THE RELATIONSHIP OF FLOUR PROTEIN CONCENTRATION, VARIOUS STARCHES AND PAN SIZE TO THE PHYSIOCHEMICAL PROPERTIES OF ANGEL FOOD CAKES USING THE OAKES CONTINUOUS MIXING SYSTEM

by 45

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INTRODUCTION

Angel food cake represents the oldest and most popular of the foam type cakes produced in America today. However, it has been comparatively recently (within the last 20 years) that angel food cake has enjoyed this position.

Prior to 1930, angel food cake was limitedly successful as a dessert item for several reasons: (1) cost of production, (2) limited understanding of the functions of ingredients, (3) unavailability of certain ingredients, (4) lack of knowledge of formula balance and (5) unavailability of equipment to perform the aeration requirements of commercial angel food cake production.

During World War 11, the Federal Government sponsored several research projects, within the various food industries, designed to find better ways of utilizing eggs. This research led to the development of many of the methods for egg processing and storage used today. Because of its large egg requirements, angel food cake immediately became one of the most important foodstuffs in conducting this research during the 1940's.

By the early 1950's, the physical and chemical properties of egg white, in relation to production of angel food cake, were well understood.

This knowledge stimulated further investigation to study the effects of other ingredients in the formulation of angel food cake.

During this time the E. T. Oakes Corporation, fabricated and introduced to the baking industry a continuous batter production unit. This new development made it possible to produce angel food cake by this process. Advantages found by bakeries using the continuous units are greater uniformity and yield, greater capacity and flexibility, improved control of specific gravity, better controls of scaling and sanitation, more precise control of temperature, lower requirements for maintenance and labor, and greater flexibility in scheduling production.

One of the most recent areas of study in the production of angel food cake has been the use of wheat starch to replace part of the flour in the formula. The studies were conducted by using conventional methods.

Although few workers have reported very successful results, it is apparent from a review of literature that relatively little research has been conducted in this area. The following variables were studied in the work reported here using the Oakes Continuous System:

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

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

(c) The size and type of pan used to bake the cakes.

The rclationship of these factors to the pH and specific gravity of the batter, baking loss, height and tenderness of the cake crust and crumb color and pH of the crumb were studied.

REVIEW OF LITERATURE

The origin and first formulas of angel food cake appear to be lost in the antiquity of history. However, in a review of early American cookbooks, angel food cake was reported in 1880 (42). Smith, (60) in 1951 defined angel food cake as "the name given to a very light spongy cake originating in America." This is a very simple definition of a complex product.

Since the development of a sponge-type cake structure is dependent on formulation, mixing techniques, production techniques, baking and cooling procedures, this review of literature will be concerned with relating these factors to the production of angel food cake. Not only these five factors, but also their interrelationships are important.

Based on the formulation, angel food cake represents a complex type of cake. Ingredients can include in addition to the three basic ingredients -- egg albumen, granulated sugar, and flour -- such items as starch, powdered sugar, cream of tartar, vanilla, salt, whipping aids and a number of sugar based syrups.

Egg albumen used for angel food cake production has been the subject of considerable research effort. This is so for two reasons: (1) the importance of egg white to the success of angel food cake cell structure, and (2) the tremendous amount of research concluded on dehydrated egg albumen during World War 11. Lowe (34) presented a complete review of the literature related to research on eggs in angel food cakes. This review reports the major literature contributions during the period and serves as an excellent source of reference to publications prior to 1955.

The quality of the egg white, whether fresh, frozen, dehydrated or dried albumen, is of extreme importance in the development of a high quality sponge. Changes in egg production patterns have influenced the composition of egg products and therefore altered quality. Cunningham *et al*. (10) studied the effects of season and age of the bird in relation to egg size, quality and yield. They concluded that egg weight varied markedly with season, tending to be larger in the spring and smaller during periods of high temperatures. In addition to these findings these workers also reported that the total volume of albumen varied with season and age of the bird. The percentage of total solids in albumen declined steadily with advancing age of the bird; and the yield of albumen solids per egg tended to be higher in early spring regardless of the age of the bird.

Cunningham *et al*. (12) in another study reported on the effects of season and age of the bird on the chemical composition of egg albumen. The results indicated that the percentages of chlorine and calcium in the albumen were highest during the warmer months and the percentage of sodium decreased gradually from January to September. Season, however had little or no effect on potassium, phosphorus and protein content. As age increased, however, protein, chlorine and phosphorus decreased with no effect on the sodium or potassium level.

Jordan and co-workers (25) reported that the quality of the shell and egg albumen performance are closely related to angel food cake quality. They concluded that eggs kept at room temperature deteriorated about three times as fast as those held at refrigerator temperatures. They also concluded that eggs held in cold storage kept their flavor quality four times longer than those held at room temperature when judged by the flavor score for angel food cakes.

The method of dehydration or drying of egg white albumen for angel food cake use has presented serious problems. One of these is the presence of glucose in egg white which is responsible for the browning reaction in spray-dried albumen. This problem can be eliminated using the method described by Banward and Ayers (4) in which the glucose is removed by employing the enzyme deoxygenase.

The effects of pH and of storage at elevated temperature on the functional properties of spray-dried egg albumen solids has presented another problem and have not been fully delineated. Hill (22) in a recent study, found spray-dried albumen at pH 8.5 produced a powder that yielded larger volume angel food cakes and had less protein damage and greater heat coagulability than other samples dried from pH 4.0 to 10.0. Spray-drying egg albumen below pH 6.5 greatly redueed the iron-complexing ability of conalbumin. Spray-drying egg albumen below 6.5 altered the ability of the rcconstituted albumen to heat coagulate when readjusted to pH 8.8. Banwart and Ayres (4) reported that angel food cakes prepared from egg albumen pan dried at pH 6.0, 7.0 and 10.0 had poorer texture and volume than cakes prepared from albumen spray dried at pH 8.0, 8.5 and 9.0.

Baldwin and co-workers (3) studied the effects of high temperature of storage on spray-dried egg albumen. They found that the foam inhibiting qualities of yolk found in commercially prepared egg albumen solids were reduced as shown by a decrease in whipping time requirements when storage temperatures were over 60°C. However, the volume of the final eake was not altered. It was also observed that angel food cakes made from egg albumen that had yolk present and had been stored at 71°C or 81°C before use were lower in the compressibility score than cakes made with yolk-free albumen.

In an early study, Miller and Winter (36) investigated heat pasteurization of liquid egg albumen. They concluded that this type of pasteurization increased the whipping time and damaged the stability of the foam when compared to non-pasteurized liquid egg albumen. However, in a more recent study, Seideman (53) reported the volume of angel food cakes could be increased by using egg albumen heated for three minutes at 58°C and adjusting the pH to 8.75. At the same time, it was observed that whipping time could be reduced.

Bergquist (6) developed a method, for which a patent was granted, whereby liquid egg albumen is treated at a low pasteurization temperature and then spray-dried and subjected to a dry heat treatment. The initial pasteurizing treatment makes the dried product particularly susceptible to the second heat treatment without affecting the functional properties of the egg albumen. Smith (59), in another patented process, presented a procedure for storing egg albumen solids for eight hours at 71°C and then for one hour at 99°C. The principal claim of this method is a reduction of viable bacteria in egg albumen solids. Brown and Zabik (8) investigated the effects of exposing egg albumen to preheating, spray drying and high temperature storage before using this ingredient in the production of angel food cakes. It was concluded that any of these heat treatments brought about the following significant changes: (1) an increase in specific gravity of both egg albumen foam and angel food cake batter, (2) a decrease in foam stability, and (3) a decrease in cake volume.

Egg albumen used for angel food cakes has been the subject of further research because of the attention now being given to liquid, frozen and dried eggs as sources of Salmonella. Frazier (16) discussed some of the organisms which may be present in dried egg albumen, listing Micrococci, Streptococci, Coliform bacteria, molds and Salmonella species as being the most prevalent. Dried egg albumen, he continued may contain from a hundred microorganisms per gram to over a hundred million, depending upon the methods of production and handling employed. The drying processes may reduce the microbial population a hundred-fold, but large numbers may still survive.

Physicochemical processes such as the use of high voltage cathode rays to destroy bacteria of the Salmonella groups has been described (41). However, this process is still in the experimental stage and is not practical at present.

Banwart and Ayres (4) demonstrated that when dried egg albumen was held at temperatures between 120-140°F, there was significant reductions in bacterial counts. Minimal reduction in the functional performance was noted if the albumen moisture levels were below 6%. The whipping rate was found to improve during storage at lower moisture levels. This observation has been verified by many commercial experiments and it is now considered common practice to hold dried albumen at a temperature of 125-128^{O}F for seven to ten days to reduce the Salmonella and improve the whipping performance. The use of chemical additives and whipping aids to improve the functional performance of the egg white solids is now an accepted commercial practice for the production of angel food cakes. Mink (39) in 1937, was the first to demonstrate that adding anionic surface-active agents to egg albumen would improve foam stability. The results showed significant improvements upon the addition of as little as 0.1 percent on a solids basis. Little or no scientific information is available to indicate the mode of action of these chemicals, but work conducted by Lundgren and O'Connel (35) indicates that the effect of anionic surface active agents is to increase the ease of surface denaturation thus permitting a stable foam to be formed more rapidly. Anionic surface active agents possess the ability to improve both shipping time and increase cake volume, while apparently having no significant deteriorating effect on cake texture and grain.

Kothe (31) investigated the use of triethyl citrate in egg albumen and reported results which paralleled those for the addition of anionic compounds. Kline and Singleton (28) patented a process using bile salts for the improvement of the whipping performance of dried egg albumen. Gorman and Keith (18) used triacetin for the same purpose. Robertson and Haney (51) reported that sodium lauryl sulfate, which when added in minute quantity increases the foaming ability of egg albumen solids in the reconstitution process. To study the similarities and differences between liquid egg albumen and dried albumen solids, the whipping foam stability test was utilized. The results indicated that egg albumen solids containing sodium lauryl sulfate resulted in increased foam stability when compared to liquid egg albumen. This difference would produce a superior quality angel food cake.

Barmore (5), in early research conducted to study the relationship of egg quality and angel food cake volume, reported that when eggs are allowed to age at room temperature for a few days the albumen becomes thin, and results in angel food cakes having smaller volume than those prepared from fresh eggs. This was attributed to a protein hydrolysis that occurs during aging which results in a liquification of the egg albumen.

Cunningham, Cotterill and Funk (11) conducted experiments to study the effects of the age of the birds on the performance of egg albumen in angel food cake. Angel food cakes were baked using the albumen from eggs laid by birds of different age over a one year period. They reported that the age of the birds had no effect on the functional capacity of egg albumen in angel food cake.

In a more recent study, Kline, Meehan and Sugihara (28) reported conflicting results. They concluded that albumen from older birds consistently yielded 3-4 percent lower angel food cake volumes than albumen from younger birds. They explained the differences in their report by concluding that the earlier reports did not lend themselves readily to quantitative conclusions. In the earlier studies there was limited information on strain and age of layers, diet variation and seasonal conditions.

Robertson and Haney (52) reported a relationship between the quality of egg albumen and angel food cake volume. In their study, egg albumen solids were used in levels from 8 to 20 percent as expressed on a 100 percent flour basis. The cake volume began to decrease as the albumen solids levels were decreased below 12.5 percent. At the 8.0 percent solids level, there was a complete cake failure and the cake collapsed during the last ten minutes of baking. Cakes containing 13.0 to 20.0 percent solids had a very good volume and structure during baking. However, and the albumin solids level was increased over 16.0%, the finished product had rough texture, dryness and poor eating qualities.

Glabau (18) demonstrated in a sequence of experiments that the degree to which the egg albumen solids are beaten, the beating speeds and the temperature of the system are very important variables in developing a stable foam. Barmore (5) reported that the finished angel food cake will be at its maximum volume when the specific gravity is between 0.15 and 0.17. However, Robinson and Haney (52) reported that the specific gravity of batter produced from a continuous mixing system should be between 0.28 and 0.32. They found that if the specific gravity was 0.22 or less the cakes baked with excessive volume and "cupping".

