ABSTRACT

THE EFFECT OF BAKING TEMPERATURE ON THE QUALITY CHARACTERISTICS OF ANGEL CAKES

by Doha A. Elgidaily

This investigation was primarily designed to determine the effect of the baking temperatures of 177°, 191°, 204°, and 218°C. on the quality characteristics of angel cakes. Data obtained from sensory evaluation and numerous objective measurements of the quality characteristics were correlated to achieve the secondary objective of this study which was to assess the validity of objective measurements that could be performed in laboratories with limited equipment.

Cakes were prepared from commercial one-step cake mixes and each of the four variables of oven temperature was replicated four times. The specific gravity and pH of the cake batter were determined as indications of control of all variables except the oven temperature. Time-temperature relationships were continuously recorded during baking from potentiometer leads positioned 2.5 and 5.0 cm. from the bottom of each cake pan.

The cakes were evaluated by a six-member panel using a 7-point numerical scale qualified with descriptive terms.

The objective measurements included index of volume, percentage of weight loss during baking, moisture determinations, percentage of sand retained, compressibility as determined by penetrometer and the Kramer shear-press readings, tensile strength, and tenderness.

The temperatures within the cake rose at a rate dependent on the oven temperature with the slowest rate of temperature rise recorded for the 177°C. oven. The differences in the maximum internal temperatures of 98.0°, 99.5°, 100.0°, and 100.4°C. reached by the cakes baked at 177°, 191°, 204°, and 218°C., respectively, were very highly significant.

The statistical analyses of sensory evaluations indicated very highly significant differences for texture, tenderness, moistness, and color of the crumb scores among the cakes baked at the four oven temperatures. Cakes of light, open texture were produced at the 177° and 191°C. baking temperatures as compared to the compact texture of cakes baked at the two other oven temperatures. The optimum moistness of angel cakes as well as the desirable white color of the crumb were secured at baking temperatures not higher than 204°C.

Statistical differences were indicated by objective measurements. Index of volume measurements showed a very highly significant and continuous decrease as the baking temperature increased. Cakes with more open texture were produced at baking temperatures of 177° and 191°C. according to the results of the sand retention test. Penetrometer measurements indicated cakes were more compressible when baked at 177° and 191°C. The shear-press measurements for compressibility based on maximum force and area-under-the-curve, showed more force was necessary to compress cakes baked at 218°C. as compared with cakes baked at the three other oven temperatures. The same trend was indicated by the tenderness measurements for the shear-press based on area-under-the-curve, showing that cakes baked at temperatures higher than 204°C. required more force to be sheared.

No significant differences among cakes baked at the four oven temperatures were indicated by the percentages of weight loss during baking, percentages of moisture, tenderness values based on maximum force, and tensile strength measurements.

Very highly significant relationships existed between texture scores and tenderness scores, moistness scores, and index of volume measurements. Very highly significant correlations were also indicated between the tenderness scores and index of volume measurements, and compressibility based on the maximum force readings of the shear-press. Area-under-the-curve tenderness values determined by the shear-press showed a very highly significant relationship with shear-press measurements for compressibility based on on both maximum force and area-under-the-curve values.

The highly significant correlation found between the sand retention test and texture scores of angel cakes, indicated the validity of this test to measure texture of angel cakes. Because of the high standard deviations, however, the reliability of this test is questioned.

The very highly significant relationship between shear-press values for compressibility as indicated by maximum force and area-under-the-curve, tenderness scores and the penetrometer values, indicated the penetrometer was a valid instrument for determining compressibility of angel cakes.

According to the results of this investigation, baking temperatures of 177° and 191°C. were more satisfactory for baking angel cakes than baking temperatures of 204° and 218°C. Thick layers developed in cakes baked at 204° and 218°C. as a result of a partial collapse of the structure after they were removed from the oven.

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INTRODUCTION

Angel cakes are one of the most delicate desserts which are usually liked for their fragile texture and subtle flavor. However, at the present time the optimum oven temperature for baking angel cakes is not clearly defined.

Angel cake formulas appearing in the recipe books published many years ago, recommended low oven temperatures of 135^{o} to 163^{o}C. for baking the cakes. It was theorized that hot oven temperatures would toughen the egg white proteins during baking and cakes with poor quality characteristics would result.

In more recent years, some angel cake formulas have suggested baking temperatures ranging from 177^{o} to 218^{o}C. with the resultant adjustment in baking time. Indications are that cakes of increased volume, moistness, and tenderness result when temperatures ranging from 177^{o} to 218^{o}C. are used although the top crust of the cakes may be cracked and/or burned when baked at the high oven temperatures.

Thus, oven temperatures ranging from low to high have been recommended for baking angel cakes. The effect of these baking temperatures on the quality characteristics of angel cakes has not been elucidated. Therefore, the primary objective of this study was to define the effect of baking temperatures of 177°, 191°, 204°, and 218°C. on the quality characteristics of angel cakes.

Quality characteristics may be determined by sensory evaluations and objective measurements. Methods used for objectively measuring the quality characteristics of angel cakes are numerous. Some measurements have been made using instruments devised by research workers within their laboratories. Fabricated instruments, such as a penetrometer and the Kramer shear-press have also been used. The accuracy and precision of these instruments may vary greatly as do the cost and availability. Therefore, to aid researchers and/or classroom instructors in assessing quality characteristics of cakes with available instruments in laboratories with limited equipment, a secondary objective of this study was to correlate data from numerous objective measurements and sensory evaluations.

REVIEW OF LITERATURE

Baking Temperatures for Angel Cakes

The conflicting reports which appear in the literature concerning the most satisfactory oven temperature for baking angel cakes, leave some doubt as to the selection of the most desirable baking temperature. According to Lowe's report (36), there is no "best" temperature as acceptable angel cakes may be baked over a range of temperatures.

Early workers (6, 22, 35, 42) recommended the use of low oven temperatures to bake angel cakes of high quality. In more recent years, moderate to high oven temperatures have been advocated to obtain angel cakes with increased volume, moistness, and tenderness (16, 40).

Rates of Temperature Rise During Baking

The rates of temperature rise during the cooking of baked products have been measured by various techniques. Read (52) used specially designed thermometers to measure the temperatures at the center and just below the surface of loaves of bread. However, it was necessary to open the oven door to read the thermometers at regular time periods.

Stout and Drosten (54) used thermometers to measure time-temperature relationships during the baking of bread at oven temperatures ranging from 200° to 250°C. The plotted time-temperature curves for the optimumly baked loaves showed a rapid rise in temperature during the first one-third of the baking period, a slow rise for the next period, and a practically constant temperature for the last one-third of the baking period.

Cakes reached a maximum temperature of 98.3°C. when baked at an oven temperature of 182°C., according to a study by Hall (21). A maximum indicating thermometer was used in the experiment.

In his investigation of the influence of altitude on characteristics of angel cakes, Barmore (5) used a single junction thermocouple lead from a Leeds and Northrup potentiometer to measure the internal temperature of cakes at a point 1.5 cm. from the bottom of the pan during baking at oven temperatures of 138°, 163°, and 180°C. When the maximum internal temperatures of cakes baked at the three temperatures were compared, Barmore noted the temperatures of cakes baked at 138° and 163°C. were the same. The highest baking temperature resulted in an increased of approximately 2°C. in the internal temperature of the cakes.

Iron constantan thermocouples, enclosed in glass sheaths, were used to measure the internal temperatures of angel cakes by Reed, Floyd, and Pittman (53) in their study of the effect of baking pans on the temperature of baking and the tenderness of angel cake. Round pans, 10 in. in diameter, were used in the experiment. Maximum internal temperatures recorded were 104°, 105°, 107°, 108°, and 110°C. for cakes baked in tin, aluminum, Russian iron, enamel, and glass pans, respectively, without center tubes. The maximum temperatures recorded for cakes baked in tin, aluminum, and Russian iron pans with center tubes were 102°, 103°, and 108°C., respectively.

Looft (35) indicated internal temperatures of angel cakes increased from 3° to 5°C. as the baking temperature increased from 150° to 170°C. However, the maximum temperature reached by the cakes during baking was dependent on the baking time. Her study showed the 96°C. internal temperature of cakes baked at 150°C. for 80 min. was only 1°C. higher than the internal temperature of cakes baked for 65 min. at the same temperature.

Miller and Derby (39) advocated the use of a multipoint recorder to determine temperature changes in the oven and at various locations within cake batters during baking. Measuring changes which occur in cake batters during baking are useful aids in comparing the effects of different ingredients or mixing techniques on the internal characteristics, according to the report.

Determination of Doneness

The browness of the crust has traditionally been used as an indication of the doneness of angel cakes (6, 42). Limited attempts have been made to define doneness by time-temperature relationships.

Bread was evaluated for doneness after baking for various periods of time in a study by Stout and Drosten (54). The data were examined in reference to time-temperature relations recorded during baking. The authors suggested an internal temperature of 100°C. must be maintained within the loaf of bread for a period of 10 min. to adequately bake the bread. They further concluded that oven temperatures should be regulated to permit maintenance of an internal temperature of 100°C. within the loaf of bread for the prescribed time period without excessive browning of the crust.

Looft (35), in her study on the optimum baking temperature for angel cakes, removed cakes from the oven when they had reached and maintained their maximum temperature for 2.5 min. Lowe (36) suggested that continuing the baking too long after the maximum temperature had been reached would bind more water and, therefore, increase the toughness of angel cakes.

Effect of Baking Temperature on Quality Characteristics

Baking temperature is an important factor in baking high quality angel cakes. However, few workers have specifically designed studies to investigate the effect of oven temperatures on quality characteristics.

Early investigations

In their reports, Barton (6) and Mortenson (42) recommended oven temperatures ranging from 149° to 177°C. to bake angel cakes with good volume and acceptable texture. These workers assumed baking temperatures above 177°C. would toughen the egg white proteins.

Halliday and Noble (22) advised baking angel cakes at an oven temperature of 149°C. for 1-1/2 hr. They believed egg white coagulated at a low temperature would be more tender than that coagulated at a higher temperature. The Institute of American Poultry Industries bulletin (28) also advocated low oven temperatures ranging from 149° to 163°C. to bake tender angel cakes of good volume.

Barmore (4) suggested oven temperatures of not less than 149°C. nor greater than 177°C. for baking angel cakes. Cakes baked at oven temperatures between 149° and 163°C. were "dry-tasting," while cakes baked at oven temperatures between 163° and 177°C. were "moist," according to the report. Tenderness of the cakes did not decrease at these higher baking temperatures. However, volume increased as the baking temperature increased.

To study the effect of high oven temperatures on tenderness of angel cakes, Barmore (5) baked a series of cakes at oven temperatures ranging from 138° to 180°C. In contrast to the expected results, Barmore found tenderness and volume of cakes increased as the baking temperature rose. Because the maximum internal temperature of the cake did not increase appreciably in proportion to oven temperature used for baking, Barmore suggested the use of these high oven temperatures did not toughen the egg white proteins.

In her study of the optimum baking temperature for angel cakes, Looft (35) investigated the effect of oven temperatures of 140°, 150°, 160°, 170°, and 180°C. on the quality characteristics. Contrary to Barmore's findings (4), the cakes baked at the lower oven temperatures, although they lost more moisture during baking, felt and tasted more moist than cakes baked at the higher oven temperatures. The volume of the cakes increased as the baking temperature temperature increased but tenderness decreased when the cakes were baked at the higher temperature. From the results of her study, Looft concluded an oven temperature of 150°C. was most desirable for baking angel cakes.

Hellickson (26) reported a project undertaken to determine the correct procedure for baking angel cakes. She recommended a baking temperature of 149°C. to consistently produce light, moist, tender angel cakes. Burke and Niles (11) found the moisture loss during baking of cakes in a 177°C. oven was less than in cakes baked at 163°C. Cakes baked at 177°C. were judged superior in volume and quality characteristics. The crusts, however, had more cracks than the crusts of cakes baked at 163°C.

Grewe and Child (19) used an oven temperature of 154°C. in their study on the effect of acid potassium tartrate on the quality characteristics of angel cakes. Hunt and St. John (27) baked satisfactory angel cakes prepared from the thick and thin portion of egg whites at an oven temperature of 163°C.

In their investigation of the effect of pan materials on the tenderness of angel cakes, Reed, Floyd, and Pittman (53) used an oven temperature of 163°C. The investigators concluded the thermal efficiencies of the aluminum, enamel, glass, Russian iron, and tin pans used in the study, affected the maximum internal temperatures of the cakes and hence, the tenderness. A low internal cake temperature yielded a more tender product as measured by breaking strength. Ranked in order of decreasing tenderness, were cakes baked in tin, aluminum, Russian iron, enamel, and glass pans.

Other reports

In 1943, Miller and Vail (40) studied the quality characteristics of angel cakes baked at 177°, 191°, 204°, 218°, and 232°C. Their results showed volume and tenderness increased with the increase in baking temperature from 177° to 218°C. Cakes baked at 204° and 218°C. received the highest palatability scores. The investigators concluded the most satisfactory baking temperatures for angel cakes were 204° and 218°C. for 35 and 30 min., respectively.

Dudgeon (16), in 1947, recommended a moderate baking temperature of 163°C. for angel cakes. When higher temperatures were used to bake the cakes, deep cracks developed in the top crust. However, the interior of the cakes was moist, tender, and delicate.

Reported research studies of angel cakes conducted by Carlin and Ayres (12, 13) and Harns et al. (23), used a baking temperature of 177°C. to study the effect of added ingredients or egg white quality on the quality characteristics of angel cakes. More recent studies on angel cakes undertaken by Funk, Zabik, and Downs (18) and Brown and Zabik (10) used a baking temperature of 177°C. in a forced convection oven to produce satisfactory angel cakes. Commercial cake mixes (2) recommend baking temperatures ranging from 177° to 191°C. and directions given on the package suggest cracks usually develop on the top surface of the cake during baking.

