THE RELATIONSHIP OF FLOUR PROTEIN CONCENTRATION AND VARIOUS STARCHES TO THE PHYSICAL AND CHEMICAL PROPERTIES OF ANGEL FOOD CAKES.

by

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INTRODUCTION

Eggs from various non-mammalians have been used in men's food since the dawn of civilization. The use of not only eggs but of their derived products as regular food pre-dates the Christian era. It has been recorded that some early cultures such as the Chinese and the Egyptian used eggs either directly or after some processing.

With the evolution of new societies and cultures, dietary habits have changed. One of the fastest changing industries in the United States and some other countries is the food industry. The continuous demand for food with convenience and higher nutritional values has placed the main responsibility on the food industry in this dynamic situation.

Eggs supply an increasing number of products, some of which are composed entirely of egg itself while others use egg products as ingredients.

Angel food cake is a very common product in the United States using eggs as an ingredient. This product with its associated production problems is the objective of this research. In the commercial production of angel food cakes several problems plague the industry. One of these problems is related to the cupping phenomenon. The cupping phenomenon is the development of depressions in the bottom and side wall of angel food cake.

In reviewing the literature, it is apparent that relatively little work has been reported concerning the cupping phenomenon. The few papers that mention this have but limited description of the phenomenon. Some studies attribute this problem to the size of the pan, others to the richness of the formula, type of eggs, type of flour, etc. None of these studies gives a proper explanation or fully answers questions raised by the baking industry.

The following variables were studied in the work reported here to determine the causative agent or agents of the cupping phenomenon.

(a) The amount of the particular starch used for the dilution of flour protein.

(b) The type of starch used in the formula.

The relationships of these factors to pH and specific gravity of the batter and weight, tenderness, crust color, crumb color and presence and intensity of the cupping phenomenon of the cakes were studied.

An increase in efficiency of production would mean a reduction in the actual cost of producing this very popular food.

REVIEW OF LITERATURE

Angel food cake according to Webster's dictionary is "a white sponge cake made of flour, sugar and whites of eggs". This is a very simple definition of a complex product, a product on which limited research has been conducted.

Development of the white sponge cake structure is dependent on formula, mixing techniques, production techniques, baking and cooling procedures. Therefore in this review of literature many of these factors will be considered as related to angel food cakes.

Lowe (25) has presented an excellent review of the literature from various laboratories on research related to eggs in angel food cakes. This review covers the literature before 1955 and served as an excellent source of reference to publications prior to that time.

The quality of fresh, frozen and dried albumen used in angel food cakes is of extreme importance in the development of a high quality sponge. Jordan et al (19) reported that shell egg quality and the performance of egg white are closely related to angel food quality. When eggs are kept at room temperature the flavor deteriorates about three times faster than when they are held at refrigerator temperatures. Eggs held in cold storage kept their flavor quality four times longer than those kept at room temperature. Eggs kept at room temperature deteriorated as much in one month as those held at cool storage for three months, or in cold temperature for four months when judged by the flavor score for angel food cakes.

Robertson and Haney (36) presented some observations about the modern treatments of egg white solids for use in bakeries. The original raw egg which should be of an acceptable quality is treated with sanitary techniques in order to assure freshness, shell cleanliness and the lowest possible number of bacteria. The flavor, keeping quality and bacterial counts are the objective characteristics used to determine the quality of the product.

Systematic research in egg processing directed attention to the naturally present glucose, which even though present in a small percentage was responsible for the brown color of the final albumen. Today the naturally occuring glucose is removed, and the pH neutralized before drying the egg whites. Removal of glucose has been done with great success by Banwart and Ayres (2) using an enzyme known as deoxygenase.

Further treatments in the processing of egg whites are related to the elimination or at least reduction of the well known pathogen, Salmonella. The most often encountered species of the pathogen, Salmonella typhimurium, was discussed by Frazier(12).

Robertson and Haney (36) discussed some substances which have been found to aid the whipping characteristic of egg whites. One of these is sodium lauryl sulfate, which when added in a minute quantity leads to superior foaming ability of egg white solids in the reconstitution process. The most common way to estimate the quality of an egg white is to prepare a whipped foam and determine the foam stability.

To study the similarities and differences between liquid egg whites and dried white solids, the whipped foam stability test was utilized. The results indicated that egg white solids performed at a higher level than the level necessary to produce a superior quality angel food cake.

Formulas calling for a very high level of sugar can use egg white solids successfully. This is possible because of the superior whipping ability of present day egg white solids.

Early production of egg white solids gave poor quality because of poor techniques and low quality of the raw material employed. The poor quality of early production of egg white solids caused bakers to be reluctant to use this product. The increased use of egg white solids has developed because of increased quality of product, storage stability at room temperature and reduced cost of shipment of a dehydrated or unfrozen product.

Physicochemical processes such as the use of high voltage cathode rays to destroy bacteria of the Salmonella group (26), high temperature storage (2), and the pasteurization process (8) give hope that new egg derivatives will be common products in a few years.

Robertson and Haney (36) reported a relationship between the quantity of egg white solids used in a formula and the volume of angel food cake. Their study used levels of from 8 to 20 per cent as expressed on a 100 per cent flour basis. The cake volume tended to decrease as the egg solids level approached 12 per cent. There was a complete cake failure when 8 per cent solids were used. At this particular solids concentration the cake collapsed during the final period of baking. Cakes containing a high concentration of solids (12 to 20 per cent) had exceptional volume and kept their structure during baking. The finished product had rough texture, dryness, and a somewhat strange eating quality as the solids increased above 12 per cent.

Kline, Meehan and Sugihara (22) studied the effect of solids content of liquid egg white on the volume of angel food cakes. A comparison of whites of eggs from young and old birds indicated a lower solids content in eggs produced by older birds. This difference in solids content resulted in a 3-4 per cent lower angel food cake volume. The use of blended dried egg white solids aided in the elimination of problems related to age of the laying flock.

Cunningham, Cotteril and Funk (9) also reported that solids content of egg whites decreased when the age of the layer increased.

Glabau (13) demonstrated that the degree to which the egg white solids are beaten, the beating speeds used and the temperature of the system are very important variables in batter preparation. It is recommended that egg white solids should be beaten to obtain an optimum "peak", which in other words means a specific gravity of about 0.15 to 0.17. If the specific gravity is above 0.17, it is due to an insufficient aeration, therefore a heavy cake with a tight texture and poor volume will be the final product. If the specific gravity is below the normal (0.15 - 0.17) the stability will be such that a considerable shrinkage will take place due to the poor stability of the foam. This shrinkage and foam stability relationship have been chemically studied by Barmore (3). He reported that the foam stability could be improved by using a minute amount of acid in the system. Slosberg _et al_. (39) substantiated the results noted by Barmore, that the addition of acid increased foam stability. They also noted that the addition of sugar and acid increased the stability of the foam to heat. The temperature of coagulation can therefore be reached before the foam has collapsed. If the foam stability is poor, large air cells are formed and this phenomenon tends to aid in causing the cake to collapse. A foam with low stability results in extreme shrinking of the cake during the last stages of baking and during the cooling time.

Grewe and Child (14) reported that the lowering of the pH with various organic acids such as citric, malic, tartaric, etc., produced an angel food cake with a fine grain and excellent whiteness. If the pH was increased to near neutral the product became yellow in color and the grain became tight and coarse.

Shellenberger et al. (38) studied the effect of particle size and its uniformity in flour on cake volume, grain, texture and crumb color. These workers classified flour into three distinct particle sizes, 0-37, 37-53, and greater than 53 microns. They reported that the 0-37μ fraction was the lowest in protein content, yielded the best volume of the final product, the best grain, texture, crumb color and general appearance.

Sollars (40) demonstrated by a sequence of experiments that bleached flour increased the volume of angel food cakes.

Harrel (16) reported a greater number of gas cells in cake prepared from bleached flours. The cakes also had better texture and grain.

Alexander (1) presented data to define the action of chlorine on the dispersability and hydration of gluten, and hydration capacity of starch. These factors are closely related to the cake performance. The amount of chlorine necessary to disperse and hydrate gluten depended upon the extent to which the flour was buffered.

Yamazaki (41) studied which chemical and physicochemical tests could be applied to flours to determine their general suitability for cakes. The chemical tests studied included the moisture, protein, ash, acid viscosity, and pH of the flour. The physicochemical tests studied were farinograph or similar rheological determinations, particle size distributions, and chlorine treatment. The results of the chemical and physicochemical tests indicate that many of these tests may serve as guides in determining the suitability of a flour for cake production. The final test for determination of flour acceptance in a particular formula is the utilization of test baking results.

There is sufficient information in the literature to define the function of the three main ingredients; flour, sugar and egg whites. High sugar content is required because sugar is the only tenderizing agent present in the system. Flour and egg white are structure builders and therefore both of them contribute to the toughness and structure of the product.

There are many ways of producing angel food cakes. Pyler (34) suggested four different methods of combining flour and sugar with the beaten egg whites to produce successful results. The basic factor in making angel food cakes is to incorporate the ingredients with the foam of the beaten egg whites in such a manner as to mix them uniformly but to avoid losing the air cells held by the foam.

Pickens (33) discussed a different method for the production of angel food cakes. He used three steps for mixing all the ingredients instead of two.

Bonavia (7) described special methods used in the continuous mixing system. He indicated some advantages of this new system. to be simplified and better control of the batter specific gravity through the utilization of a homogeneous mixture of the ingredients and compressed air. The batter temperature can also be controlled efficiently by cooling the mixing heads. Continuous mixing results in improved grain structure, softness of crumb and texture.

The relationship speed vs time in angel food cake production is one of the most critical variables found in the cake industry. Young (42) in his description of some new equipment used today in the baking industry reported mixing combinations of RPM and times which save considerable time and about 15 percent of the ingredients. The use of the "aeration blender" has been reported to increase cake volume.

