed at the air/liquid interface in the egg white foam. Should this be the case, the addition of sufficient NaOH to the completed foam in amounts

sufficient to neutralize completely the previously added acid, should produce a cake identical to one in which the NaOH had been replaced by water, since this treatment was found not to affect the properties of the foams (3). This prediction was tested and found to be incorrect. That is, the addition of the NaOH neutralized both the acid and the favorable effect of the acid. The cake was reduced to the small volume in the presence of the neutralized acid just as in the absence of both acid and base.

In the previous study (3) it was found that for a pH of about 8.0 the foam stability was practically the same for the three kinds of acid used—acid tartrate, acetic, and citric. But at a pH of about 6.0 there was considerable difference in the foam stability, the acid tartrate producing the most stable foam, the acetic acid the least stable, and citric acid an intermediate degree of stability. From this finding it was predicted that the cakes would give equivalent texture with the three acids at a pH of 8.0, but that the texture would vary with the degree of stability when the pH was about 6.0. This was exactly the case.* The cakes† had an equal texture at a pH of 8.0, but at a pH of 6.0 the texture of the acetic acid cake was very coarse, the citric acid cake less coarse, and the potassium acid tartrate cake the least coarse of the three.

On adding still more acid than was necessary to produce a pH of 6.0 in the finished cake, the relation of the cake texture to the foam stability was even more noticeable.

AMOUNT OF REDUCING SUGAR PRODUCED.—It has been suggested that the reason that acid was necessary for the production of successful angel food cake was due to the inversion of sucrose. In order to test this idea, a number of cakes baked with varying amounts of potassium acid tartrate were analyzed for total reducing sugar by the method of A.O.A.C., XXIV, 28 (31), and for levulose by the method of Jackson and Mathews (32).

The results are given in table 2 and show that in the presence of the most commonly used amount of acid only about 1 percent of the sucrose present in the cakes was hydrolyzed. The data also agrees qualitatively with that of Stadler (33). The data indicate that there was considerable hydrolysis other than that of the sucrose. This may come from the starch or perhaps a negligible amount from glucoproteins which have been shown to be present in egg white (34, 35).

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*The acetic acid was added in 30 ml. of water, and in order to make the conditions similar, 30 of water was added along with the other two acids.
†Formula: 120 gms. egg white, 0.5 gms. sodium chloride, 150 gms. sucrose, 70 gms. ... baked at 163° C. for 45 minutes.

TABLE 2.—CAKE REDUCING SUGAR CONTENT

Grams KHC₄H₄O₆	pH*	A.	B.	C.	D.
1.5	7.2	0.25	0.0	0.0	0.009
3.0	6.8	0.55	0.0	0.0	0.022
4.5	5.4	1.97	16.5	0.8	0.55
6.0	4.7	2.77	25.2	1.9	2.85

* Values taken from other data of identical recipe and manipulations.
A. Percentage of invert sugar found in the cake, on the dry basis.
B. Percentage of invert sugar found to be levulose.
C. Percentage of sucrose inverted to produce the levulose.
D. Percentage of sucrose inverted per hour at equivalent pH and at 95° C. according to Stadler (33).

Formula: 210 gms. egg white, 0.5 gms. NaCl, 150 gms. sucrose, 50 gms. of flour C, baked at 173° C. for 36 minutes.

It was not believed that this 2 percent hydrolysis could have any noticeable effect on the characteristics of the cakes, but in order to check the idea several cakes were baked from batters containing no acid but in which 0.25 to 2.5 percent of the sugar present was invert sugar. The cakes were complete failures. Their volumes were low; they were yellow and were very tough. They appeared identical to cakes in which all the sugar present was sucrose and to which no acid had been added. This showed that the ability of the cakes to maintain their relatively large volume in the presence of acid was not due to the hydrolysis brought about by the acid.

BAKING TEMPERATURE.—Various sources (29, 30, 5, and 36) recommend temperatures from 149° to 177° C. for the baking of angel food cakes. Halliday and Noble state that cakes will be more tender if baked at a low temperature, because egg white coagulated at a low temperature is more tender than that coagulated at a higher temperature.

In order to investigate the effects of baking temperature, a series of cakes* was baked at oven temperatures varying from 138° to 180° C. for periods of time sufficient to produce about equal amounts of caramelization, as indicated by crust color.

Instead of becoming tougher as the oven temperature was increased, the cakes appeared more tender. However, since the high oven temperature produced the largest cakes, and the tenderness was found to increase with cake volume, this increase in tenderness with oven temperature may be considered as merely a result of the increased cake volume and was not caused by any effect on the material itself.

The reason high oven temperatures do not produce tougher cakes is because the maximum temperature inside the cake does not change appreciably, regardless of oven temperature. This fact is shown in figure 5, where a change in oven temperature of 40° C. produced a change in internal cake temperature of only 2° C.** Even by increasing

*Formula: 210 gms. egg white, 4.0 gms. potassium acid tartrate, 0.5 gms. sodium chloride, 150 gms. sucrose, and 60 gms. flour B.
**The method of measuring this temperature will be described in another portion of this bulletin.

the baking period by one half, as in the case of the 178° C. cake, figure 5, the temperature was not raised more than 1° C. by the extra 15 minutes. All cakes, except the 178° C. cake just mentioned, were
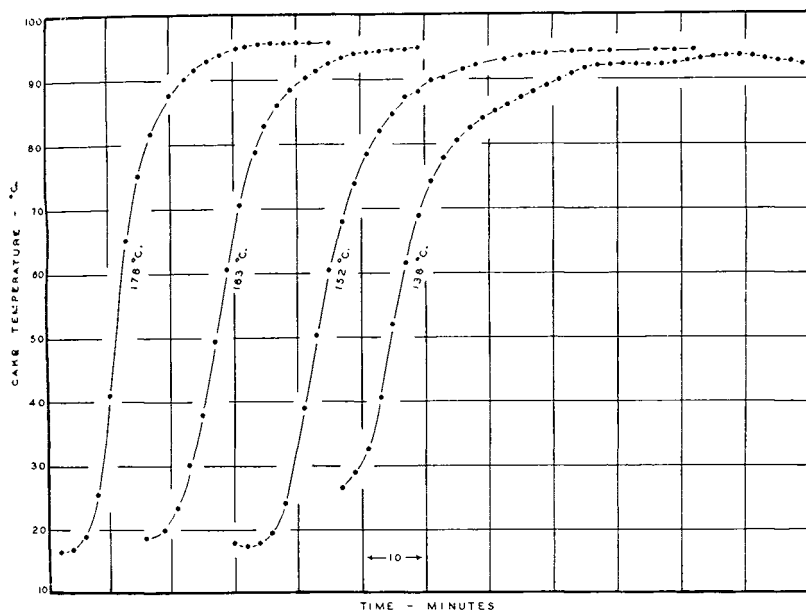
Figure 5.—The effect of oven temperature on the internal cake temperature.

baked just long enough to give as nearly equal a crust color as was possible, regardless of oven temperature. This required 30 minutes at 180° C. and 100 minutes at 138° C.
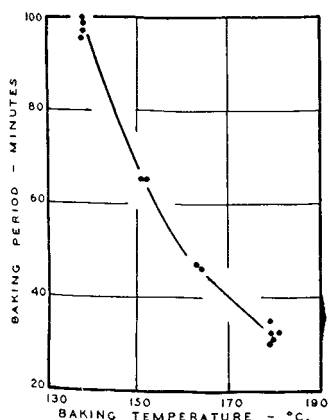
Figure 6.—The relation of baking period to baking temperature.

Figures 6, 7, and 8 show changes in the baking time, the amount of evaporation, and the cake volume, with increase in oven temperature. The recipe employed was as follows: 210 grams egg white, 4 grams of potassium acid tartrate, 0.5 grams of sodium chloride, 150 grams sucrose, and 60 grams of flour B.

Egg Age.—Eggs several days old are considered by bakers to give a very poor angel food cake. The work of this laboratory has also confirmed this belief. The general consensus is that this is due to the liquefaction of egg white, which is one of the results of aging. But Hunt and St. John (1) have shown

that even slightly better cakes can be made from thin than from thick egg white. These two types of egg white are found in the same egg. They have been shown to be chemically identical by Almquest and Lorenz (53). These investigators have also shown that thick white contains a fiber network of ovomucin which entraps the ordinary liquid whites, while in the thin white this network is not present.
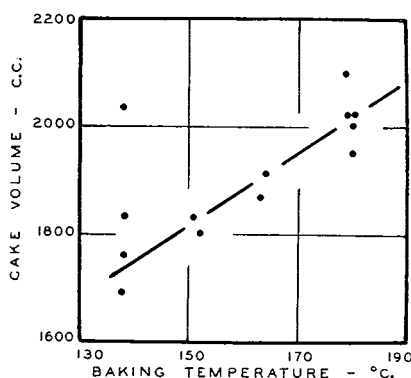

Figure 7.—The amount of evaporation as affected by the baking temperature.

Figure 8.—The influence of baking temperature on cake volume.

The findings of this laboratory agree in the main with those of Hunt and St. John. It was necessary, however, to beat the thick egg white much longer to obtain the same foam specific gravity. The effect of the age of eggs on angel food cakes, therefore, can not be attributed to mere liquefaction.

The foam produced from thick white did not behave as that from thin white, although the specific gravities were identical. That made from thick white was stiffer and in the trade would be called "dryer". Under the microscope the structure appears very different (fig. 9). The foam from the thin white contains much larger bubbles than the other, and this is thought to explain the difference in macroscopic appearance. The larger bubbles permit of thicker cell walls, which doubtless slide across each other with less friction.

This difference in structure is doubtless a result of some effect of plasticity on the mechanism of beating. It seems probable that, because of the liquid nature of the thin white, a given amount of air may be incorporated much more easily and more quickly than in thick white. In other words, the beater is able to spread the thin white into thinner layers, which entrap air, more easily than it can the thick white. The surprising thing, however, was that once the batter was completed the structure appeared to be identical, which explains why the cakes were identical.

Balls and Swenson (37), in a recent article, state their conclusion that there is a splitting of the proteins in egg white during the storage, and that this is catalyzed by tryptic proteinase. They also suggest that
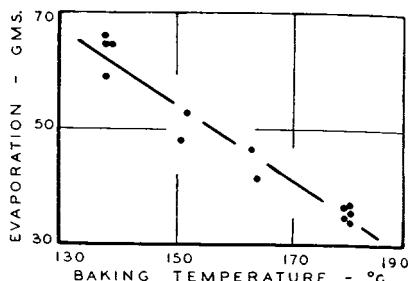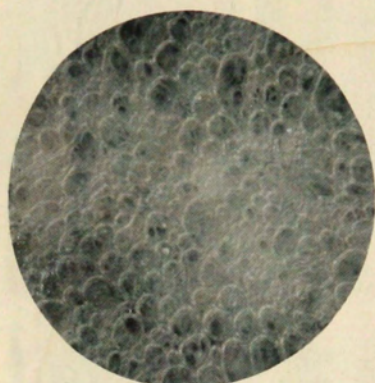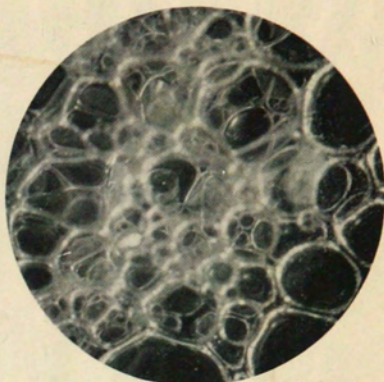
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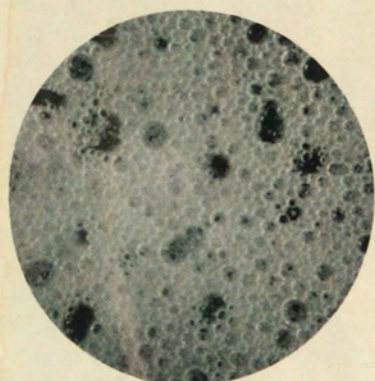
BATTER FROM
THICK WHITE

BATTER FROM
THIN WHITE

Figure 9.—Photomicrographs of egg white foams and completed cake batters.

the physical liquefaction "is due to this proteolysis". A few hours after injecting a "strong" solution of trypsin into fresh eggs, they acquired the appearance of eggs held in cold storage for months.

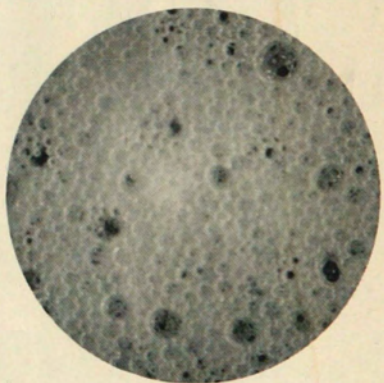The author has suspected for some time that some such change was taking place during the aging of eggs, because it has been shown (in this laboratory and in others) that the effects of the age of the eggs on the cakes baked from old eggs could not be explained adequately by assuming that liquefaction was the only responsible factor. Therefore, after the publication of the above mentioned article, a number of cakes*

*Formula: 210 grams of egg white, 4.0 grams of potassium acid tartrate, 0.5 grams of sodium chloride, 150 grams of sucrose, 50 grams of flour C, baked at 163° C. for 45 minutes.

were baked from egg white artificially aged by introducing 5.5 parts of a commercial trypsin preparation (Pfanstiehl) per 1.000 parts of egg white.