Sensory Evaluation of Quality Characteristics

According to Griswold (20), sensory evaluation is essential to most food experiments because the important questions of how a food tastes, smells, looks, and feels to the ultimate consumer can only be answered in this way. Sensory evaluation is, however, subject to human judgment which is individual and not always consistent.

Boggs and Hanson (8) reported panel evaluation is usually desirable for evaluating food acceptability not as an entity in itself, but as a basis for correlation with objective measurements. Funk, Zabik, and Downs (18) stated sensory evaluations are essential to validate objective measurements.

Several systems are available for sensory evaluation. As reported by Griswold (20), numerical scoring of product characteristics is the most frequently used test to evaluate food quality. The numerical scale may or may not be qualified with descriptive adjectives. However, descriptive adjectives are helpful to the judge while he is evaluating a product.

Meyer (38) reported numerical scoring of product characteristics is useful for obtaining a basis by which changes caused by preparation methods can be evaluated. Qualities commonly evaluated in baked products are appearance, color, aroma, flavor, tenderness, moistness, and general acceptability.

From an extensive review of the literature, Amerine, Pangborn, and Roessler (1) concluded careful selection of judges is essential to achieve maximum discrimination among the products subject to evaluation. Some form of screening is helpful to eliminate judges who are unable to discriminately evaluate food products.

The size of the panel needed for sensory evaluation of a food product varies with the sensitivities of the judges as well as the range in acceptability of the product. According to Lowe (36), small expert panels of four to ten members are satisfactory for laboratory studies.

Amerine, Pangborn, and Roessler (1) inferred the influence of health, age, sex, and smoking on panel performance is not critical. However, the results of the sensory panel performance may be influenced by emotional factors, interest, motivation, knowledge, comparison of results, adjustment to the test situation, and memory.

Many factors such as environment, sample preparation, serving conditions, and the number of samples served may influence the results of the sensory evaluation (1). Environmental factors may be controlled with the use of specially designed taste panel rooms. Controlling such factors as sample temperature, size, and identification are essential. Samples are best identified by a code rather than by the name of the treatment. The number of samples served at one time is dependent on the nature of the food product being tested and the method of scoring. More samples can be tasted at a session if the flavor is bland rather than strong. Also, more samples can be effectively evaluated at a session if a simple method of scoring is used rather than a complex scoring method.

Objective Measurements of Quality Characteristics

Objective measurements of quality characteristics generally offer more possibility for accuracy and precision than do subjective evaluations. Therefore, to evaluate differences among several variables, many investigators subject food products to a series of objective measurements. Commonly used measurements include volume, moisture, cell structure, compressibility, tensile strength, and tenderness.

Volume

The volume of baked products may be determined by seed displacement. This method, as described by Binnington and Geddes (7), involves the displacement of a free-flowing solid material such as various types of seeds. Cake volume has been determined according to this method by many researchers (12, 13, 23, 27, 32, 35, 46).

Brown and Zabik (10) measured the volume of angel cakes baked in 15-1/2 x 4 x 4-in. pans before the cooled cakes were removed from the pans. The surface of the cake was covered with Saran before rape seeds were carefully poured onto the cake. The volume of the cake was calculated as the difference between the milliliters of seed measured with the cake in the pan and the milliliters of seed which the empty pan held.

Because volumetric measurements by seed displacement methods damaged the fragile structure of sponge cakes, Platt and Kratz (49) devised a method for determining an index to volume of baked products using a planimeter. After the outlines of representative slices of the cake were drawn on sheets of paper, a planimeter was used to determine the area within each outline. The results from several measurements were averaged for the index to volume of the cake. This method has subsequently been used by other research workers (40, 44).

Moisture

Brown and Zabik (10) determined the percentage of moisture in angel cakes by drying 2-gm., shredded samples to a constant weight in a vacuum oven at 90° to 100°C. and 29 in. of mercury. These research workers found no significant differences in the percentage of moisture of angel cakes prepared from liquid and spray-dried egg albumens.

Volatile losses occurring during baking have been calculated from the difference in the weight of the cake batter and the baked cake. Kraatz (32) found volatile losses increased as baking time at a given temperature increased. According to the results of her study on baking times and temperatures of angel cakes, cakes baked at 150°C. for 45 min. lost 13.2 per cent moisture while cakes baked at 170°C. for 25 min. lost only 10.2 per cent moisture.

In a study reported by Miller and Vail (40), angel cakes baked at 177°C. for 40 min., 191°C. for 35 min., 204°C. for 30 min., 218°C. for 25 min., and 232°C. for 21 min. lost 43.1, 36.7, 33.3, 32.9, and 30.6 per cent in weight during baking, respectively.

Cell structure

The cell structure or texture of baked products may be studied from permanent recordings made by ink prints or photography. Sand retention tests offer a quantitative measurement of the size of pores of baked products.

Ink prints and photography. Mohs (41) used a paste-like mixture of lamp black and oil to moisten the cut surface of bread. The slice was then pressed upon a piece of unsized paper to give an impression of the cell structure and shape of the bread. Child and Purdy (15) made ink prints of cake slices using stencil ink which was transferred to the cut surface of the cake by means of a soft brush. The surface of the cake was then pressed upon a piece of paper.

In their report, Platt and Kratz (49) noted only fair success in obtaining ink prints of sponge cake slices because the delicate grain of the product did not lend itself to this treatment. Therefore, they used photography to obtain permanent records of their baking studies, as did Harrel (24) and Heald (25). The shape and grain of baked products were recorded by Cathcart (14) by passing light through a thin slice of the product which had been placed on a sheet of photographic projection paper.

Contact prints, made from thin slices of a baked product, were suggested in a study by Matejovsky (37). The slice was placed between two glass plates, the lower of which was covered with a piece of filter paper which had been soaked in a 75 per cent solution of glycerine in water. The slice was then taken to a dark room and transferred to a piece of photographic paper. After exposure to a source of illumination, the photographic paper was developed in the usual manner. A number of prints were collected and used as a basis of comparison in analysis. A scale of porosity was developed using numbers from one to ten to denote increasing size of pores and this scale permitted accurate and easy comparison of results, according to the report.

Sand retention test. Because photographic records do not give results which can be measured quantitatively, Swartz (55) developed a sand retention test to estimate the grain of baked products. For this determination, a weighed piece of cake is placed on a board set at a 40° or 45° angle and sand is sifted over it. The piece of cake is then rotated to permit sand that is not retained in the pores to fall off. The sample is reweighed and the percentage of sand retained is calculated. If the grain of the product is coarse, more sand is retained than if the grain is fine, according to the report. The amount of sand retained was also influenced by the location from which the sample was taken, moisture content of the product, and the manner of adding the sand, according to the report.

Compressibility

Many of the methods described by various investigators for measuring compressibility of a baked product are based on the same principle. A sample of a given product is subjected to a specified weight for a given period of time. The amount of depression is measured. The instrument constructed for measuring compressibility obeys Hooke's law in that the strain produced is in proportion to the strain producing it.

Devised instruments and pentrometers. Making use of the above principle, one of the early devices for compressibility was developed by Katz as reported by Powers and Simpson (50). The descent of a weighed plunger, as it compressed the baked product for a period of 3 min., was indicated by means of a pointer. Platt (48) developed a similar device by attaching a plunger to the bottom of one pan of a large analytical balance. The depression of the plunger into a slice of bread was recorded in millimeters by the pointer on the balance. Similar instruments were devised and used by Miller and Vail (40), and Powers and Simpson (50) for compressibility measurements.

Bailey (3) also devised a compressibility tester by allowing an object of known weight to rest on a prism of bread for a period of time. Owen and Van Duyne (44) determined compressibility of cakes using a devised compressometer. This instrument, which was similar to that of Platt (48), had been modified by attaching a small electric motor which raised the platform holding the cake sample at a uniform rate.

King, Whiteman, and Rose (30), and King, Morris and Whiteman (31) measured the compressibility of cakes using a penetrometer. The amount of depression produced by the disc was recorded in centimeters on the scale machined on the moveable post which held the disc. Paul, Batcher, and Fulde (46), using a Precision Universal Penetrometer fitted with a flat disc, determined compressibility of cake by measuring the distance the crumb was flattened by the known weight of the disc over a specified period of time.

Kramer shear-press. The Kramer shear-press was developed to measure the tenderness of fruits and vegetables (33). The basic unit of the shear-press consists of a piston moving at a predetermined rate of speed, powered by a hydraulic drive system. The applied force is measured by compression of a proving ring dynometer. A sensitive pressure gauge, connected to the proving ring and through an amplifier to a recording device, provides a continuous recording of time-force curves to indicate the force required to compress a food product.

In a review article, Kramer (34) stated the shear-press could be used to measure quality characteristics, such as compressibility, of baked products. Funk, Zabik, and Downs (18) investigated the use of the shear-press to measure compressibility of angel cakes of three degrees of toughness. The plunger from the succulometer cell and the fixed-blade upper assembly of a standard shear-compression cell were used to measure the compressibility of cake samples. Very highly significant correlations between the two different sets of Kramer shear-press measurements of compressibility and sensory evaluations of tenderness were obtained in this investigation.

Brown and Zabik (10) measured compressibility of angel cakes prepared with albumen processed in five different ways, using the Kramer shear-press and statistically significant differences were found. Parks, Zabik, and Stine

(45) obtained no significant differences among five variables of chocolate cakes when the Kramer shear-press was used to measure compressibility.

Tensile strength

Platt and Kratz (49) developed one of the first and most widely used procedures for determination of tensile strength of cake. In this procedure, they suspended an hourglass-shaped cake sample, which measured 3.8 cm. across the center, from one end by a clamp. A small container was hung from a clamp on the opposite end of the cake sample. The investigators allowed water to flow into the container at a constant rate of 200 gm. per min. until the total weight caused the cake sample to break or tear across the center section. Tensile strength was calculated from the total weight consisting of the combined weights of the container, water, lower clamp, and cake sample, divided by the area of the break.

Barmore (4, 5), Kraatz (32), Looft (35), and Miller and Vail (40) devised similar instruments to measure tensile strength of angel cakes. In her study of the effect of baking temperature on characteristics of angel cakes, Looft (35) found no significant correlations between tenderness scores and tensile strength measurements. Nevertheless, in studies conducted by Briant and Williams (9), Jordan, Barr, and Wilson (29), and Peet and Lowe (47), high correlations were obtained between sensory evaluation and tensile strength of yellow cakes as measured by similar devised instruments.

Tensile strength of angel cakes was measured by Reed, Floyd, and Pittman (53). However, sand rather than water was used with the instrument described by Platt and Kratz (49). Pyke and Johnson (51) used a similar procedure to that of Platt and Kratz (49) for tensile strength determinations. The instrument was modified to reduce the potential danger of accidental damage to the cake samples by using flat pieces of wood, rather than metal clamps to grip the cake samples.

Funk, Zabik, and Downs (18) used a specially designed attachment for the Kramer shear-press to measure the tensile strength of hourglass-shaped angel cake samples. The attachment was designed from the instrument described by Platt and Kratz (49). Readings of the ram upstroke were obtained by rewinding the chart-drive cable of the shear-press. Very highly significant correlations between the shear-press measurements of tensile strength and sensory evaluations of tenderness were obtained in the study when calculations were based on the maximum force, but no correlation was found when calculations were based on area-under-the-curve.

Brown and Zabik (10) measured the tensile strength of angel cake slices in their study on the functional properties of heat treated liquid and spray-dried albumen. No significant differences among cake samples were obtained in this study.

In their study on the substitution of foam spray-dried acid whey solids for buttermilk solids in chocolate cake, Parks, Zabik, and Stine (45) found no significant differences in tensile strength among the five cake variables included in the study. These workers used the Kramer shear-press method as described by Funk, Zabik, and Downs (18) with the modification of a more sensitive electronic recorder for the shear-press.

Tenderness

The objective measurement of tenderness is complex, according to Griswold (20), because it must reflect the action of teeth in cutting, shearing, tearing, grinding, and squeezing. Hence, compressibility and tensile strength measurements may be determined as an indication of tenderness (20).

The Kramer shear-press equipped with the standard shear-compression cell, was used by Funk, Zabik, and Downs (18) to measure tenderness of angel cake samples. The correlations calculated from shear-press measurements and sensory evaluations of tenderness were very highly significant. Brown and Zabik (10) also measured tenderness of angel cake samples using the Kramer shear-press. However, no significant differences were found among cakes prepared from albumen processed in five different ways.

EXPERIMENTAL PROCEDURE

The primary purpose of this study was to investigate the effect of baking temperatures of 177°, 191°, 204°, and 218°C. on the quality characteristics of angel cakes. The quality characteristics were determined by sensory evaluation and objective measurements. A secondary purpose was to assess the validity of objective measurements which could be made in laboratories with limited equipment by correlating appropriate combinations of data obtained by sensory evaluations and/or objective measurements.

Design of the Experiment

Angel cakes were prepared from a common lot of household-size packages of commercial, one-step cake mix.[1] To provide sufficient slices of cake for sensory evaluation and objective measurements, two cakes were required for each replication. Therefore, the contents of two packages were combined for each batch of cake batter which was divided into two equal portions for baking. Each of the four variables of baking temperature was replicated four times.

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[1] General Mills, Inc., Minneapolis, Minnesota.