It has long been recognized that a small amount of acid is a necessary ingredient for the production of high quality angel food cake. Barmore (5) studied the chemical effects of acidifying angel food cake batter and concluded the addition of acid was necessary and favorable for two reasons. First, the acid stabilizes the foam so that during baking the heat may have time to penetrate the foam and permit the temperature of coagulation to be reached before large air cells are produced and thus cause the structure to collapse. Second, acid prevents extreme shrinkage during the last minutes of baking and the cooling period. Slosberg *et al.* (58) substantiated Barmore's results and concluded that lowering the pH from its normal value of approximately 8.5 to a value as low as 6.5 increased the stability of liquid albumen to heat.

Pyler (50) suggested the addition of 1.5 to 1.75 percent acid based on the weight of liquid egg white to be usually sufficient to produce a pH within the optimum range of 5 to 6.5 for angel food cake. However, Miyakara and Berquist (40) noted that since egg albumen solids are usually close to pH 7, whereas the liquid albumen are usually over 8.0 pH the dry albumen requires less acid. Robertson and Haney (52) reported similar findings and suggested the level of acid required in the formula be reduced by one half when egg albumen solids are used.

Grewe and Child (20) demonstrated by using various acids such as sodium potassium tartrate, citric, malic, etc., a fine grained angel cake with excellent whiteness resulted. They also noted that the omission of acid resulted in a yellow, course grained cake.

Shellenberger, Wichser and Lakamp (56) studied the relationship of flour particle size and uniformity to cake properties. These workers used the patent, straight, and clear grade flours of a soft red winter wheat. The flour grades were then fractionated into three particle size groups, 0-37, 37-53, and over 53 in diameter. They found that differences in granulation were neglegible for the three grades of flour. However, they reported that the 0-37 fraction, for each flour grade, was lowest in ash, viscosity and protein, and produced the best cakes when grain, volume and texture were measured.

Wichser (62) investigated the effects of particle size of flours from both hard and soft winter wheats on angel food cake production. He reported that angel food cakes of excellent quality can be produced from certain air classified fractions of hard winter wheat flours. Similarly, he demonstrated that certain fractions of air classified soft wheat flour had protein levels as high as 20-25% and produced angel food cakes of mediocre quality. However, it was noted that the cakes made from a fraction of soft wheat flour that contained 20% protein had a slight advantage over a parent hard wheat flour with a protein content of 11.7%.

The use of bleaching agents such as chlorine in angel food cake flour is a common practice. Workers in this area are generally in agreement that the improvements caused in cake flour by bleaching is not primarily an improvement in color (true bleaching), but rather improvements in grain, volume and texture (maturing action). The reduction in pH is well known and it is assumed that normal gluten characteristics are destroyed; however, very little is known about the basic chemistry of flour bleaching.

Harrel (21) while investigating this maturing action of bleached flour, concluded that a greater number of gas cells was also formed which consequently aided in the improvement of grain, volume and texture of the finished product.

Alexander (2) reported evidence that the chlorine in bleached flour causes a dispersion of the gluten. When mixed with other ingredients, the pH of the dispersed gluten remains lower than that of the batter. In addition to this, the dispersed gluten has a greater capacity for absorbing water and, thus favorably affecting the maturing action.

Prouty (49) outlined an excellent procedure for determining the suitability of flour for cake production. The procedure employs the use of both chemical and physiochemical tests in outlining flour specifications. Briefly, the chemical tests involve determining moisture, protein, ash, acid viscosity, and pH of the flour. The physiochemical tests are those which involve the farinograph, gassing power, amylograph, MacMichael Viscometer, and also determinations of particle size distributions and chlorine treatments.

High sugar percentages are required in angel food cakes because sugar is the only tenderizing agent in the system. Both the flour and egg albumen are responsible for the structure of the cake and therefore contribute to the toughness of the product.

Robertson and Haney (52) studied the relationship between richness of the formula, pan size and the "cupping" phenomenon. Sugar levels ranged from 270% to 360% based on the weight of flour. They reported that as the sugar level in the foam increased, the eggs were required to carry more of the bulk and a stiffer, more stable, foam resulted. They also concluded that large sized pans could be used when the higher levels of sugar were used and that smaller pans must be used with lower levels of sugar. They reported that if the reverse procedure was used, "cupping" became evident. The word "cupping", as used in the literature, refers to a serious angel food cake fault characterized by the development of indented areas on the bottom of the cake. The problem is commonly associated with industrial production, and its cause is not well understood.

The color of both crumb and crust is important to the quality of angel food cake. Today, three broad types of browning rcactions are recognized as related to foods (23).

1. Carmelization. This type of browning takes place when polyhydroxycarbonyl compounds are heated at normal baking temperatures in the absence of amino compounds.

2. Oxidative Reactions. These reactions are both numerous and various and may be triggered by physical means. Oxidativc browning may also be auto- or reagent-induced or enzyme catalyzed.

3. Carbonyl Amino Reactions. This class of browning includes the reactions of ketones, aldehydes and reducing sugars with amines, amino acids, peptides and proteins; it is the most common type. This type plays the most important role in the browning of baked goods. It is commonly called the Maillard reaction, named in honor of L. C. Maillard (36), who explicated the browning factors involved in the reaction.

Carbonyl or potential carbonyl groups are the usual groups that bring about browning. Sugars are examples of naturally occuring compounds that can yield a multiplicity of carbonyl groups. In view of the high levels of sugar required in angel food cake production, the importance of the browning reaction becomes more apparent.

Wolfrom et al. (63) investigated the effects of chemically blocking the carbonyl groups of sugars. They concluded this hindrance of the functional groups inhibited the browning reaction. This was also substantiated by Singh, Dean and Cantor (55). It has been demonstrated by Tan et al. (61) that browning could be eliminated, or at least severely retarded, by using a solvent that extracted the browning system by removing, among other things, the carbonyl groups.

Pecherer (43) investigated the relationship of amino compounds to browning and concluded that the reactions proceeded more rapidly and intensely in the presence of these compounds. It is believed that in the interaction between the amines and reducing sugars, the latter are transformed into enediols and osones, and to reductones and dehydro reductones which provide α-dicarbonyl or conjugated dicarbonyl groups and color.

Normally, crumb browning is not a serious problem in producing angel food cake unless part or all of the sucrose has been replaced by dextrose or invert sugars. Sucrose remains as a non-reducing sugar during baking. Consequently, it is unable to react with the free amino groups to form the first condensation products of the Maillard reaction (36). Miller et al. (38) demonstrated that the browning reaction takes place in cake crumb when the reducing sugar concentration replaces approximately 50 percent of the sucrose in the formulation.

Regardless of the type of browning, there is sufficient evidence in the literature to conclude that browning is the result of the formation of unsaturated, colored polymers of varying composition (13,26,33,64).

Angel food cake is unlike most cakes in that it is extremely delicate and requires, inter alia, to be produced carefully. However, it is similar to most types of cakes in that it can be produced by several methods. Peterson (45) described four different ways of combining flour and sugar with the beaten egg albumen to produce successful results. Barmore (5) investigated these four methods and found that not all of them gave equally satisfactory results. Pickens (47) outlined a different method for the production of angel food cakes. He used three steps instead of two for mixing all the ingredients.

One of the most critical variables in the cake industry is the relationship of whipping speed versus time in angel food cake production. Young (65) suggested a reduction in the whipping time requirement in a discussion of "Pressure Aeration" a relatively new concept in angel food cake production. In addition to reducing whipping time this system is able to produce cakes of greater volume, finer grain, softer and more tender texture, and of greater freshness stability than can be btained by conventional methods.

The relationship of time versus temperature is another extremely critical variable in angel food cake production. Pyler (51) has shown this relationship graphically. He concluded that the egg albumen should be held within a range of 50° to 70°F during mixing. A decrease in volume was noted for cakes produced outside this range.

Dubois (14) investigated the use of wheat starch in angel food cakes. He found that optimum benefits resulted when wheat starch replaced 30% of the flour. Among the observed advantages of wheat starch in foam cakes are: (1) improved volume, (2) grain, (3) texture, (4) eating properties, and (5) retention of freshness.

Aira and Hurley (1), using conventional methods, studied the effect of dilution of flour protein on the incidence of "cupping". The initial protein level of the flour was 9.3%. The flour protein was then diluted with several starches, at one percent intervals, until a protein level of 4.3% was reached. They reported that regardless of the starch used, all cakes exhibited evidence of "cupping" at the 5.3% protein level. They also observed angel food cakes produced from unmodified, high amylose content starches produced more symmetry faults at higher protein levels than did low amylose starches.

They concluded, therefore, maintaining the protein level of the flour above 5.3% and the total batter protein above 4.7% minimizes the "cupping" phenomenon.

Bonavia (7) discussed some advantages of continuous mixing over conventional methods for producing angel food cakes of high quality. Principal among these are simplified control of the specific gravities of the slurry and batter, reduction in mixing time requirements and therefore more production efficiency, fineness of grain structure and softness of crumb texture. These last two advantages are very difficult to duplicate by conventional mixing methods.

Recommended baking temperatures for angel food cakes vary from 350°-400°F. Holliday and Noble (24) theorized, that since egg whites that are coagulated at lower temperatures are more tender than whites coagulated at elevated temperatures, baking at lower temperatures would yield more palatible cakes.

Barmore (5) investigated this theory and was not able to substantiate such results. In this study, he baked angel food cakes in two ovens with a temperature difference of 72°F. He noted that the internal temperature varied by only 3.6°F. He concluded, on the basis of results of a scoring test, that as the oven temperature increased, the cakes improved on both volume and tenderness.

MATERIALS, METHODS AND EQUIPMENT

In conducting this study, nine commercially prepared samples of starch were obtained and utilized to dilute a commercial cake flour of 7.4% protein content to various protein levels. The Oakes Continuous Cake System was employed to prepare angel food cakes from the various diluted flours.

MATERIALS

The starch samples were divided into three groups based on the structure and composition of the starch.

Group A - Native Starches

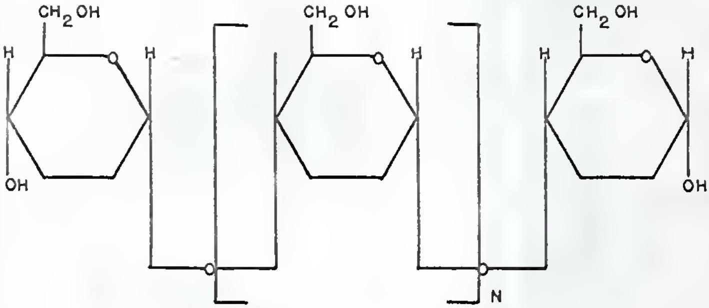
1. Unmodified commercial wheat starch.

   Unmodified commercial wheat starch is commonly produced in the United States by the following procedure: (a) mixing the flour and water, (b) washing the starch from the dough, (c) recovering the starch and gluten, (d) refining the fractions, and (e) drying each fraction.

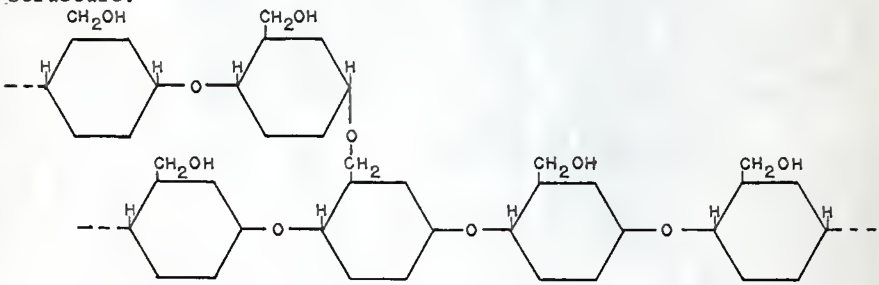
2. Unmodified corn starch (food grade).

   Natural corn starch possesses the properties of being able to form viscous, relatively short and opaque pastes with typical cereal flavor. Corn starch pastes also form stiff gels, much stiffer than comparable wheat starch gels, unless they have received special treatment.

Ordinary wheat and corn starches contain about 23-27% amylose and 73-77% amylopectin. The linear or amylose fraction of these starches is represented by the following structure:



and the branched or amylopectin fraction by the following structure:



As shown by the above structure, the linear portion of these starches is composed of a series of D-glucopyranose units joined together by α-D (1, 4) linkages. The branched portion is similar in structure but contains side chains originating at an α-D (1, 6) linkage.