The egg whites to which the trypsin had been added and allowed to stand for an hour or more behaved just as egg whites from naturally aged eggs. Cakes made from these trypsin treated whites acted similarly to those made from aged egg whites, i. e., they appeared to be satisfactory when taken from the oven but on cooling would shrink to a low volume.

From tests which were made it seems that a mere reduction of protein content due to the tryptic action does not explain the effect of the proteolysis. That is, the substitution of various amounts of water for egg white, which would be similar to a reduction in protein content, does not produce similar effects.
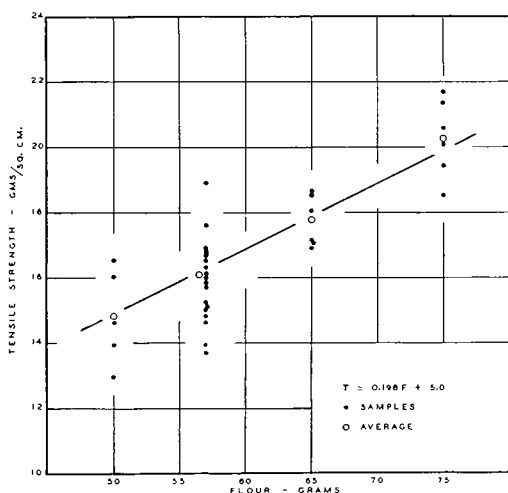
Figure 10.—The relation of tensile strength to flour content.

VARIATION IN FLOUR AND SUGAR CONTENT.—The next variables investigated were the amounts of the two ingredients, flour and sugar. The amount of egg white,[*] potassium acid tartrate, and sodium chloride remained constant. The cakes were baked at 5,000 feet of elevation, at 166° C. (330° F.) for 45 minutes, allowed to cool for 2 hours, and then tested for tensile strength.

The results (figs. 10 and 11) show that the tensile strength was a linear function of the flour or sugar content. A decrease in sugar increased the toughness, while flour had the opposite effect.

EFFECT OF ALTITUDE.—In this phase of the study, cakes were baked at atmospheric pressures corresponding to sea level, 5,000 and

*Formula: 210 gms. egg white, 4.0 gms. potassium acid tartrate, 0.5 gms. sodium chloride, flour C, and baked at 163° C. for 45 minutes.

T = -0.085 S + 29.5

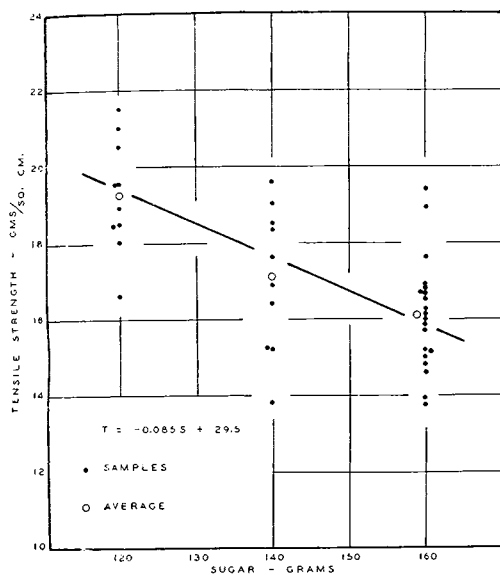• SAMPLES

○ AVERAGE

Figure 11.—The relation of tensile strength to sugar content.

10,000 feet of altitude. The rate of expansion during baking was carefully followed, and after the cakes had cooled the amount of swelling of the starch, the percent of the protein not coagulated, the tensile strength, and the compressibility were determined.

The expansion characteristics were determined by means of a cathetometer set up to sight through the glass oven door. These cakes* were baked in pans that were just large enough to hold all the batter; thus the amount of expansion could be followed throughout the baking period.

Measurements on the amount of swelling of the starch were attempted, following the method of Katz (38). The cake** crumb was forced through a 200-mesh wire screen with water and a brush, then diluted to 300 ml. in a graduated cylinder, and saturated with toluene. After standing for 24 hours, the volume of the sediment was read and the mixture shaken. The volume was again read after another 24 hours. Analysis was made of the cake crumb for moisture at the same time, so that the data could be calculated to the dry basis.

After the second settling, the liquid was decanted through a filter, acidified, and evaporated nearly to dryness and then analyzed for total protein nitrogen by the Kjeldahl method. It was desired to analyze for the amount of dissolved starch also, but no method could be found or devised that would work in the presence of sucrose.

The measurement of tensile strength** was made as previously described. Measurements were made on the compressibility by measur-

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*Formula: 210 gms. egg white, 4.0 gms. potassium acid tartrate, 0.5 gms. sodium chloride, 150 gms. sucrose, 60 gms. flour B, and baked at 164° C. for 45 minutes. Only 1220 ml. of the completed batter was used in the pan for baking in order to make the results comparable, which is correct for 5,000 feet altitude.

**Formula: 210 gms. egg white, 4.0 gms. potassium acid tartrate, 0.5 gms. sodium chloride, 140 gms. sucrose, 57 gms. flour C, and baked at 159° C. for 50 minutes.

ing the penetration of a round plunger, 1.25 inches in diameter, acting under a constant load for 1 minute.

Figure 12 shows the results of the expansion studies. In general the higher the altitude the faster the expansion and the greater the maximum expansion.
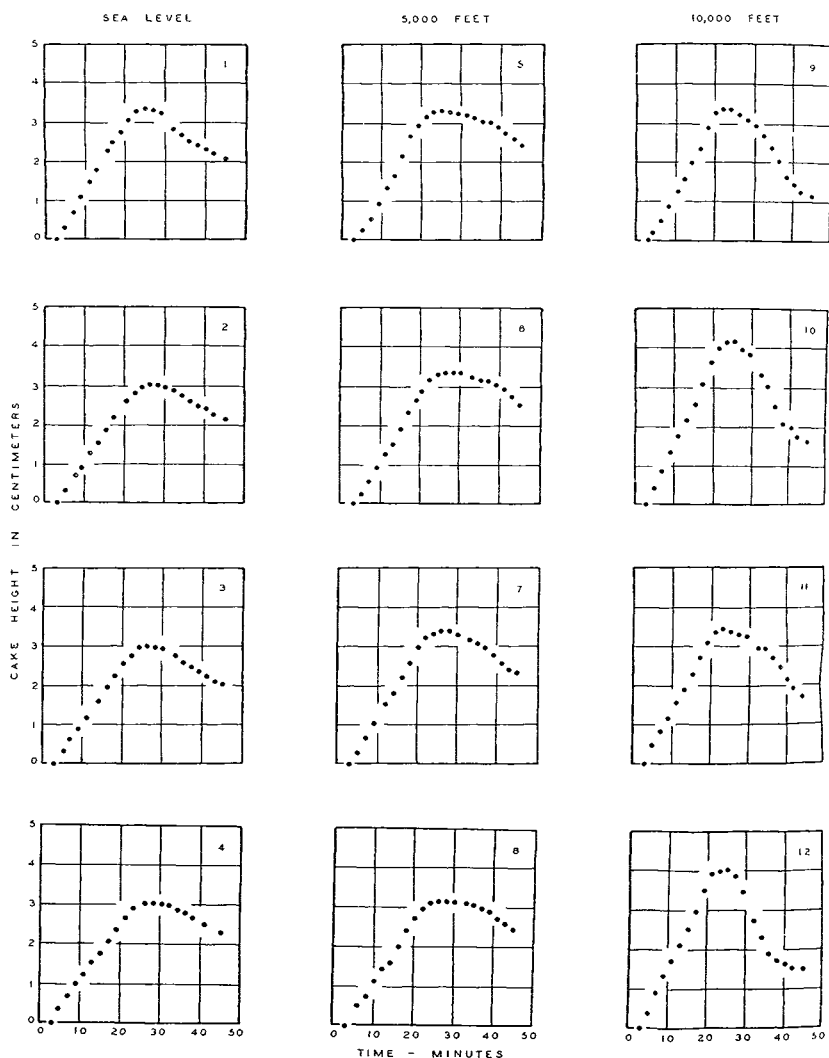

Figure 12.—The expansion characteristics of cakes baked from the same recipe as influenced by altitude.

There was some indication of decreased swelling of the starch, and of a slight increase in the amount of soluble protein with increases in

altitude; but the data was not consistent, and the change, if real, was small in both cases.

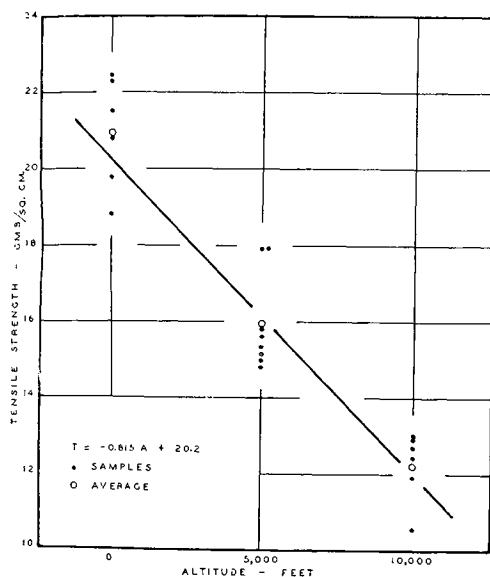There was one very decided effect which occurred as a result of

Figure 13.—The relation of tensile strength to altitude.

changes in altitude, and that was in the tensile strength. An increase in altitude produced a cake much more tender than the same formula baked at sea level. Usually it was found that cakes of low volume were tougher than those of a larger volume, other things being equal. However, those cakes baked at 10,000 feet were decidedly more tender, despite the fact that their volume was approximately 450 ml. less, than those baked at 5,000 feet (fig. 13). The possible causes will be discussed later.

The final cake volumes increased to a maximum when the tensile strength was about 16 grams per sq. cm., but on further reduction of tensile strength the volume dropped to a very low value (fig. 14).
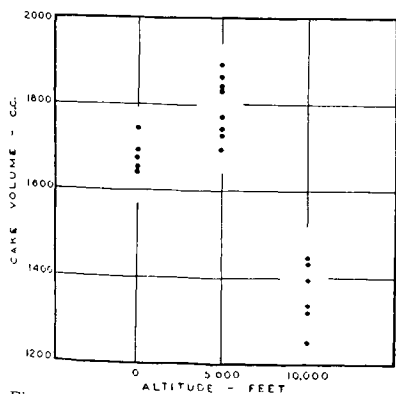
Figure 14.—The effect of altitude on the volume of cakes baked from the same formulae.

This phenomenon is thought to be a result entirely of the relative strength of the structure, i. e., tensile strength. At sea level the cake was tough enough to resist the expansive forces tending to raise it, allowing the gases to escape rather than to expand the cake completely. The structure of these cakes was strong enough to stand after all the pressure produced by the heated gases had been lost, and so the cake maintained most of the volume previously attained. At 5,000 feet these two effects were very nearly balanced, so that the expanding gases worked much more efficiently, although the difference between the final volume and the maximum

volume during baking was probably greater for these cakes than for those baked at sea level. Those baked at 10,000 feet, although they doubtless reached a greater maximum volume during baking than any of the others, were not built strong enough to hold up after the pressure of the heated gases inside had returned to atmospheric.

This effect was also evident in the expansion studies. The higher the altitude, the more the expansion. However, in those cakes baked at sea level and 5,000 feet, there was a tendency to recede from the maximum volume more slowly than in those baked at 10,000 feet.

No data is included in this publication on the tensile strength of the samples taken from the bottom of the cake. This is because the bottom samples could not always be obtained, especially in those cakes baked at high altitudes. Likewise, no data on the compressibility was included, because the test was not developed as completely, nor as many tests made, as in the study of tensile strength. Suffice it to say that the data in both cases indicates changes parallel to the test of tensile strength of the top samples; that is, when the top samples showed a decrease in tensile strength, the bottom samples showed a similar change, and these same variables increased the compressibility.

It was noticed that, as the atmospheric pressure was lowered, cakes baked at the same oven temperature would not brown as rapidly as the same formula baked at pressures corresponding to lower altitudes. The reason for this is evident on assuming that the browning of the crust was due largely to caramelization of the sucrose, and that this caramelization is dependent on the temperature.

The force which prevents the temperature of the crust from reaching that of the oven is the absorption of heat by the process of evaporation, which is continuously taking place. The rate of heat absorption and heat dissipated by evaporation are very nearly balanced during the latter part of the baking period.