Preliminary Investigations

The procedure for mixing the cake was established through preliminary investigations. The directions of the manufacturer of the cake mix were followed after weights, given in ounces, and measures, given in cups, had been converted to grams and milliliters, respectively.

The baking time for each of the four oven temperatures was also established by preliminary investigations. Doneness of the cakes was determined according to the directions given on the package. When the cracks which developed in the top of the cake felt "dry to touch," the cakes were removed from the oven. Baking times of 44, 39, 35, and 32 min. were defined for the oven temperatures of 177°, 191°, 204°, and 218°C., respectively.

Method of Preparation

For each batch of cake, 650 ml. of distilled water at 15°C. were poured into a 20-qt. mixing bowl for a Hobart mixer, Model A-200. After weighing 850 gm. of cake mix on a 5-kg. capacity torsion balance, it was added to the water. With the mixer set at speed one, the mixture was blended for 30 sec. using the whip attachment. After the sides and bottom of the bowl were scraped with a rubber spatula, mixing was continued at the same speed for an additional 30 sec. The sides and bottom of the bowl were again scraped before the mixture was whipped at speed three for 4-1/2 min. To insure accurate timing, a GraLab timer, Model 171 was used. The specific gravity and pH were determined to insure uniformity of the cake batter.

Baking and Storage Procedure

Using 685 gm. per pan, the cake batter was poured into two tared, ungreased 16 x 3-1/4 x 4-in. aluminum pans. To dispell any large air pockets, a metal spatula was used to cut through the batter five times in a lengthwise direction.

Time-temperature relationships were continuously recorded during baking with a 12-point Brown Electronic Potentiometer high-speed recorder. Two iron constantan thermocouples were suspended into the cake batter and held in place by clamping to an aluminum bar which spanned the longitudinal center of the baking pan (Figure 1). The potentiometer leads were positioned 2.5 and 5.0 cm. from the bottom of the baking pan.

Mean progressive time-temperature relationships were determined for each baking temperature. The initial temperature recordings from each of the two points within each of the eight cakes baked at each of the four oven temperatures of 177°, 191°, 204°, and 218°C., were averaged. At 5-min. intervals throughout the baking period, temperature recordings from each of the two points were averaged. The final

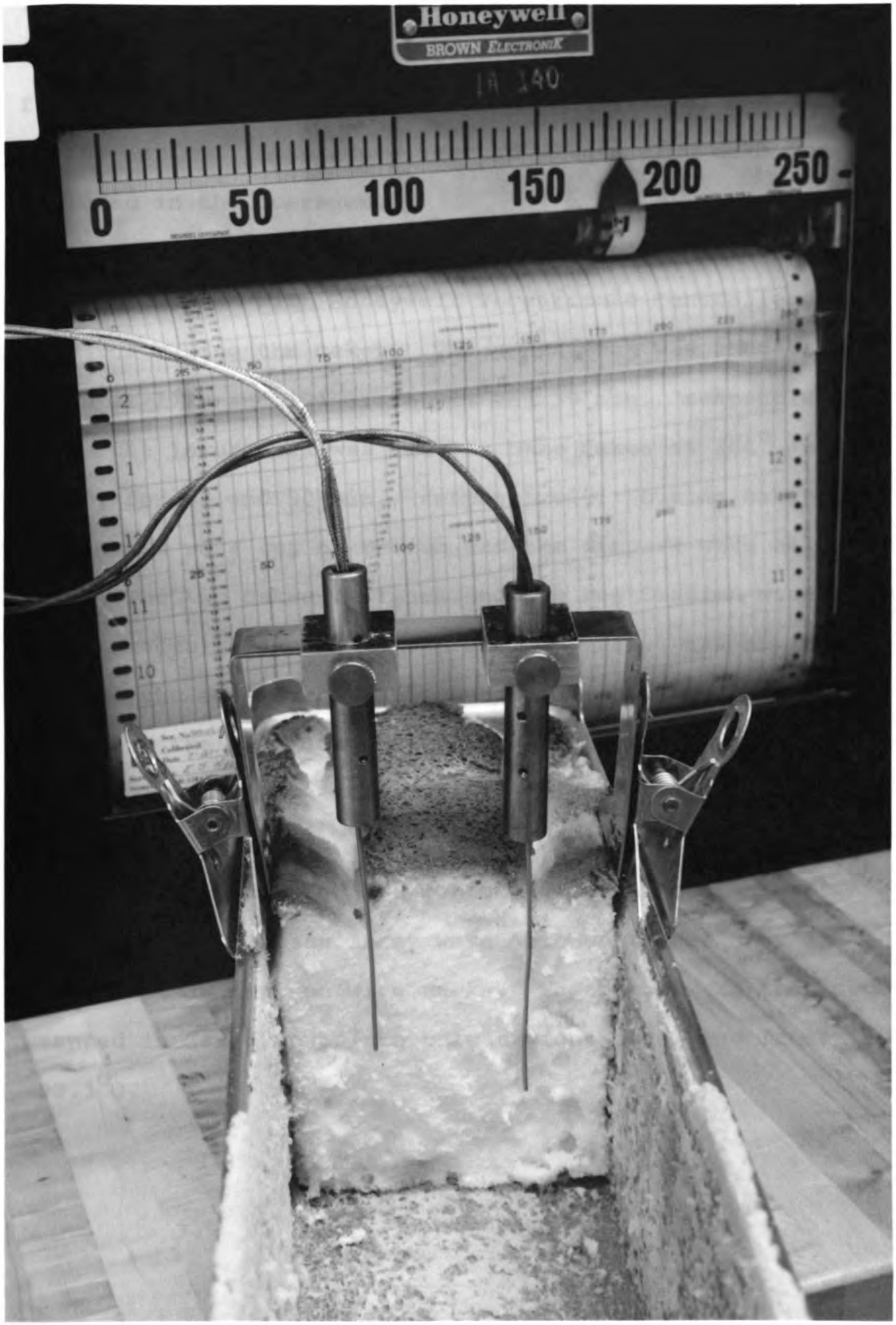

FIG. 1 Positions of potentiometer leads during baking of angel cakes at four oven temperatures.

5-min. interval of the baking period was reduced in length for 1 to 3 min. for the baking times of 44, 39, and 32 min. so the maximum temperature reached within each cake was included in the averages.

Two institutional heavy-duty Hotpoint ovens, Model HJ225, equipped with Honeywell Versatronic Controllers were used for baking the cakes. The upper deck was used to bake cakes at 177° and 191°C. for 44 and 39 min., respectively, while the lower deck was used to bake cakes at 204° and 218°C. for 32 and 30 min., respectively. During baking, oven grids were set on medium and the dampers were half open. The two cakes representing one replication were baked simultaneously, in the same preheated oven. All baking at each of the four oven temperatures was completed before resetting the oven controller to a different temperature.

Immediately after baking, the potentiometer leads were carefully removed. The cakes were then inverted and cooled in the pans for 1-1/2 hr. After the cakes were removed from the pans, they were allowed to cool for an additional 30 min. on wire racks. The cakes were then coded, wrapped in Saran, put into polyethylene bags, and frozen at -23.3°C.

Objective Measurements of Cake Batter

Control over all conditions of the study except the variable of oven temperature was necessary. As measures of control, the specific gravity and pH of the cake batter were determined.

Specific gravity of batter

The specific gravity of the batter of each replication was determined according to the method of Platt and Kratz (49). The technique used in this study involved a comparison of the average weight of one-third cup of cake batter to the average weight of one-third cup of distilled water at 25°C. The cake batter was carefully spooned into the one-third cup measure, leveled with a spatula and weighed to the nearest 0.1 gm. on a Mettler balance, model P-1000. The specific gravity was computed by dividing the weight of the cake batter by the weight of the distilled water. One determination of specific gravity was made from the batter of each replication.

pH of batter

The pH of the cake batter was determined using a Beckman Zeromatic pH meter equipped with calomel and glass electrodes. The batter used to measure the specific gravity was divided into two portions, duplicate readings of the pH were recorded and then averaged.

Subjective Evaluation of Baked Cakes

The investigator subjectively evaluated the appearance of each cake prior to preparing it for freezer storage. The color of the top, sides, and bottom, texture of the sides, and appearance of cracks which developed on the top of each cake were evaluated using descriptive terms (Appendix).

Preparation of Samples

All cakes were sliced in the frozen state using a Hobart slicer, Model 410, set at 70. Slices of cake were designated for sensory evaluation and objective measurements according to randomly devised rotation plans developed for each of the four replications of the variables (Figure 2). The four rotation plans permitted evaluation of samples from different positions within the cake by panelists and the objective measurements. All frozen slices of cake were individually re-wrapped in Saran and placed in polyethylene bags. They were stored in a -23.3°C. freezer until subsequent thawing and evaluation.

Sensory Evaluation

A circle, 5.25 cm. in diameter, was cut from the center of each frozen slice of cake designated for sensory evaluation using the previously described rotation plan

Rotation Plan I		Slice	Rotation Plan II	
Cake A or C	Cake B or D	number	Cake A or C	Cake B or D
Tensile strength		End	Tensile strength	
Compressibility	Judge 3	1	Sand retention	Tensile strength
Judge 1	Judge 2	2	Judge 5	...
Moisture	Tensile strength	3	Judge 3	Judge 6
Sand retention	Judge 4	4	...	Moisture
Volume	Volume	5	Volume	Volume & Tenderness
Judge 6	Moisture	6	Judge 1	Judge 2
Judge 2	Judge 3	7	Tensile strength	Compressibility
Volume & Penetrometer	Volume & Sand retention	8	Volume & Tenderness	Volume
Tenderness	Judge 1	9	Judge 4	Judge 3
Compressibility	Tensile strength	10	Penetrometer	Judge 4
Judge 5	Volume	11	Judge 6	Volume & Tensile strength
Volume	...	12	Volume & Compressibility	Judge 5
Penetrometer	Judge 5	13	Judge 1	Sand retention
Tensile strength	Judge 4	14	Moisture	Penetrometer
Tenderness	Judge 6	15	Judge 2	...
Tensile strength		End	Tensile strength	

FIG. 2 Sequences for cutting and evaluating the slices of angel cakes according to four rotation plans.

Rotation Plan III			Rotation Plan IV	
Cake A or C	Cake B or D	Slice number	Cake A or C	Cake B or D
Tensile strength		End	Tensile strength	
Judge 4	Moisture	1	Judge 1	...
Tensile strength	Judge 6	2	Tenderness	...
Penetrometer	Compressibility	3	Sand retention	Judge 4
Judge 5	Tensile strength	4	Judge 6	Judge 3
Volume	Volume	5	Volume & Sand retention	Volume & Tensile strength
Judge 3	Tenderness	6	Tensile strength	Compressibility
Sand retention	Penetrometer	7	Judge 4	Judge 1
Volume	Volume	8	Volume & Moisture	Volume & Tensile strength
Judge 6	Tensile strength	9	Judge 5	Judge 2
Judge 1	Judge 2	10	Judge 6	Judge 5
Judge 4	Volume	11	Compressibility	Volume & Penetrometer
Volume & Tenderness	Judge 2	12	Volume	Judge 3
Compressibility	Judge 3	13	Judge 2	Tenderness
Sand retention	Judge 1	14	Penetrometer	Moisture
Moisture	Judge 5	15	...	...
Tensile strength		End	Tensile strength	

FIG. 2 Continued

(Figure 2). The cake sample was wrapped in Saran and placed on a white, paper plate which had previously been coded with a random number. Samples were allowed to stand at room temperature for 1-1/2 hr. to thaw and come to room temperature before evaluation. Two samples from each of three replications were randomly presented at each session to each of the six, trained, panel members. Tap water, at room temperature, was served with the samples.

A numerical scale was used to evaluate the cakes for texture, tenderness, moistness, and color of the crumb. The scoring range was from 1 to 7, with 1 indicating the poorest and 7, the highest quality. Descriptive terms for the values of 1, 4, and 7, aided the panelist in the evaluation. The score card and instructions to the taste panel are included in the Appendix.

Objective Measurements

Several objective measurements were used to evaluate the quality characteristics of angel cakes. These included measurements of volume, moisture, cell structure, compressibility, tensile strength, and tenderness.

Index of volume

The index of volume for each replication was determined by averaging readings of three slices from each of the two cakes comprising a replication. Slices were taken from the center and a distance half-way between the center and both ends of the cake (Figure 2). The index of volume was made as outlined by Platt and Kratz (49). Defrosted cake slices were placed on sheets of paper and carefully traced. The area was measured by tracing the outline of the cake slice with a K & E Compensating Polar Planimeter. Each tracing was repeated three times, the readings were averaged, and converted to square centimeters.

Moisture of cake

The percentage of weight loss during baking was calculated as an indication of the moistness of the cakes. The percentage of moisture in the cakes was also determined.

Percentage of weight loss during baking. All cakes were weighed to the nearest gram before they were removed from the baking pans. The percentage of weight lost during baking was calculated according to the formula:

$$\frac{\text{Weight loss, in grams}}{\text{Weight of batter, in grams}} \text{ X } 100$$

The percentages of weight loss of the two cakes representing one replication were averaged.

Moisture determinations. Cake moisture was determined according to the A.O.A.C. method, 16-3 (b) (43). The designated, frozen cake slices were defrosted at room temperature for 1-1/2 hr. After removing the Saran wrapping from the slice, duplicate, shredded samples from each of the two cakes which comprised a replication, were weighed in tared aluminum-foil dishes to the nearest 0.0000 gm. using a Mettler balance, Model H15. The samples were dried for 5 hr. at 90° to 100°C. and 28 in. of mercury. Dried samples were cooled for 30 min. in a dessicator before reweighing. Four values were averaged to determine the moisture content of each replication.