Group B - High Amylose Starches

1. Corn starch of 55-percent amylose content.

This starch was a pure food starch produced from a special hybrid type. The remaining 45 percent was composed of amylopectin (branched chain polymer).

2. Corn starch of 70-percent amylose content.

This was an unmodified high-amylose starch. The uniqueness of this high-amylose starch is further emphasized by the fact that the amylopectin portion contains longer branches (34-36 anhydroglucose units in length) than does the amylopectin fraction of common food grade corn starch (20 anhydroglucose units in length) (30).

3. Corn starch of 70-percent amylose content treated to contain 10 percent hydroxymethyl propyl groups.

This starch is described as a high-amylose corn starch which has been derivatized by approximately 10 percent added hydroxymethyl propyl groups (44). These groups are added by first dispersing the starch in sodium hydroxide at room temperature. The solution is then sprayed with nitrogen to remove residual air and finally propylene oxide is introduced in the sodium hydroxide solution. This treatment retards retrogradation and also dccreases the pasting temperature so that the starch can be cooked under reasonable conditions and the paste is stable enough to apply as and cdible film (44).

Group C - Cross-Linked Starches, Products of American Maize-Products Company (Listed by Trade Names).

1. Amaizo W-13.

This is a slightly cross-linked waxy maize starch produced by an exclusive process. The uniqueness of Amaizo W-13 in food processing is demonstrated by the ability of the starch molecules to resist acid hydrolysis, overcooking, and mechanical shear (44).

2. Amaizo Polar-Gel 1.

This starch is a slightly inhibited waxy maize starch similar to Amaizo W-13. It is unique in that it is dually cross-linked. This characteristic lends greatly to the principle function of this starch. That is, to improve stability of food products stored under all types of drastic conditions (44).

3. Amaizo 400 Stabilizer.

This is an intermediately cross-linked starch designed to produce gels with a soft, tender body, high clarity and semi-firm consistency. In producing Amaizo 400 Stabilizer, the starch molecules are chemically altered to produce increased resistance to overcooking and overmixing especially in high-acid media (44).

4. Amaizo W-11.

This is a heavily modified (cross-linked) waxy maize starch. Modification is designed to improve the naturally high resistance of amylopectin type starches toward acid conditions, prolonged cooking under high temperatures, high processing techniques and drastic in-process handling involving homogenization, pumping or extremes of production agitation (44).

Cross-linked or "inhibited" starches first came into prominence after World War 11. Waxy corn starch had been produced commercially, (53) by 1942, but unmodified waxy starch pastes proved too cohesive and broke down too rapidly under shear to be acceptable in many food uses.

Cross-linked starches for food use may be prepared by the reaction of ungelatinized starch with epichlorohydrin (31), Phosphorous oxychloride (15), water-soluble metphosphates (27), acrolein (57), cyanuric chloride (17), or mixtures of citric acid with acetic anhydride (9).

The commercial cake flour used in this research was Pillsbury's Celebrity, Code No. 3726. The original protein content of this flour was 7.4 percent on a 14% moisture basis.

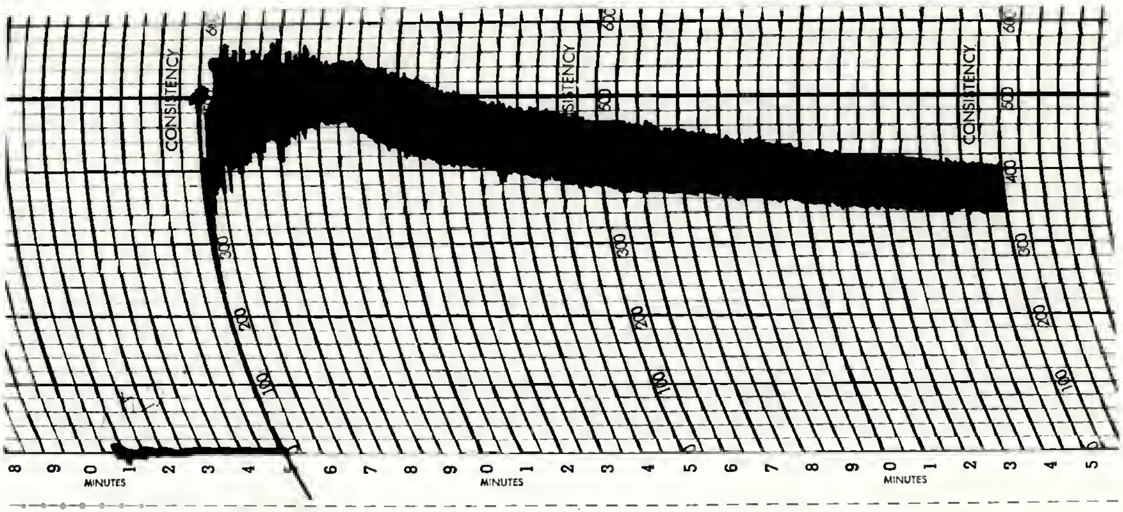


Fig. 1 Farinogram curve of commercial cake flour.

METHODS AND EQUIPMENT

The following formula was used throughout the experimentation.

Ingredient	Percentage	Grams
Spray Dried Albumen	6.00	2,862
Water	36.00	17,172
Sugar (Granulated)	34.72	16,561
Sugar (Powdered)	6.00	2,862
Flour	12.54	5,982
Starch	3.46	1,650
Vanilla	.60	286
Salt	.60	286
Cream of Tartar	.08	39
Total	100.00	47,700

Mixing Procedure

The Oakes Continuous Mixing System Model 4MBIA was used as the mixing and aeration equipment for the development of the angel food cake batter. This system was originally introduced into the baking industry as a continuous unit for handling marshmallow and other types of aerated cake coatings. Since that time, through several innovations, the Oakes Continuous System has gained wide acceptance in the production of all kinds of cake, especially the foam type.

Standardization of the Methodology.

The procedure used in conducting these experiments is appropriately presented by discussing the three basic units of Oakes System: (a) the incorporation tank, (b) the holding tank, and (c) the mixing unit. (Figure 2 shows a schematic unit flow.)

The initial mixing of ingredients took place in the incorporation tank. The water, vanilla, and a mixture of the dry albumen and granulated sugar were introduced simultaneously into the incorporation tank and mixed by a high speed impeller. It was found necessary to blend the spray dried albumen and the granulated sugar by sifting. This greatly decreased the reconstitution time and produced a more uniform slurry. The high speed mixing proceeded for approximately five minutes or until the specific gravity reached 0.90. The remaining ingredients were then introduced in a similar manner and mixing continued until a uniform slurry with a specific gravity between 0.84 and 0.87 was obtained.

The slurry was then transferred to the holding tank by means of a No. 2 Waukesha Sanitary Pump. The essential function of the holding tank was to serve as a continuous reservoir for the slurry, thus producing a uniform head pressure at the time of production.

The slurry was then pumped into the Oakes Continuous Mixing Unit. Air undcr high pressure (135 p.s.i.) was injected into the slurry as it was pumped into the final mixing stage within the Oakes Continuous Mixing Head.

In the processing of angel food cakes, the best results were obtained by maintaining the back pressure at 95-100 p.s.i. and the specific gravity at 0.25-0.30. Back pressure, in this instance, may be defined as the resulting pressure within the mixing unit caused by the movement of the highly-aerated batter. Maintaining the back pressure and the specific gravity within these ranges was found to be dependent upon a delicate balance between the volume of air incorporated into the system and the production rate. The speed of the mixing head was not an important consideration unless extremely high or low speeds were used.

The production rate was controlled by the pump speed of the mixing unit and for this research the speed was maintained at 100 rpm. The volume of air injected under pressure into the slurry was measured by a Flowrator. The volume of air flowing through the Flowrator Instrument is proportional to the scale reading of the float position. For example, twice the volume of air flows at a scale reading of 10 as at a scale reading of

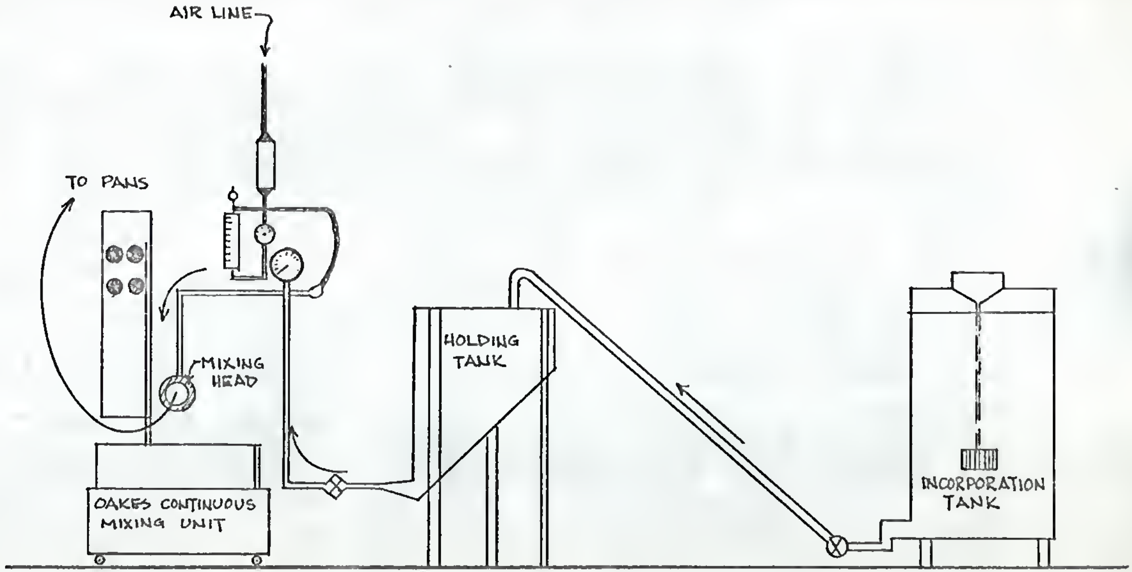


Fig. 2 Schematic flow of Oakes Continuous Mixing System.

5. In conducting this research the Flowrator was held at 12.

Within the Oakes Continuous Mixing Head, the slurry was developed into the normal characteristic appearance of angel food cake batter immediately before baking. The speed setting for the Oakes Continuous Mixing head was 3.5. This is approximately equivalent to 830 rpm.

The foam batter from the mixing head passed through a plastic tube (20' x 1/2") and was deposited directly into angel food baking pans. The cakes were baked for 30 minutes at 400°F in a Reed, 8 bun pan, revolving, direct-fired gas oven.

Two types of pans and three different sizes were used in this research:

(a) Household - or Consumer-type

(b) Commercial - or Industrial-type

1. Large commercial
2. Small commercial

A detailed description of these pans is presented in Table 1.

TABLE 1. Description of Angel Food Cake Pans Used in Experiments

Type	Household	Large Commercial	Small Commercial
Material	Aluminum	Steel	Steel
Outside Diameter (Top)	10"	10 1/2"	9 1/2"
Outside Diameter (Bottom)	8 1/4"	9 1/4"	8 1/4"
Center Diameter (Top)	1"	2 3/4"	2 1/4"
Center Diameter (Bottom)	1 1/2"	3"	2 1/2"
Depth	4 3/8"	3 3/4"	3 3/4"
Grams of Batter Deposited	750	650	575

The rate of production of angel food cake batter was approximately 80 lbs. per hour. Prior to the scaling of the batter into pans, the Oakes Continuous Mixing Unit was operated for about five minutes to allow the system to stabilize before taking a specific gravity reading. When this had been done, five cakes were scaled for each pan type (for a total of 15 cakes). After scaling for each pan type, an additional specific gravity reading was taken to prevent any unnoticed fluctuation in the uniformity of the batter.

Over thirty preliminary production trials were carried out by the above procedure before the actual research began. Information derived from this preliminary experimentation was extremely valuable for several reasons. First, it afforded a comprehensive knowledge of operating the Oakes Continuous System. Second, it was possible to predict, without bias, the outcome of the final product.

Description of Starch Experiments.

Four experiments were made involving the various starches in angel food cake production. The experiments are outlined below.

Experiment 1. Wheat starch was used to dilute the protein content of a commercial cake flour. The original protein content of the flour was 7.4 percent on a 14% moisture basis. Samples of this flour were then adjusted to 6.4, 5.4, 4.4, and 3.4 percent protein content by the addition of wheat starch. Angel food cakes were produced from the resulting five flours of varying protein levels using the prescribed formula.