At reduced pressures, evaporation takes place faster provided the temperature is maintained constant* (39, 40, 41), apparently because of the reduced obstruction offered by the air molecules. The increased speed of evaporation at high altitudes causes the temperature in the cake to drop, because not enough heat can be supplied at that difference between oven and cake temperature to maintain that rate. This reduction continues until the temperature has been lowered to a point where the heat absorbed by water evaporating again equals the heat transferred to the cake crust. Therefore, other things being equal, the higher the altitude the lower the temperature of an evaporating solution, or cake crust, even though the boiling point is not reached.

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*Investigations on distilled water at a constant temperature of 90.9° C., evaporating into a room whose relative humidity was 38 percent ± 2 percent at various altitudes, showed that the rate of evaporation increased 15 percent at 5,000 feet and 29 percent at 8,000 feet above that at sea level, although the boiling point was never reached.

Because of this reduction in crust temperature, with changes in altitude, it is necessary either to raise the oven temperature or to increase the length of the baking period, or both. Either change will cause the crust to dry out more, thus permitting the same temperature to be reached regardless of altitude, and so equal caramelization of the sucrose in the crust results.

The hypothesis that caramelization occurs at a given temperature, regardless of moisture content, was tested by boiling concentrated solutions of sucrose until caramelization began at sea level and at 10,000 feet altitude. It was found that when the heat was removed, so that the maximum boiling point reached was 181° to 182° C., the resulting sucrose glass was a clear, dark amber on cooling. All the samples were heated under uniform conditions and boiled slowly until the temperature reached 181-182° C. and then cooled under uniform conditions.

The color of the various sugar glasses was identical as long as the maximum boiling point was the same within $\pm$ 0.5° C., regardless of the altitude. However, the samples, after removing the test tubes, had an entirely different feel when handled. Those heated at sea level were sticky, while the others were much less so. On analysis, by heating at 100° C. in a vacuum oven to constant weight (2½ hours), the sea level sample was found to contain 2.1 percent water, while the one heated at 10,000 feet contained 1.7 percent water.

This shows that caramelization of sucrose containing small amounts of water is dependent on the temperature, regardless of the moisture content. It also shows that the previously described reason for the changes in the browning of the crust with changes in altitude was correct. It is entirely possible that the same temperature would not produce the same effects if the moisture content varies over wide ranges, say zero to 10 percent.

Internal Cake Temperature and Amount of Evaporation.— The effects of altitude on evaporation and on internal cake temperature were investigated also. The cakes* were baked in the round tube pans 20 cm. in diameter with sloping sides, and of about 2,300 ml. capacity. The temperature measurements were made with an error of not more than $\pm$ 0.15° C. by means of a calibrated, single junction thermocouple and a Leeds and Northrup type K-2 potentiometer.

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*Formula: 210 gms. egg white, 4.0 gms. potassium acid tartrate, 0.5 gms. sodium chloride, 150 gms. sucrose, 50 gms. flour C. and baked at 164° C. for 45 minutes.
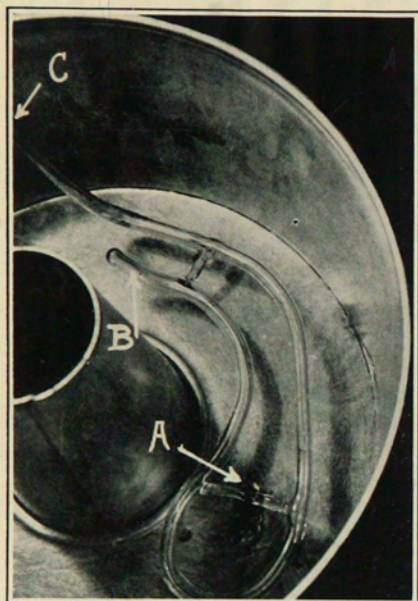
Figure 15.—The temperature measuring pan and shield.

The thermocouple was made of B. S. gauge no. 34 copper and no. 25 constantan. It was slipped into the glass shield, shown in figure 15, so that about 25 cm. (C to B) of the couple were buried in the cake batter. This was done in order to prevent heat being conducted by the wires down to the junction inside the cake. The shield was supported 1.5 cm. from the bottom of the pan by means of glass legs, and held down by a short spring at A.

The thermocouple was made long enough that the shield and couple could be placed in the cold pan outside the oven before the batter was put in place, and also that the temperature of the cake could be measured during the cooling period, after the cake had been removed from the oven, as well as during the baking period.

The evaporation studies were made by means of a rack suspended inside the oven from a balance on the top, figure 16. The cakes could be set on this rack and weighed from time to time during the baking to ± 0.1 gram.

Figure 17 shows the effect of altitude on cake temperature. The maximum temperature approximated very nearly

Figure 16.—The method of measuring the rate of evaporation.

that of the boiling point of pure water at that altitude. The true boiling point of the batter could not have been less than 101.2° C. at sea level, assuming that the sucrose were the only ingredient tending to raise the boiling point, and that all the water present were free to act as the solvent, which was certainly not the case.

There was no consistent change in the rate of temperature increase within the cake with variation in atmospheric pressure, i. e., air density. This was to be expected, since at this temperature most heat transfer is caused by radiation rather than by convection currents or air conductivity.
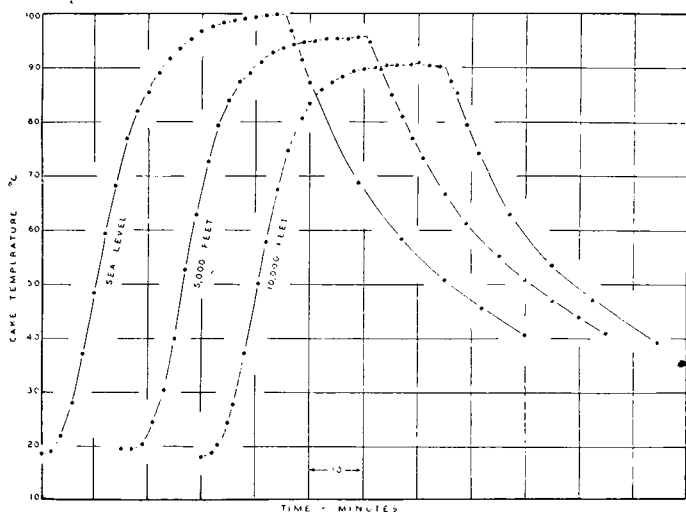
Figure 17.—The influence of altitude on the internal cake temperature throughout the baking and cooling period.

There was a decided effect on the rate and total amount of evaporation, which is shown in figure 18. This is very easily explained as
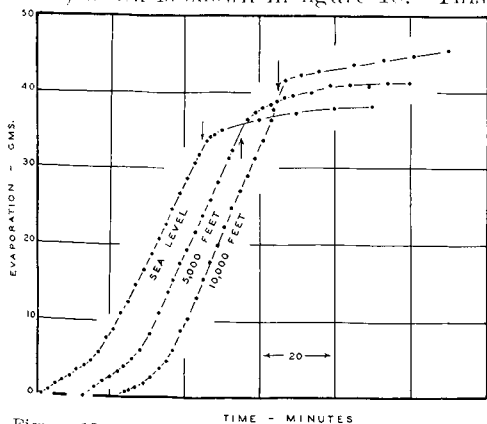
Figure 18.—The relation of rate and amount of evaporation as influenced by altitude. (The arrows represent the point at which the cake was removed from the oven.)

due to the temperature difference between the cake and the oven, which increased with altitude and so allowed more heat to transfer from the oven to the cake. The excess heat had to be used up by additional evaporation, since this was certainly the main means of dissipating the heat.

The simplified radiation equation (42) is as follows:

Rate of heat gained or lost $=$ (hr. $+$ hc) $A\Delta t$

Where hr is the radiation coefficient, hc is the convection coefficient, A is the area, and Δt the temperature difference. The quantity (hr $+$ hc) A may be allowed to equal a constant (K) which was the same in each case, since the oven conditions were approximately the same at each altitude. Applying the equation to the conditions at 5,000 feet, we find K equal to 8.14 calories per degree. The calculations were then made for the expected heat transfer at sea level and 10 feet, and are shown in the last column of table 3.

TABLE 3.—EFFECT OF ALTITUDE ON HEAT TRANSFER

Altitude feet	Temp. diff. °C.	Rate of evap. gms./min.	Max. temp. °C.	Latent heat of vapor cal./gm.	Heat loss by evap. cal./min.	Calc. heat loss due to Δt cal./min.
0	66.1*	0.99	99.5	539.5	534	538
5,000	70.6*	1.06	95.0	542.3	575	575
10,000	76.4*	1.15	90.2	545.3	627	622

*These values were obtained by subtracting from the oven temperature the value of the maximum temperature measured 1.5 cm. from the edge of the cake. It will be shown later that the evaporation takes place almost entirely in the outer centimeter of the cake, so these temperature differences are probably much too large. However, it is believed that the actual difference will vary with the altitude in a manner similar to the values given. The agreement between the calculated and observed differences in the amount of evaporation substantiates this belief.

The explanation in this case is not in any way similar to that of the effect of altitude on the rate of evaporation from free water surfaces exposed to natural weather conditions as found by Rohwer (39). There the rate of evaporation is dependent on the degree of saturation of the air, and at 100 percent relative humidity the rate of evaporation becomes zero, unless the temperature is changed. Here the amount of evaporation was dependent on the amount of heat transfer. However, the cause of the drop of the maximum temperature inside the cake with increases in altitude has been explained already and is apparently due to the same phenomena that explain Rohwer's results.

The water evaporating escapes as steam, and since the temperature of the cake* and the weight are known, it is possible to calculate the volume of steam that was released at various altitudes. It was necessary to apply Dalton's law of partial pressures, i. e., that the volume of the evaporating water vapor was proportional to the partial pressure of the water vapor and the standard barometric pressure of the corresponding altitude. Although at 5,000 and 10,000 feet the temperatures were slightly higher than the boiling point of pure water, the vapor pressure was taken as exactly that of barometric pressure. Obviously this does not accurately represent actual conditions, because the real vapor pressures were not as high as they would be for pure water, on account of the large amount of material in solution. It was

*Here again, it is desirable to call attention to the fact that the temperature measurements were not made at the point of maximum evaporation, and that it has been assumed that the temperature measured was the temperature of the water vapor escaping. It is certain, however, that the actual temperature cannot be less nor much greater than that given.

not possible to calculate them accurately because of the uncertainty as to the amount of "bound" water, or the amount of water not free to dissolve the sugar and salts, but held by the protein and starch present. However, the changes in the volumes found at various altitudes probably very nearly represent actual conditions, since the actual and assumed vapor pressures should differ by an approximately constant amount regardless of altitude. The specific volumes were obtained converting the values obtained from steam tables (43) to liters per gram.

The results of the calculations show, table 4, that at 10,000 feet there was about 70 percent and at 5,000 feet about 28 percent more volume of vapor escaping than at sea level.

TABLE 4.—EFFECT OF ALTITUDE ON VOLUME OF VAPOR ESCAPING

Altitude	Bar. press. mm. Hg.	Rate of evap. gms./min.	Temp. cake °C.	Specific volume L./gm.	Vapor press. mm. Hg.	Volume of vapor escaping L./min.
0	760	0.99	99.0	1.73	733	1.65
5,000	632	1.06	95.0	1.99	634	2.11
10,000	523	1.15	90.2	2.35	530	2.70

A series of analyses was made to determine, if possible, how much of the moisture evaporating came from the crust and how much from the interior of the cake. The data (table 5) indicates the startling fact that no moisture was lost from that part of the cake inside of 1 centimeter from the outer edges; in fact, there was a very slight increase in moisture content.

TABLE 5.—MOISTURE ANALYSIS

Oven temp. °C.	Top crust 2 mm.*	Next to top 8 mm.*	Center portion	Batter	Next to bottom 8 mm.*	Bottom crust 2 mm.*
143	13.1	27.2	45.65	45.5	35.4	24.9
165	25.9		45.5	45.0	35.3	
177	17.3	37.1	45.65	45.3	42.0	31.7
	5 mm.*	8 mm.*			8 mm.*	8 mm.*
163†	28.6	46.7	46.5	.....	46.4	42.2

*These distances represent the approximate thickness of the sample taken.
†The samples for this analysis were taken 10 minutes after the cake had come out of the oven.

However, there must have been some moisture loss as shown by the following explanation. The cake rises to an estimated volume of 2,500 to 3,000 ml. during baking, although the final volume is 1,600 to 1,800 ml. The expansion of the air due to the change in temperature cannot account for more than 300 to 350 ml. of this expansion. For example, a normal cake batter had a specific gravity of 0.301 and contained 414 grams of material, and so occupied 1,380 ml. This same batter, on centrifuging out the air, had a specific gravity of 1.19, and so would have occupied 350 ml. In other words, the batter contained 1,030 ml. of air. This amount of air, on being heated from 20° C. to 100° C. would expand only ($\frac{393}{293} \times 1030$) — 1030 or 350 ml. regardless of the altitude. The rest of the expansion of the cake, the 700 or 1,200 ml., would have to be caused by the only other source—water vapor. Evidently some water vapor used in expansion must be lost during the

early part of the baking period, that is, previous to reaching the maximum volume, because at 100° C. the pressure of the water vapor in the cake is nearly 760 mm., and the presence of the 1,380 ml. of air would increase the total pressure to a value considerably greater than the possible value inside the cake, although that was probably slightly greater than atmospheric pressure. At least 1,000 to 1,200 ml. of air and water vapor are lost during the raising of the cake, but just what percent of this is water vapor is impossible to say. As the cake shrinks, during the latter part of the baking period, still more of the internal gases escape, which are doubtless nearly pure water vapor.