Edelman and Cathcart (11) reported that homogenizing or comminuting had a deleterious effect on eating quality and volume. Homogenization produced angel food cakes with fine crumb structure.

Pence and Stanbridge (30) reported that firming of crumb becomes progressively faster if the storage temperature is increased.

Wheat starch has been used advantageously by Dubois (10) and others in angel food cakes to produce products with better volumes, grain, texture, eating properties, and retention of freshness.

The development of indented areas of various sizes on the bottom of the cake is known as "cupping". It is a common problem associated with industrial production.

Robertson and Haney (36) reported a correlation between the richness of the formula, pan size and the cupping phenomenon. In their study, cake formulas of various richness were baked in pans of various sizes. They reported that larger sized pans can be used when richer formulas are used and that smaller pans must be used with lean formulas. If the reverse is used there is a greater presence of the cupping phenomenon.

The previous studies indicated many variables are present in the production of angel food cakes. However little or no information is available on (a) the relationship of flour protein level or (b) the effect of various starches as diluting agents for flour protein to cupping, specific gravity of batter, pH of batter, weight of the cake, volume of the cake, pH of crumb, tenderness, color of crust and crumb and concentrations of furfural and hydroxymethyl furfural.

The color of crust and crumb is important to angel food cake quality. Three types of browning reactions have been identified in the area related to foods (18).

1. Carbonyl - amino reactions are reactions of aldehydes, ketones, and reducing sugar with amines, amino acids, peptides and proteins.
2. Caramelization occurs when sugars and polyhydroxycarboxylic acids are heated to relatively high temperatures without the presence of amino groups. This type of reaction requires more energy (heat) to occur than the first one.
3. A third type of browning is associated with an oxidative reaction which may or may not be enzyme catalyzed.

The browning reaction was first described in 1912 by Maillard (6).

Nordin and Johnson (27) reported that the browning reaction associated with reducing sugars is the Maillard type rather than caramelization. As the concentration of amino-acids is increased the phenomenon is accelerated (15).

Barnes and Kaufman (4) described the possible relationships between the browning reaction and the development of flavors in many foodstuffs.

Joslyn and Ponting (20) reported that browning, of whatever type, is the result of the formation of unsaturated colored polymers of varying composition which are related to the presence of original carbonyl or potential carbonyl groups.

Patton and Chism (29) described the complexity of browning reactions using chromatographic tools. They found about 15 different components in a glucose-aqueous ammonia system and around 24 compounds in a glucose-glycine reaction mixture.

Hodge (18) reported that polyhydroxy compounds and sugars in which the carbonyl function is blocked do not produce the browning reaction. The same effect is observed when some reagents combine with carbonyl groups.

Sugars are an example of naturally occuring compounds with many carbonyl groups. Reducing sugars are transformed (dehydration - fission) to enedioles and osones, and reductones and dehydro-reductones, which provide α -dicarbonyl or conjugated dicarbonyl groups.

Simple organic compounds undergo polymerization and browning at ordinary temperatures and even at high degree of purity. Especially important in that group are the α , β unsaturated aldehydes, α dicarbonyl compounds, diacetyls and reductones. The presence of oxygen or an oxidation product is required for the browning of these types of compounds in the pure state. The production of a brown crust color in baked products appears to be the result of carbonylamino reactions.

MATERIALS AND METHODS

Starch Samples.

Six commercially prepared samples of starch were obtained and used to dilute commercial cake flour of 9.3 percent protein content used in these experiments. Common names of the starches are:

a. Commercial wheat starch.

b. Unmodified corn starch (food grade).

c. Gelatinized wheat starch.

d. 55-per cent-amylose corn starch.

e. 70-per cent-amylose corn starch.

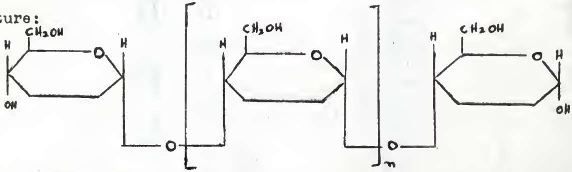
f. 70-per cent-amylose corn starch treated to contain 10 per cent hydroxy propyl groups.

The samples were typical of products marketed for use in food industries. The first three starches are widely used in food applications. The other three starches are new products with limited industrial applications.

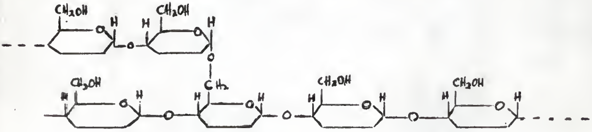
General Description of the Starches.

Wheat starch is probably the most difficult of all starches to prepare in high yield and acceptable degree of purity. Problems arise in the preparation of wheat starch due to the tendency of the wheat gluten to become a very sticky mass in the presence of small amounts of water, and a slimy paste in the presence of larger amounts of water. This problem is not encountered in the preparation of corn starch. Ordinary wheat and corn starches have about 27 per cent amylose and 73 per cent amylopectin (23).

Linear or amylose fraction is represented by the following structure:



and the branched or amylopectin fraction by the following structure:



Gelatinized starch is "native" starch of which the spherocrystalline structure has been disorganized by some means such as heating in water or treating with aqueous alkaline solution. When the starches are heated with water above certain temperatures, they form a viscous paste. The ease of paste formation differs from starch to starch and often varies with the previous treatment of the starch, i.e., whether during manufacture it has been subject to the action of alkali or acid for excessive periods of time or in excessive concentration. The viscosity of pastes produced after acid treatment of the starch is generally lower than normal, because of hydrolysis therefore it allows a more thorough agitation and dissemination of heat throughout the whole paste when it is being made.

The drying treatment accorded to the starch during manufacture is a factor in determining the viscosity of the starch paste. One which has been dried at a very low temperature generally shows a greater paste viscosity than one which has been quickly dried at an elevated temperature (35).

Bear and Samsa (5) interpret the swelling and gelatinising phenomena shown by the starch granules as an actual contraction and thickening of radially oriented starch molecules rather than ordinary osmotic or hydration effect alone.

Different workers give different temperatures at which the various starches gelatinize. The reason of this disagreement is not only due to the different conditions of the experiments, but also because many research workers take the gelatinizing point as the one in which the anisotropy disappears from all the starch granules present in the system, while other workers take it to be when the majority of the granules show loss of anisotropy, but it is difficult to know the quantitative meaning of "majority" and the practical way of measuring it. Still other workers define paste formation as gelatinization.

Wheat starch gelatinization has been described as taking place in two different steps (21) which have been designated the first order and second order of gelatinization. The first order is reached when starch is heated between $60^{o}$and $70^{o}C$ in an excess of water, (this is loss of anisotropy) or to 100°C with an accurate 45 per cent water present in the system. At this stage the granules are somewhat swollen, they can readily absorb certain stains, and undergo change in X-ray spectrum. This corresponds to the change in starch on baking (17). The second order occurs when starch is heated in an excess of water at 100°C (extensive paste formation). In this stage the granules have an amorphous X-ray pattern and are highly swollen.

The 55-per cent-amylose corn starch was a pure food starch produced from a special hybrid type. The amylopectin fraction (branched chain polymer) accounts for the remaining 45 per cent (31).

The 70-per cent-amylose starch was an unmodified high - amylose starch. The uniqueness of this high-amylose corn is further emphasized by the fact that the amylopectin portion of high - amylose starch shows much longer branches (34-36 anhydroglucose units in length) than the amylopectin portion of common corn starch (20 anhydroglucose units in length) (31). Thus not only the straight chain amylose molecules can associate with each other but also the longer amylopectin branches tend to associate more readily. This factor is responsible for greater film strength.

The 70-per cent-amylose corn starch treated to contain 10 per cent hydroxy propyl groups is described as high-amylose corn starch which has been derivitized by about 10 per cent added hydroxy propyl groups (31). These groups are added by sparging with nitrogen to remove residual air and introducing propylene oxide in a NaOH solution containing the starch that is going to be treated (37). This treatment retards retrogradation and also decreases the pasting temperature so that the starch can be cooked under reasonable conditions and the paste is stable enough to apply as an edible film (31).

The final method developed for the production of angel food cakes was the result of tests and experimentations. Preliminary studies involved the establishment of all parameters. The following procedure was used.

First stage

Dry albumen	41.3 gr.
Monocalcium phosphate	4.6 gr.
Granulated sugar	96.5 gr.
Water	288.5 gr.

Second stage

Powdered sugar	211.7 gr.
Cake flour	93.6 gr.
Wheat starch	25.0 gr.
Sodium bicarbonate	1.0 gr.
Salt	3.8 gr.

Mixing procedure

The first stage was mixed in a Hobart A-200 mixer equipped with a wire whip. The water was placed in the mixer bowl. The dried albumen, $CaHPO_4$ and sugar were dry - blended and added to the water in the mixer bowl. The mixture was allowed to reconstitute for 6 minutes at low speed. The mixture was then whipped for 8 minutes at second speed and then at third speed for 21 seconds.

The dry ingredients of the second stage were dry blended prior to their addition. The Hobart A-200 mixer was equipped with a "B" flat paddle prior to the addition of the second stage. The mixer was operated at low speed during the second stage addition. The second stage was folded in during a 1-minute interval. Thirty second additional mixing was allowed after complete folding in of the second stage to obtain better batter uniformity.

The batter was scaled in a experimental cake pan and baked at 375°F for about 33 minutes. The batter was scaled at 709 grams per pan to produce optimum baking conditions.

Double amounts were scaled in all the experiments, consequently two cakes were made from each batch.