Experiment 11. In this study, the original flour with protein content of 7.4 percent was used. Unmodified corn starch (food grade), 55 percent amylose corn starch, 70 percent amylose corn starch, and 70 percent amylose corn starch with 10 percent hydroxy methyl propyl groups substituted into the formula for wheat starch. This investigation was conducted to compare the effects of the various types of corn starches to that of wheat starch which is traditionally used in angel food cake production. The final protein content of the flour was 5.7 percent based on the original wheat starch present in the basic formula.

Experiment 111. Because in Experiment 1 angel food cakes produced by diluting the flour protein content to 6.4 percent (in addition to the normal amount of wheat starch in the formula) showed the most successful results, Experiment 111 was designed to study the effects of diluting the original flour (7.4 percent protein) to 6.4 percent protein content with unmodified corn starch, 55 percent amylose corn starch, 70 percent amylose corn starch, and 70 percent amylose corn starch with 10 percent hydroxy methyl propyl groups. Wheat starch was used in fulfilling the starch requirement in the formula. The protein content of the flour after diluting with the various corn starch and wheat starch was 5.0%.

Experiment 1V. Experiment 1V was similar to Experiment 11 in that corn starches were substituted for wheat starch in the formula. The important difference in this study was that modified corn starches were used. These starches included Amaizo W-11, Amaizo Polar-Gel 1, Amaizo 400 Stabilizer, and Amaizo W-13. The final protein content of the diluted flour was 5.7%.

Physiochemical Determinations of Cake Characteristics. The following determinations were conducted:

1. Specific gravity of batter.
2. Baking loss of the cake.
3. Height of the cake.
4. Crumb pH.
5. Penetrometer value.
6. Crust color.
7. Crumb color.
8 Effects of pan size.

Specific Gravity of Batter. This was obtained by dividing the weight of a precise volume of batter by the weight of an equal volume of water.

Baking Loss. The baking loss was determined by weighing the finished cake in grams and subtracting this weight from the original batter weight. A thirty minute cooling period (at room temperature) was allowed after the cakes were removed from the oven before reweighing.

Height of the Cakes. The height of the cakes was measured in millimeters by removing a longitudinal section of the cake and recording the average of three different (outer, middle and inner) measurements.

Crumb pH. This determination was made by using a Waring blender and a Beckman Expanomatic pH meter. Ten grams of cake crumb were placed in the blender with 100 cc. of distilled water. The blender was operated for 1 min. at high speed and a pH determination was made on the homogenized solution.

Penetrometer Value. This determination was made using a Precision Universal Penetrometer (48). To determine the rate of penetration, a ASTM grease penetration cone was used. The point of the cone was adjusted so it just touched the surface of the sample. The clutch trigger was depressed permitting the cone to descend into the sample. The clutch trigger was released after 5 seconds time as measured by 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 by a photovolt reflectometer. The selected filter was designed to furnish the widest range of readings in order to distinguish small differences in shade (46). The amber filter, with a setting of 57.5 was used. Two standards were used: a white standard with a value equal to 100 and a black standard with a value equal to 0. The reflectance of the sample was obtained by using the following formula.

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

rx = reflectance of sample

rd = reflectance of dark standard

rl = reflectance of light standard

gx = photovolt reflectometer reading of sample.

RESULTS AND DISCUSSION

Batter and cake characteristics resulting from the dilution of proteim of commercial cake flour with nine different starches, using three different pan sizes are reported in Tables 1 to 15. The results reported are pH of the batter, specific gravity of the batter, baking loss of the cake, height of the cake, pH of the crumb, penetrometer value, crust reflectance index and crumb reflectance index. These characteristics are discussed separately for the four experiments with occasional reference to each other where significant similarities and differences occur.

Plates 1 to lV are photographs of each of the four experiments. In plate lV, the modified waxy corn starches: Amaizo W-11, Amaizo Polar Gel 1, Amaizo W-13, and Amaizo 400 Stabilizer are represented by Roman numerals 1, 11, 111, and lV respectively.

A graphic presentation of the results for Experiments 1 to lV are presented in Figures 5 to 72 in the appendix.

EXPERIMENT 1.

<u>pH of the Batter</u>: The results of pH determinations for Experiment 1 are presented in Tables 1 to 3. The results indicate that as the protein concentration decreased the pH of the batter increased. This pH change may have been related to

the amount of chlorinated flour present in the batter. Flour treated with chlorine has a lower pH than the same flour prior to treatment. The relationship between pH and protein was common for the three different pans sizes used.

Specific Gravity of the Batter: The specific gravity of the batter was found to increase as the protein level decreased until the protein concentration of the flour reached 4.4%. At flour protein levels of 4.4 and 3.4% the specific gravity of the batter began to increase. This reversal of effect on the specific gravity was the result of having to increase the volume of air incorporated into the system to maintain the back pressure between 95 - 100 p.s.i. It appears that an angel food cake batter intended for use in continuous batter production should contain approximately 5.4% protein concentration based on the experimental formula.

Baking Loss of Cake: The baking losses of the cakes are presented in Tables 1 to 3. This variable appears to be influenced by the volume of air incorporated into the system and the protein level of the cake flour. At high protein levels (7.4 and 6.4%) and at low protein levels (4.4 and 3.4%) the baking loss was high. Production of cakes at 4.4 and 3.4 protein levels required increasing the volume of air incorporated into the batter in order to maintain the back pressure

TABLE 1.

Batter and cake characteristics obtained from dilution of flour protein with wheat starch using household-type pans.

Protein Concentration (%)	7.4	6.4	5.4	4.4	3.4
Batter pH	6.08	6.12	6.16	6.26	6.22
Batter Specific Gravity	0.225	0.250	0.350	0.325	0.300
Baking Loss of Cake (gms)	49.5	51.2	39.2	41.5	54.5
Height of Cake (mm)	103.0	107.0	86.0	80.5	74.0
Crumb pH	6.35	6.45	6.47	6.50	6.70
Penetrometer Value (mm)	35.2	35.6	31.8	29.8	29.2
Crust Reflectance Index	40.0	40.5	42.0	45.5	48.5
Crumb Reflectance Index	74.0	75.5	76.5	80.5	84.5

TABLE 2.

Batter and cake characteristics obtained from dilution of flour protein with wheat starch using large commercial-type pans.

Protein Concentration (%)	7.4	6.4	5.4	4.4	3.4
Batter pH	6.09	6.13	6.16	6.19	6.21
Batter Specific Gravity	0.225	0.250	0.350	0.325	0.300
Baking Loss of Cake (gms)	65.0	68.5	55.5	59.5	65.5
Height of Cake (mm)	97.5	100.5	83.5	76.5	72.5
Crumb pH	6.35	6.40	6.47	6.60	6.69
Penetrometer Value (mm)	36.7	37.2	31.6	31.0	29.5
Crust Reflectance Index	35.0	36.0	38.5	41.0	43.0
Crumb Reflectance Index	71.5	72.0	74.0	79.5	80.5

TABLE 3.

Batter and cake characteristics obtained from dilution of flour protein with wheat starch using small commercial-type pans.

Protein Concentration (%)	7.4	6.4	5.4	4.4	3.4
Batter pH	6.06	6.10	6.15	6.18	6.20
Batter Specific Gravity	0.225	0.250	0.350	0.325	0.300
Baking Loss of Cake (gms)	59.5	64.0	50.5	57.0	61.5
Height of Cake (mm)	105.0	109.0	92.0	88.0	78.0
Crumb pH	6.40	6.45	6.50	6.60	6.64
Penetrometer Value (mm)	37.0	37.5	34.6	29.0	28.9
Crust Reflectance Index	32.0	33.5	35.0	37.5	40.0
Crumb Reflectance Index	69.0	69.5	73.5	82.5	84.0

TABLE 4.

Batter and cake characteristics obtained from dilution of flour protein with corn starch containing 70% amylose replacing wheat starch in formula using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	7.4	7.4	7.4
Batter pH	6.00	6.00	6.00
Batter Specific Gravity	0.250	0.250	0.250
Baking Loss of Cake (gms)	50.5	75.0	54.5
Height of Cake (mm)	74.5	73.0	80.0
Crumb pH	6.15	6.25	6.30
Penetrometer Value (mm)	34.5	28.6	30.1
Crust Reflectance Index	34.5	32.5	41.5
Crumb Reflectance Index	60.5	62.0	62.5

TABLE 5.

Batter and cake characteristics obtained from dilution of flour protein with corn starch containing 70% amylose plus 10% added hydroxymethyl propyl groups replacing wheat starch in the formula using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	7.4	7.4	7.4
Batter pH	6.05	6.05	6.05
Batter Specific Gravity	0.250	0.250	0.250
Baking Loss of Cake (gms)	44.0	52.0	48.0
Height of Cake (mm)	71.0	69.5	78.5
Crumb pH	6.30	6.35	6.35
Penetrometer Value (mm)	30.0	26.4	27.3
Crust Reflectance Index	45.4	41.5	43.5
Crumb Reflectance Index	61.5	62.5	63.0

TABLE 6.

Batter and cake characteristics obtained from dilution of flour protein with corn starch containing 55% amylose replacing wheat starch in the formula using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration	7.4	7.4	7.4
Batter pH	6.00	6.00	6.00
Batter Specific Gravity	0.375	0.375	0.375
Baking Loss of Cake (gms)	35.0	51.5	50.5
Height of Cake (mm)	74.5	73.5	84.5
Crumb pH	6.20	6.20	6.25
Penetrometer Value (mm)	32.5	29.5	30.0
Crust Reflectance Index	50.5	42.5	44.5
Crumb Reflectance Index	67.5	67.0	67.5

TABLE 7.

Batter and cake characteristics obtained from dilution of flour protein with food grade corn starch replacing wheat starch in the formula using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	7.4	7.4	7.4
Batter pH	6.10	6.10	6.10
Batter Specific Gravity	0.350	0.350	0.350
Baking Loss of Cake (gms)	38.0	54.0	46.7
Height of Cake (mm)	80.5	75.5	85.5
Crumb pH	6.25	6.30	6.30
Penetrometer Value (mm)	31.0	30.0	30.5
Crust Reflectance Index	52.0	40.5	51.0
Crumb Reflectance Index	66.0	63.5	67.0

TABLE 8.

Batter and cake characteristics obtained from dilution of flour protein to 6.4% with corn starch containing 70% amylose plus normal amount of wheat starch using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	6.4	6.4	6.4
Batter pH	6.15	6.15	6.15
Batter Specific Gravity	0.250	0.250	0.250
Baking Loss of Cake (gms)	45.5	60.5	60.5
Height of Cake (mm)	96.5	96.0	109.0
Crumb pH	6.40	6.40	6.45
Penetrometer Value (mm)	33.8	36.4	37.0
Crust Reflectance Index	46.5	44.5	45.0
Crumb Reflectance Index	70.0	68.0	67.0

TABLE 9.

Batter and cake characteristics obtained from dilution of flour protein to 6.4% with corn starch containing 70% amylose plus 10% added hydroxymethyl propyl groups plus normal amount of wheat starch using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	6.4	6.4	6.4
Batter pH	6.18	6.18	6.18
Batter Specific Gravity	0.275	0.275	0.275
Baking Loss of Cake (gms)	41.0	57.5	49.0
Height of Cake (mm)	91.5	88.0	99.0
Crumb pH	6.40	6.40	6.45
Penetrometer Value (mm)	30.8	33.7	35.1
Crust Reflectance Index	45.00	40.00	43.5
Crumb Reflectance Index	80.0	66.5	68.0

TABLE 10.

Batter and cake characteristics obtained from dilution of flour protein to 6.4% with corn starch containing 55% amylose plus normal amount of wheat starch using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	6.4	6.4	6.4
Batter pH	6.14	6.14	6.14
Batter Specific Gravity	0.300	0.300	0.300
Baking Loss of Cake (gms)	45.0	57.5	57.0
Height of Cake (mm)	88.5	85.0	95.5
Crumb pH	6.20	6.20	6.25
Penetrometer Value (mm)	31.3	33.5	34.2
Crust Reflectance Index	46.5	45.5	46.0
Crumb Reflectance Index	69.0	68.5	68.0

TABLE 11.