It is difficult to believe that this water could be lost by the center of the cake and then ultimately regained. The only explanation, although it seems improbable, which will account for the findings is that most of the water vapor which caused the expansion came from the sides and the bottom, and in its attempt to get away had to pass through the main part of the cake. The reason it was not all absorbed was because of the temperature of this part of the cake.

Another reason why the water vapor used in raising the cake must come from the bottom and sides is because, if it came from the inside of the cake alone, there would seem to be no explanation for the greater expansion at higher altitudes. The tendency would be merely to saturate the air spaces in the cake with water vapor. Evidently about equivalent amounts of water, regardless of the source, were released, which caused expansion, and since the density was less the higher the altitude, the greater was the vapor volume.

The calculations of the volume of water vapor escaping per minute apply only to that outer-centimeter portion of the cake.

Since there was evidently no moisture lost by any portion of the cake farther from the outer edge than 1 centimeter, there could have been no temperature difference between this 1 centimeter point and the center of the cake. If there had been, heat would have been conducted inward, and evaporation would have taken place. The temperature gradient was then in this centimeter, the outer crust having a temperature approaching that of the oven and dropping to 100° C. (sea level) within a centimeter or less.

Cake baked at the low temperature, and for a long time, appeared to contain less moisture, because the center of the cake felt and tasted much drier than that baked at the higher temperature for a short time. The data (table 5) show that one was just as moist in the center as the other. The difference in feel was apparently occasioned by the difference in the condition or location of the moisture. Perhaps in the low temperature cake the moisture had been more completely removed from the sugar solution and absorbed by the starch or protein, because of the greater length of time the cake was maintained at a high temperature.

CALCULATION OF EQUATIONS.—It has been assumed that the tensile strength, in the case of all three variables, i. e., flour and sugar content and altitude, was a linear function of the variable, respectively. The equations of the lines drawn in figures 10, 11, and 13 are given below.

$$T = 0.198 \ F + 5.0 \tag{1}$$

$$T = -0.085 \ S + 29.5 \tag{2}$$

$$T = -0.815 \ A + 20.2 \tag{3}$$

Where T is the tensile strength in grams per sq. cm., F is the weight of flour, and S the weight of sugar, in grams, used with 210 grams of egg white, and where A is the altitude in thousands of feet. Combining the variables the following equation was obtained:

$$T = 0.198 \ F - 0.085 \ S - 0.815 \ A + C. \tag{4}$$

The constant C was found to equal 22.7, 22.3, and 20.8 when substituted back in the data on variation in flour, sugar, and altitude, and averaged 21.9. Therefore

$$T = 0.198 \ F - 0.085 \ S - 0.815 \ A + 21.9 \tag{5}$$

It was found that there was a minimum tensile strength of about 17.0 grams per sq. cm. required in order to produce a successful cake. When the recipe was adjusted so that the tensile strength was less, the cake "fell" badly. It seems that the structure simply was not strong enough to support itself unless its strength was equal to, or greater than, this minimal value. Since it is desirable to produce cakes with as low a tensile strength as possible, or as tender as possible, we substitute for T in the above equation the value of 17.0 and get

$$0.198 \ F - 0.085 \ S - 0.815 \ A + 4.9 = 0$$

or

$$F - .429 \ S - 4.12 \ A + 24.7 = 0 \tag{6}$$

Basis, 210 grams of egg white.

For any amount of egg white (E in grams) depending on the size of cake desired

$$S_6 = S_E \ \frac{210}{E}$$

likewise

$$F_6 = F_E \ \frac{210}{E}$$

Where S_E and F_E equal the amount of sugar or flour in grams to be used with E grams of egg white.

Changing the basis to 16 ounces of egg white, it is only necessary to correct the factor A and the constant C by the value

$$\frac{16 \times 28.35}{210 \times 28.35} = .0761$$

Then

$$F' - .429 \ S' - .314 \ A + 1.880 = 0 \tag{7}$$

For any amount of egg white (E' in ounces) depending on the size of cake desired

$$S'_7 = S'_{E'} \frac{16}{E'}$$

$$F'_7 = F'_{E'} \frac{16}{E'}$$

Where $S'_{E'}$ and $F'_{E'}$ equal the amount of sugar or flour in ounces to be used with E' ounces of egg white.

Again changing the basis to 1 cup of egg white, and the method of determining the amount of flour and sugar from grams to tablespoons (allowing one tablespoon of flour to weigh 6 grams, and sugar to weigh 12.5 grams), it is necessary to correct the expression of the relation of flour to sugar, due to the fact that 1 tablespoon of flour weighs $\frac{6}{12.5}$ as much as a tablespoon of sugar. Therefore

$$\frac{.429 \times 12.5}{6} = 0.894$$

The A and C factors must also be corrected for the change in method of determining the quantity of ingredients by $\frac{246}{210 \times 6}$ Therefore

$$F'' - \frac{.429 \times 12.5}{6} S'' - \frac{4.12 \times 246}{210 \times 6} A + \frac{24.7 \times 246}{210 \times 6} = 0$$

or $F'' - 0.894\, S'' - 0.804\, A + 4.82 = 0$ (8)

For any amount of egg white (E'' in cups), depending on the size of the cake desired,

$$S''_s = S''_{E''} \frac{1}{E''}$$

$$F''_s = F''_{E''} \frac{1}{E''}$$

Where $S''_{E''}$ and $F''_{E''}$ equal the amount of sugar or flour in tablespoons to be used with E'' cups of egg white.

APPLICATION OF EQUATIONS.—On attempting to apply equation 6 it was found that there were limits in the amount of flour beyond which it was not practical to go, provided the corresponding amount of sugar was also used. At all altitudes, it seemed to require at least 40 grams of flour for 210 grams of egg white in order to produce a cake that would not fall, regardless of sugar content. It was also found that about 80 grams of flour was the maximum amount for 210 grams of egg white. With more than the above amount of flour, the

better was found to shrink in volume considerably during the mixing of the flour; the final cake was too dry, and the cells became seriously coarse. This seemed also to be the case at all altitudes.

Equation 6 was tested, between the above limits, by baking 82 cakes at various altitudes, and with three kinds of flour—A, B, and C. It was found to predict the results surprisingly well (average difference between the calculated and observed values of tensile strength was 3.4 grams per sq. cm.). Of all the cakes baked, only three had a tensile strength less than that calculated. One reason for this is that the values on which the equation was based were obtained with one lot of flour, while all the values obtained in testing the equation were obtained from another lot of the same kind of flour. Analysis showed no appreciable difference in moisture or protein content, but it is generally accepted that flours vary slightly from lot to lot, even from the same mill under careful control.

The average difference between the calculated and observed tensile strength values was about equal for two of the flours used—A and C, but for flour B the average difference was considerably greater.

Analysis showed A and B to have about 5 percent greater protein content than C. No satisfactory explanation for this difference in tensile strength could be found.

Flour B had another characteristic which was entirely different from A or C. When being mixed into the meringue, the volume change was usually positive, rather than negative as in the case of A or C. This behavior makes flour B much superior to the others, because it can be mixed completely with the other ingredients without the loss in volume which occurs when flours A or C are used. Mixing is important, because incomplete mixing is thought to be one of the causes of uneven cake texture.

This property of flour B was thought to be attributable to the difference in the rate or amount of absorption of water, but no direct evidence of this could be detected. However, Alsberg (44) has found that fine grinding of flour increases the rate of absorption of water. Several other differences have been found between very finely and less finely ground flours by Alsberg and Griffing (45). They found that the more finely ground flour was more extractable by cold water, had greater diastatic activity, and would yield less gluten on washing. This was thought to be a result of injury of some of the starch granules, resulting in a particle that was more accessible. These injured starch granules were shown to stain with congo red, while those which had not been injured did not stain at all.

These tests were made on all three kinds of flour. The cold water extract and the gluten washing were made according to A. O. A. C., 1919 (46), the diastatic activity by the method of Blish and Sandstedt (47). Since no difference in the number of stained starch granules

could be detected on treating with congo red, an attempt was made to determine the sorption of the dye by another method. This was as follows: A mixture of 1 gram of flour, 15 ml. of 0.02 percent solution of congo red, and a few glass beads were shaken and then centrifuged. The resulting clear solution then was examined for amount of dye

The results, table 6, show that all the tests indicated that A and C are ground more finely than B. The color of the flour extract in B was about half as red as the solution which had contained no flour, while the extracts from A and C were practically colorless. Doubtless practically all the congo red was absorbed by the gluten of the flours, rather than by any injured starch granules. However, regardless of what happened, it is a method of distinguishing between the three kinds of flour.

TABLE 6.—FINE GRINDING TESTS

Kind of flour	Cold water extract, percent soluble	Diastatic activity mgms. maltose per gm. flour	Gluten obtained gms. dry gluten per 100 gms. flour
B	5.5	10.1	4.9
A	8.1	13.0	2.5
C	8.0	14.1	1.5

In order to check the conclusion of the previous tests, the rate of settling, or particle size, of the three kinds of flour was attempted according to the method of Markley (48). By this method it was possible to determine the size of about 93 percent of the flour, but by the time that amount of material had settled out the remainder was settling so slowly that the sensitivity of the method would not justify drawing any conclusions. No significant difference in the particle size of the three flours could be detected in the coarser 93 percent, but since the other tests indicated finer grinding in A and C than in B, it was concluded that the difference, if any, in particle size must be in the finest 7 percent of the flour.

The shrinkage of volume which resulted on adding the flours A or C to the meringue was found to increase as the amount of flour was increased.

Because of changes made in the formulae for the three levels of altitude, there was progressively less sugar added with the flour as the altitude increased. This permitted the interesting comparison of the influence of the amounts of sugar added with the flour on the shrinkage in volume due to the addition of the mixture. The data was not conclusive but indicates that the larger the amount of sugar added with the flour the less the shrinkage. However, that difference in volume change can be accounted for merely by the volume the sugar occupies when in solution. In other words, the addition of sugar with flour does not appear to affect the volume shrinkage when a correction is made for the volume occupied by the sugar in solution.

RECIPES.—The recipes for every 1,000 feet of altitude from sea level to 15,000 feet were calculated from equations 6, 7, and 8 between the limits of 40 to 80 grams of flour per 210 grams of egg white or amounts equivalent to these. They have been plotted in three dimensions in figure 19 and are given in tables 7, 8, and 9.
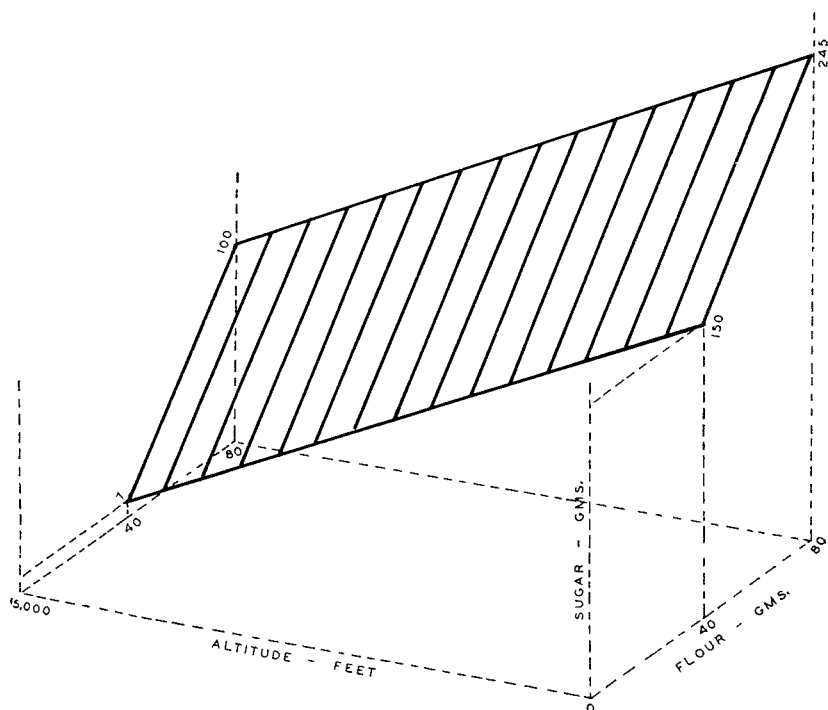
Figure 19.—A three dimensional plot of the recipes given in table 8.

The following weights and the corresponding measuring units have been used in this publication.