Structure of the cell

While in the frozen state, a circle, 5.25 cm. in diameter, was cut from the center of each slice of cake designated for sand retention in the rotation plan (Figure 2). The samples were re-wrapped in Saran and allowed to thaw at room temperature for 1-1/2 hr. The samples were then weighed to the nearest 0.00 gm. using a Torbal torsion balance, Model PL-800. According to the method of Swartz (55), approximately 1 tsp. of sand was sprinkled over each piece of cake which had been placed on a 45°, inclined plane. The device holding the cake sample was revolved twice. The sample was then reweighed and the percentage sand retention was calculated using the formula:

$$\frac{\text{Weight of sand retained}}{\text{Original weight of sample}} \times 100$$

Duplicate measurements were averaged to indicate the structure of the cells of the cake.

Compressibility of cake

Compressibility was measured with a Precision Universal Penetrometer and a Kramer shear-press. For both measurements, circles of cake 5.25 cm. in diameter, were cut from frozen cake slices. Each sample was re-wrapped in Saran and allowed to defrost at room temperature for 1-1/2 hr.

Penetrometer measurements. A flat disc, weighing 25.5 gm., was positioned on the surface of the cake sample. The disc was allowed to compress the sample for a 30-sec. period and the amount of compressibility was expressed in millimeters. The values from two samples from each replication were averaged.

Kramer shear-press measurements. Compressibility of cake samples was determined according to the method of Funk, Zabik, and Downs (18) using the plunger of the succulometer cell of the Kramer shear-press, Model SP12, equipped with an electonic recorder, Model E2EZ. The 100-lb. electronic proving ring at a range of 5 lb. and a pressure of 25 lb. was used. A circular sample of cake, 5.25 cm. in diameter and 2.00 cm. in thickness, was depressed on a wooden plate placed on the support plates at the base of the main column of the shear-press. Each cake sample was depressed to a uniform thickness of 1.16 cm. during a 30-sec. downward stroke of the plunger (Figure 3). Compressibility was

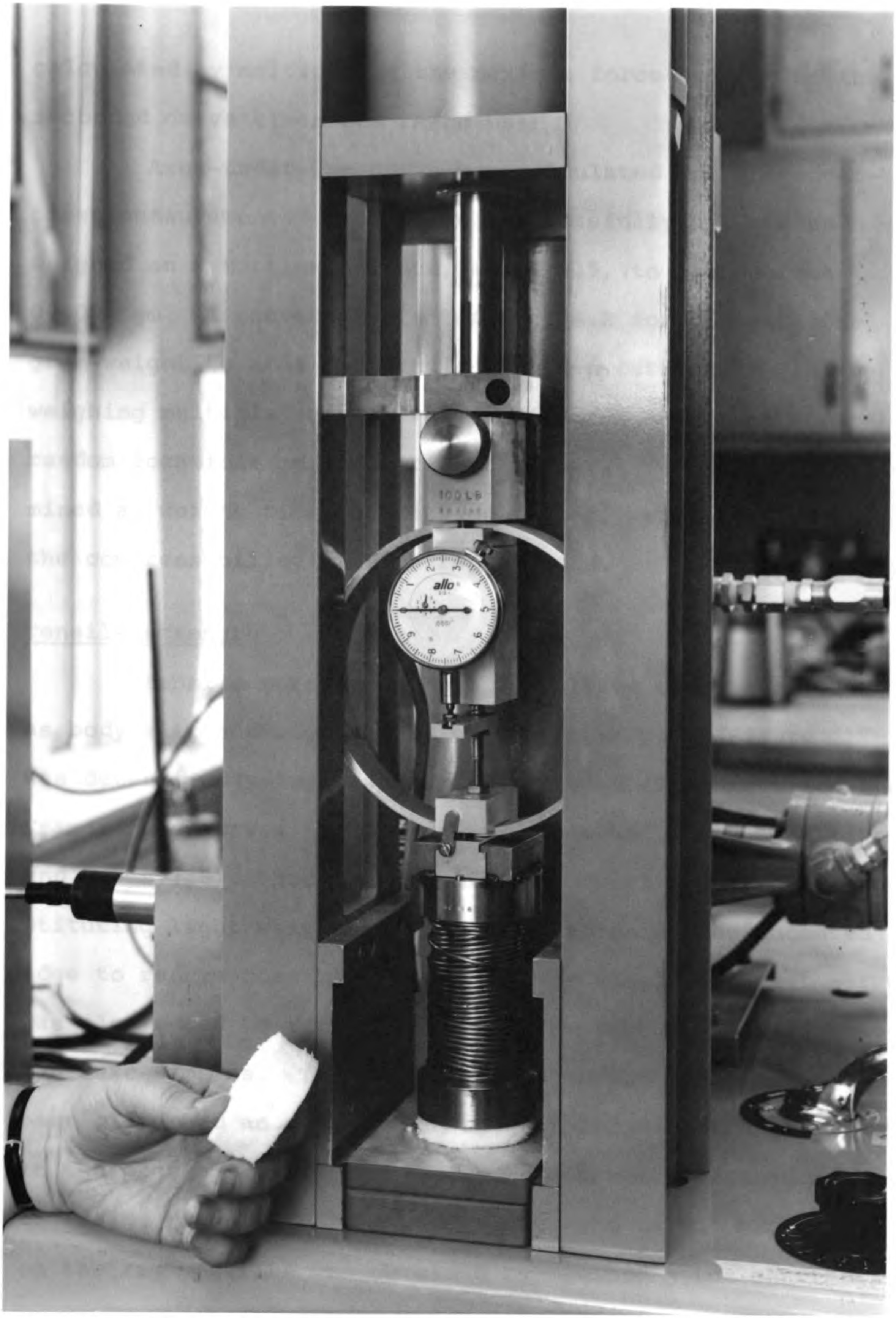

FIG. 3 Compressibility measurements of angel cakes using the Kramer shear-press.

calculated by multiplying the maximum force reading on the recorded curve times the range used.

Area-under-the-curve was calculated for the shear-press measurement. Each curve was carefully cut out and weighed on a Mettler balance, model H15, to the nearest 0.0000 gm. A conversion factor of 174.2 for changing the gram-weight to area had previously been determined (18) by weighing multiple squares varying in area and taken from random locations on similar chart paper. Two values, determined as weight times conversion factor, were averaged for the compressibility of each replication.

Tensile strength

Tensile strength of all end slices of cake as well as body slices designated in the rotation plan (Figure 2) was determined using a specially designed attachment for the Kramer shear-press, according to the method of Funk, Zabik, and Downs (18). Acco clamps, No. 325, were modified by substituting light weight springs and flattening the indented edge to reduce possible damage to cake samples. A set screw was also added to further regulate the force placed against the cake samples. The clamps were attached to a U-shaped base plate and an upper assembly just large enough to attach to the proving ring. The 100-lb. electronic proving ring, the 1-lb. range, and 25-lb. pressure were used. A reading on the ram upstroke was obtained by rewinding the chart-drive cable of the shear press (Figure 4). Samples of cake were cut from frozen cake slices, 2.00 cm. thick, with an hourglass-shaped cutter measuring 2.54 cm. across the center. The width of the break was measured with vernier calipers. The formula

$$\frac{\text{Maximum graph reading X Range}}{\text{Area of the break (in cm}^2\text{)}}$$

was used to calculate tensile strength. The results of three measurements were averaged to determine the tensile strength of the cake body of each replication. Tensile strength values of end slices represent an average of the four end slices of each replication.

Tenderness of cake

The standard shear-compression cell of the Kramer shear-press was used to measure tenderness of the cakes. For this measurement, the 100-lb. proving ring, a range of 50-lb. and 25-lb. of pressure were used. The cake samples, 5.39 cm. square and 2.00 cm. thick, were weighed to the nearest 0.00 gm. using a Torbal torsion balance, Model PL-800. The cake samples were sheared during a 30-sec. downstroke of the upper assembly of the shear-compression cell. Between all tenderness measurements, the cell was washed in tepid water and dried with unheated forced air. Tenderness was calculated as:

$$\frac{\text{Maximum graph reading X Range}}{\text{Sample weight}}$$

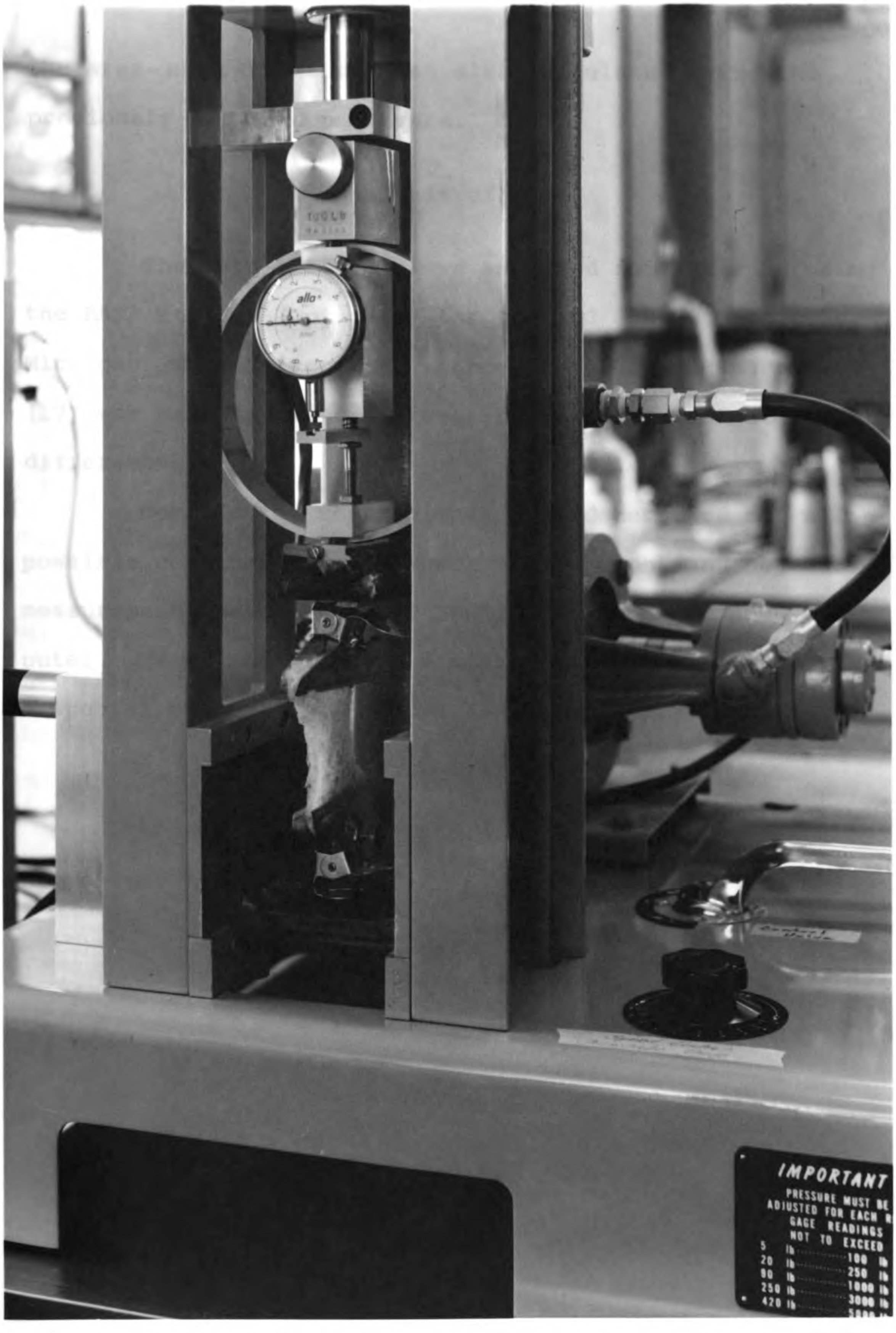

FIG 4. Tensile strength measurements of angel cakes using the Kramer shear-press.

The area-under-the-curve was also calculated using the previously outlined procedure.

Analysis of Data

The data obtained were analyzed for variance using the RAND Routine (Option 1) for the CDC 3600 computer at Michigan State University. Duncan's Multiple Range Test (17) was used to pinpoint further the sources of significant differences.

Correlation coefficients were determined for all possible combinations of sensory evaluations and objective measurements using a BASTAT Routine for the CDC 3600 computer. Means and standard deviations were calculated using a special program for the CDC 3600 computer.

RESULTS AND DISCUSSION

This study was undertaken to determine the effect of baking temperatures of 177^{o}, 191^{o}, 204^{o}, and $218^{o}C$. on the quality characteristics of angel cakes, as measured by sensory evaluation and numerous objective measurements. The investigation included two phases: (1) a study of the effect of oven temperatures on quality characteristics of angel cakes in an attempt to define the most desirable baking temperature for the product, and (2) assessment of validity of simple objective measurements, as would be available in laboratories with limited equipment, by correlating appropriate data obtained by objective measurements and sensory evaluations.

Tables of averages, grand averages, standard deviations, as well as the statistical analyses, accompany the discussion of the results. A table of the correlation coefficients calculated from appropriate combinations of the data is included in the Appendix.

Objective Measurements of Cake Batter

To insure uniformity of the cake batter, two objective measurements were used. The specific gravity and the pH were determined.

Specific gravity of batter

The specific gravity of each batch of cake batter is presented in Table 1. Analysis of variance showed highly significant differences in specific gravity measurements among the cake batters produced for the four variables of oven temperature. Significant differences existed among the four replications of each variable. Examination of the data showed variations in the specific gravity occurred only during the first two days of cake preparation. Therefore, experimental errors involving the use of the balance explain variances which occurred.

pH of batter

The pH values of each batch of angel cake batter along with grand averages and standard deviations for each variable are presented in Table 2. Analysis of the data showed no significant differences in pH values of cake batters. The average pH value for all cakes was 6.2.