Batter and cake characteristics obtained from dilution of flour protein to 6.4% with food grade corn starch plus normal amount of wheat starch using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	6.4	6.4	6.4
Batter pH	6.20	6.20	6.20
Batter Specific Gravity	0.300	0.300	0.300
Baking Loss of Cake (gms)	50.5	63.5	52.0
Height of Cake (mm)	98.0	90.0	100.0
Crumb pH	6.35	6.45	6.45
Penetrometer Value (mm)	30.5	32.9	34.0
Crust Reflectance Index	46.0	42.0	44.0
Crumb Reflectance Index	68.0	67.5	67.0

TABLE 12.

Batter and cake characteristics obtained from dilution of flour protein with Amaizo W-11 modified waxy maize starch replacing wheat starch in formula using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	7.4	7.4	7.4
Batter pH	6.20	6.20	6.20
Batter Specific Gravity	0.275	0.275	0.275
Baking Loss of Cake (gms)	41.5	57.5	54.0
Height of Cake (mm)	79.5	73.0	84.5
Crumb pH	6.55	6.60	6.60
Penetrometer Value (mm)	28.8	31.9	32.4
Crust Reflectance Index	41.0	64.0	37.5
Crumb Reflectance Index	68.0	66.5	65.0

TABLE 13.

Batter and cake characteristics obtained from dilution of flour protein with Amaizo 400 Stabilizer modified waxy maize starch replacing wheat starch in formula using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	7.4	7.4	7.4
Batter pH	6.24	6.24	6.24
Batter Specific Gravity	0.300	0.300	0.300
Baking Loss of Cake (gms)	44.0	64.0	53.5
Height of Cake (mm)	83.0	78.0	91.5
Crumb pH	6.55	6.60	6.65
Penetrometer Value (mm)	33.4	35.2	35.4
Crust Reflectance Index	41.5	35.0	38.5
Crumb Reflectance Index	67.0	66.5	66.0

TABLE 14.

Batter and cake characteristics obtained from dilution of flour protein with Amaizo Polar Gel 1 modified waxy maize starch replacing wheat starch in formula using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	7.4	7.4	7.4
Batter pH	6.19	6.19	6.19
Batter Specific Gravity	0.325	0.325	0.325
Baking Loss of Cake (gms)	42.5	61.5	53.0
Height of Cake (mm)	83.5	74.5	89.0
Crumb pH	6.50	6.55	6.60
Penetrometer Value (mm)	32.5	33.0	34.4
Crust Reflectance Index	41.0	31.0	33.0
Crumb Reflectance Index	68.0	67.0	66.0

TABLE 15.

Batter and cake characteristics obtained from dilution of flour protein with Amaizo W-13 modified waxy maize starch replacing wheat starch in formula using household - large commercial - and small commercial-type pans.

Pan Type	Household	Large Commercial	Small Commercial
Protein Concentration (%)	7.4	7.4	7.4
Batter pH	6.17	6.17	6.17
Batter Specific Gravity	0.275	0.275	0.275
Baking Loss of Cake (gms)	45.5	63.0	56.5
Weight of Cake (mm)	85.5	79.5	90.0
Crumb pH	6.45	6.50	6.55
Penetrometer Value (mm)	32.3	33.3	33.5
Crust Reflectance Index	36.0	29.0	30.0
Crumb Reflectance Index	65.0	64.0	64.0

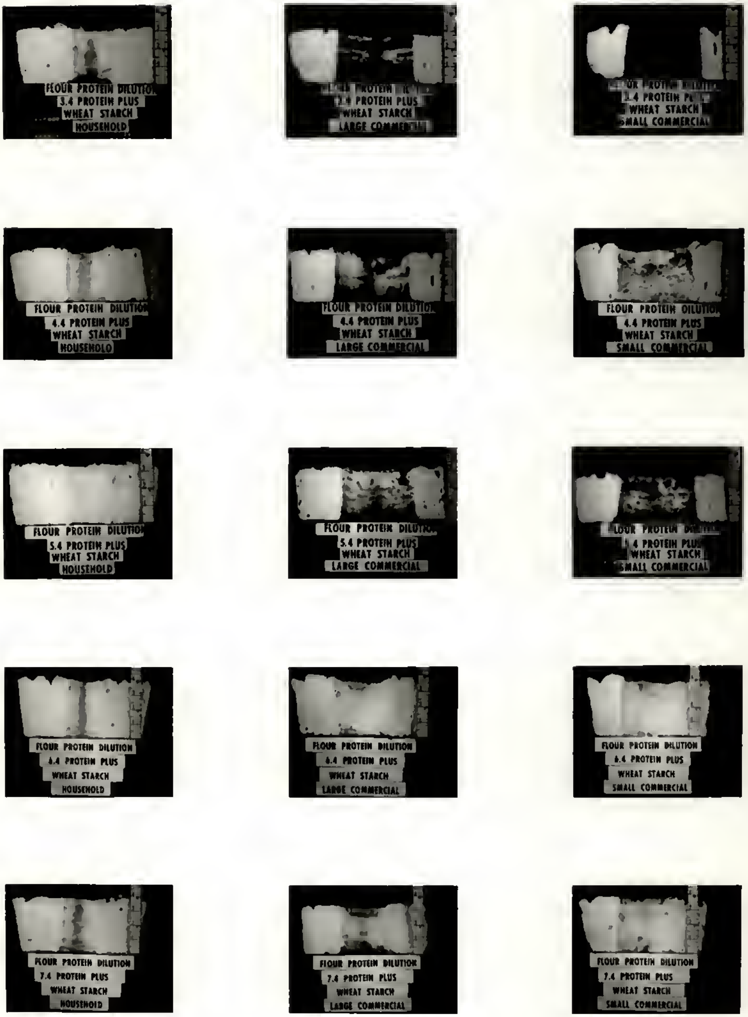


Plate I Physical characteristics of angel food cakes prepared with flour diluted with wheat starch.

Plate II Physical characteristics of angel food cakes prepared with original flour diluted with various corn starch.

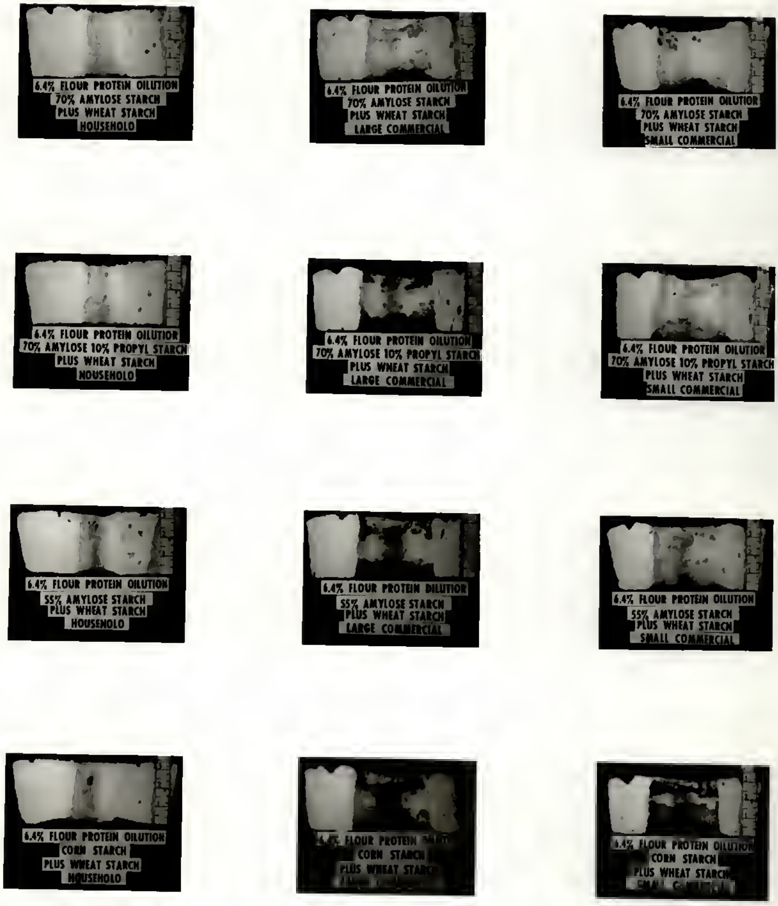
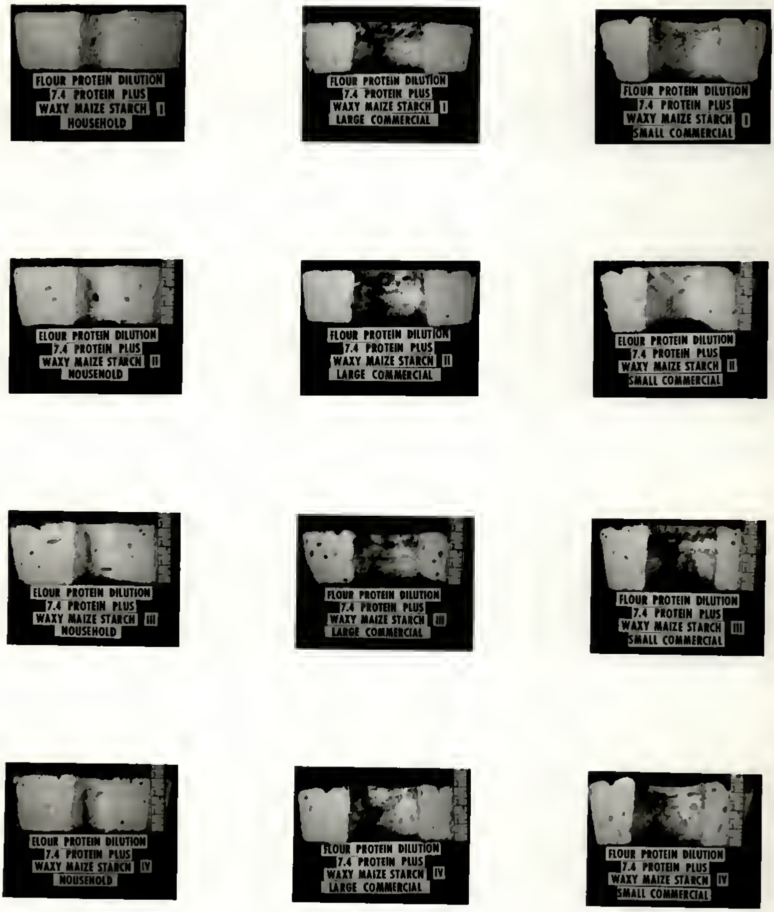


Plate III Physical characteristics of angel food cakes prepared with flour diluted to 6.4% with various corn starches plus normal amount of wheat starch in formula.



Plates IV Physical characteristics of angel food cakes prepared with flour diluted with modified waxy maize starches.

within the required range. Cakes produced from cake flour of 5.4% protein had the smallest baking loss. Cakes produced at this level were made from a flour of low protein content with no additional air being incorporated into the system. The different types of pans had a more significant effect on the baking loss. The average baking loss for consumer, large commercial and small commercial pans was 47.2, 63.0 and 58.6 grams respectively.

Height of Cake and Penetrometer Value: The height of the cakes and the penetrometer values were closely related in this series. With the exception of cakes produced from flour of 6.4% protein content, the height and the penetrometer values decreased with decreasing protein levels. These results are presented in Tables 1 to 3.

Pan size cannot be considered to have had an important affect on either of these two variables because of differences in the heights of the pans and number of grams of batter deposited in the pans.

pH of the Crumb: The pH of the crumb increased as the protein concentration; the results are presented in Tables 1 to 3. This trend was indentical to observations noted for pH of the batter.

Color of the Crust: It was observed that as the flour protein content decreased, the color of the crust increased. The results of crust reflectance index are presented in Tables 1 to 3.

There appeared to be a relationship between the pH of the batter and the formation of crust color. As the pH increased, the cake batter became more alkaline and approached the optimal level for the browning reaction. The product also became more dense, thus allowing more intimate contact between the free amino radicals of the flour and the free sugar.

The type of pan was found to have an important influence on the formation of crust color. The average value for the crust reflectance index of cakes baked in consumer, large commercial and small commercial pans was 43.3, 33.2 and 33.4 units respectively. The large commercial and small commercial pans were steel whereas the consumer pans were aluminum. This factor may account for the similarity between the reflectance of cakes baked in large and small commercial pans. The reflectance values of crust for cakes baked in the two types of steel pans differed by only 0.2 units but the aluminum pans differed by approximately 10 units from the values for the cakes baked in the steel pans.