1 cup	=236.6	ml., or ½ pint or 16 tablespoons
1 tablespoon	= 3	teaspoons
1 cup egg white	=246	grams or 8.7 ounces
1 cup cake flour	= 96	grams or 3.4 ounces
1 cup sugar	=200	grams or 7.1 ounces
1 tablespoon flour	= 6	grams or 0.21 ounces
1 tablespoon sugar	= 12.5	grams or 0.44 ounces
1 teaspoon cream of tartar	= 4	grams or 0.14 ounces
1 teaspoon flavoring	= 5	grams or 0.18 ounces

TABLE 7.—RECIPES FOR ANGEL FOOD CAKE
Given in Grams of Sugar for 40 to 80 Grams of Flour

Altitude in feet	Flour (grams)								
	40	45	50	55	60	65	70	75	80
	Sugar (grams)								
0	150.5	162.5	174.0	186.0	197.5	209.5	221.0	232.5	244.0
1,000	141.0	153.0	164.5	176.0	187.5	199.5	211.0	222.5	234.5
2,000	131.5	143.5	155.0	166.5	178.0	189.5	201.0	213.0	224.5
3,000	122.0	133.5	145.5	157.0	168.5	180.5	192.0	203.5	215.0
4,000	112.5	124.0	135.5	147.5	159.0	170.5	182.5	194.0	205.5
5,000	103.0	114.5	126.0	138.0	149.5	161.0	172.5	184.5	196.0
6,000	93.0	105.0	116.5	128.0	139.5	151.5	163.0	174.5	186.5
7,000	84.0	95.0	107.0	118.5	130.0	142.0	153.5	165.0	177.0
8,000	74.0	85.5	97.5	109.0	120.5	132.5	144.0	155.5	167.0
9,000	64.5	76.0	87.5	99.5	110.0	122.5	134.5	146.0	157.5
10,000	55.0	66.5	78.0	90.0	101.5	113.0	124.5	136.5	148.0
11,000	45.0	56.5	68.5	80.0	91.5	103.5	115.0	126.5	138.5
12,000	35.5	47.0	59.0	70.5	82.0	94.0	105.5	117.0	129.0
13,000	26.0	37.5	49.5	61.0	72.5	84.0	96.0	106.5	119.0
14,000	16.5	28.0	39.5	51.5	63.0	74.5	86.5	98.0	109.5
15,000	7.0	18.5	30.0	41.5	53.5	65.0	76.5	88.5	100.0

$$F - .429\ S - 4.12\ A + 24.7 = 0$$

Egg white	210 grams
Cream of tartar	4 grams
Salt	1 gram
Flavoring (vanilla)	5 grams

TABLE 8.—RECIPES FOR ANGEL FOOD CAKE
Given in Ounces of Sugar for 3 to 6 Ounces of Flour

Altitude in feet	Flour (ounces)						
	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	Sugar (ounces)						
0	11.4	12.5	13.7	14.9	16.1	17.3	18.5
1,000	10.6	11.8	13.0	14.1	15.3	16.5	17.7
2,000	9.9	11.0	12.2	13.4	14.5	15.7	16.9
3,000	9.2	10.3	11.5	12.7	13.8	15.0	16.2
4,000	8.4	9.6	10.8	11.9	13.1	14.3	15.5
5,000	7.7	8.9	10.0	11.2	12.4	13.5	14.7
6,000	7.0	8.2	9.3	10.5	11.7	12.8	14.0
7,000	6.3	7.4	8.6	9.8	10.9	12.1	13.2
8,000	5.5	6.7	7.8	9.0	10.2	11.3	12.5
9,000	4.8	6.0	7.1	8.3	9.5	10.6	11.8
10,000	4.0	5.2	6.4	7.5	8.7	9.9	11.0
11,000	3.3	4.5	5.7	6.8	8.0	9.2	10.3
12,000	2.6	3.8	4.9	6.1	7.3	8.4	9.6
13,000	1.9	3.0	4.2	5.4	6.5	7.7	8.9
14,000	1.1	2.3	3.5	4.6	5.8	7.0	8.1
15,000	.4	1.6	2.7	3.9	5.1	6.2	7.4

$$F - .429\ S - .314\ A + 1.88 = 0$$

Egg white	16.0 ounces
Cream of tartar	0.3 ounce
Salt	0.07 ounce
Flavoring (vanilla)	0.4 ounce

TABLE 9.—RECIPES FOR ANGEL FOOD CAKE
Given in Tablespoons of Sugar for 8 to 15 Tablespoons of Flour

Altitude in feet	Flour (tablespoons)							
	8	9	10	11	12	13	14	15
	Sugar (tablespoons)							
0	14½	15½	16½	17¾	18¾	20	21	22¼
1,000	13½	14½	15¾	16¾	18	19	20¼	21¼
2,000	12½	13¾	14¾	16	17	18¼	19¼	20½
3,000	11¾	12¾	14	15	16	17¼	18½	19½
4,000	10¾	12	13	14	15¼	16½	17½	18½
5,000	10	11	12	13¼	14¼	15½	16½	17¾
6,000	9	10	11¼	12¼	13½	14½	15¾	16¾
7,000	8	9¼	10¼	11½	12½	13¾	14¾	16
8,000	7¼	8¼	9½	10½	11¾	12¾	14	15
9,000	6¼	7½	8½	9¾	10¾	12	13	14
10,000	5¼	6½	7½	8¾	10	11	12	13¼
11,000	4½	5½	6¾	8	9	10	11¼	12¼
12,000	3½	4¾	5¾	7	8	9¼	10¼	11½
13,000	2½	3¾	5	6	7¼	8¼	9½	10½
14,000	1¾	2¾	4	5	6¼	7½	8½	9½
15,000	1	2	3	4¼	5¼	6½	7½	8¾

$$F - 0.894\ S - 0.805\ A + 4.83 = 0$$

Egg white   1 cup
Salt   ¼ teaspoon
Cream of tartar   1 teaspoon
Flavoring (vanilla) 1 teaspoon

EXPANSION CHARACTERISTICS FOR CORRECTED RECIPES.—Expansion studies similar* to those previously described were made, using formulae calculated from equation 6.

The results, figure 20, show that from sea level to 5,000 feet there was little or no general change in expansion characteristics, but at 10,000 feet there was a decided change. No explanation is offered for this behavior. The previously noted effect (fig. 12) of the increased amount of expansion with increases in altitude has been reversed by the correction of the formulae. That is, the cakes expanded more at the lower than at the higher altitude when the recipes are corrected for the effects of altitude.

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*Formulae: 210 gms. egg white, 4.0 gms. potassium acid tartrate, 0.5 gms. sodium chloride, baked at 164° C. for 45 minutes.

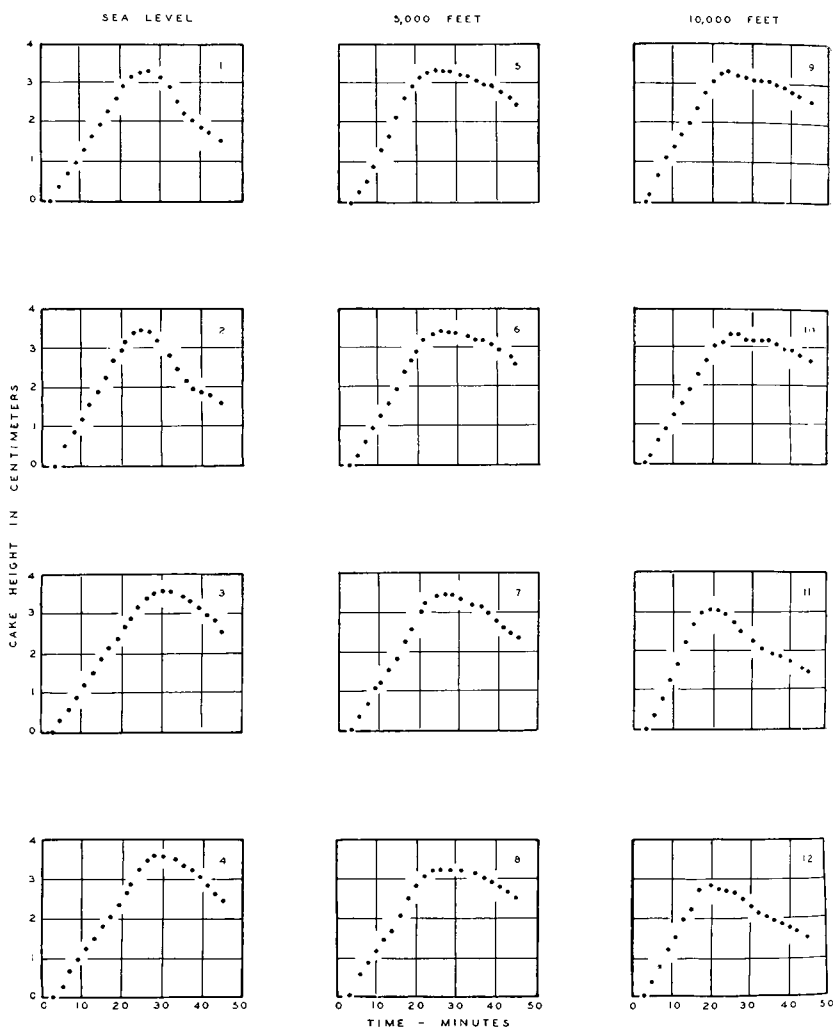| Cake nos.	Flour B gms.	Sucrose gms.
1, 2	50	174
3, 4	65	210
5, 6, 7, 8	60	150
9, 10	65	113
11, 12	50	78

Figure 20.—The influence of altitude on the expansion characteristics of cakes baked from recipes calculated from equation 6.

It appears that there was no consistent difference in the rate of rising, and that the time required to reach the maximum height was related more closely to the maximum height than to the altitude.

SUCROSE VS. LEVULOSE CAKES.—Since levulose is 1.7 times as sweet as sucrose, it was thought that it might be possible to produce cakes at high altitude just as sweet as those at sea level by substituting levulose for sucrose in amounts sufficient to give equivalent sweetness. This would be possible only if levulose could be substituted for sucrose approximately gram for gram, and not molecule for molecule.

Dr. J. B. Ekeley of the Department of Chemistry, University of Colorado, was so good as to donate sufficient levulose to make a test of the idea. Four cakes* were baked, two of which contained only sucrose and two of which contained only levulose as the sugar. No. 301, figure 21, was one of the sucrose cakes, and no. 300 was one of the levulose cakes. They were nearly identical; however, the latter shrank slightly more during the last part of the baking period, and the crust colored much more quickly.
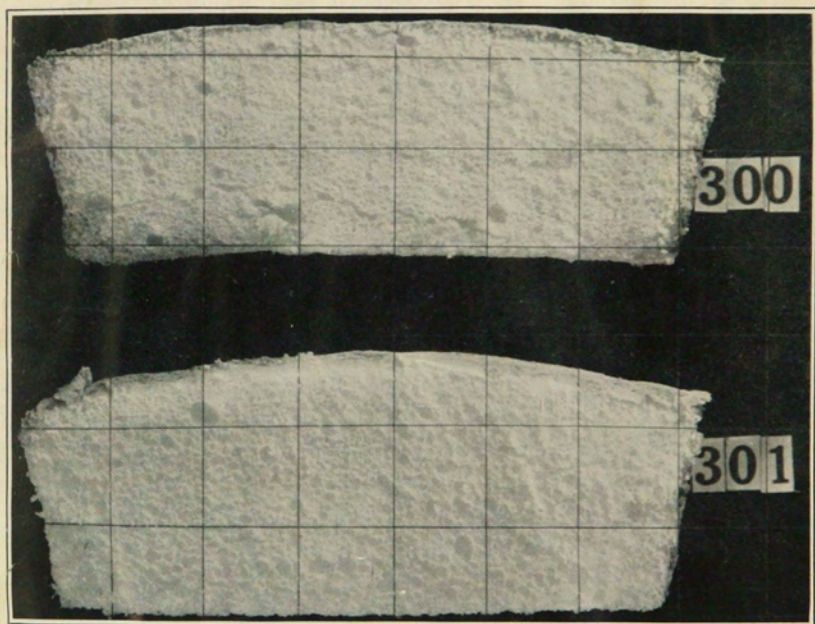

Figure 21.—Levulose (number 300) and Sucrose (number 301) cakes.

This shows that the effect of sucrose in the cakes is mainly physical, rather than chemical; otherwise it would be necessary to substitute levulose in proportion to its molecular weight. It also shows that if the price of levulose becomes sufficiently low there should be a market for it in baking at high altitudes.

COAGULATION OF EGG WHITE.—In attempting to clear up several points in connection with the cake studies of this laboratory, a series of experiments was carried out to determine the effects of temperature, acid, and sucrose content on the properties of coagulating and coagulated egg white. It was possible to explain the effect of increased tenderness of cakes with an increase in sugar content as being due to a

*Formula: 52 gms. egg white, 1.0 gm. potassium acid tartrate, 0.2 gm. sodium chloride, 37.5 gms. of the sugar, 15 gms. of flour B, and baked at 165° C. for 29 minutes for the levulose cake and 35 minutes for the sucrose cake.

reduced amount of coagulation. If this were the case, it would be
reasonable to expect that the temperature at which coagulation starts
would be higher as the sugar content increased. The increased tender-
ness obtained for increases in altitude also can be explained as being
due to the decreased internal cake temperature and its effect on the
coagulated egg white. It is generally understood that custards or egg
whites cooked at temperatures below 100° C. are more tender than those
subjected to a higher temperature. It was also thought that possibly
some effect of the acid ingredient could be determined by a study of
its effect on the coagulating protein.