Rates of Temperature Rise During Baking

Potentiometer leads were placed at two points within each cake. Mean progressive time-temperature relationships were plotted for the eight cakes baked at each of the four oven temperatures of 177°, 191°, 204°, and 218°C.

TABLE 1 Specific gravity values of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C.	191°C.	204°C.	218°C.
1	.35[a]	.37	.35	.38
2	.35	.36	.35	.37
3	.35	.36	.35	.36
4	.34	.35	.35	.35
Grand average	.35	.36	.35	.37
Standard deviation	.005	.008	.000	.013

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	0.00027	8.02**
Replicates	3	0.00016	4.59*
Error	9	0.00003	
Total	15		

[a] Each value represents one determination.

*Significant at the 5% level of probability.

**Significant at the 1% level of probability.

TABLE 2 pH values of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C.	191°C.	204°C.	218°C.
1	6.2[a]	6.3	6.2	6.2
2	6.3	6.3	6.2	6.3
3	6.2	6.3	6.2	6.2
4	6.2	6.1	6.2	6.2
Grand average	6.2	6.3	6.2	6.2
Standard deviation	0.05	0.10	0.00	0.05

[a] Each value represents an average of two determinations.

Time-temperature relationships recorded 2.5 cm. from the bottom surface of the cake pan

As shown in Figure 5, temperatures within the cakes rose at a rate dependent on the oven temperature with the slowest rate of temperature rise recorded for the 177°C. oven. After an initial period of time, which increased as the oven temperature decreased, the temperatures within all cakes rose at a very rapid rate. Very rapid rates of temperature rise were noted for all cakes until an internal temperature of approximately 85°C. had been reached. Thereafter, the rates of temperature rise decreased.

Moisture was lost by evaporation during baking as indicated by the percentages of weight loss (Table 9).

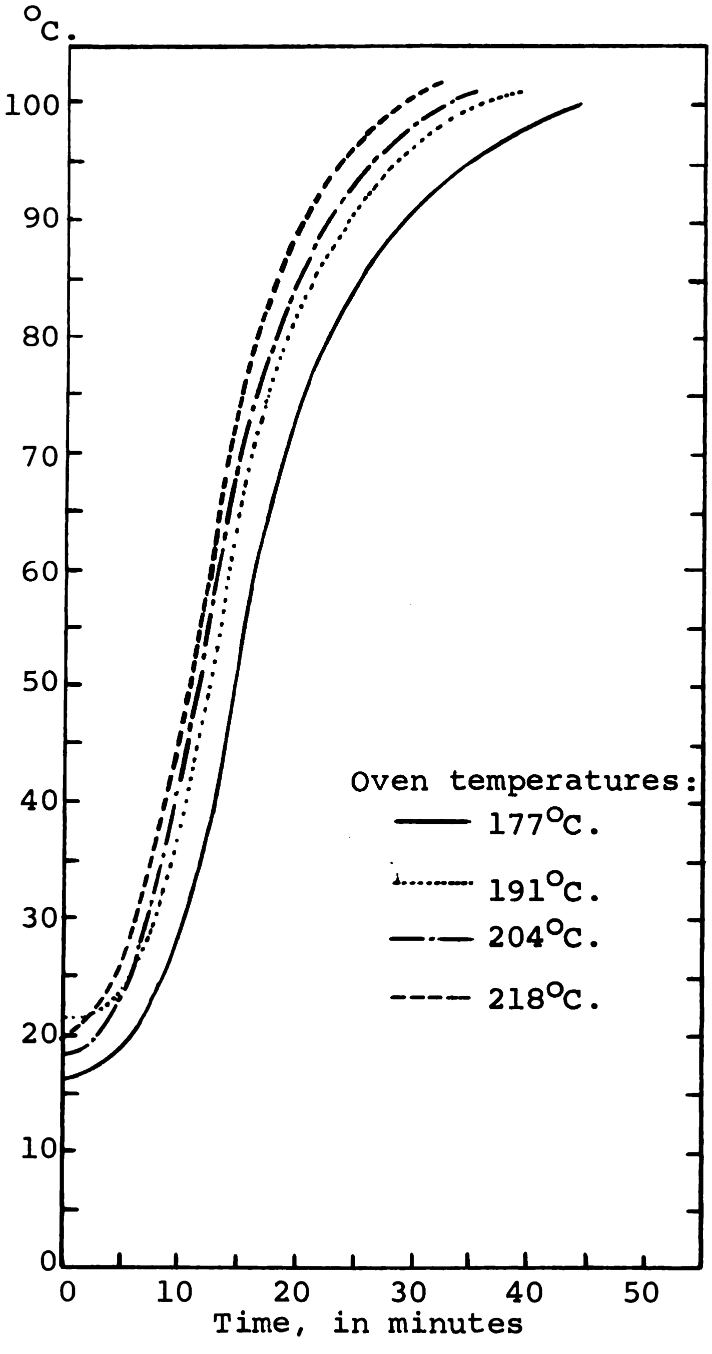

FIG. 5 Average rates of temperature rise as measured 2.5 cm. from the bottom of the pans used for baking angel cakes at four oven temperatures.

Also, gelatinization of the starches as well as the hygroscopic properties of sugar present in the cake batter would determine the moisture distribution within the cake at a particular time during the baking process. According to Barmore (4), the endothermic process of egg white coagulation in angel cakes is influenced by the ingredients present as well as their concentration. A combination of these factors probably account for decreases in the rates of temperature rise during the latter part of the baking period.

Time-temperature relationships recorded 5.0 cm. from the bottom surface of the cake pan

Time-temperature relationships plotted from data recorded 5.0 cm. from the bottom surface of the cake pan showed a very rapid rise during the first 5 min. of baking as shown in Figure 6. For the next eight to eleven minutes of baking, the rate of temperature rise within cakes baked at the four oven temperatures decreased. The potentiometer lead positioned 5.0 cm. from the bottom surface of the pan was near the exterior of the cake batter when the baking began. Hence, the recording reflects the temperature at the surface of the cake batter during the initial baking period. As the cake increased in volume during baking, the recording from the potentiometer lead indicated a decrease in the rate of temperature rise within the cake for a period of time.

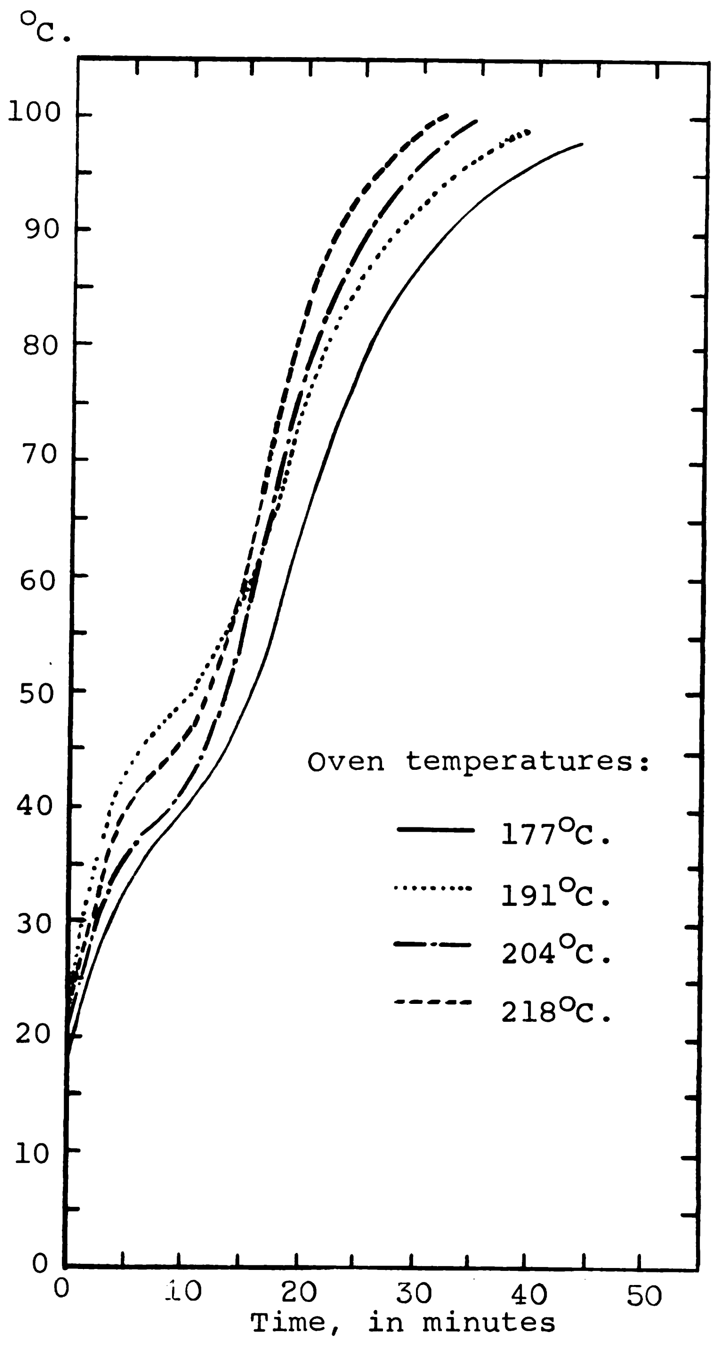

FIG. 6 Average rates of temperature rise as measured 5.0 cm. from the bottom of the pans used for baking angel cakes at four oven temperatures.

Very rapid rates of temperature rise were noted for cakes baked at 191°, 204°, and 218°C. until the internal temperature of the cakes reached approximately 82°C. Thereafter, rates of temperature rise decreased. The very rapid rates of temperature rise for cakes baked at 177°C., decreased when the internal temperature of the cakes reached approximately 77°C. (Figure 6). These decreases in the rates of temperature rise probably reflect moisture changes and/or protein coagulation within the cake during the baking process.

A comparison of the average time-temperature relationships recorded from the two points within each cake shows that after the first 10 to 15 min. of baking time, temperatures recorded at a point 2.5 cm. from the bottom of the cake were higher than those recorded at a point 5.0 cm. from the bottom of the cake. This was as expected because heat within the cake would be transferred by conduction and/or convection from the outer surfaces toward the center of the cake.

Maximum internal temperatures of cakes

The maximum internal temperatures recorded for the cakes baked at each of the four oven temperatures as well as grand averages, standard deviations, and statistical analyses, are presented in Table 3. Very highly significant

TABLE 3 Data and statistical analyses for the maximum internal temperature recorded for angel cakes baked at four oven temperatures[a]

Means, grand averages, and standard deviations

	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
	°C.	°C.	°C.	°C.
1	98.0[b]	99.3	99.5	100.8
2	98.3	99.5	100.5	100.3
3	98.0	99.5	100.3	100.0
4	97.8	99.5	99.5	100.5
Grand average	98.0	99.5	100.0	100.4
Standard deviation	0.2	0.1	0.5	0.3

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	4.244	34.86***
Replicates	3	0.077	0.64
Error	9	0.122	
Total	15		

Duncan's Multiple Range Test[c]

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
$\underline{B,C,D} > A$	$D > B$	

[a] Thermocouples inserted 5.0 cm. from the bottom of the pan.

[b] Each value represents an average of temperature readings from the two cakes comprising one replication.

[c] Values underscored by the same line are not significantly different (17).

*** Significant at the 0.1% level of probability.

differences were found among the maximum internal temperatures recorded for angel cakes.

According to further analysis using Duncan's Multiple Range Test (17), a very highly significant increase existed between the maximum internal temperatures of cakes baked at 191°, 204°, and 218°C. compared with the maximum internal temperature of cakes baked at 177°C. At the 1% level of probability, the maximum internal temperatures of cakes baked at 218°C. were higher than those baked at 191°C.

The average maximum internal temperature of cakes baked at 218°C. was 2.4°C. higher than average maximum internal temperatures of cakes baked at 177°C. These results appear to agree with the findings of Barmore (5), indicating the maximum internal temperature of cakes does not increase in proportion to increases in oven temperatures used for baking angel cakes.

An examination of the time-temperature data plotted for the angel cakes (Figures 5,6), showed the maximum internal temperatures of cakes were not maintained for the final minutes of the baking period as Looft (35) had indicated in her study. However, Looft indicated maximum internal temperatures of angel cakes increased as the baking time increased. The cakes used in this investigation were subjectively evaluated as done during preliminary investigations when baked for the prescribed times. These conflicting results suggest further investigations are needed to define doneness of angel cakes as determined by maximum internal temperatures and/or time-temperature relationships.

Subjective Evaluation of Baked Cakes

Using the form which appears in the Appendix, the investigator subjectively evaluated the cakes after they were baked. During baking, all cakes baked at the four oven temperatures developed lengthwise cracks at each side of the top. These cracks appeared deeper in cakes baked at 204° and 218°C. than the cracks present in the tops of cakes baked at the two other oven temperatures. After removal from the oven, the portion of the cake between the cracks tended to collapse in cakes baked at 204° and 218°C. Perhaps the rapid expansion of the air during baking produced a delicate structure within these cakes and when they were removed from the oven, the crust was too heavy to be supported by the cake structure. Hence, the cake partially collapsed. The extent of collapse was dependent on the baking temperature, being more pronounced in cakes baked at 218°C.