Color of the Crumb: The color of the crumb followed the same trend as the color of the crust. That is, as the protein concentration decreased, the color of the crumb increased. These results are presented in Tables 1 to 3. This change may have been related to the density of the crumb structure. The type of pan (aluminum or steel) was not an influencing factor on the whiteness of the crumb.

EXPERIMENT 11.

The results of substituting corn starches of 55%, 70%, and 70% amylose content treated to contain 10% hydroxymethyl propyl groups, and ordinary corn starch (food grade) for wheat starch are presented below.

pH of the Batter: The average pH of the batters produced from high-amylose corn starches was approximately 0.08 lower than the average pH of the batters produced from wheat starch in Experiment 1, based on the same dilution of flour protein. Ordinary food grade corn starch, however, showed a slightly smaller value than that for wheat starch in Experiment 11. The difference was 0.01 pH units.

Specific Gravity of the Batter: The specific gravity values of the batters produced from corn starch of 70% amylose content before and after treatment hydroxymethyl propyl groups were comparable to the specific gravity of the batter produced in Experiment 1 using wheat starch at the same flour dilution. The results are presented in Tables 1 to 5.

Corn starch of 55% amylose content and food grade corn starch, with any amylose content of approximately 27%, produced batters with specific gravities considerably higher; the results are presented in Tables 6 and 7. Since all batters are produced within the same operating range on the Oakes Continuous System, there is an apparent relationship of amylose content of corn starch and specific gravity of the batter.

Baking Loss of the Cake: The baking losses of cakes produced in Experiment 11 are presented in Tables 4 to 7. Starch of 70% amylose content with 10% hydroxymethyl propyl groups, corn starch of 55% amylose content and food grade corn starch gave average baking losses of 48.0, 45.6 and 46.2 grams respectively. The unmodified corn starch of 70% amylose content had an average baking loss of 60.0 grams. As in Experiment 1, notable differences were observed when different pan sizes were used, no matter which starch was used. The cakes baked in the large commercial pans showed the largest baking losses, followed by those in the small commercial and consumer pans respectively.

Height of the Cake and Penetrometer Value: The data presented in Tables 4 to 7, indicate that the relationship of height to penetrometer value was not as significant as in Experiment 1. From the results presented in Tables 4 to 7, it is apparent that the type of starch tested had a significant influence on the tenderness of the cake.

It was noted that without exception all corn starches produced cakes that were lower in height and rate of penetration than cakes produced from wheat starch. The differences in height and penetrometer values were lower than for cakes prepared with wheat starch in Experiment 1 when the same dilution of flour protein and pan sizes were compared.

pH of the Crumb: The values for pH of the crumb obtained in Experiment 11 were approximately 0.1 lower than comparable pH values in Experiment 1 when wheat starch was used.

Color of the Crust: The crust reflectance index was on the average higher for cakes made with the various corn starches than for those made with wheat starch in Experiment 1 (43.3 and 35.7). The only exceptions were the cakes produced using corn starch of 70% amylose content, the average value for which was close to the values reported in Tables 1 to 4, for cakes prepared with wheat starch.

The effect of pan size and composition, however, was not as important in influencing the reflectance index of the crust in Experiment 11 as in Experiment 1. One exception was noted when food grade corn starch was used; the results are presented in Table 7. The findings indicate that the crust color of cakes produced from high amylose corn starches may be independent of the metallic composition of the pan or that the rate of heat transfer does not influence the crust color to any significant amount in cakes prepared from corn starch.

Color of the Crumb: The average color of the crumb for cakes made with all types of corn starch used in Experiment 11 was 7.3 units below that for the comparable dilution of flour protein in Experiment 1. The data for color of the crumb are presented in Tables 1 to 7.

The color of the crumb showed little variation dependent on pan size or metallic composition. The intensity of crumb color appeared to be less dependent upon pan composition than upon types of starch.

EXPERIMENT 111.

The results of Experiment 1 indicated that angel food cakes produced from flour diluted to protein content of 6.4% with wheat starch, in addition to the normal amount of wheat starch prescribed by the formula produced the most acceptable cakes. The cakes made with added wheat starch were superior in volume and tenderness. The results of Experiment 11 indicated that cakes prepared with added high-amylose and food grade corn starches were inferior to those prepared with added wheat starch in Experiment 1 when volume, tenderness and crumb colors were compared. The baking losses noted in Experiment 11 were on the average less than the baking losses observed in Experiment 1 for the same concentration of flour protein. Baking loss differences amounted to 8.1.

Experiment 111 was designed to study the effects of producing angel food cakes from cake flour diluted to 6.4% by the various corn starches, in addition to the normal amount of wheat starch prescribed by the formula. The final protein content of a mixture of the flour, corn starch and wheat starch was 5.0%.

pH of the Batter: The pH of the batter in Experiment 111 varied slightly from that in Experiments 1 and 11 when the average values for the experiments were compared. The results are presented in Tables 1 to 11.

Specific Gravity of the Batter: The specific gravity of the batter in Experiment 111 followed the same trend as in Experiment 11. Corn starch of 70% amylose content, unmodified and modified to contain 10% hydroxymethyl propyl groups, produced batters with the lowest specific gravities. Food grade corn starch and that with 55% amylose content produced higher specific gravities than the two other corn starches. Although this was the observed trend in Experiment 11 also, it was noted that the differences among specific gravities in Experiment 111 were less than those in Experiment 11 (Tables 4 to 11). It is apparent from this experiment and Experiment 1 that addition of wheat starch producсs batter of a lower specific gravity than low amylose corn starches under the same operating conditions of the Oakes Continuous System.

<u>Baking Loss of thc Cakc</u>: Thc gram-weight losses that occurred during baking are presented in Tables 8 to 11. The results obtained in Experiment 111 support the conclusions drawn from data obtained in Experiments 1 and 11 relative to baking losses. It was found that in Experiment 1 where only wheat starch was used the average baking loss per cake was 58.0 grams, and in Experiment 11, where various corn starches were used, the average gram-loss was 49.9. In Experiment 111 the average baking loss for all cakes, using a comparable dilution of flour protein as in Experiment 1 and 11, was 53.3 grams. Since this value is between the average value for baking losses in Experiment 1 and 11 and also represents the baking loss for cakes produced from flour diluted with a combination of the two types of cereal starches, it is in agreement with the observation that the average baking loss in grams is higher for cakes produced from flour diluted with wheat starch than for cakes made from flour diluted with one of the various types of corn starch used.

The style and composition of pan used also influenced the baking loss. For cakes baked in consumer type pans the average loss was 45.5 grams compared to an average loss of 57.2 grams for those baked in commercial type pans.

Height and Penetrometer Value: The results of cake height and penetrometer values are presented in Tables 8 to 11. The results of height and tenderness values followed a trend similar to that of baking loss. The average height and penetrometer values for all cakes produced in Experiment 111 were between the corresponding values in Experiments 1 and 11. For Experiments 1, 11 and 111 the respective average values for height were 103.8, 76.7 and 94.7 mm and for penetrometer values were 36.6, 30.0 and 33.6 mm.

pH of the Crumb: The pH of the crumb was similar to values found in Experiments 1 and 11. The pH of the crumb was increased as compared to the pH of the batter. This trend was common for Experiments 1, 11 and 111 but with little evidence to indicate any significant differences between experiments.

Color of the Crust: The average reflectance index for crust color in Experiment 111 was found to be higher than for comparable dilutions of flour protein in Experiments 1 and 11; the data is presented in Tables 1 to 11. The observed increase was approximately 8 photovolt units.

The type of pan used had an evident effect on the color of the crust, although it was not as pronounced in Experiment 111 as in Experiments 1 and 11. The average reflectance index in photovolt units for consumer, large commercial and small commercial pans respectively was 48.0, 43.0 and 44.6.

Color of the Crumb: The results presented in Tables 8 to 11 indicate only a small variation in crumb color between the various cakes made with corn starches. However, in comparing the reflectance indexes for Experiments 1, 11 and 111, it was observed that using wheat starch in combination with any one of the four corn starches produced cake with crumb reflectance index within the range of that for cake made with only wheat or corn starch as diluent.

EXPERIMENT IV.

Experiment IV was designed to study four modified corn starches in the production of angel food cake. These starches represented a cross-section of the various types of inhibited corn starches and had previously been used commercially in the production of other kinds of baked goods.

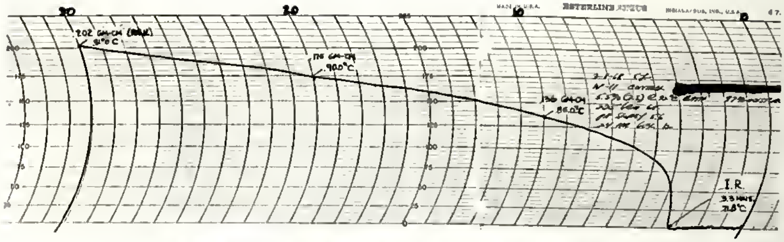
Modified or "inhibited" corn starches are products capable of withstanding adverse conditions of temperature and storage. To date, these starches have been particularly successful in the food processing industries.

Quality control of modified starches is a critical factor in producing them. Probably the most important single control employed by the starch industry in the use of the Corn Industries Viscometer (CIV). Routine tests for consistency are made in the starch industry to: (a) control the reaction during chemical modification so that uniform products may be obtained, and (b) provide a final test of quality of the finished product.

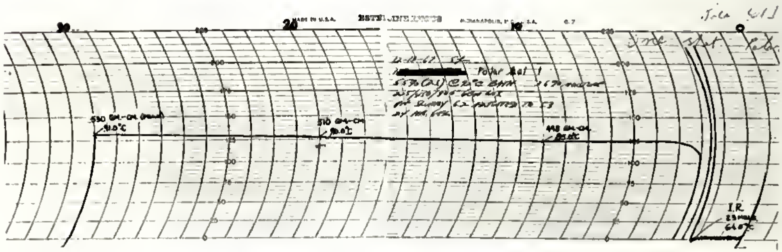
Plates V and VI represent the CIV curves for several commercially available modified corn starches: Amaizo W-11, Amaizo Polar Gel 1, Amaizo W-13, and Amaizo 400 Stabilizer, in comparison with unmodified food grade waxy corn starch.

Amaizo W-11 is a highly cross-linked starch. This starch, as indicated by the CIV curves, has approximately three times as great resistance force as the other cross-linked starches over the same temperature range. Also within this range the curve obtained for Amaizo W-11 starch did not reach its peak point as did those of the less inhibited starches, a fact indicating the relatively high resistance of this starch to normal cooking and baking temperatures.

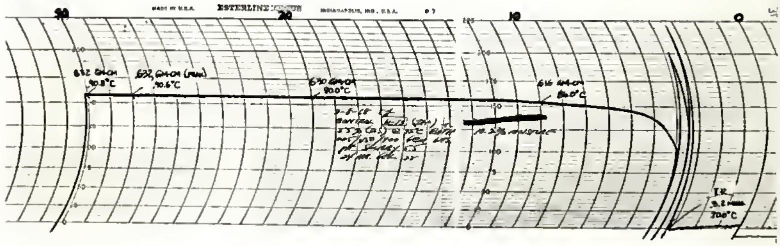
The remaining three modified starches, Amaizo Polar Gel 1, Amaizo W-13 and Amaizo 400 Stabilizer, demonstrate similar stability to heat. Over approximately the same time and temperature ranges in which unmodified waxy corn starch exhibits



AMAIZO-W11 MODIFIED CORN STARCH

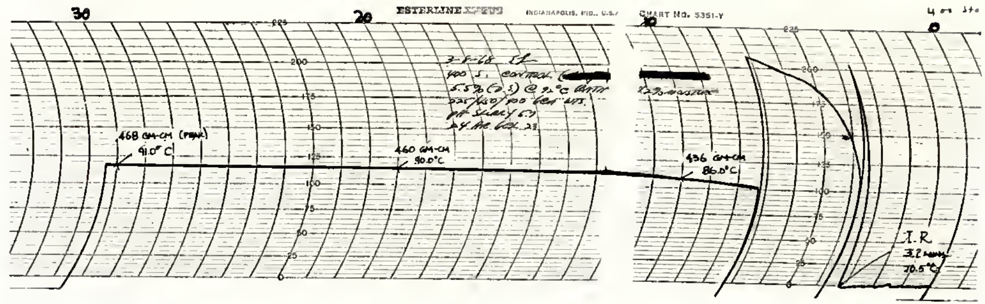


AMAIZO POLAR GEL1 MODIFIED CORN STARCH

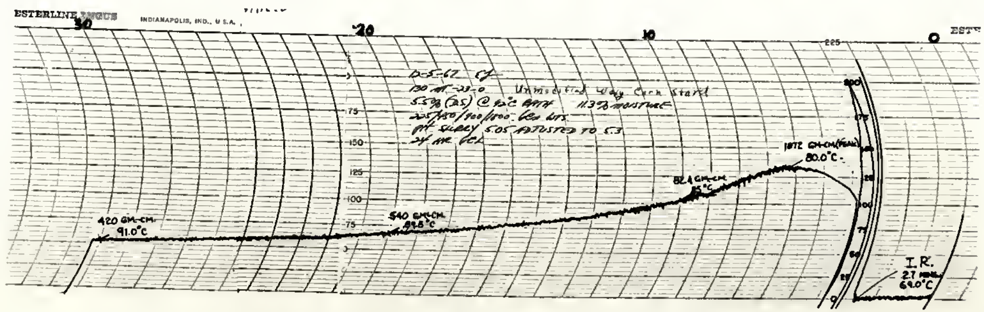


AMAIZO-W13 MODIFIED CORN STARCH

Plates V Corn Industries Viscometer (CIV) curves of modified waxy maize starches.