A series of experiments was made with the following additions
per 100 grams of egg white: A.* From 0 to 90 grams of sugar but
no acid. B.* From 0 to 90 grams of sugar, but all containing 1.9
grams of potassium acid tartrate. C.* From 0 to 1.9 grams of potas-
sium acid tartrate but no sugar. D.* From 0 to 1.9 grams of potas-
sium acid tartrate and 71 grams of sugar. These samples were mixed
until solution was complete, then centrifuged for a short time in order
to free them from air bubbles. The centrifuge tubes were then placed
in a 2-liter beaker and held against one side by a heavy wire coil. The
beaker was filled with water above the level of the samples in the tubes,
then heated with a gas burner so adjusted that the temperature of the
bath rose about 5° C. per minute between 30° and 50° C. It will be
noted that this was about the rate of temperature change in the cakes.
During the heating the bath was stirred vigorously. Photographs
were taken of samples at three intervals: the first, at the first definite
appearance of coagulation; and the last, as the last tube began definitely
to show coagulation. The second was taken at some intermediate point.
The temperature was recorded at the time of taking the photographs.
Figure 22 constitutes the data. The results show that as the sugar
content was increased, in the absence of acid, the temperature** at
which coagulation became evident was higher (A). The same result
was obtained in the presence of acid, except that the acid lowered the
temperature at which coagulation began (B). The presence of acid
in the absence of sugar (C), as well as in the presence of sugar (D),
decreased the temperature of initial coagulation. However, the addi-
tion of sugar increased the temperature of initial coagulation, as was
expected from the experiment B. The reduction of the temperature
of initial coagulation, on account of the presence of acid, was not
found to be equal to the elevation in the temperature produced by
the addition of sugar. The result of the acid or both acid and
sugar in amounts used in the baking of cakes (and 71 grams per
100 grams of egg white) was to raise the temperature at which
coagulation began.

*See figure 22, where letters A, B, C, and D refer to groups pictured.
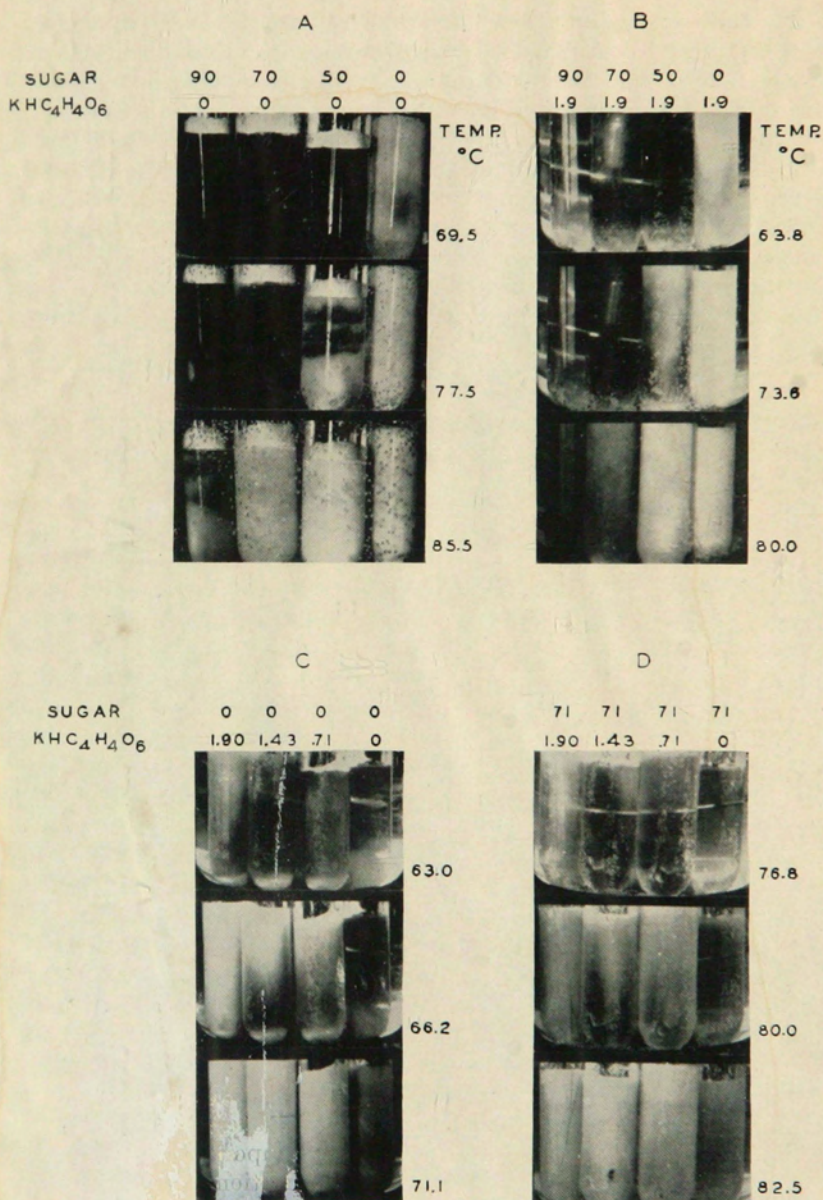**The temperature recorded was that of the bath and not that of the egg white.

Figure 2.— The effect of acid and sucrose on the temperature of initial coagulation of egg white.

The results of this group of experiments indicate that increases in the sugar content should produce a more tender cake by reason of the reduced range of temperature over which coagulation takes place,

if the following assumptions are correct : that there is less coagulation
the shorter the temperature range producing coagulation ; and that
the less the amount of coagulation the more tender the cake. However,
the addition of increasing amounts of acid has the opposite effect on
coagulation in plain egg white. From the above reasoning, the more
acid used the tougher the resulting cake should be. However, no dif-
ference was found in the tensile strength of cakes caused by changes
in the content of potassium acid tartrate. This comparison shows that
no satisfactory conclusion applicable to the angel food cake study can
be drawn from the influence of acid and sucrose content on the
temperature of initial coagulation.

Another series of experiments on egg white heated at various
temperatures for 40 minutes was designed to reveal the changes in the
structural properties.

The egg white was mixed thoroughly and placed in a cement

Figure 23.—The molds used in the
study of the coagulation of
egg white.

briquette mold with a copper plate
on each side (fig. 23). The plates
were held in place by eight screws
evenly spaced around the edge of the
mold. It was filled through a ½-inch
hole, into which a tight fitting plug
could be screwed. After filling, the
molds were immediately and com-
pletely immersed in a water bath,
maintained at the desired temperature
to within ± 0.1° C., and left for 40
minutes. At the end of that time they
were removed and hung in the same
position for 2 hours to cool before
samples were taken for the various
tests. The molds were never complete-
ly tight, so that when expansion took
place due to changes in temperature,
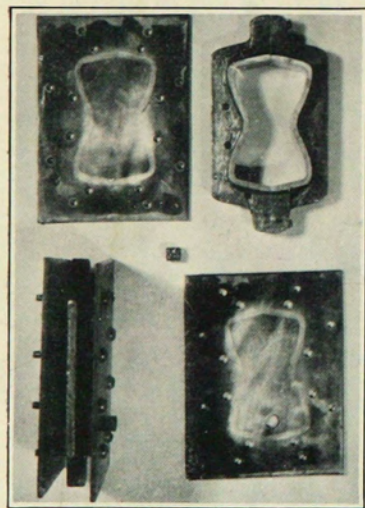excess material was extruded.

After cooling the mold was care-
fully removed, and using a sharp, thin-
bladed knife, the block of coagulated egg white was cut as smoothly
as possible into five slices, approximately 5 mm. thick.

The first test made was similar to the tensile strength measure-
ments made on cakes, the method having been described at the begin-
ning of this report and illustrated in figure 2. The samples were cut
out in the center with a large cork borer, giving a shape similar to,

but smaller than, the samples used in the cake tests. The cross sectional area at the narrowest place was generally about 0.25 to 0.33 square centimeters.

The second test was that of the penetration of a steel ball, $\frac{1}{2}$-inch in diameter, on which a constant weight of 53 grams was acting. The apparatus used (figure 24) was copied from Platt (9), who used a
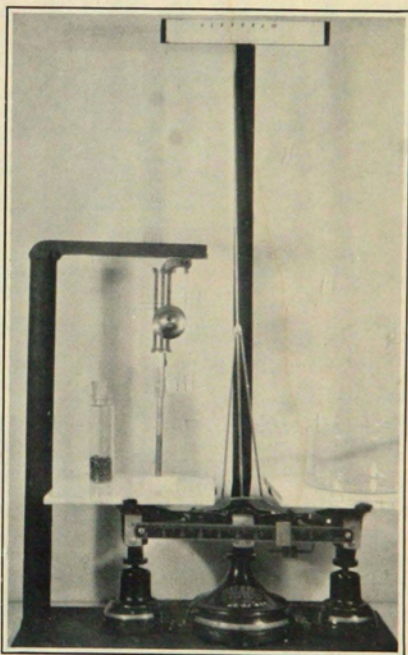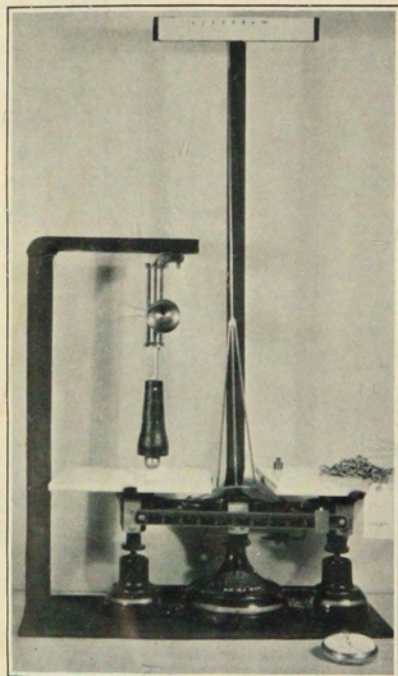

Figure 24.—The apparatus used in the ball penetration tests.

Figure 25.—The apparatus used in the $\frac{1}{4}$-inch rod penetration test.

similar device with another type of balance for measuring the compressibility of bread. The slices of coagulated egg white were placed under the ball with just enough weight on the opposite side to hold the ball against the sample. The difference between the position of the pointer at this time and its position before the sample was put in place gave the thickness. The chain, weighing 53 grams, was then slowly put in place and the stop-watch started. The penetration obtained after 1 minute was calculated to a basis of samples 5 mm. thick and reported in this manner, since there was found to be some difference due to thickness.

The third test was made by means of a method similar to one devised by various individuals to determine ripeness of fruits and berries (12-20). The test consisted of forcing a $\frac{1}{4}$-inch rod, with a

flat end, into the sample until it suddenly yielded, allowing "complete" penetration compared to the "½-inch ball" penetration test. For this the apparatus shown in figure 25 was used. The vessel on the right pan held the water, and the weight on the left pan equaled the weight of the empty vessel. The thickness of the sample could again be measured, if desired, but the thickness seemed to make no difference in this test. Water was run into the vessel at the rate of 200 grams per minute, until the material yielded. Figure 26 shows the nature of
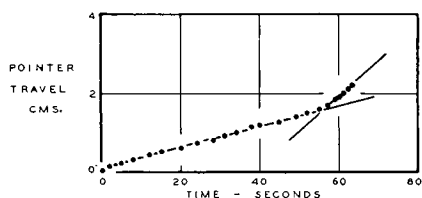

Figure 26.—Pointer travel, or penetration, as the weight acting was increased at the rate of 200 grams per minute.

the action of the plunger plotted against the time, after the beginning of the addition of the water. The yield point was taken at the point at which the break in the curve occurs and was called the value for the "¼-inch-rod penetration".

The first variable investigated was that of the effect of various temperatures of coagulation. It was found that successful samples could be obtained for the tests when the temperature of coagulation was as low as 77.5° C., but below that point the samples were too tender to handle. Also at this temperature the coagulated egg white hung so tightly to the mold that it split down the center, as a result of shrinking on cooling. This ruined the samples for tension tests and made the two penetration tests less certain.
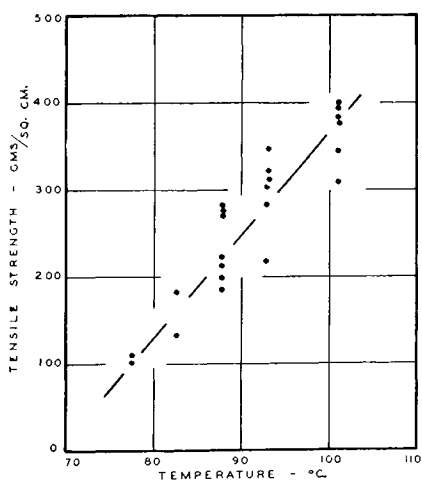

Figure 27.—The effect of the temperature of coagulation on the tensile strength of the resulting egg white.