The 9.3-per cent protein content of the original flour was adjusted to 8.3, 7.3, 6.3, 5.3, and 4.3-per cent protein content by the addition of starch. This series of dilutions was made with each of the six starches previously mentioned.

Determinations

The following determinations were conducted.

1. Batter pH.
2. Batter specific gravity.
3. Weight of the cake.
4. Height.
5. Crumb pH.
6. Penetrometer value.
7. Crust color.

8. Crumb color.

9. Concentration of furfural and hydroxy-methyl-furfural.

10. Cupping effect; if present.

Batter pH: This determination was made by use of a Beckman Expandomatic pH meter; a 50-ml. sample was used for the determination. The pH meter was calibrated by using a set of buffers of known pH value.

Batter specific gravity: This was obtained by dividing the weight of a precise volume of batter by the weight of the same volume of water.

Weight and height of the cakes: Cake weight and height were determined by weighing the cake in grams, and measuring the height of the cake in millimeters respectively.

Crumb pH: 10 gr. of cake crumb were placed in a Waring blender with 100 cc of distilled water. The blender was operated for 15 seconds. The pH determination was made on the homogenized solution.

Penetrometer value: This determination was done with a Precision Universal Penetrometer (28). A ASTM grease penetration cone was used to determine the rate of penetration. The prepared sample was placed in position on the base. The height of the mechanism head was adjusted so as to bring the point of the penetrating instrument exactly into contact with the surface of the sample. The clutch trigger was depressed allowing the cone to descend into the sample. The clutch trigger was released after 5 seconds timed with a stop watch. The depth of penetration was read directly in tenths of millimeters and recorded in millimeters.

Crust and crumb color: Crust and crumb color were measured with a photovolt reflectometer. The selected filter furnished the widest spread of readings in order to distinguish small differences in shade (32). The amber filter (57.5) was used. A white standard of 100 value and a dark standard of zero value were used. The reflectance of the sample from the reading with suppresed zero was obtained by using the following formula.

$$rx = rd + \frac{gx(rl - rx)}{100}$$

rx = Reflectance of sample

rd = Reflectance of dark standard

rl = Reflectance of light standard

gx = Photovolt reflection meter reading of sample.

<u>Determination of furfural (2-furaldehyde) and HMF (5-hydroxy methyl-2-furaldehyde)</u>.

Seven different steps have been completely demonstrated in the sugar - amino system. For discussion purposes three stages of development are considered.

I. Initial stage (colorless mixture)
   - A. Sugar - amine condensation
   - B. Amadori rearrangement

II. Intermediate stage (colorless or yellow)
   - C. Sugar dehydration
   - D. Sugar fragmentation
   - E. Amino-acid degradation

III. Final stage (highly colored)

F. Aldol condensation

G. Formation of nitrogenous polymers and copolymers.

All the reactions from I-B to completion follow spontaneously.

As the solutions are concentrated, as in food dehydration, the reversible sugar-amino condensation (Reaction A) goes toward completion.

Preparation of P-ADA:

P-ADA (P-Aminodimethylaniline stannous chloride) was prepared by dissolving 10 gr. of P-amino dimethylaniline monohydrochloride (Eastman reagent) in 60 ml. of hot 95 per cent ethyl alcohol, and adding 1.06 gr. of stannous chloride dehydrated (Fisher reagent). The mixture was cooled to room temperature and 100 ml. of concentrated HCl were added. The white to colorless crystals which formed were filtered by means of a vacuum system, washed rapidly with a small quantity of 95-per cent ethyl alcohol and dried for about 50 hours in a vacuum desiccator.

The yield was about 14 gr. of P-aminodimethylaniline stannous chloride double salt.

Preparation of Standard Curve

Different solutions of furfural were prepared, ranging from .002 mg./ml. to .05 mg./ml. One ml. of furfural in benzene of each dilution was added to 4 cc. of C_6H_6 and then the resulting 5 cc. were added to 5 cc. of a .025M solution of the P-ADA reagent in absolute methanol. The solution was mixed well and allowed to stand at room temperature for 30 minutes for the appropriate color development. The optical density was measured at 495 mμ in a Universal spectrophotometer Coleman model 14. A mixture of 5 ml. of P-ADA and 5 ml. of C_6H_6 was used as a blank.

Technique for Furfural and HMF Determination

A 10 gr. sample of the ground crust was extracted five times in an Omni mixer (2 minutes each) at about 10°C with 25 ml. of benzene. The combined benzene extracts were centrifuged until the supernatant liquid was completely clear (about 25 minutes). Otherwise a turbid solution with high absorbance was observed. The combined furfural and HMF were determined by a modified Linko technique (24). The optical density of the solution was compared with the standard curve to determine the concentration of furfural and HMF.

"Cupping" Effect Measurement.

In this project the "cupping" effect was scored on the following basis.

0 = no cupping effect.

+ = Small cupping effect, affecting less than 25 per cent of the surface.

++ = Regular cupping effect, affecting about 25 per cent of the surface.

+++ = Large cupping effect, affecting more than 25 per cent of the surface.

++++ = Very large cupping effect, affecting about 50 per cent of the surface.

RESULTS AND DISCUSSION

Batter and cake characteristics resulting from the protein dilution of the commercial cake flour with six different starches are reported in Tables 1 to 6. The results reported are pH of batter, specific gravity of batter, weight of cake after baking, height of cake, pH of crumb, penetrometer value, color of crust and crumb, furfural and HMF, and cupping effect.

pH of batter: All of the cake batters prepared were subject to pH determinations. The results of pH determinations are presented in Tables 1 through 6 and plotted in Figures 1 to 3. It was observed that the higher the protein concentration the lower the pH of the batter. This trend was common for all of the series of protein dilutions except gelatinized wheat starch, which behaved in the opposite manner. The changes in pH values in each series were small. The smallest variation observed within a series (0.08) was in gelatinized wheat starch. The largest variation (0.33) was observed in the series diluted with corn starch. The lowering of the pH of batter with the increase in protein content of the flour is easily understood if the pH of the original cake flour is taken into consideration. The pH of the flour was 4.8 to 4.9. The increase of pH of the batter with the increase of protein concentration of the flour in the series diluted with gelatinized wheat starch may be due in part to the free sulfur dioxide (SO_2) used in the preparation of the starch and the heat treatment received in processing.

Specific gravity of batter: The specific gravity of the batter increased as the cake flour protein concentration increased. (Tables 1 to 3 and Figures 4 to 6). This observation was true for all starches but gelatinized wheat starch. In making the flour dilutions with this starch the specific gravity of the batter became greater as the protein concentration decreased. This was due to the poor capacity of the system to incorporate air in the liquid phase of the batter. The non-incorporation of air may be related to the lesser availability of the water due to the higher affinity of the molecules of gelatinized starch for water.

Weight and height: The weight and height of the cakes are very closely related (Figures 7 to 12). It is evident that the higher (bigger volume) the cake the lighter its weight. This relationship appears to be related to the water retention capacity and rate of evaporation throughout the entire system. As the protein concentration of the flour decreased, the weight of the cake also decreased. This observation was true when wheat starch and 70-per cent-amylose starch were used for adjusting the flour protein dilutions. When flour protein was diluted with corn starch, gelatinized wheat starch, 55-per cent-amylose starch, and 70-per cent-amylose 10-per cent-propyl starch the opposite trend was observed. As the protein concentration of the flour decreased, the height of the cake increased. This observation was true when wheat starch and 70-per cent-amylose starch were used for adjusting the flour protein levels. When flour protein was diluted with corn starch, gelatinized wheat starch, 55-per cent-amylose starch, and 70-per cent-amylose 10-per cent-propyl starch the opposite trend was observed.

pH of crumb: The crumb pH of the cakes increased as the protein concentration decreased. (Figures 13 to 15). This trend was observed for all the samples of starches except gelatinized wheat starch. When gelatinized wheat starch was used a higher pH was observed as compared to any other series of dilutions. When wheat starch was used to adjust the different dilutions, the pH decreased when the protein concentration decreased. This same trend was observed in batter pH.

In any dilution of any series the pH of the batter was lower than the pH of the crumb. This phenomenon was observed without exception throughout all the experiments.

Penetrometer values: The tenderness measurement (penetrometer value) increased when the protein concentration was decreased. (Figures 16 to 18). This observation was noticed in the following series: wheat, corn, and 70-per cent-amylose starch. In the series diluted with gelatinized wheat starch, 55-per cent-amylose starch, and 70-per cent-amylose 10-per cent-propyl starch the opposite effect was observed. A general statement can be made about the relationship between volume and tenderness values: the higher the volume of the cake the more tender it is. In this work this was true for each series except the one using unmodified corn starch.

Color of crust: The type of starch used in making the dilutions had a very determinant effect on the crust color of the cakes (Figures 19 to 21). Some starches like wheat starch and 70-per cent-amylose starch have the tendency to allow browner crusts than the other starches. The series diluted with gelatinized starch had a very pale color and had the poorest crust color. In each series it was observed that as the protein content increased the crust color also increased. Possible explanations for the increasing of color intensity when the cake flour protein is increased are the following: (a) Increase in the number of exposed amino-acid groups (amino-acid with free R-CHNHCOOH or $R\text{-}CHCONH_2$). (b) More water is bound by the flour protein therefore the "solution" is more concentrated and the reactions toward the melanoidins polymers and copolymers are accelerated. There appeared to be a relationship between pH of the batter and crust color formation for each series of starch dilutions. As the pH increased (within the series) the intensity of the brown color decreased. This phenomenon was observed in all the series except in the gelatinized wheat starch series.

It can be concluded that the brown color of the crust was also influenced to some extent by the pH of the system.

Color of the crumb: The color of the crumb increased its whiteness as the protein concentration decreased (Figures 19 to 21). This trend was observed in each series. The variation in crumb color between the two extreme concentrations of each series was very small.