AMAIZO 400 STABILIZER MODIFIED CORN STARCH



UNMODIFIED WAXY CORN STARCH

Plate VI Corn Industries Viscometer (CIV) curves for modified and unmodified waxy maize corn starches.

severe breakdown, these starches show slight increase in viscosity. This is easily observed by comparing the increases in both the resistance force and the slope of the curves.

Unmodified waxy corn starch reached its peak viscosity at the relatively low temperature of 80.0°C and 1072 gcm of torque. The CIV curve declined over a 30 minute period until a temperature of 91.0°C was reached and the exerted force had fallen to 420 gm-cm. The loss of 652 gm-cm of torque was characteristic of the rapid breakdown of an unmodified waxy corn starch over this narrow temperature range.

pH of the Batter: The pH values of the batters produced from all of the modified corn starches used in Experiment IV were slightly higher than those found in the other three experiments when the same amount of cream of tartar was used in the formula. The data are presented in Tables 12 to 15. One possible explanation for this difference in pH is that modified starches are produced under alkaline conditions which influence the pH of the starch.

Specific Gravity of the Batter: The specific gravities of the batters produced froj the modified corn starches were within the range recommended for producing superior angel food cakes. The degree of cross-linkage apparently had less effect on the specific gravity than did the type of cross-linkage.

For cakes in which use was made of either Amaizo W-11 or Amaizo W-13 starch, which respectively represent the greatest and least cross-linked starches, the specific gravities of the batters were the same - 0.275. In contrast, when Amaizo Polar Gel 1, a dually cross-linked starch, was used to dilute the flour, the batter had a specific gravity of 0.325.

Baking Loss of Cake: The type of cross-linking in the starch used to dilute the flour apparently had little effect on the baking loss when the flour modified starches were compared. Figures for the average baking loss for all of the modified starches were within ± 4 grams of each other.

The data shown in Tables 12 to 15 indicate that the size and type of pan used influenced the baking loss. The average baking loss for consumer, large commercial and small commercial pans was 43.4, 61.5 and 54.2 grams respectively. These findings followed the same trend for all experiments.

Height and Penetrometer Value: In Experiment IV, the height - penetrometer relationship was less significant than in the previous experiments. The results presented in Tables 12 to 15 indicated that the type of modified starch used influenced both the volume and tenderness of the cakes.

Although average differences were small, when Amaizo W-11, a heavily cross-linked starch, was included in the formula, the cakes gave the poorest results for the two determinations being discussed. Cakes containing lightly cross-linked Amaizo W-13, in comparison, had approximately average penetrometer values but had largest volume as represented by height measurements.

<u>pH of the Crumb</u>: The pH of the crumb was higher than the pH of the batter. Increases in pH were common for all experiments and the size of these increases were approximately equivalent.

<u>Color of the Crust</u>: With the exception of cakes made with inclusion of Amaizo W-13 starch, the reflectance index for all cakes containing modified starch was similar when the batters were baked in comparable pans. The results of crust color determinations are presented in Tables 12 to 15. Cakes produced from batters including Amaizo W-13 starch had lower photovolt unit values indicating darker crusts.

Pan size and pan composition were the more important variables in determining crust color. As in all experiments using large commercial pans resulted in lowest values. The average figure was 39.8, 32.2 and 35.1 photovolt units for consumer, large commercial and small commercial pans respectively.

<u>Color of the Crumb</u>: The intensity of the crumb color for

modified starches followed the same trend as the crust color. Cakes in which Amaizo W-13 starch was used showed slightly lower values than did those in which Amaizo W-11, Amaizo Polar Gel 1 or Amaizo 400 Stabilizer was used. These values, as presented in Tables 12 to 15, were typical for all types of corn starch.

SUMMARY AND DISCUSSION

This study was conducted to determine the effects of dilution of flour protein, use of various starches and pan size on the production of angel food cakes using the Oakes Continuous System. To conduct this study, four experiments were designed using a commercial flour with an original protein content of 7.4%. Nine commercially prepared starches were used to dilute the protein content of the flour. The starches were commercial wheat starch, corn starch (food grade), 55% amylose corn starch, 70% amylose corn starch, 70% amylose corn starch treated to contain approximately 10% hydroxymethyl propyl groups, Amaizo W-11, Amaizo W-13, Amaizo Polar Gel 1 and Amaizo 400 Stabilizer. Three types of pans were used to bake the cakes: consumer, large commercial and small commercial.

The primary objective of Experiment I was to dilute the flour protein content with wheat starch in 1% step intervals, from 7.4% to 3.4%, to determine the most successful cakes from the standpoint of tenderness and volume. From the data obtained in this experiment, it was apparent that cakes produced from the flour containing 6.4% protein showed the best results when these two properties were measured. A mixture of the flour of 6.4% protein content and the normal amount of wheat starch prescribed in the formula produced a final protein level of 5.0%.

Cakcs produccd from dilutions of flour protein below 6.4% showed increasing adverse values for height and penetrotion as the protein level of thc flour decreased.

Experimcnt 11 was designed to study the effects of producing cakes from the original cake clour (protein content of 7.4%) with various corn starches being substituted for wheat starch. This study was conducted to determine the similarities and differences between cakes produced from the various kinds of starch at the same level of flour protein. The starches used were: corn starch (food grade), 55% amylose corn starch, 70% amylose corn starch, and 70% amylose corn starch treated to contain approximately 10% hydroxymethyl propyl groups. In comparing results for the same protein dilution of Experiment I with Experiment II, several differences appeared to be evident.

It was noted that for cakes produced from the corn starches containing less amylose (food grade corn starch and corn starch of 55% amylose content) the specific gravity of the batter was higher than for cakes produced from high-amylose corn starches or wheat starch.

When height, penetration and baking loss values were determined, the average figure for each of these determinations was found to be higher for cakes produced from wheat starch than for those in which the various corn starches were used. In comparing these averages, it was observed that the values obtained from cakes produced from the two corn starches of 70% amylose content came closer to approximating the values observed for wheat starch in Experiment I than did corn starch of 55% amylose content or food grade corn starch.

The crumb reflectance in for cakes produced from the various corn starches were found to be lower than for cakes produced from wheat starch in Experiment I when the same protein dilution was attained. This was indicative of a decrease in the intensity of crumb color for cakes made from the corn starches.

Since the data obtained in Experiment I indicated the most successful results were for cakes produced from a flour protein content of 6.4%, Experiment III was designed to study the affect of diluting the protein concentration of the flour to 6.4% with the various corn starches. Wheat starch was also used, in the amount prescribed in the formula, because of the apparent beneficial effects of this starch in comparison to the various corn starches. In comparing Experiments I and II, wheat starch was generally found to be superior to the various corn starches on the basis of the physiochemical determination. It might be expected, therefore, that cakes produced from a combination of of wheat starch and corn starch would show average values that were between those for cakes produced respectively from wheat starch and corn starch. From the tabulated data for Experiment III this was found to be true.

Experiment IV was conducted to stydy the effects of modified or "inhibited" waxy maize starches on the production of angel food cakes. This research followed the same design as Experiment II using the following modified starches: Amaizo W-11, Amaizo Polar Gel 1, Amaizo 400 Stabilizer and Amaizo W-13. Angel food cakes produced from modified starches followed a similar trend in physiochemical properties as did those in Experiment III. That is cakes produced in Experiment IV generally were better than cakes produced from the unmodified corn starches (Experiment II). In contrast, however, cakes produced from the modified starches in Experiment IV were generally inferior to cakes produced in Experiment 1 (for the same dilution of flour protein) where wheat starch was used.

Probably the most important bendfit derived from using a modified starch is the increased stability to resist adverse changes that occur during food processing. From the results of the various determinations, it was noted that the differences between the modified starches studied were small.

The effect of pan size and type for all experiments was most pronounced for the baking loss and crust color. The baking loss for all experiments was greatest when large commercial pans and least when consumer pans were used. From all data, it is apparent that pan size, as well as the type of pan (aluminum or steel), influenced the baking loss. Use of small commercial pans consistantly led to smaller baking losses than occurred in large commercial pans.

The color of the crust (measured in photovolt units) generally followed the same trend as did the baking loss with use of consumer, small commercial and large commercial pans, respectively, producing increased browness of crust color.

APPENDIX

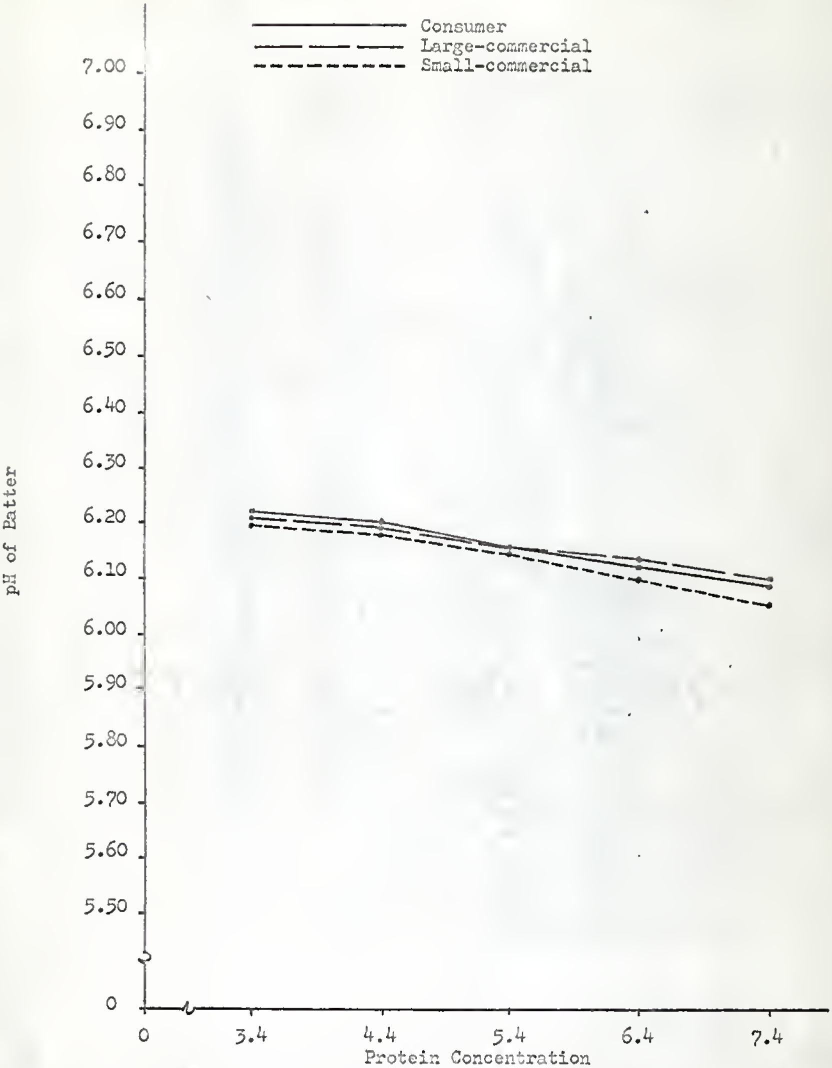


Fig. 3 The effect of dilution of flour protein with wheat starch on the pH of the batter.