All three tests (figs. 27, 28, and 29) show that there was a decided increase in tenderness of the coagulated egg white as the temperature of coagulation was reduced. The only irregularity obtained was at 101° C. in the ball penetration test. Here the data indicate that the change from 93° to 101° C. produced no increased toughness and may have decreased it slightly. The fault must be in the method, since the other two methods clearly indicate an increased toughness for the corresponding temperature increases.

In order to be sure that the heating and cooling period did not produce appreciable evaporation,

moisture determinations were made on two batches of egg white before and after heating at 82° and 101° C. The results, table 10, show that relatively little evaporation took place.

A series of tests was made of the effect of potassium acid tartrate on the properties of coagulated egg white. All samples were mixed thoroughly with the desired amount of acid and placed in the mold. They were then put in the bath and held at a constant temperature of 92.7° C. for 40 min-
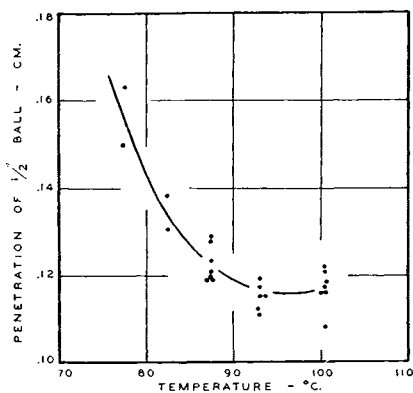

Figure 28.—The effect of the coagulation temperature on the amount of penetration of the ½-inch ball.

TABLE 10.—MOISTURE IN EGG WHITE

Temperature °C.	Percent before heating	Percent after heating
82	87.4	86.0
101	86.9	84.4

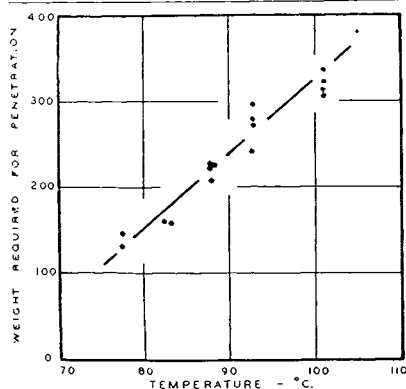Figure 29.—The effect of the temperature of coagulation on the weight required to produce "complete" penetration.

utes, removed and allowed to cool for 2 hours before testing. These tests were not as satisfactory as those on the untreated egg white. The acid present apparently caused the liberation of carbon dioxide on heating, which formed bubbles throughout the sample. These bubbles introduced errors which could not accurately be determined. However, the data were corrected as well as possible, and the results indicate certain changes which were thought to be actual.

The results of one of the tests (fig. 30) show that after the addi-

tion of about 0.25 parts of potassium acid tartrate to 100 parts of egg white the tenderness remains constant.

The ¼-inch-rod penetration test was not at all successful. The material seemed to compress indefinitely and would not yield as the untreated egg white had done. The ball penetration test was also unsatisfactory, probably for the
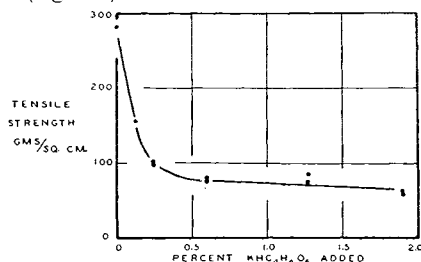

Figure 30.—The effect of the potassium acid tartrate on the tensile strength of egg white.

same reason; however, this test did indicate an increase in tenderness. The results of the tensile strength tests (fig. 30) showed that acid definitely produced a more tender product, and that the addition of more than 0.25 parts of potassium acid tartrate to 100 parts of egg white made no significant change in tenderness.

It was hoped that it would be possible to carry the investigation of the effects of the acid, sucrose, and temperature further, but so far no successful method of handling or testing the material has been devised.

The data show that as the temperature of coagulation is decreased, or, if potassium acid tartrate is added, the egg white becomes more tender. There is some indication that the product also becomes more tender as the sucrose content is increased.

From the data obtained it is impossible to say whether the reduced maximum temperature at high altitude is responsible for a part of the reduction in tensile strength or not. It is doubtful if egg white containing flour, sugar, and acid would, in coagulating, behave similarly to pure egg white. However, there is no evidence to the contrary.

ERRORS

The errors in the measurements of such properties as specific gravity and volume were not appreciable, and probably did not amount to over 2 or 3 percent. In subtracting the volumes of the meringue and batter to find the volume change on the addition of the flour to the meringue, the absolute errors were carried along, so that in some instances where the volume change was small the error might be as much as 200 percent. However, the scatter of the points in figure 4 indicates that the error was not generally greater than $\pm$ 15 ml.

All ingredients were weighed to $\pm$ 0.1 gram, so that any error from this source was negligible.

The major errors that were introduced were occasioned by manipulation during the preparation of the batter. Attempts continually were made to standardize the procedure so as to eliminate variations due to this sort of thing. The determination of the specific gravity and the calculation of foam volume were made in order to evaluate the effects of various methods or to detect undesirable changes.

The oven temperature varied as much as 4.5° C. from the average. This may have had some effect, but if so it was not detected.

The errors in the tensile strength, the ball penetration, and the ¼-inch-rod penetration measurements, it is believed, were caused mainly by the variation in the samples. The best evaluation of errors from this source can be obtained from the scatter of points in the various plots. The only error in measurements that might be considered as influencing the results was that of the cross-sectional area at the point of separation in the tensile strength measurements of the

coagulated egg white. There the area was small, and a possible error in measuring the dimensions would make appreciable error in the area. The other errors due to weighing, measuring, etc., were negligible compared to the variation in samples.

The variation in the pressure, when the altitude was different from 5,000 feet, was seldom more than ± 1.5 mm. of mercury, so that at 10,000 feet this would only be about ± 0.3 percent variation in pressure. This certainly would not be expected to cause a variation in results. The natural variation in atmospheric pressure would probably exceed the above value, although the change does not take place in 2 or 3 minutes as it does in the laboratory.

The apparent errors in some analyses were due largely to sampling In some cases material was lost in several steps of the procedure, but there seemed to be no better method, and since no great difference in the results was observed, no further time was spent in refining the procedure.

DISCUSSION

It is not maintained that the most desirable method of mixing angel food cakes has been found. Too few experiments have been performed. The data do indicate, however, that the best products are obtained when as much of the sugar as possible is added to the egg white foam before the addition of any of the flour. The limiting factor in the amount of sugar added before the flour depends on the ability of the individual or the machine to distribute the flour evenly. It is possible, however, that the sugar does not aid in even distribution of flour. If this could be shown to be the case, then all the sugar should be added alone and beaten in well before any flour is added, because of its favorable effect on volume.

The foam structure seems to maintain its volume better when it contains at least some of the sugar; because, although the sugar increases the volume of the solution, and so the foam to which it is added, the volume shrinkage on the addition of the flour was the greatest when all the sugar was added with the flour. Therefore, the actual volume shrinkage was still greater than the data indicate by the amount of the volume occupied by the sugar in solution and the suspended flour particles. Thus, by adding as much as possible of the sugar before the flour, the volume of the batter will be greater and likewise the resulting cake.

The egg whites should be beaten to some specific gravity not less than 0.150. Lighter foams were too unstable, but when the foam was heavier than about 0.170 the cake volume was not as large as possible because of the lack of foam or batter volume. In the light foams, the shrinkage on the addition of the flour was the greatest, and the texture was poor, as a result of the decreased foam stability.

Evidently there are at least two favorable and necessary effects produced by acid in the production of angel food cakes. The first is the stabilizing of the foam so that the heat may have time to penetrate and the temperature of coagulation to be reached before the foam has collapsed sufficiently to produce large air cells in the resulting cake. Thus the structure becomes rigid and maintains the cell size existing at the time the coagulation takes place. The second effect prevents the extreme shrinking of the cake during the last part of the baking period and during the cooling period.

These two effects were shown by the use of various amounts of the different acids. Acetic or citric acid, in the amounts that were shown to produce unstable foams in the foam studies (3), prevented the extreme shrinking in the cakes, but did not produce as fine a texture as did the potassium acid tartrate. Thus, in the case of the first two acids, the stabilizing effect was more or less absent, but the acids prevented the extreme shrinking, while with the acid tartrate both effects were continuously evident. It was predicted from the foam studies that the difference in the stabilizing effect of the three acids would give the difference in cake texture which was found.

It seems likely that these two effects may be very closely related. It has been concluded that the effect of the acid on the foam stability was the result of some action on the coagulating or coagulated protein at the liquid/air interface. Also the second effect probably is explained by some action of the acid on the coagulating or coagulated protein. If one assumes that the protein coagulated by adsorption at the interface was similar to the protein coagulated by heat, then both effects of the acid in the cake may be due to one and the same action of the acid.

The effect of acid was not the result of the production of invert sugar from sucrose.

The data on the effect of oven temperature on angel food cake characteristics show that the high temperature $180°$ C. produces the most successful product. The evaporation was less, and the volume was greatest at this high temperature. The tensile strength was found to be less for the high oven temperature, but this was indirectly dependent on the temperature and directly dependent on the cake volume.

It has been stated by various individuals that a high oven temperature produces a tough cake. This statement was evidently made on two assumptions: first, that the internal temperature of the cake was raised considerably by an increase in oven temperature; second, that a change in temperature of coagulation changes the physical properties of egg white as has been the experience in custards, etc. It has been shown by this laboratory that the maximum internal cake temperature was not influenced appreciably by the oven temperature, and that the cakes baked at the high temperature were even more tender, because of their volume than those baked at lower temperatures.

There seems to be no reason to doubt the general opinion of those who bake this type of cake that the whites from old eggs are not satisfactory ingredients, and that a change in recipe will not correct completely for their effects. The mere liquefaction of the egg whites with age does not explain the results, because identical cakes may be made from thick or thin fresh egg white.* Apparently the protein hydrolysis described by Balls and Swenson (37) does explain the results. The change in the egg white which produces the undesirable shrinking of the cake, therefore, seems to be due to the slow tryptic splitting of the proteins, and for some reason or other these simpler proteins do not produce a satisfactory structure.

Almost every characteristic of the cakes investigated was found to change slightly with changes in altitude. The rate of temperature change within the cake was the only item not found to indicate some regular change with altitude.

No conclusive evidence was obtained regarding the effect of altitude on the size of the starch grains. It was expected that possibly the decrease in temperature at high altitudes might cause sufficient difference in the amount of water absorbed by the starch to be detectable, and so affect the physical properties of the coagulating protein.

It has been assumed that the time-temperature area under curves, such as those in figure 17, is the effective factor in coagulating protein. This product becomes less as the altitude is increased. Therefore, the indication regarding effect of altitude on the amount of soluble protein, if real, is certainly in the right direction.

The change in cake volume with altitude has already been explained as due to the difference in tensile strength. That is, the cakes at sea level, using the 5,000 feet formula, were so tough that the expanding gases did not raise them properly. At 5,000 feet the expansive forces had increased sufficiently to raise the cakes to a very satisfactory degree, while at 10,000 feet they were raised high enough to tear the structure considerably, resulting in reduced tensile strength. On using the corrected formulae, the volumes were much more nearly equal, regardless of the altitude.

The difference in the browning of the crust has been shown to be a result of caramelization of the sugar and the reduced temperature of the crust at high altitudes.

For purposes of a more concrete illustration of the effects of altitude on evaporation, cake temperature, etc., consider two sets of conditions: the first, a solution at sea level of some non-volatile solute in water, and that the temperature is maintained at 90° C. because the amount of heat put in is just balanced by evaporation; the second, a similar solution at some higher altitude, say 5,000 feet, supplied with exactly the same amount of heat as in case one. In case two, the tem-

*In this particular the findings of this laboratory are not in agreement with statements by Dr. Stanley and Dr. King of the Bureau of Home Economics (49, 50).

perature will be less, because of the increased rate of evaporation at higher altitudes for any given temperature, which seems in turn to be caused by less obstruction to evaporation by the air molecules. In order that the rate of evaporation be the same in the two cases, the temperature must drop to a level at which the rate of evaporation at this elevation is equal to that at the lower altitude, which it does. At this point the heat supplied is just balanced by the heat dissipated in evaporation.

The above cases are almost identical to the baking of cakes at various altitudes in so far as temperature and evaporation are concerned. The only difference is that, instead of having a constant amount of heat supplied at the different altitudes, one has a constant oven temperature. This explanation for the drop in temperature in the solution explains the drop in temperature inside the cakes as the altitude is increased. At high altitudes more heat is conducted into the cake than at low altitudes because of the greater temperature difference between cake and oven. Therefore, the rate of evaporation is slightly higher at high altitudes in order to dissipate the slightly greater amount of heat.