Cupping phenomenon: The cupping effect was observed to be particularly large in the series in which the dilutions were made using high amylose starch (Tables 1 to 6). When 70-per cent-amylose 10-per cent-propyl starch was used the cupping phenomenon decreased considerably. Wheat starch presented cupping in the two final dilutions (5.3 and 4.3-per cent protein). Corn starch presented cupping in the three final dilutions (6.3, 5.3 and 4.3-per cent protein). Gelatinized starch did not give any indications of the phenomenon in any of the dilutions made in its series. Characteristics of the final products and cupping effect can be seen in Figures 23 to 28.

Standard Curve: The standard curve for the 2-furaldehyde (furfural) and 5-hydroxy- methyl -2- furaldehyde (HMF) determination was plotted and is presented in Figure 22.

Table 1. Optical density values of standard solutions of furfural.

Furfural Concentration	O.D
.050 mg/ml.	.94
.040 mg/ml.	.76
.030 mg/ml.	.57
.020 mg/ml.	.39
.010 mg/ml.	.20
.002 mg/ml.	.03

The relationship of furfural and O.D are shown to be linear (Figure 22).

The furfural and HMF concentration were obtained from reading the O.D of all the different dilutions for each of the six types of starches used. In this experiment every O.D was compared with the standard curve in order to obtain the concentration in mg/cc.

The following data appear to show a relationship between flour protein concentration and furfural HMF concentration in the cake crust.

Table 2. Optical density value comparison of various protein concentrations and furfural H.M.F.

Type of starch used for dilution	Protein conc.	O.D	Furfural HMF conc. (mg/cc)
Wheat starch	9.3	.83	.045
	8.3	.72	.038
	7.3	.72	.038
	6.3	.71	.037
	5.3	.63	.034
	4.3	.59	.030
Corn starch	9.3	.62	.034
	8.3	.58	.030
	7.3	.56	.028
	6.3	.52	.025
	5.3	.51	.025
	4.3	.49	.024
Gelatinized starch	9.3	.57	.029
	8.3	.48	.024
	7.3	.43	.022
	6.3	.38	.019
	5.3	.31	.015
	4.3	.24	.012
55-per cent-amylose starch	9.3	.69	.036
	8.3	.59	.030
	7.3	.59	.029

	6.3	.55	.027
	5.3	.50	.025
	4.3	.47	.023
70-per cent-amylose starch	9.3	.80	.043
	8.3	.79	.042
	7.3	.79	.042
	6.3	.72	.038
	5.3	.64	.034
	4.3	——	——
70-per cent-amylose 10-per cent-propyl groups starch	9.3	.58	.030
	8.3	.57	.029
	7.3	.57	.029
	6.3	.53	.027
	5.3	.52	.026
	4.3	.47	.023

Table 3. Batter and cake characteristics obtained from dilution of flour protein with wheat starch.

Protein concentration	9.3	8.3	7.3	6.3	5.3	4.3
Batter pH	5.41	5.42	5.50	5.56	5.59	5.61
Batter sp.gr.	.340	.330	.326	.320	.312	.305
Weight of the cake	654	652	650	648	645	641
Height	99.6	102.8	104.3	106	108.1	110.7
Crumb pH	5.80	5.85	5.98	6.07	6.12	6.13
Penetrometer value (mm)	34.0	34.1	35.1	37.3	38.3	40.0
Crust color	20.98	24.2	24.4	24.9	28.5	29.4
Crumb color	75.2	76.3	77.1	77.6	78.2	79.5
Furfural and HMF (mg/cc)	.045	.038	.038	.037	.034	.030
Cupping effect	0	0	0	0	+	+

Table 4. Batter and cake characteristics obtained from dilution of flour protein with corn starch.

Protein concentration	9.3	8.3	7.3	6.3	5.3	4.3
Batter pH	5.32	5.43	5.47	5.51	5.56	5.65
Batter sp.gr.	.339	.333	.329	.322	.318	.310
Weight of the cake	641	642	644	645	648	649
Height	107.2	106	106.4	105	103	103
Crumb pH	5.72	5.79	5.86	5.98	6.04	6.12
Penetrometer value (mm)	32.3	33.9	34.7	35.1	35.7	36.3
Crust color	27.7	29.0	30.2	32.2	32.8	34.2
Crumb color	72.5	73.9	75.9	77.8	79.1	83.9
Furfural and HMF (mg/cc)	.034	.030	.028	.026	.025	.024
Cupping effect	0	0	0	+	++	+++

Table 5. Batter and cake characteristics obtained from dilution of flour protein with gelatinized wheat starch.

Protein concentration	9.3	8.3	7.3	6.3	5.3	4.3
Batter pH	5.74	5.71	5.69	5.68	5.68	5.66
Batter sp.gr.	.350	.359	.373	.389	.396	.412
Weight of the cake	650	651	653	654	655	657
Height	90	85	75	63	58	50
Crumb pH	6.50	6.45	6.37	6.34	6.25	6.25
Penetrometer value (mm)	36.4	35.4	32.3	30.1	28.1	25.1
Crust color	29.8	35.3	41.2	47.3	53.8	61.0
Crumb color	74.5	74.9	75.7	76.3	76.5	79.1
Furfural and HMF (mg/cc)	.029	.024	.022	.019	.015	.012
Cupping effect	0	0	0	0	0	0

Table 6. Batter and cake characteristics obtained from dilution of flour protein with 55 per cent amylose corn starch.

Protein concentration	9.3	8.3	7.3	6.3	5.3	4.3
Batter pH	5.41	5.50	5.53	5.58	5.63	5.67
Batter sp.gr.	.338	.327	.321	.314	.309	.301
Weight of the cake	642	646	648	649	650	657
Height	104	100	95	90	86	74
Crumb pH	5.62	5.63	5.69	5.79	5.85	5.93
Penetrometer value (mm)	32.7	32.3	31.2	30.0	29.0	26.3
Crust color	26.8	28.6	29.0	30.2	32.2	34.2
Crumb color	80.2	81.0	82.0	83.0	84.7	86.0
Furfural and HMF (mg/cc)	.036	.030	.029	.027	.025	.023
Cupping effect	0	0	++	++	+++	++++

Table 7. Batter and cake characteristics obtained from dilution of flour protein with 70 per cent amylose corn starch.

Protein concentration	9.3	8.3	7.3	6.3	5.3	4.3
Batter pH	5.41	5.44	5.52	5.54	5.56	5.57
Batter sp.gr.	.344	.337	.330	.321	.319	.31
Weight of the cake	651	650	648	647	643	------
Height	96.5	97.8	98.5	99.1	101.3	------
Crumb pH	5.68	5.69	5.72	5.75	5.81	------
Penetrometer value (mm)	29.9	32.6	34.9	36.1	37.4	------
Crust color	20.3	21.4	21.7	23.6	25.6	------
Crumb color	76.7	77.1	78.1	78.4	81.0	------
Furfural and HMF (mg/cc)	.043	.042	.042	.038	.034	------
Cupping effect	0	0	+	++	+++	------

Table 8. Batter and cake characteristics obtained from dilution of flour protein with 70 per cent amylose - 10 per cent propyl starch.

Protein concentration	9.3	8.3	7.3	6.3	5.3	4.3
Batter pH	5.31	5.35	5.41	5.47	5.55	5.56
Batter sp.gr.	.346	.340	.333	.326	.322	.309
Weight of the cake	642	646	648	650	650	652
Height	103	99.8	95	90	87	86
Crumb pH	5.64	5.65	5.70	5.75	5.80	5.92
Penetrometer value (mm)	34.9	32.8	32.4	31.0	29.7	29.3
Crust color	26.5	27.0	27.8	29.1	30	32.8
Crumb color	74.5	74.9	75.6	76.0	76.0	76.9
Furfural and HMF (mg/cc)	.030	.029	.029	.027	.026	.023
Cupping effect	0	0	0	0	+	++

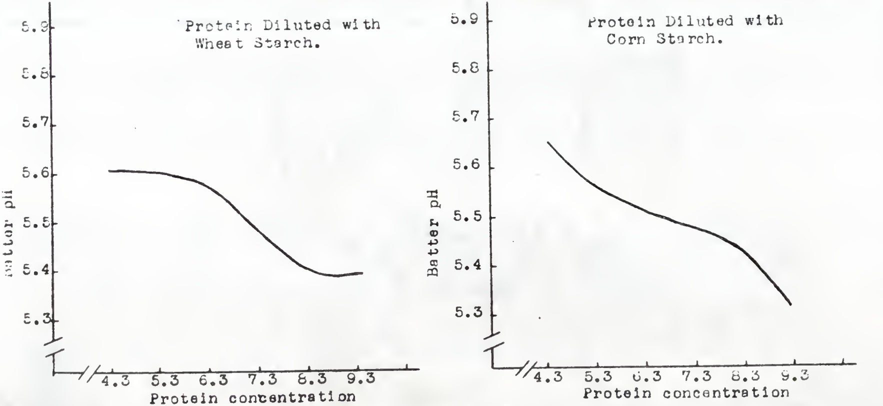


Figure 1. **The effect of dilution of protein with wheat starch and corn starch on the pH of the cake batter.**

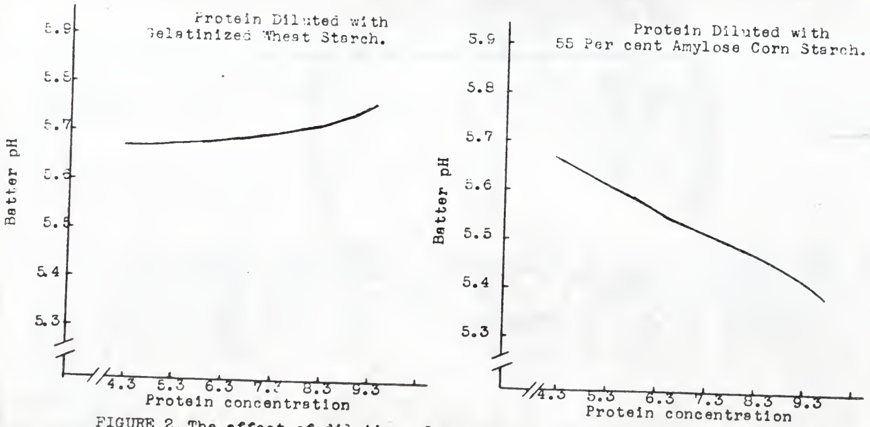


FIGURE 2. The effect of dilution of protein with gelatinized wheat starch and 55 per cent-amylose corn starch on the pH of the cake batter.