The color of the sides and bottom of cakes baked at 177° and 191°C. was very light golden brown, while the sides and bottoms of cakes baked at the two higher temperatures tended to be golden brown in color. The color of the top crust ranged from golden brown, to slightly dark brown, to very dark brown, to burned when the cakes were baked at 177°, 191°, 204°, and 218°C., respectively.

No differences were observed in the texture of the sides and bottom of cakes baked at the four oven temperatures. All cakes were sticky on the sides and bottom surfaces.

Sensory Evaluation

Texture, tenderness, moistness, and color of crumb were the characteristics of angel cakes evaluated by a trained taste panel to study the effects of four baking temperatures. Sensory judgments were based on a 7-point scale, indicating a range from poor to excellent quality. Scores of all judges were averaged for each of the four quality characteristics of each replication. Based on this average score of the quality characteristics for each cake, grand averages were computed.

Texture

The texture scores, grand averages, standard deviations, and statistical analyses are presented in Table 4. Analysis of variance for texture scores disclosed very highly significant differences attributable to baking temperatures. Grand average texture scores were 5.0, 5.1, 4.5, and 3.3 for angel cakes baked at 177°, 191°, 204°, and 218°C., respectively. Further analysis of the data using Duncan's

TABLE 4 Data and statistical analyses of sensory scores for texture of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
1	5.1[a]	5.0	4.7	3.0
2	4.9	5.3	3.9	2.8
3	5.1	4.9	4.7	3.7
4	5.0	5.0	4.7	3.8
Grand average	5.0	5.1	4.5	3.3
Standard deviation	0.1	0.2	0.4	0.5

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	2.608	24.97***
Replicates	3	0.135	1.29
Error	9	0.104	
Total	15		

Duncan's Multiple Range Test[b]

Significant at $P \leq 0.001$	Additional at	
	$P < 0.01$	$P < 0.05$
$\underline{A,B,C} > D$		$\underline{A,B} > C$

[a] Each value represents an average of two evaluations for each of the six judges.

[b] Values underscored by the same line are not significantly different (17).

*** Significant at the 0.1% level of probability.

Multiple Range Test (17), indicated cakes baked at 218°C. had poorer texture than cakes baked at 177°, 191°, and 204°C. This difference was significant at the 0.1% level of probability. At the 5% level of probability, cakes baked at 204°C. scored lower in texture than cakes baked at 177° and 191°C.

These findings indicated baking temperatures above 191°C. resulted in cakes poor in texture. The judges commented on the texture of cakes baked at 204° and 218°C. as being compact in some areas as indicated by the presence of thick layers. As previously indicated, these thick layers probably developed within cakes baked at the two higher oven temperatures as a result of the partial collapse of these cakes after they were removed from the oven.

Tenderness

The tenderness scores for each replication of angel cakes as well as the grand averages and standard deviations for each of the four baking temperatures are presented in Table 5. Analysis of variance showed very highly significant differences in tenderness among the cakes. Cakes baked at 177°C. received a grand average score of 6.1 for tenderness while grand average tenderness scores for cakes baked at 191°, 204°, and 218°C. were 5.8, 5.6, and 4.6, respectively. Duncan's Multiple Range Test (17) exhibited a very highly significant decrease in tenderness scores of cakes baked at 218°C., compared with tenderness scores of cakes

TABLE 5 Data and statistical analyses of sensory scores for tenderness of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
1	6.1[a]	5.4	5.8	4.8
2	6.3	6.0	5.4	4.3
3	5.9	5.7	5.7	4.7
4	6.2	6.1	5.5	4.5
Grand average	6.1	5.8	5.6	4.6
Standard deviation	0.2	0.3	0.2	0.2

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	1.792	26.01***
Replicates	3	0.005	0.07
Error	9	0.069	
Total	15		

Duncan's Multiple Range Test[b]

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
$\underline{\text{A,B,C}}$, > D		A > C

[a] Each value represents an average of two evaluations for each of the six judges.

[b] Values underscored by the same line are not significantly different (17).

***Significant at the 0.1% level of probability.

baked at the three other oven temperatures. The baking temperature of 177°C. produced more tender cakes at the 5% level of probability than did the baking temperature of 204°C. No significant differences in tenderness scores existed between cakes baked at 177° and 191°C.

The results of this study disclosed a decrease in tenderness if the baking temperature used for angel cakes was higher than 191°C. These results are in disagreement with data reported by Miller and Vail (40) who indicated tenderness of angel cakes increased with the increase in baking temperature from 177°C. to 218°C.

Tenderness scores for angel cakes were correlated with texture scores. The very highly significant correlation coefficient ($r = 0.89$) indicated tender cakes had medium-sized air cells with thin cell walls.

Moistness

Moistness scores, grand averages, standard deviations and statistical analyses are presented in Table 6. The analysis of variance computed from moistness scores showed highly significant differences attributable to baking temperatures. Further analysis of the data, using Duncan's Multiple Range Test (17), indicated moistness scores averaging 5.7, 5.5, and 5.6 for cakes baked at 177°, 191°, and 204°C., respectively, were not significantly different. A very highly significant difference existed between the

TABLE 6 Data and statistical analyses of sensory scores for moistness of angel cakes baked at four oven temperatures [a]

Means, grand averages, and standard deviations

Replication	Oven Temperature			
	177°C. A	191°C. B	204°C. C	218°C. D
1	5.2	4.5	6.2	4.2
2	6.0	5.8	5.7	3.8
3	5.3	5.0	5.2	3.9
4	5.8	5.7	5.3	4.8
Grand average	5.7	5.5	5.6	4.2
Standard deviation	0.3	0.4	0.5	0.5

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	2.072	17.92***
Replicates	3	0.281	2.43
Error	9	0.116	
Total	15		

Duncan's Multiple Range Test[b]

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
A,B,C, > D		

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[a] Each value represents an average of two evaluations for each of the six judges.

[b] Values underscored by the same line are not significantly different (17).

***Significant at the 0.1% level of probability.

moistness scores averaging 4.2 for cakes baked at 218°C. and the moistness scores of cakes baked at the three other oven temperatures, however.

Miller and Vail (40) reported moistness of angel cakes increased as baking temperatures increased from 177° to 232°C. However, cakes baked at 232°C. in their study, were rated as soggy by the taste panel, according to the report. Barmore (4) also found high baking temperatures increased the moistness of angel cakes.

Moistness scores were correlated with texture scores. The very highly significant correlation coefficient ($r = 0.80$) indicated optimum moistness was associated with desirable texture of angel cakes.

Color of crumb

The analysis of variance calculated from the sensory scores of the color of crumb, showed very highly significant differences due to baking temperatures. Duncan's Multiple Range Test (17) indicated very highly significant differences existed between the color of crumb of cakes baked at 177° and 218°C. The panelists evaluated the color of crumb of cakes baked at 177°C. as whiter in color than a similar evaluation of color for cakes baked at 218°C. The color of crumb for cakes baked at 191° and 204°C. was significantly whiter than the color of crumb of cakes baked at 218°C. (Table 7). The panelists commented that the samples from

TABLE 7 Data and statistical analyses of sensory scores for color of the crumb of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
1	6.5[a]	6.3	6.2	5.0
2	5.4	6.1	5.9	5.3
3	6.1	6.0	6.2	5.6
4	6.3	6.0	6.1	5.5
Grand average	6.3	6.1	6.1	5.4
Standard deviation	0.2	0.1	0.1	0.3

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	0.726	16.10***
Replicates	3	0.004	0.09
Error	9	0.045	
Total	15		

Duncan's Multiple Range Test[b]

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
A > D	$\underline{\text{B,C}} > \text{D}$	

[a] Each value represents an average of two evaluations for each of the six judges.

[b] Values underscored by the same line are not significantly different (17).

*** Significant at the 0.1% level of probability.

cakes baked at 218°C. appeared yellow. The means, grand averages, and standard deviations of sensory scores of color of crumb are presented in Table 7.

A general comment made by taste panel members indicated samples from all four variables of baking temperature were "sparkling" and "glistened." This phenomenon was further investigated and was then attributed to ingredients contained in the cake mix and/or the bright lights under which the cake samples were evaluated.

Objective Measurements

The numerical data from objective measurements used to indicate the quality characteristics of angel cakes baked at four oven temperatures were subjected to analysis of variance. Duncan's Multiple Range Test (17) was used to pinpoint significant differences disclosed by the analysis of variance. Simple correlations were calculated for all appropriate combinations of sensory evaluations and objective measurements.

Index of volume

Means, grand averages, standard deviations and statistical analyses of data for the index of volume of angel cakes are presented in Table 8. When the data were analyzed for variance, very highly significant differences attributable to baking temperature were found in the index of volume.

TABLE 8 Data and statistical analyses of index of volume of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
	Sq.Cm.	Sq.Cm.	Sq.Cm.	Sq.Cm.
1	101.1[a]	101.1	97.6	75.6
2	108.2	96.7	95.5	78.6
3	108.5	98.2	92.1	83.2
4	109.0	101.6	89.9	80.7
Grand average	106.7	99.4	93.8	79.5
Standard deviation	3.7	2.3	3.4	3.2

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	529.212	40.33***
Replicates	3	2.247	0.17
Error	9	13.122	
Total	15		

Duncan's Multiple Range Test[b]

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
A,B,C > D A > C		A > B

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[a] Each value represents an average of six determinations.

[b] Values underscored by the same line are not significantly different (17).

*** Significant at the 0.1% level of probability.

Further analysis using Duncan's Multiple Range Test (17) showed cakes baked at 218°C. were smaller in volume than cakes baked at 177°, 191°, and 204°C., a difference significant at the 0.1% level of probability. Also, very highly significant differences were found between the index of volume for cakes baked at 177° and 204°C. At the 5% level of probability, cakes baked at 177°C. had greater volume than cakes baked at 191°C.

The grand averages of 106.7, 99.4, 93.8, and 79.5 sq. cm. for cakes baked at 177°, 191°, 204°, and 218°C., respectively, showed a continuous decrease in the index of volume as the baking temperature increased. These results are in disagreement with data reported by Miller and Vail (40) showing the volume of angel cakes increased as baking temperatures increased from 177° to 218°C. Volume of cakes prepared from a basic recipe, was indicated by the area of a slice of cake in their study.

The index of volume was correlated with texture scores. The very highly significant correlation coefficient (r = 0.86) suggested that an increase in the index of volume was associated with an open texture of the angel cake samples. As the index of volume decreased, judges evaluated the texture of the cake samples as more compact.

The correlation coefficient (r = 0.90) calculated for the index of volume and tenderness scores showed tenderness of the cake increased as the volume increased. Samples from cakes with a high index of volume broke easily and were easily chewed by the judges.

The volume of the cakes increased as the baking time increased according to the very highly significant correlation coefficient ($r = 0.92$) calculated for this relationship. Apparently, the long baking time permitted complete expansion of the air before proteins coagulated and starches gelatinized to form a stable structure for the cakes.

Moisture of cake

As an indication of the moistness of the cakes, the percentages of weight loss during baking were calculated. The percentages of moisture in the cakes was also determined.

Percentage of weight loss during baking. Mean percentages of weight loss from angel cakes during baking ranged from 10.8 per cent to 11.31 per cent (Table 9). Analysis of variance showed no significant differences among the cakes baked at four oven temperatures.

These results do not agree with data reported by Looft (35). According to her report, cakes baked at higher temperatures lost less moisture during baking than cakes baked at lower temperatures.

A significant negative correlation coefficient ($r = -0.51$) was found between percentages of weight loss during baking and moistness scores. These results do not support comments made by the panelists indicating cakes baked at an oven temperature of 218°C. were too moist.

TABLE 9 Percentage of weight loss during baking angel cakes at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C.	191°C.	204°C.	218°C.
	%	%	%	%
1	10.88[a]	10.73	10.08	11.31
2	10.95	10.65	10.73	10.95
3	10.37	10.88	10.51	10.80
4	10.73	10.58	10.81	10.73
Grand average	10.73	10.71	10.51	10.95
Standard deviation	0.26	0.13	0.33	0.26

[a] Each value represents an average of two determinations.

Moisture determinations. The mean percentages of moisture, grand averages, and standard deviations are presented in Table 10. Analysis of variance showed no significant differences in the moisture content among cakes baked at the four oven temperatures. The moisture content for all angel cakes included in this study averaged 42.60 per cent.

The percentages of moisture were correlated with sensory scores of moistness and the percentages of weight loss during baking. Neither correlation was significant.

TABLE 10. Percentages of moisture of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C.	191°C.	204°C.	218°C.
	%	%	%	%
1	39.90[a]	44.09	44.42	41.95
2	44.51	42.18	43.04	42.70
3	44.30	43.58	38.46	43.92
4	39.73	44.39	40.87	43.50
Mean	42.11	43.56	41.70	43.02
Standard deviation	2.65	0.98	2.61	0.87

[a] Each value represents an average of four determinations.

Percentage of sand retention

Samples from cakes baked at 177°, 191°, 204°, and 218°C. retained an average of 102.99, 83.72, 81.72, and 60.32 per cent, respectively, of the sand sprinkled over them to measure the coarseness of the grain (Table 11). Analysis of variance showed the differences among the four variables were highly significant. When Duncan's Multiple Range Test (17) was used for further analysis of the data, very highly significant differences existed between samples of cake baked at 177° and 218°C. The percentage of sand retained by cakes baked at 177°C. was significantly larger than the percentage of sand retained by cakes baked at 191°C. and at 204°C. While no significant differences existed in the percentage of sand retained by cakes baked

TABLE 11 Data and statistical analyses for percentage of sand retained by angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
	%	%	%	%
1	87.85[a]	79.90	82.32	43.86
2	108.41	90.16	94.20	60.66
3	123.28	80.63	82.42	66.70
4	92.40	84.17	67.92	70.06
Grand average	102.99	83.72	81.72	60.32
Standard deviation	16.15	4.68	10.76	11.64

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	1217.707	11.55**
Replicates	3	217.724	2.07
Error	9	105.415	
Total	15		

Duncan's Multiple Range Test[b]

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
A > D		B,C > D A > B,C

[a] Each value represents an average of two determinations.