If one compares the data at some one altitude, it will be found that the rate of evaporation increased steadily as the temperature within the cake increases, but that it reached its maximum value when the temperature was about 85° C. In other words, the maximum rate of evaporation was reached before the maximum temperature was attained. This was as expected, since it was found that nearly all the evaporation took place from the outer centimeter, where a high temperature was reached more quickly than further inside the cake where the recorded temperatures were measured.

There are apparently at least two factors which are believed to increase the tenderness of the cakes as the altitude is increased. These are the increased expansion and the reduced internal temperature. The increased expansion is probably because of the increased volume required by the water vapor liberated at low atmospheric pressures. An increased tenderness caused by reduced internal temperature is assumed by applying the knowledge gained in the study of the effect of temperature on coagulating egg white.

It is not likely that the increased expansion is the result of the reduced temperature or the assumed result of reduced temperature, i. e., decreased tensile strength. If the charts of the temperature vs. time, and height vs. time, are compared, it will be seen that the temperature up to the point of maximum volume is almost identical, regardless of the altitude, provided the same recipes are used. Therefore, although coagulation resulting from high temperature doubtless stops expansion, the reduced internal cake temperature cannot be responsible for the increased expansion at high altitudes.

Certainly increased expansion cannot be the whole cause of increased tenderness, because it will be noticed that in the expansion studies on the corrected recipes the sea level cakes raised more than those baked at the higher altitude, although the strength of the structures was about the same in each case.

It seems likely that the reason the flour increases the strength is because of the protein it contains, although we have no evidence, nor could we find any, other than that, as one increases the flour content, the strength of the cake crumb increases.

Just why the sugar decreases the strength is not at all evident. It may be because of its effect on the coagulating protein,* or it may hinder the binding of the protein particles. It is not likely that the cause is molecular, since levulose of only about half the molecular weight may be substituted approximately gram for gram.

The study of the effect of acid on the temperature of initial coagulation would indicate that various amounts of acid should affect the tenderness of the resulting cake (which was not the case), provided that the sooner coagulation commences the more complete the reaction, and that the strength of the cake is a function of the amount of coagulation.

The effect of increases in sugar concentration would indicate an effect similar to that found in the cake.

Although the recipes for angel food cake have a great practical value, the author feels that the most valuable result of the work is the finding that this type of flour mixture yields to investigation, and that the recipe conforms to a systematic scheme and is not a "hit or miss" proposition as formerly supposed. This result gives hope of proving that the more complex types of flour mixtures conform to some definite order.

SUMMARY

Various methods and manipulations have been investigated for the production of angel food cakes, and the following is considered to be the best: The whites of fresh eggs should be beaten, with about 1 to 2 percent potassium acid tartrate, to a specific gravity of not less than 0.150 and not more than 0.170. Part or all of the sugar should be added to this foam and *beaten* in for about 30 seconds. Then the flour and any remaining sugar should be added and *stirred* in just sufficiently to insure even distribution throughout the batter. The batter then should be placed in a tube pan and baked at 180° C. (350° F.) for about 30 to 40 minutes, depending on the size of the cake.

*It has been found that there was a difference in the amount of protein dissolved from the baked cake with differences in the sugar content of the batter. In a recipe containing 150 gms. sugar, 1 to 2 percent more of the protein was dissolved out of 5 grams of cake by means of 400 ml. of water and one hour of shaking, than for the recipe containing 120 gms. of sugar. However, since the total amount dissolved was never greater than 10 percent nor less than 5 percent, this difference was not thought to be important.

The effect of acid on the production of the cake has been shown to be different for the various kinds of acid. The general effect of acid is apparently the result of its action on the coagulating or coagulated protein; and was not caused by an inversion of the sucrose.

The temperature of the oven has been shown not to affect the tenderness of the cake appreciably, and certainly not in the manner stated by some writers. The higher temperature produces the more desirable product.

The data indicate that the undesirable effect of egg age is caused by hydrolysis of the proteins, and not by liquefaction alone.

A method of measuring tensile strength or tenderness has been successfully used.

On the basis of the effect of changes in amounts of ingredients and in altitude on the tensile strength, an equation has been obtained which expresses all the possible combinations of ingredients for the production of a successful angel food cake for any altitude, and this equation has been tested up to 15,000 feet altitude.

With increases in altitude it has been shown that the amount of expansion during baking increases; the cake becomes more tender; the final cake volume changes and is related to the tenderness; the amount and rate of evaporation increases; the maximum internal cake temperature decreases; the volume of the vapor escaping increases; and the color of the crust becomes lighter. An explanation for each effect has been given.

A study has been made of the influence of acid and sugar on the temperature of initial coagulation of egg white, and of the effects of temperature and acid content on the properties of coagulated egg white.

Methods have been devised and used successfully to test the properties of coagulated egg white.

It has been shown that the lower the temperature of coagulation the more tender the resulting material, and that acid also makes a similar change in its properties.

ACKNOWLEDGMENTS

REFERENCES

(1) HUNT AND ST. JOHN
1931. Angel Food Cake From the Thick and Thin Portions of Egg White. J. Home Econ. 23, 1151. Also, Scientific Paper No. 192, College of Agr. and Exp. Sta., State College of Washington.

(2) GREWE AND CHILD
1930. The Effect of Acid Potassium Tartrate as an Ingredient in Angel Cake. Cer. Chem. 7, 245.

(3) BARMORE, M. A.
1934. The Influence of Chemical and Physical Factors on Egg White Foams. Colorado Exp. Sta. Tech. Bul. 9.

(4) MENDELSOHN, S.
1933. Tartrate Substances Used in Baking Powders. American Journal Pharmacy 105, 301.

(5) LOWE, B.
1932. Experimental Cookery. John Wiley & Sons, New York.

(6) HARREL, C. G.
1927. Value of Hydrogen-ion Concentration and Buffer Value Determinations in Testing and Use of Flours. Cer. Chem. 4, 423.

(7) LA MOTTE, KENNEY AND REED
1932. pH and Its Practical Applications, p. 145, Williams and Wilkins Company, Baltimore.

(8) MACLEOD AND NASON
1930. Chemistry and Cookery. McGraw-Hill, New York.

(9) PLATT, W.
1930. Staling of Bread. Cer. Chem. 7, 1.

(10) PLATT AND KRATZ
1933. Measuring and Recording Some Characteristics of Test Sponge Cakes. Cer. Chem. 10, 73.

(11) REED, S. J.
1931. Some Factors Affecting the Quality of Angel Food Cake. M.S. Thesis, Kansas State College of Agr. and App. Sci.

(12) SAYRE, WILLAMAN AND KERTESZ
1931. Factors Affecting the Quality of Commercial Canning Peas. Tech. Bul. No. 176, New York State Agri. Exp. Sta., Geneva, New York.

(13) BONNEY, CLIFFORD AND LEPPER
1931. An Apparatus for Determining the Tenderness of Certain Canned Fruits and Vegetables. Circ. 164, U. S. Dept. of Agr., Washington, D. C.

(14) DARROW, G. M.
1931. Effect of Fertilizers on Firmness and Flavor of Strawberries in North Carolina. Am. Soc. Hort. Sci. Proc. 231-5.

(15) Cochran and Webster
1931. Effect of Fertilizers on the Handling Qualities and Chemical Analyses of Strawberries and Tomatoes. Amer. Soc. Hort. Sci. Proc. 236-443.

(16) Shoemaker and Greve
1930. Relation of Nitrogen Fertilizer to the Firmness and Composition of Strawberries. Ohio Agr. Exp. Sta. Bul. 466.

(17) Clark, J. H.
1928. Pressure Tests of Strawberries. N. J. Agr. Exp. Sta. Ann. Report, p. 227.

(18) Blake, M. A.
1929. Device for Determining the Texture of Peach Fruits for Shipping and Marketing. N. J. Agr. Exp. Sta. C 212.

(19) Allen, F. W.
1929. Use of the Pressure Tester in Determining the Maturity of Bartlett Pears for Eastern Shipment. Calif. Agr. Dept. Bul. 18:346-9.

(20) Blake, M. A.
1928. Some Results of Flesh Texture Tests with Peaches. Amer. Soc. Hort. Sci. 300-5.

(21) Dack, Woolpert, Noble and Halliday
1931. Experimental Study of Possible Routes of Contamination of Cakes with Food Poisoning Staphylococci. Jour. of Preventive Medicine 5, 391.

(22) Hall, H.
1930. Cake Temperature While Baking, and Its Effects on the Starches of Cake Flours. Baker's Helper. p. 340, February 1.

(23) Stout and Drosten
1933. Heat Flow Through Bakery Products, I. Time-Temperature Relationships Existing During the Baking of Bread. J. Ind. and Eng. Chem. 25, 428.

(24) Balland
1893. Compt. rend. 117, 519.

(25) Balland
1893. Jour. de Pharm. et Chim. Series 5, tome 27, p. 16.

(26) Mallett, J. W.
1888. Experiments upon Alum Baking Powders, and the Effects upon Digestion of the Residues Left Therefrom in Bread. Chem. News. Nos. 1515-1516.

(27) Read, O. B.
1930. The Baking Temperature of Bread. Proc. Iowa Acad. Sci. 37, 231.

(28) Reussol, J.
The Survival of Pathogenic Bacteria in Bread After Baking. Rev. intend. mil. 20, 122. Chem. Ab, 2 115 (1908).

(29) HALLIDAY AND NOBLE
1928. Hows and Whys of Cooking. University of Chicago Press.

(30) PETERSON, M. W.
1930. Baking Flour Mixtures at High Altitudes. Colo. Exp. Sta. Bul. 365.

(31) A. O. A. C.
1930. Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists.

(32) JACKSON AND MATHEWS
1932. Some Physical Properties of Levulose and Its Estimation by Copper Reduction Methods. Research Paper 426. Also Bureau of Standards Journal of Research 8, 403.

(33) STADLER, F. G.
1932. The Inversion Problem in Sugar Manufacture. International Sugar Journal 34, 273. Also Archief, deel III, Mededeelingen, No. 18, pp. 689, (1931).

(34) LEVENE AND MORI
1929. The Carbohydrate Group of Ovomucoid. Jour. Biol. Chem. 84, 49.

(35) LEVENE AND ROTHEN
1929. On the Molecular Size of the Carbohydrates Obtained from Egg Proteins. Jour. Biol. Chem. 84, 63.

(36) ....
1933. A Treatise on Cake Making. Standard Brands Inc., New York City, N. Y.

(37) BALLS AND SWENSON
1934. Proteolysis in Stored Eggs. Ind. and Eng. Chem. 26, 570.

(38) KATZ
1928. Gelatinization and Retrogradation of Starch in Relation to the Problem of Bread Staling. Walton's Comprehensive Survey of Starch Chemistry, Chem. Cat. Co., New York.

(39) ROHWER, C.
1931. Evaporation from Free Water Surfaces. U. S. Dept. Agr. Tech. Bul. 271.

(40) MARVIN, C. F.
1915. Vapor Pressure, Relative Humidity, and Temperature of the Dew Point. U. S. Dept. of Agr., Weather Bureau, 235.

(41) VAILLANT, P.
.... The Evaporation of Aqueous Solutions. Compt. rend., 148, 1099. Also Chemical Abstracts 4, 2061 (1910).

(42) WALKER, LEWIS AND MCADAMS
      1923.   Principles of Chemical Engineering.   McGraw-Hill
      Book Company, New York.

(43) KEENAN, J. H.
      1930.   Steam Tables and Mollier Diagram.   American Society
      of Mechanical Engineers, New York.

(44) ALSBERG, CARL L.
      1935.   Wheat Studies of the Food Research Institute.   Starch
      and Flour Quality.   XI, 229.

(45) ALSBERG AND GRIFFING
      1925.   The Effect of Fine Grinding on Flour.   Cer. Chem. 2,
      325.

(46) A. O. A. C.
      1919.   Official and Tentative Methods of Analysis of the Asso-
      ciation of Official Agricultural Chemists.   2nd Edition.

(47) BLISH AND SANDSTEDT
      1933.   An Improved Method for the Estimation of Flour
      Diastatic Value.   Cer. Chem. 10, 189.

(48) MARKLEY, MAX C.
      1934.   Flour Particle Size by the Sedimentation Method.   Cer.
      Chem. 11, 654.

(49) KING, FLORENCE B.
      1934.   Private Communication.

(50) STANLEY, LOUISE
      1934.   The Bureau of Home Economics Studies Eggs and
      Poultry.   U. S. Egg and Poultry Magazine, June, p. 14.

(51) BARMORE, MARK A.
      1935.   The Baking of Angel Food Cake at Any Altitude.   Colo.
      Exp. Sta., Tech. Bul. 13.

(52) GREGG, W.
      1922.   The Standard Atmosphere.   Nat. Advisory Committee
      for Aeronautics Technical Report 147.

(53) ALMQUIST AND LORENZ
      1932.   Liquefaction of Egg Whites.   U. S. Egg and Poultry
      Magazine 38, 20, April.