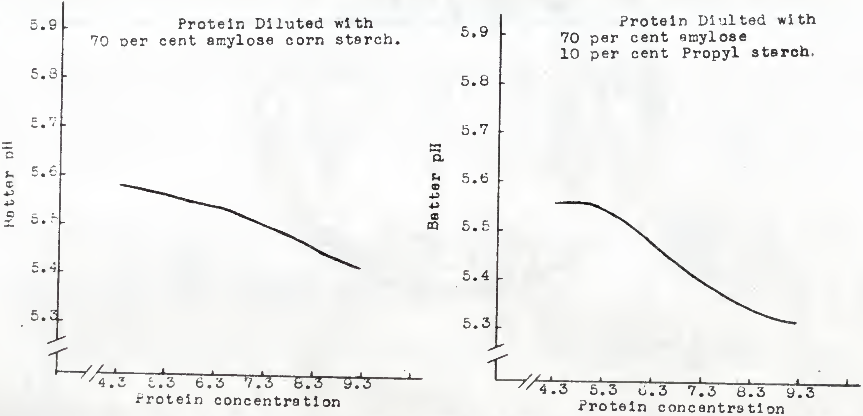


FIGURE 3. The effect of dilution of protein with 70 per cent —amylose corn starch and 70 per cent-amylose-10 per cent - propyl starch on the pH of the cake batter.

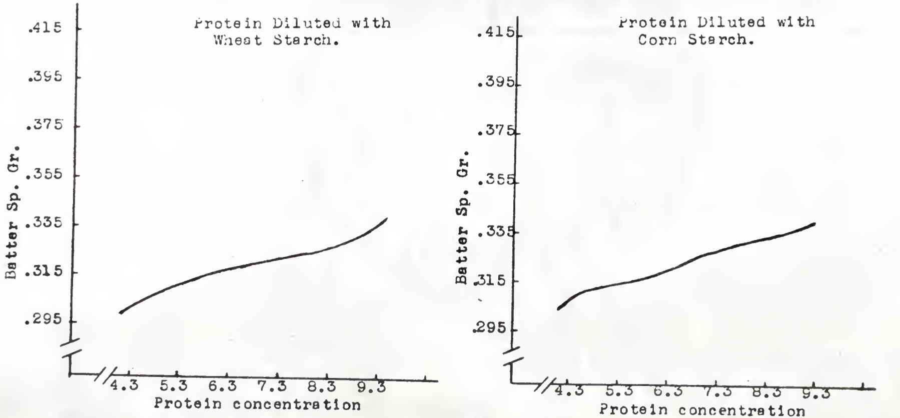


FIGURE 4. **The effect of dilution of protein with wheat starch and corn starch on the specific gravity of the cake batter.**

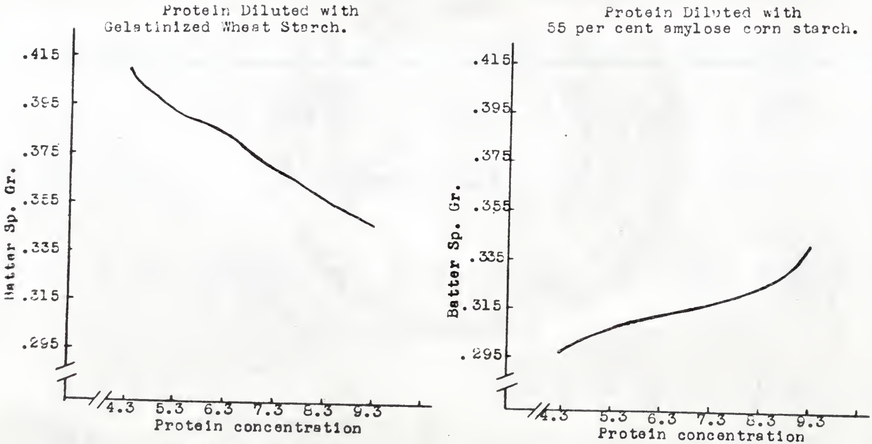


FIGURE 5. The effect of dilution of protein with gelatinized wheat starch and 55 per cent amylose corn starch on the specific gravity of the cake batter.

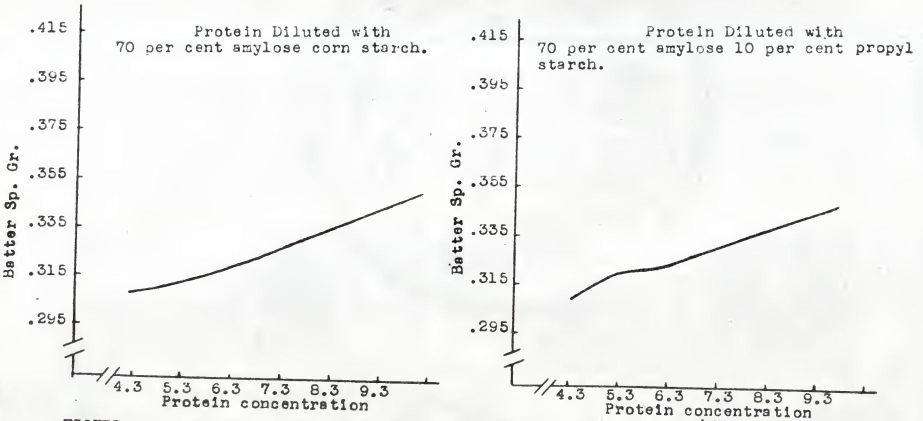


FIGURE 6. The effect of dilution of protein with 70 per cent amylose corn starch and 70 per cent amylose 10 per cent propyl starch on the specific gravity of the cake batter.

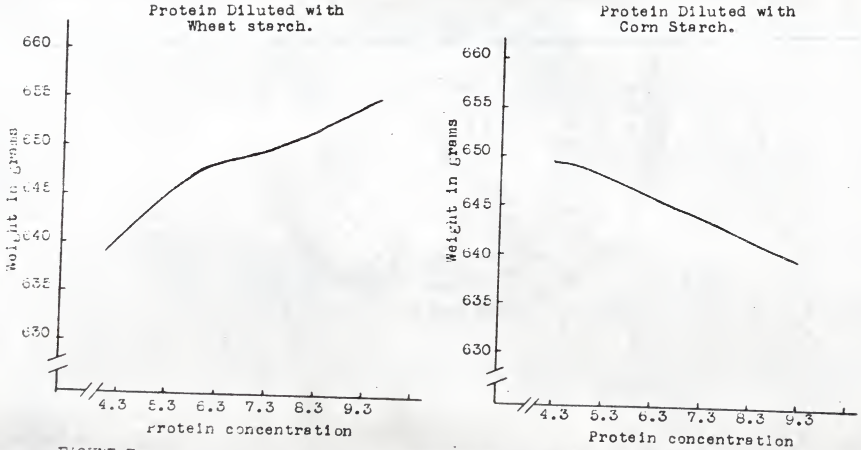


FIGURE 7. The effect of dilution of protein with wheat starch and corn starch on the weight of the cake.

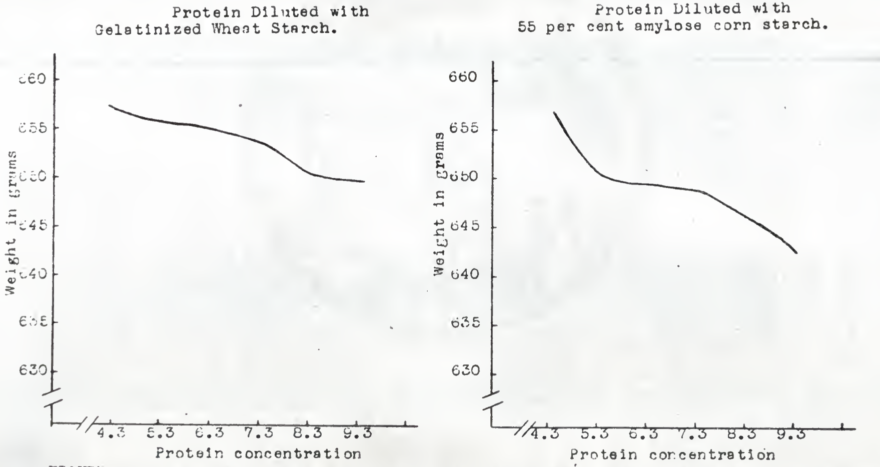


FIGURE 8. The effect of dilution of protein with gelatinized wheat starch and 55 per cent amylose corn starch on the weight of the cake.