[b] Values underscored by the same line are not significantly different (17).

**Significant at the 1% level of probability.

at 191° and 204°C., both of these cakes retained a significantly higher percentage of sand than cakes baked at 218°C.

The correlation coefficient ($r = 0.70$) showed a highly significant relationship between the percentage of sand retained and the texture scores. Cakes with a more open structure, as indicated by high texture scores, retained more sand than cakes with a compact structure which received low texture scores. The very highly significant correlation coefficient ($r = 0.87$) between the percentage of sand retained and the index of volume support this conclusion.

Swartz (55) used butter cakes to develop the sand retention test. In butter cakes, a coarse-grained product denotes poor quality and the product is characterized by large pores which retain a high percentage of sand. In angel cakes, however, Funk, Zabik, and Downs (18) noted the pores decreased in size as the quality of the cake decreased. The results of this study support this conclusion since more sand was retained by cakes receiving high texture scores.

According to the results of this study, the sand retention test is a valid measurement for determining the texture of angel cakes. The high standard deviations suggest irregularities of the grain of cake samples from the four variables of baking temperature. The texture of the angel cakes varied within a slice of cake and hence, the location from which the sample was taken would influence the amount of sand retained.

Compressibility

The compressibility of angel cakes was determined by two instruments. The penetrometer and the Kramer shear-press, with the appropriate attachment, were used.

Penetrometer measurements. Means, grand averages, standard deviations, and statistical analyses of the penetrometer measurements of compressibility are presented in Table 12. When the data were analyzed for variance, very highly significant differences existed among the cakes baked at four oven temperatures. Duncan's Multiple Range Test (17) indicated very highly significant differences existed between cakes baked at 177° and 218°C. The lower baking temperature produced more compressible cakes than the 218°C. baking temperature. At the 1% level of probability, cakes baked at 218°C. were less compressible than cakes baked at 191° and 204°C. There was a significant decrease in the compressibility of cakes baked at 204°C. when compared with those baked at 177°C. No significant differences existed in compressibility between cakes baked at 177° and 191°C. or at 191° and 204°C.

When the penetrometer values were correlated with texture scores, a very highly significant correlation coefficient (r = 0.87) was found. This correlation suggests

TABLE 12 Data and statistical analyses of penetrometer measurements of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
	mm.	mm.	mm.	mm.
1	13.7[a]	7.7	13.9	0.5
2	14.7	11.9	4.7	0.8
3	14.5	6.5	9.3	1.0
4	14.7	14.2	8.7	3.7
Grand average	14.4	10.1	9.2	1.5
Standard deviation	0.5	3.6	3.8	1.5

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	115.196	14.20***
Replicates	3	5.197	0.64
Error	9	8.114	
Total	15		

Duncan's Multiple Range Test[b]

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
A > D	B,C > D	A > C

[a] Each value represents an average of two determinations.

[b] Values underscored by the same line are not significantly different (17).

***Significant at the 0.1% level of probability.

that as the size of the pores of angel cakes increase, the cake becomes more compressible. Apparently the open texture characterized a fragile cake which was easier to compress than cakes characterized by a close, compact texture.

The very highly significant correlation coefficient ($r = 0.88$) between the penetrometer values and the index of volume emphasizes the relationship between the open texture and the compressibility of the cakes. As the index of volume increased, the cakes were more easily compressed.

The correlation coefficient ($r = 0.93$) between penetrometer values and tenderness scores was very highly significant. The compressibility of cakes increased as the tenderness increased.

Kramer shear-press measurements. Values for Kramer shear-press measurements for compressibility were expressed as maximum force and area-under-the-curve. Means, grand averages, standard deviations, and statistical analyses for shear-press measurements expressed as maximum force are presented in Table 13. When the data were analyzed for variance attributable to baking temperature, very highly significant differences existed. Further analysis of the data using Duncan's Multiple Range Test (17) indicated cakes baked at 177° and 191°C. required less force to compress them, at the 0.1% level of probability, than cakes baked at 218°C. Highly significant differences existed in the force required for compressibility between cakes baked at 204° and

TABLE 13 Data and statistical analyses of Kramer shear-press measurements for compressibility, expressed as maximum force, of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
	Lb.force	Lb.force	Lb.force	Lb.force
1	0.24[a]	0.58	0.31	2.54
2	0.20	0.41	0.68	2.45
3	0.21	0.55	0.63	1.44
4	0.24	0.35	0.63	1.16
Grand average	0.22	0.47	0.56	1.90
Standard deviation	0.02	0.11	0.17	0.70

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	2.270	16.13***
Replicates	3	0.111	0.79
Error	9	0.141	
Total	15		

Duncan's Multiple Range Test[b]

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
$\underline{A,B} < D$	$C < D$	

[a] Each value represents an average of two determinations.

[b] Values underscored by the same line are not significantly different (17).

***Significant at the 0.1% level of probability.

218°C. There were no significant differences in the force required to compress cakes baked at 177°, 191°, and 204°C.

A very highly significant negative correlation coefficient ($r = -0.87$) existed between tenderness scores of cakes and the force needed to compress them. This correlation suggested that as angel cakes increased in tenderness, they needed less force to compress them.

The volume of the cakes decreased as the values of compressibility based on maximum force, increased, according to the very highly significant negative correlation coefficient ($r = -0.89$) calculated for this relationship. The increase in the maximum force required to compress cakes of low volume is perhaps due to the presence of thick layers which developed in cakes baked at 204° and 218°C.

A very highly significant negative correlation coefficient ($r = -0.87$) was found between the shear-press and penetrometer measurements of compressibility. The cakes which required less force, as indicated by the shear-press measurements, were more compressible, as shown by penetrometer measurements.

Grand averages for area-under-the-curve values of compressibility were 0.32, 0.66, 0.69, and 2.28 sq. cm. for cakes baked at 177°, 191°, 204°, and 218°C., respectively. Means for each cake along with the standard deviations and statistical analyses are presented in Table 14. When analyzed for variance, very highly significant differences

TABLE 14 Data and statistical analyses of Kramer shear-press measurements for compressibility, expressed as area-under-the-curve, of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
	Sq.Cm.	Sq.Cm.	Sq.Cm.	Sq.Cm.
1	0.33[a]	0.79	0.44	2.81
2	0.31	0.57	0.85	3.01
3	0.32	0.77	0.76	1.86
4	0.31	0.50	0.72	1.45
Grand average	0.32	0.66	0.69	2.28
Standard deviation	0.00	0.15	0.18	0.75

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	3.099	19.91***
Replicates	3	0.153	0.98
Error	9	0.156	
Total	15		

Duncan's Multiple Range Test[b]

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
A,B,C < D		

[a] Each value represents an average of two determinations.

[b] Values underscored by the same line are not significantly different (17).

***Significant at the 0.1% level of probability.

attributable to baking temperatures were found. Duncan's Multiple Range Test (17) showed very highly significant differences existed only between cakes baked at 218°C. and those baked at the three other oven temperatures, indicating the largest amount of force was required to compress cakes baked at 218°C.

The correlation coefficient (r = 0.99) between values for compressibility based on maximum force and area-under-the-curve showed a very highly significant relationship. As the maximum force for compressibility increased, the area-under-the-curve increased accordingly.

A very highly significant negative correlation coefficient (r = -0.88) was also indicated between area-under-the-curve values for compressibility and the penetrometer readings. The cakes which were more compressible as shown by the penetrometer required less force to compress them as indicated by the shear-press.

Tensile strength measurements

The Kramer shear-press was used to measure tensile strength of body and end slices of the angel cakes. Values for these measurements are expressed as the maximum force required to break hourglass-shaped samples of cake.

Tensile strength of body slices. Analysis of variance for tensile strength of the body slices of the angel cakes showed no significant differences attributable to baking temperatures. Among replications of the four variables, however, significant differences existed (Table 15). Visual differences were apparent in the cake samples. As mentioned previously, thick, compact layers developed in the cakes baked at 204° and 218°C. when they were removed from the oven. The thick, compact layers caused by partial collapse of the cake structure, determined the location of the break. Cake samples in which the layer was present tended to pull apart very easily. Also, as noted by Funk, Zabik, and Downs (18), difficulties were encountered in performing the tensile strength measurements. Although every attempt was made to prevent it, a few cake samples were damaged while clamping them in position for the measurement.

The tensile strength of body slices of angel cakes was correlated with tenderness scores, index of volume, and compressibility as determined by the penetrometer and shear-press. No significant correlations resulted.

Tensile strength of end slices. The analysis of variance indicated significant differences in end slices of cakes baked at different oven temperatures (Table 16). At the 1% level of probability, end slices of cakes baked at 218°C. broke easier than the end slices of cakes baked at 191°C., according to analysis using Duncan's Multiple Range Test (17). End slices from cakes baked at 177°C. had less tensile strength, at the 5% level of probability, than those baked at 191°C. Means, grand averages, and standard

TABLE 15 Data and statistical analyses of Kramer shear-press measurements for tensile strength of body slices of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177^{o}C. A	191^{o}C. B	204^{o}C. C	218^{o}C. D
	Lb.force /cm.^{2}	Lb.force /cm.^{2}	Lb.force /cm.^{2}	Lb.force /cm.^{2}
1	0.030[a]	0.033	0.027	0.037
2	0.020	0.028	0.027	0.025
3	0.020	0.025	0.024	0.012
4	0.024	0.023	0.018	0.023
Grand average	0.024	0.027	0.024	0.024
Standard deviation	0.005	0.004	0.004	0.010

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	0.00001150	0.56
Replicates	3	0.0001025	4.99*
Error	9	0.00002	
Total	15		

[a] Each value represents an average of three determinations.

*Significant at the 5% level of probability.

TABLE 16 Data and statistical analyses of Kramer shear-press measurements for tensile strength of end slices of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replications	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
	Lb.force /cm.^{2}	Lb.force /cm.^{2}	Lb.force /cm.^{2}	Lb.force /cm.^{2}
1	0.030[a]	0.049	0.038	0.024
2	0.034	0.042	0.033	0.023
3	0.035	0.038	0.039	0.033
4	0.025	0.043	0.041	0.040
Grand average	0.031	0.043	0.038	0.030
Standard deviation	0.005	0.005	0.003	0.008

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F. Statistic
Temperature	3	0.000149	4.29*
Replicates	3	0.0000132	0.38
Error	9	0.00003	
Total	15		

Duncan's Multiple Range Test

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
	D < B	A < B

[a] Each value represents an average of four determinations.

*Significant at the 5% level of probability.

deviations for Kramer shear-press measurements of tensile strength are presented in Table 16.

These results indicate the baking temperature of 177° and 218°C. yielded end cake slices with almost equal tensile strength. The end slices from all cakes, regardless of the baking temperature, were free from the thick, compact layers which were present in body slices of cakes baked at 204° and 218°C. Here again, some cake samples were damaged as they were placed in the apparatus.

Tenderness measurements

The analysis of variance showed no significant differences in tenderness of angel cakes baked at four oven temperatures (Table 17). The grand averages of 2.44, 2.34, 2.27, and 2.46 lb. force/gm. for cakes baked at 177°, 191°, 204°, and 218°C., respectively, are presented in Table 17 along with mean values for each replication and the standard deviations.

Significant differences were found between replications, according to the analysis of variance. The thick, compact layers present in part of the cake slices may explain the differences between replications.

Maximum force values for tenderness were correlated with maximum force and area-under-the-curve values for compressibility. Neither correlation was significant.

TABLE 17 Data and statistical analyses of Kramer shear-press measurements for tenderness, expressed as maximum force, of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C.	191°C.	204°C.	218°C.
	Lb.force /gm.	Lb.force /gm.	Lb.force /gm.	Lb.force /gm
1	2.17[a]	2.46	2.15	2.07
2	3.10	2.40	2.94	2.72
3	2.17	2.16	1.97	2.51
4	2.31	2.34	2.01	2.55
Grand average	2.44	2.34	2.27	2.46
Standard deviation	0.45	0.13	0.46	0.28

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	0.032	0.52
Replicates	3	0.312	4.96*
Error	9	0.063	
Total	15		

[a] Each value represents an average of two determinations.

*Significant at the 5% level of probability.

Mean values, grand averages, and standard deviations for area-under-the-curve values for tenderness, as well as statistical analyses are presented in Table 18. When the area-under-the-curve tenderness values were analyzed for variance, very highly significant differences attributable to baking temperatues were found. Further analysis of the data using Duncan's Multiple Range Test (17) showed very highly significant differences in tenderness between cakes baked at 218° and those baked at 177° and 204°C. The baking temperatures of 177° and 204°C. produced more tender cakes than did the 218°C. baking temperature. Cakes baked at 191°C. were more tender at the 1% level of probability, than cakes baked at 218°C. The tenderness values for cakes baked at 177°, 191°, and 204°C. were not significantly different.

The area-under-the-curve tenderness values are not in agreement with maximum force values for tenderness. Examination of the shear-press data indicated the recorded maximum force required to shear samples of cake increased as the baking temperature increased. However, the average weight of the samples showed values of 8.63, 10.25, 10.15, and 13.75 gm. as the baking temperature increased from 177°, 191°, 204°, and 218°C., respectively. Sample weight was an integral part of the formula for calculating maximum force while it was not reflected in area-under-the-curve values. Apparently, weight increased in the same ratio as did the recorded maximum force readings on the graph.