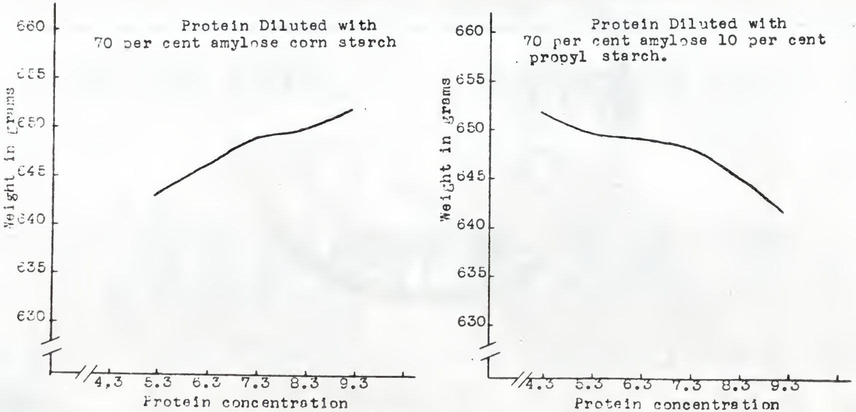


FIGURE 9. The effect of dilution of protein with 70 per cent amylose corn starch and 70 per cent amylose 10 per cent propyl starch on the weight of the cake.

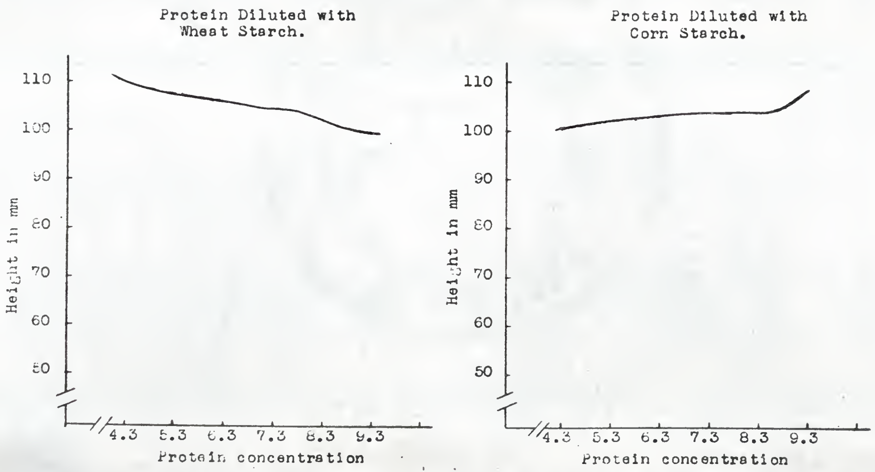


FIGURE 10. The effect of dilution of protein with wheat starch and corn starch on the height of the cake.

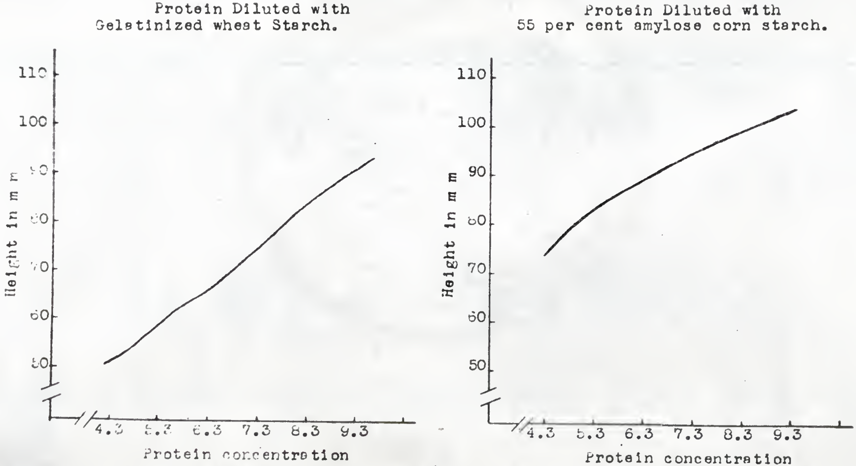


FIGURE 11. The effect of dilution of protein with gelatinized wheat starch and 55 per cent amylose corn starch on the height of the cake.

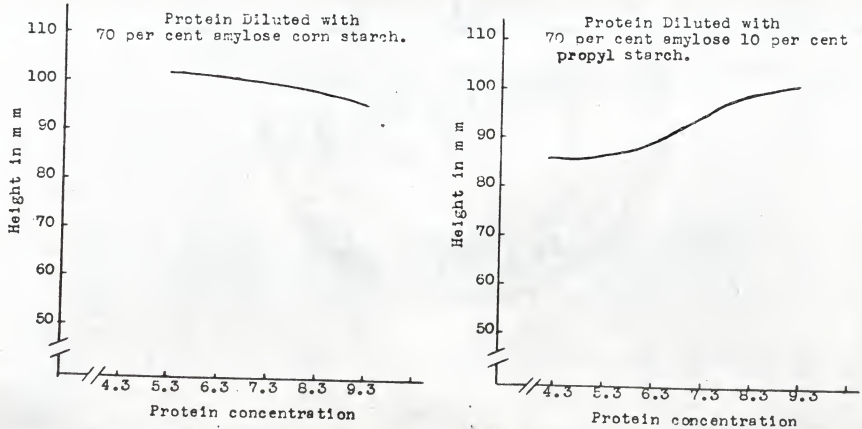


FIGURE 12. The effect of dilution of protein with 70 per cent amylose starch and 70 per cent amylose 10 per cent propyl starch on the height of the cake.

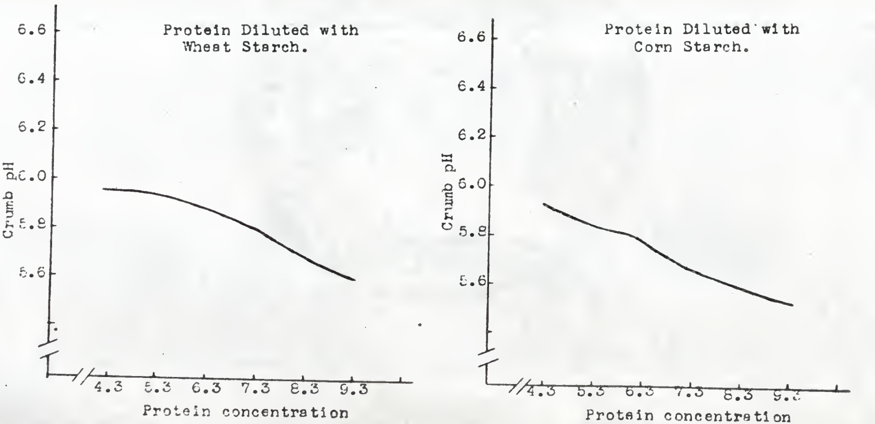


FIGURE 13. The effect of dilution of protein with wheat starch and corn starch on the pH of the cake crumb.

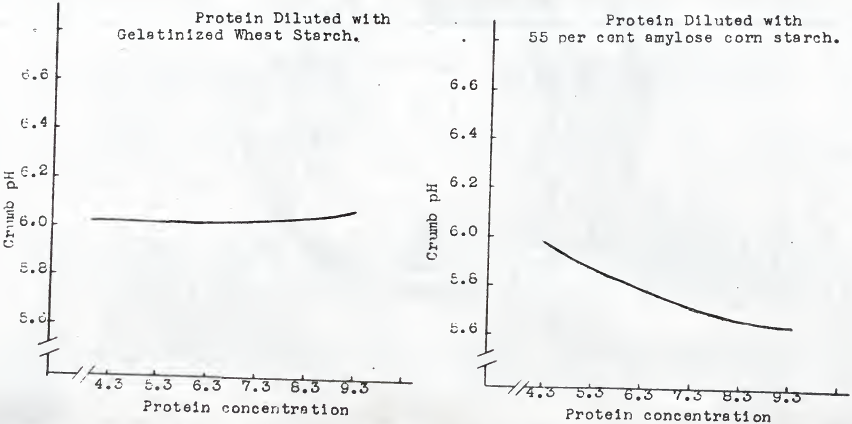


FIGURE 14. The effect of dilution of protein with gelatinized wheat starch and 55 per cent - amylose starch on the pH of the cake crumb.

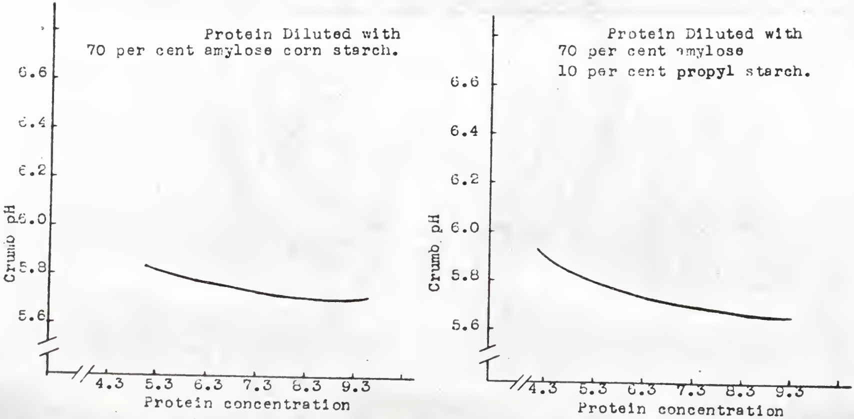


FIGURE 15. The effect of dilution of protein with 70 per cent amylose starch and 70 per cent amylose 10 per cent propyl starch on the pH of the cake crumb.

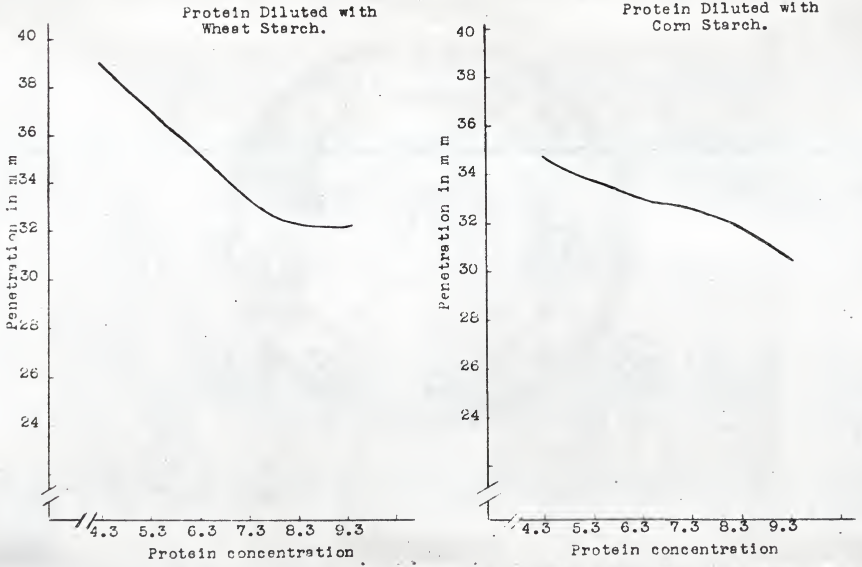


FIGURE 16. The effect of dilution of protein with wheat starch and corn starch on the penetration in m m.

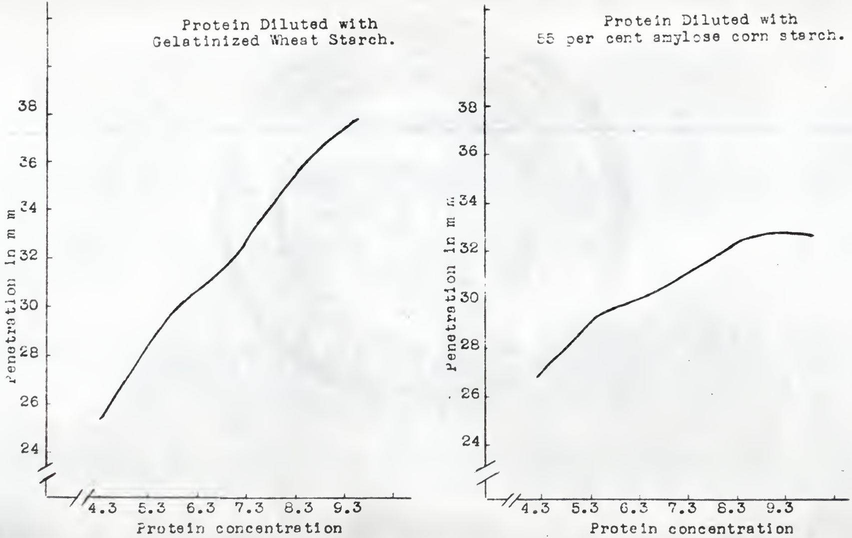


FIGURE 17. The effect of dilution of protein with gelatinized wheat starch and 55 per cent amylose starch on the penetration in m m.

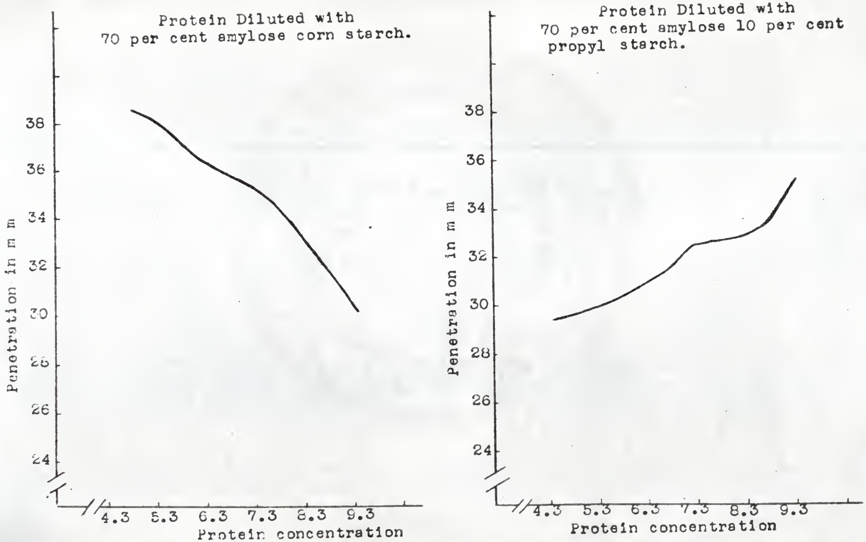


FIGURE 18. The effect of dilution of protein with 70 per cent amylose corn starch and 70 per cent amylose 10 per cent propyl starch on the penetration in m m.

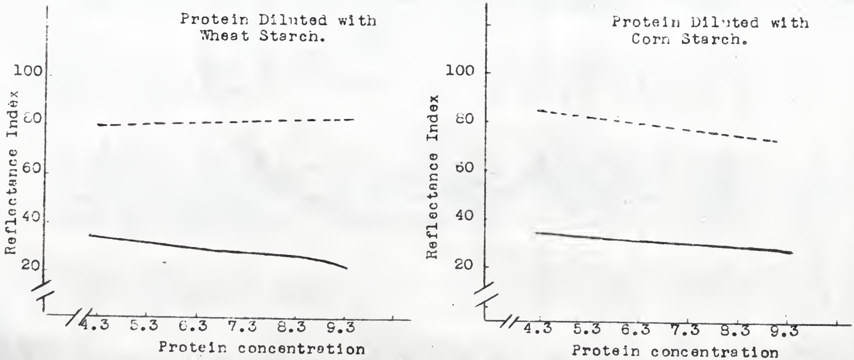


FIGURE 19. The effect of dilution of protein with wheat starch and corn starch on crust and crumb reflectance index.

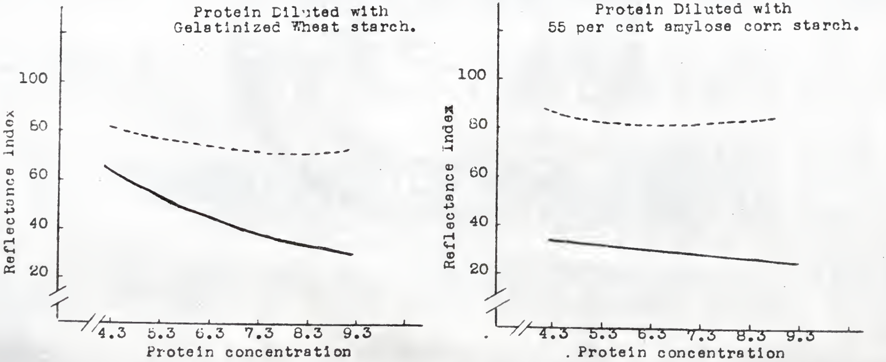


FIGURE 20. The effect of dilution of protein with gelatinized wheat starch and 55 per cent amylose starch on crust and crumb reflectance index.

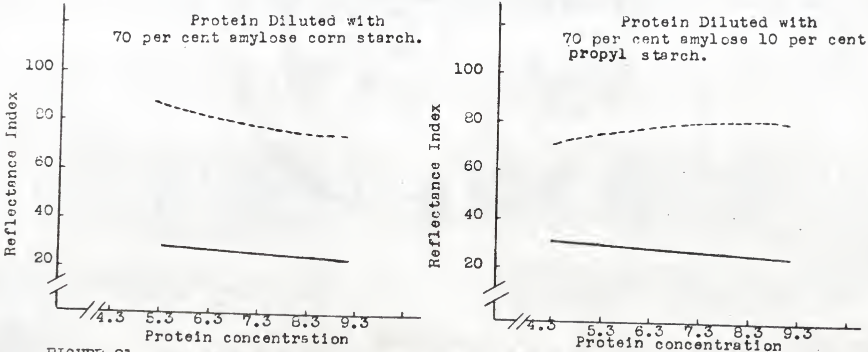


FIGURE 21. The effect of dilution of protein with 70 per cent amylose corn starch and 70 per cent amylose 10 per cent propyl starch on crust and crumb reflectance index.

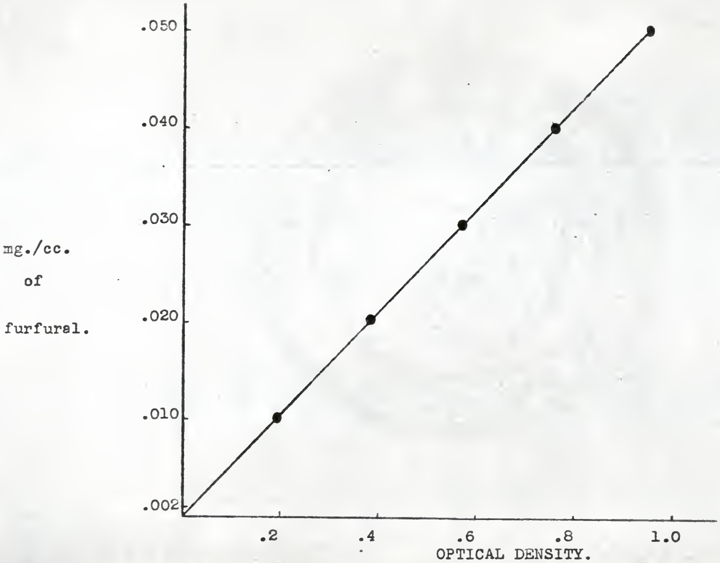


FIGURE 22. Furfural and hydroxy methyl furfural determination standard curve.

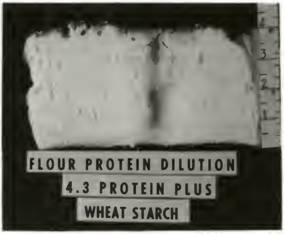


FIGURE 23. Physical characteristics of angel food cakes prepared with cake flour diluted with wheat starch.