TABLE 18 Data and statistical analyses of Kramer shear-press measurements, for tenderness, expressed as area-under-the-curve, of angel cakes baked at four oven temperatures

Means, grand averages, and standard deviations

Replication	Oven Temperatures			
	177°C. A	191°C. B	204°C. C	218°C. D
	Sq.Cm.	Sq.Cm.	Sq.Cm.	Sq.Cm.
1	2.29[a]	3.48	2.46	5.32
2	3.15	3.17	4.13	7.02
3	2.28	3.35	2.88	4.02
4	2.13	3.07	2.77	4.63
Mean	2.46	3.27	3.11	5.25
Standard deviation	0.46	0.18	0.69	1.30

Statistical Significance

Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Square	F Statistic
Temperature	3	5.785	16.48***
Replicates	3	1.351	3.85
Error	9	0.351	
Total	15		

Duncan's Multiple Range Test[b]

Significant at	Additional at	
$P \leq 0.001$	$P < 0.01$	$P < 0.05$
$\underline{A,C} < D$	$B < D$	

[a] Each value represents an average of two determinations.

[b] Values underscored by the same line are not significantly different (17).

***Significant at the 0.1% level of probability.

Very highly significant correlation coefficients (r = 0.91 and r = 0.93) existed between area-under-the-curve values for tenderness and maximum force and area-under-the curve values for compressibility, respectively. These correlations suggested as the force needed to shear the cake increased, the force needed to compress it also increased.

A negative correlation coefficient (r = -0.84) showed a very highly significant relationship between penetrometer values and area-under-the-curve values for tenderness. This correlation indicated cakes which were less compressible by the penetrometer, needed more force to be sheared by the shear-press. This indicates the penetrometer is a reliable test for measuring compressibility of angel cakes.

Validity of Objective Measurements

The percentage of weight loss during baking and the percentage of moisture were determined as indications of the moistness of the angel cakes. Both of these objective measurements indicated no significant differences among the cakes baked at four oven temperatures. However, sensory evaluations of moistness indicated significant differences attributable to baking temperatures. When the percentages of moisture were correlated with moistness scores, the correlation was not significant. The percentages of weight loss and moistness scores showed a significant correlation.

Because the two measurements agree in their assessment of the moistness of the cake, they are considered valid. Perhaps the judges were influenced by other factors such as texture and tenderness of the cake samples in their evaluations of moistness.

The highly significant relationship found between the percentage of sand retained and the texture scores of angel cakes suggests the sand retention test is a valid measurement to determine the texture of angel cakes. However, the high standard deviations of the test values as presented in Table 11, point out some limitations of this test. The location from which the samples are taken, moistness of the cake, manner of adding the sand, as well as the interpretation of the test results must be considered.

The penetrometer values showed very highly significant correlation coefficients with the shear press values for compressibility expressed as maximum force and area-under-the-curve, and tenderness scores as well as area-under-the-curve values for tenderness. Therefore, under the conditions of this study, the penetrometer is a valid instrument for compressibility measurements of angel cakes.

The validity of the Kramer shear-press for measuring the quality characteristics of angel cakes has been assessed. Funk, Zabik, and Downs (18) determined that the shear-press could be used for measurements of compressibility, tensile strength, and tenderness to define quality characteristics.

SUMMARY AND CONCLUSIONS

The primary purpose of this study was to investigate the effect of the baking temperatures of 177°, 191°, 204°, and 218°C. on the quality characteristics of angel cakes as measured by sensory evaluations and objective measurements. A secondary purpose was to assess the validity of objective measurements which could be performed in laboratories with limited equipment by correlating appropriate data obtained from these measurements with Kramer shear-press data and sensory evaluations.

Cakes were prepared from household-size packages of commercial cake mix following the one-step procedure suggested by the manufacturer. Ingredients were weighed or measured to the nearest gram or milliliter. To provide sufficient slices for sensory evaluations and objective measurements, the contents of two packages were combined for mixing and then the batter was divided into two equal portions for baking. The specific gravity and pH of the cake batter were determined as indications of control of all variables except the oven temperature. Time-temperature relationships were continuously recorded during baking from potentiometer leads positioned 2.5 and 5.0 cm. from the bottom of each cake pan. Each variable was replicated four times.

After the cakes had been cooled and weighed to determine losses during baking, they were wrapped in Saran, put into polyethylene bags and frozen at -23.3°C. until needed for subsequent evaluation. The cakes were sliced from the frozen state for sensory evaluation and objective measurements.

The cakes were evaluated by a six-member, trained taste panel using a 7-point numerical scale. Descriptive terms aided the panelists in their evaluations. Objective measurements were index of volume, percentages of weight loss during baking, moisture determinations, percentage of sand retained, compressibility as indicated by penetrometer and Kramer shear-press readings, tensile strength, and tenderness.

Highly significant differences were present in the specific gravity measurements of the cake batter. These differences are probably attributable to experimental errors. No significant differences were found in the pH values of the cake batter.

The temperatures within the cakes rose at a rate dependent on the oven temperature with the slowest rate of temperature rise recorded for the 177°C. oven. Grand average maximum internal temperatures of 98.0°, 99.5°, 100.0°, and 100.4°C. were recorded for cakes baked at temperatures of 177°, 191°, 204°, and 218°C., respectively. The differences in the maximum internal temperatures were very highly significant.

The statistical analyses of sensory evaluations indicated very highly significant differences for texture, tenderness, moistness, and color of the crumb scores among the cakes baked at the four oven temperatures. Cakes of light, open texture were produced at the 177° and 191°C. baking temperatures as compared with the compact texture of cakes baked at the two other temperatures. Tenderness of cakes decreased when cakes were baked at temperatures higher than 191°C. The optimum moistness of angel cakes as well as the desirable white color of the crumb were secured at baking temperatures not higher than 204°C.

Statistical differences were indicated by objective measurements. Index of volume measurements showed a very highly significant and continuous decrease as the baking temperature increased. Cakes with more open texture were produced at baking temperatures of 177° and 191°C. according to the results of the sand retention test. Penetrometer measurements indicated cakes were more compressible when baked at 177° and 191°C. The shear-press measurements for compressibility based on maximum force and area-under-the-curve, showed more force was necessary to compress cakes baked at 218°C. compared with the three other oven temperatures. The same trend was indicated by the values of tenderness measurements for the shear-press based on area-under-the-curve, showing that cakes baked at temperatures higher than 204°C. required more force to be sheared.

No significant differences among cakes baked at the four oven temperatures were indicated by the tenderness values of the shear-press based on maximum force, tensile strength measurements by the shear-press, percentages of moisture in the cake, and percentages of weight loss during baking.

Very highly significant relationships existed between texture scores and moistness scores, tenderness scores, and index of volume measurements. Very highly significant correlations were also indicated between the tenderness scores and index of volume measurements and compressibility measurements based on the maximum force readings of the shear-press. Area-under-the-curve tenderness values determined by the shear-press showed a very highly significant correlation with shear-press measurements for compressibility based on both maximum force and area-under-the-curve values.

The highly significant correlation found between the sand retention test and texture scores of angel cakes suggested the validity of this test to measure texture of angel cakes. Because of the high standard deviations, however, the reliability of this test is questioned.

The very highly significant relationships between shear-press values for both maximum force and area-under-the-curve measurements of compressibility, tenderness scores and the penetrometer values indicated the penetrometer was a valid test to determine compressibility of angel cakes.

According to the results of this investigation, baking temperatures of 177° and 191°C. were more satisfactory for baking angel cakes than baking temperatures of 204° and 218°C. Thick layers developed in cakes baked at 204° and 218°C. as a result of a partial collapse of the structure after they were removed from the oven. The top crust of these cakes was deeply cracked and the surface was very dark brown to burned. Perhaps the crust was too heavy to be supported by the delicate structure of the cakes and hence, the cakes collapsed when they were removed from the oven.

Further research seems to be needed in the two following areas: (1) an investigation to clearly define doneness of angel cakes as determined by maximum internal temperature reached by the cake and/or time-temperature relationships, and (2) further analysis to determine the factors influencing sensory evaluations of angel cakes.

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APPENDIX

EVALUATION SHEET FOR SUBJECTIVE EVALUATION OF ANGEL CAKES

Date:

Oven temperature: Baking time: Replication No.:

ATTRIBUTES	CAKE A OR C	CAKE B OR D
Appearance of the cake: Cracks: Slightly deep Very deep Collapse:		
Color: Top: Golden brown Dark brown Very dark brown Burned Sides and bottom: White Light golden Golden brown		
Texture of the sides and bottom: Dry Moist Sticky		

ANGEL CAKE TASTE PANEL

GENERAL INSTRUCTIONS

1. You have been provided with a written schedule of dates and times the panel will meet. Cake samples will be available at 10 A.M. in the taste panel room of the Institution Administration Department. You may evaluate your samples at your convenience between 10 and 11 A.M.

2. Please refrain from smoking, eating, or drinking for one-half hour prior to evaluation. Please do not give any facial or vocal reactions as you evaluate your sample.

3. The samples are coded with random numbers and are presented in a randomized fashion. Please start with the sample in the upper left-hand corner of the tray and proceed toward the right. The lower row should be evaluated in the same order.

4. Each sample is to be evaluated on a separate score sheet using a 7-point scale, a score of 7 being the highest given. Four attributes are to be judged. Descriptive terms for the scores of 7, 4, and 1 are given to help in your evaluation. Quality characteristics for standard and below standard angel cakes are also listed for each attribute.

5. Place a check, using a red pencil, in the block which most nearly fits your evaluation of each quality characteristic of the sample. Score each sample independently of others. BE SURE THE PLATE CODE MATCHES THE SCORE CARD.

6. You may rinse your mouth between sample evaluations with the water provided.

* * * * * * * * * * * * *

Texture. Please break the cake sample in half. Evaluate the texture of the sample on the freshly broken surface of the cake.

Tenderness. Evaluate the tenderness of the sample by breaking or tearing AND masticating.

Moistness. Evaluate the sample on the basis of your first impression of mouth feel.

Color. Evaluate the color of the sample on a freshly broken surface.

BE SURE YOU HAVE RECORDED YOUR EVALUATION OF FOUR QUALITY CHARACTERISTICS FOR EACH CAKE SAMPLE. PLEASE WRITE IN (OR UNDERLINE) descriptive terms when scores of 4 or lower are given to indicate the reason for the score.

ANGEL CAKE SCORE SHEET

Judge:__________________________

Date: __________________________ Sample Code:______________

Quality characteristics of standard and below standard angel cakes

Angel cake	Texture	Tenderness	Moistness	Color
Standard	Small sized air cells. Thin cell walls. Uniform grain.	Cakes tear easily but without falling apart.	Moist without being sticky.	Very white.
Below Standard	Very large uneven air cells. Thick cell walls. Layering of compact material.	Tough, rubbery, resistant to tearing. Cake has tendency to crumble.	Sticky and gummy or dry.	Any color other than white.

1. Please evaluate sample on the attributes listed and defined above.
2. Check to make sure the random number on the score sheet is the same as for the sample.
3. Please be sure you have 4 checks on each score sheet before leaving taste panel room.

Attribute		7	6	5	4	3	2	1
TEXTURE	air cells	small sized			large, uneven sized			unacceptable
	cell walls	thin			thick			
	grain	uniform			compact			
TENDERNESS		tears easily without falling apart.			tough, rubbery or has tendency to crumble			unacceptable
MOISTNESS		moist without being sticky			sticky or dry			unacceptable
COLOR		very white			any color other than white			unacceptable

General Comments:

TABLE 19 Summary of correlation coefficients calculated from sensory evaluation and objective measurement data of angel cakes baked at four oven temperatures

Relationship	Correlation Coefficient
Tenderness scores/Texture scores	0.89***
Moistness scores/Texture scores	0.80***
Index of volume/Texture scores	0.86***
Index of volume/Tenderness scores	0.90***
Index of volume/Time of baking	0.92***
Percentage of weight loss/Moistness scores . . .	-0.51*
Percentage of moisture/Moistness scores	-0.03
Percentage of moisture/Percentage of weight loss	-0.08
Percentage of sand retention/Texture scores . .	0.70**
Percentage of sand retention/Index of volume . .	0.87***
Penetrometer measurements/Texture scores	0.87***
Penetrometer measurements/Index of volume . . .	0.88***
Penetrometer measurements/Tenderness scores . .	0.93***
Compressibility, maximum force/Tenderness scores	-0.87***
Compressibility, maximum force/Index of volume .	-0.89***
Compressibility, maximum force/Penetrometer measurements	-0.87***
Compressibility, area-under-the-curve/ Compressibility, maximum force	0.99***
Compressibility, area-under-the-curve/ Penetrometer measurements	-0.88***
Tensile strength of body slices/Tenderness scores	0.00
Tensile strength of body slices/Index of volume	-0.09
Tensile strength of body slices/Penetrometer measurements	-0.07
Tensile strength of body slices/Compressibility, maximum force	0.21
Tensile strength of body slices/Compressibility, area-under-the-curve	0.17
Tenderness, maximum force/Compressibility, maximum force	0.07
Tenderness, maximum force/Compressibility, area-under-the-curve	0.10
Tenderness, area-under-the-curve/Compressibility maximum force	0.91***
Tenderness, area-under-the-curve/Compressibility area-under-the-curve	0.93***
Tenderness, area-under-the-curve/Penetrometer measurements	-0.84***

*Significant at the 5% level of probability.
**Significant at the 1% level of probability.
***Significant at the 0.1% level of probability.

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