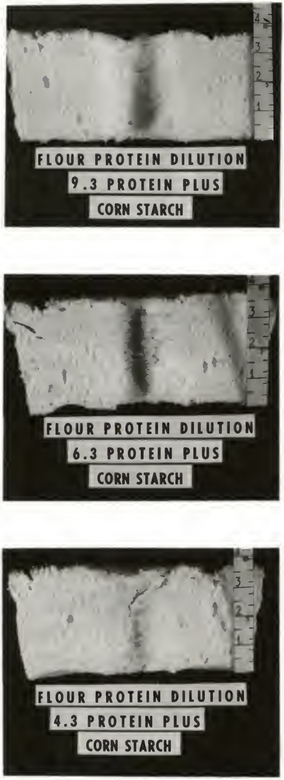
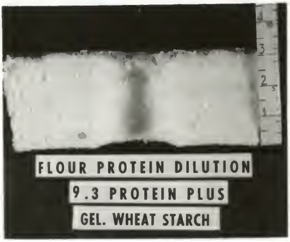


FIGURE 24. Physical characteristics of angel food cakes prepared with cake flour diluted with corn starch.



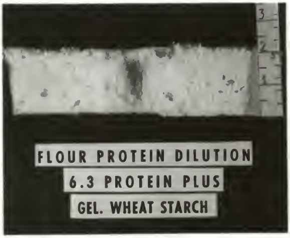
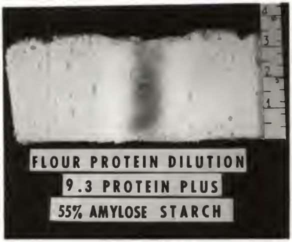
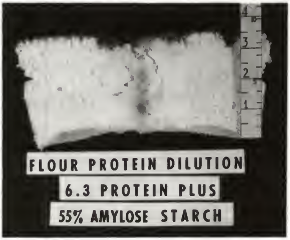


FIGURE 25 . Physical characteristics of angel food cakes prepared with cake flour diluted with gelatinized wheat starch.





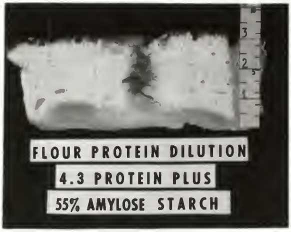
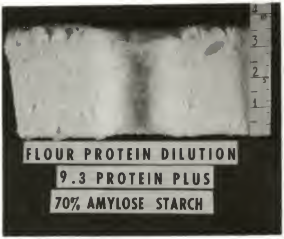


FIGURE 26. Physical characteristics of angel food cakes prepared with cake flour diluted with 55% amylose starch.



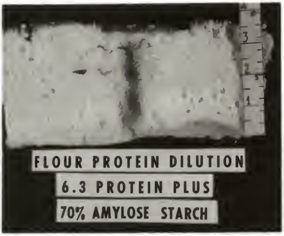
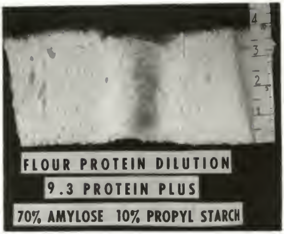
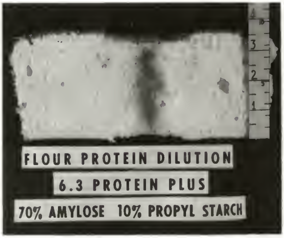


FIGURE 27. Physical characteristics of angel food cakes prepared with cake flour diluted with 70% amylose starch.





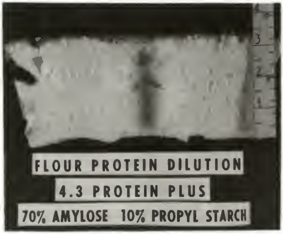


FIGURE 28. Physical characteristics of angel food cakes prepared with cake flour diluted with 70% amylose 10% propyl starch.

SUMMARY AND DISCUSSION

This study was conducted to determine the effect of flour protein dilution and starch type on the production of cupping in angel food cakes. To conduct this study, commercial cake flour containing 9.3 per cent protein was used. The flour protein was diluted in 1 per cent steps to the protein level 4.3 per cent. The protein dilution was conducted with wheat starch, unmodified corn starch, gelatinized wheat starch, 55-per cent-amylose starch, 70-per cent-amylose starch and 70-per cent amylose plus 10-per cent-propyl starch.

Protein concentration of the flour and of the cake batter had little effect on cupping until the protein level of the flour reached 5.3 per cent. At the protein level of 5.3 per cent in the flour, all of the starches except gelatinized wheat starch produced cakes with the cupping effect noted. The cupping effect could be noted at 7.3 per cent flour protein when 55-per cent-amylose and 70-per cent-amylose starches were used.

From the results obtained in this study, it appears that the type of starch used has a great deal of effect on the cupping phenomenon. In commercial cake production, it appears that as long as the flour protein level is not diluted to the low of 5.3 per cent and the total batter protein content does not fall below 4.67 per cent the cupping phenomenon can be minimized.

It was noted that starches with high amylose content and not modified produced more serious cupping than did starches that were modified. The addition of 10-per cent propyl groups greatly reduced the susceptibility of angel food cakes to cupping.

The starches with propyl groups were developed for utilization in the formation of edible films. It appears that the addition of these propyl groups gives the high amylose starch additional stability when used in the production of angel food cakes. This increased stability allows the protein content of the flour to be decreased to 5.3 per cent before cupping is noted.

It appears from this work that the use of gelatinized wheat starch in the production of angel food cakes is not practical. When cakes were prepared using gelatinized wheat starch, the following characteristics were noted: Crumb was very tough, sticky, poor structure, and poor palatability.

Using the furfural and hydroxy-methyl-furfural (HMF) determination of color, there appeared to be an almost perfect correlation between the concentration of furfural and HMF in the crust and the protein concentration of the system.

There appeared to be a relationship between the batter pH and the crust color formation for each series of starch dilution studies. It was observed that as the pH increased, within each series, the intensity of brown color decreased. This phenomenon was observed in all of the series except in the gelatinized wheat starch series. It appears that in the production of angel food cakes the basic browning reaction (Maillard reaction) follows the same conditions as are noted in pure chemical reactions between proteins and sugars. As the acidity of the solution is increased, the rate of reaction and the forming of the brown color is increased.

The batter pH and the cake crumb pH appeared to have a direct correlation. This relationship was almost linear. As the batter pH increased, the cake crumb pH also increased.

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THE RELATIONSHIP OF FLOUR PROTEIN CONCENTRATION AND VARIOUS STARCHES TO THE PHYSICAL AND CHEMICAL PROPERTIES OF ANGEL FOOD CAKES.

by

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An investigation into the relationship of flour protein content to angel food cake quality was conducted, with special attention being paid to the protein level and type of starch used to dilute the protein.

In this study six commercially prepared samples of starch were obtained and used to dilute the commercial cake flour of 9.3 per cent protein content to 4.3 per cent protein content at 1 per cent intervals. The starches were: commercial wheat starch, unmodified corn starch (food grade), gelatinized wheat starch, 55-per cent-amylose corn starch, 70-per cent-amylose corn starch and 70-per cent-amylose corn starch treated to contain 10-per cent-hydroxy propyl groups. The following determinations were used to measure batter and cake characteristics: pH of the batter, specific gravity of the batter, weight and height of the cake, pH of the crumb, penetrometer value, crust color, concentration of furfural and hydroxy-methyl-furfural, and "cupping" phenomenon. The general tendency observed was that as the protein concentration decreased the pH of the batter increased. One marked exception was the behavior of the batter when gelatinized wheat starch was used.

Changes in the specific gravity of the batter were closely related to the protein content of the flour. The batter tended to be lighter when the protein concentration was decreased. The opposite was however observed in the series diluted with gelatinized wheat starch.

It became evident that usually the higher the cake (larger volume) the lighter its weight.

As the protein concentration of the flour decreased the weight of the cake also decreased. This was observed when wheat starch and 70-per cent-amylose starch were used to adjust the flour protein. When the flour protein was diluted with corn starch, gelatinized wheat starch, 55-per cent-amylose and 70-per cent-amylose 10-per cent-propyl starch the opposite trend was observed.

The crumb pH of the cakes increased as the protein concentration decreased. This tendency was observed for all the samples of starches except gelatinized wheat starch.

Tenderness increased when the protein concentration was decreased in the series of wheat starch, corn starch, and 70-per cent-amylose starch. The opposite effect was noticed in the series diluted with gelatinized wheat starch, 55-per cent-amylose starch, and 70-per cent-amylose 10-per cent-propyl starch.

The type of starch used in making the dilutions had a very determinant effect on the crust color of the cakes. Some starches such as wheat starch, and 70-per cent-amylose starch had a tendency to produce cakes with browner crust than those prepared with the other starches. In each series it was observed that as the protein content increased the intensity of the crust color also increased. The whiteness of the crumb intensified as the protein concentration decreased.

Furfural and hydroxymethyl-furfural were determined by spectrophotometric technique. It appears that the concentration of these two heterocyclic compounds in the crust have an almost perfect correlation to the protein concentration of the system.

The "cupping" phenomenon is the development of indented areas on the bottom and sides of the cake. Cupping was observed to be particularly large in the series diluted with amylose starch.

When 70-per cent-amylose 10-per cent-propyl starch was used the cupping decreased considerably. Cupping occurred when wheat starch was used to dilute the protein to the 5.3 and 4.3 per cent levels. Cupping was noted in the cakes made with unmodified corn starch at 6.3, 5.3 and 4.3-per cent protein level. The series in which gelatinized starch was used did not give any indications of the phenomenon.