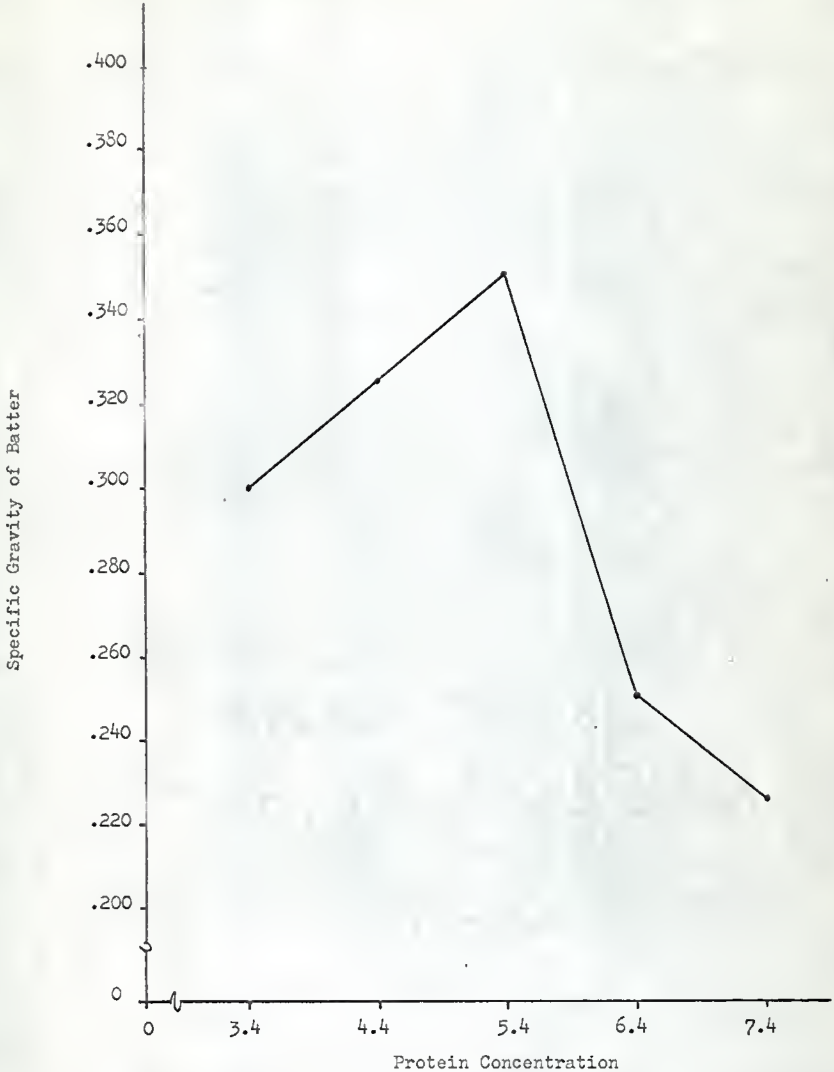


Fig. 4 The effect of dilution of flour protein with wheat starch on the Specific Gravity of the Batter.

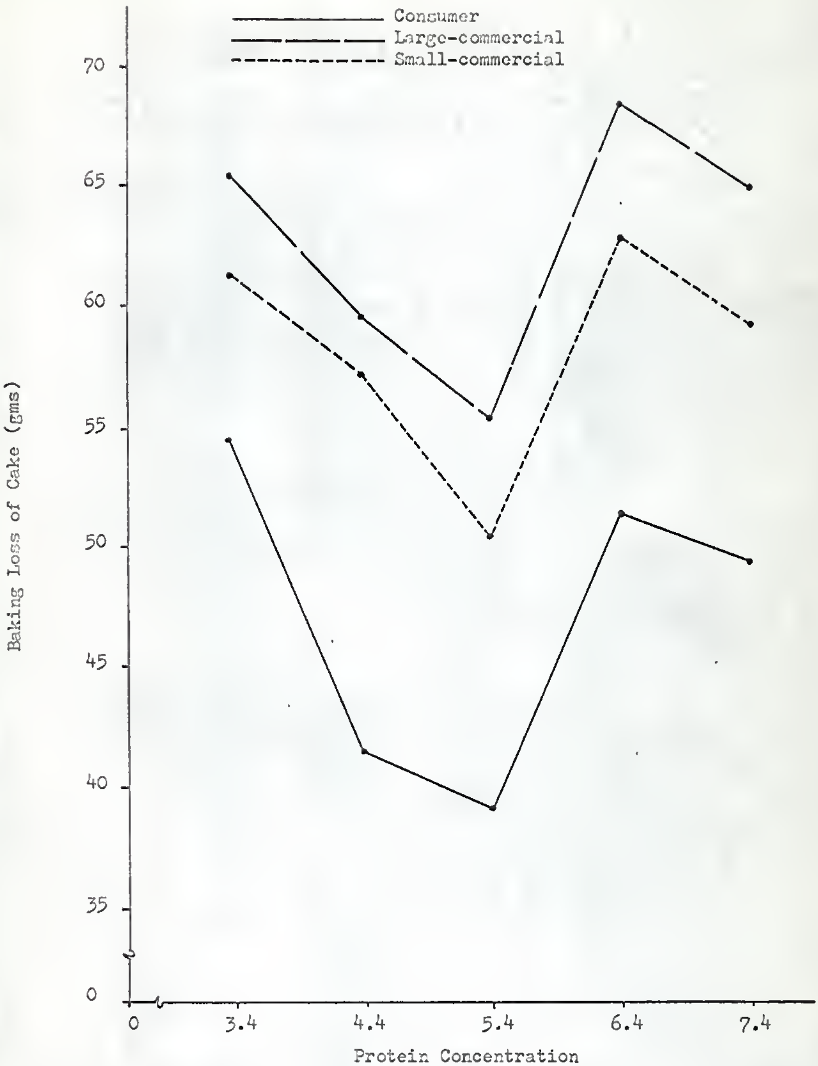


Fig. 5 The effect of dilution of flour protein with wheat starch on the baking loss of the cake.

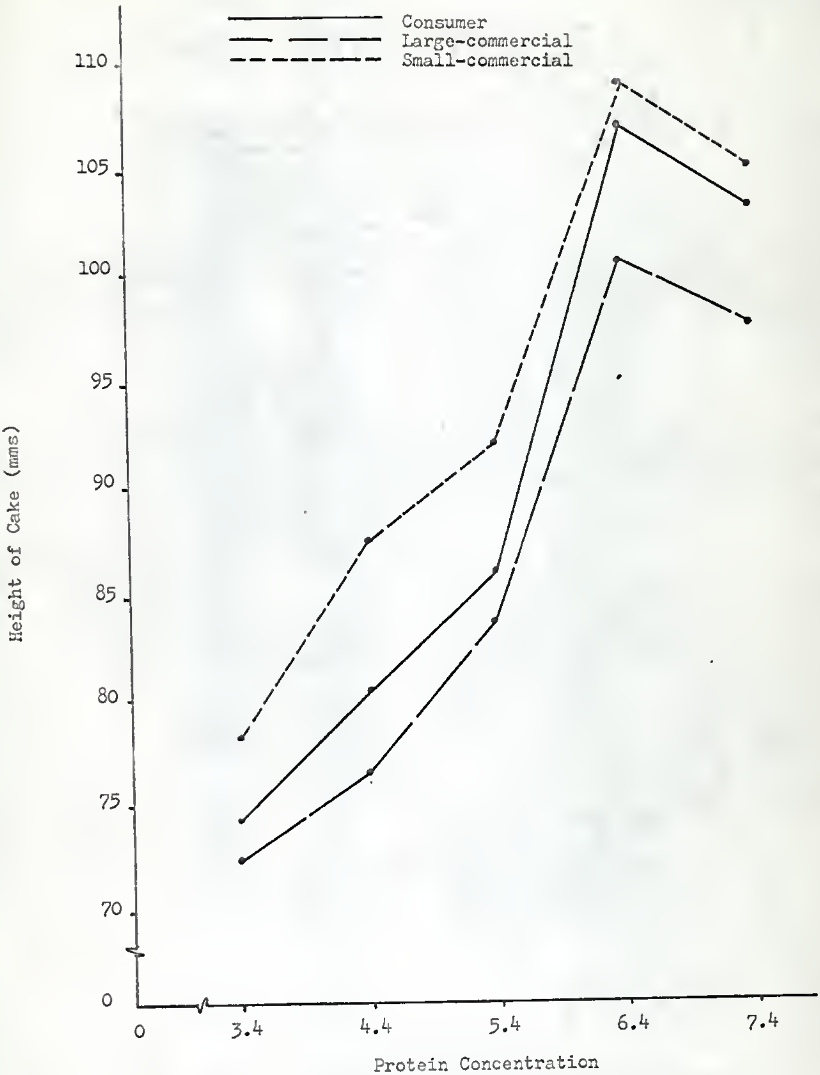


Fig. 6 The effect of dilution of flour protein with wheat starch on the height of the cake.

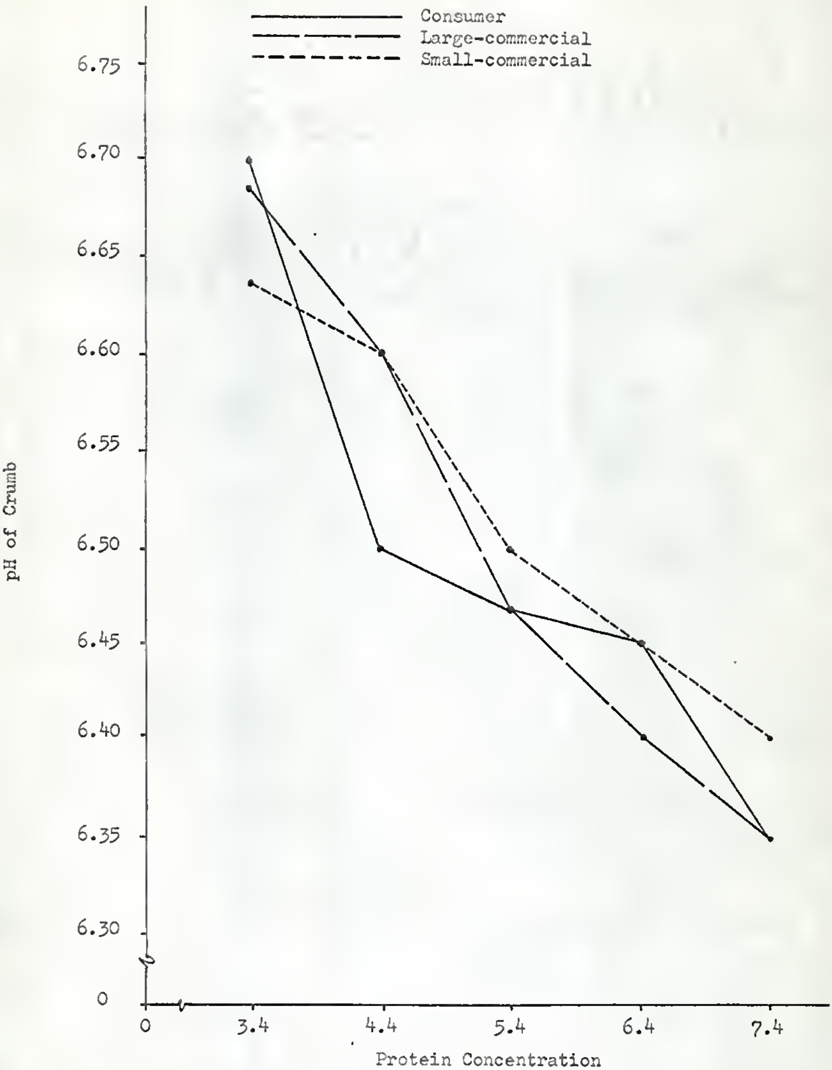


Fig. 7 The effect of dilution of flour protein with wheat starch on the pH of the crumb.

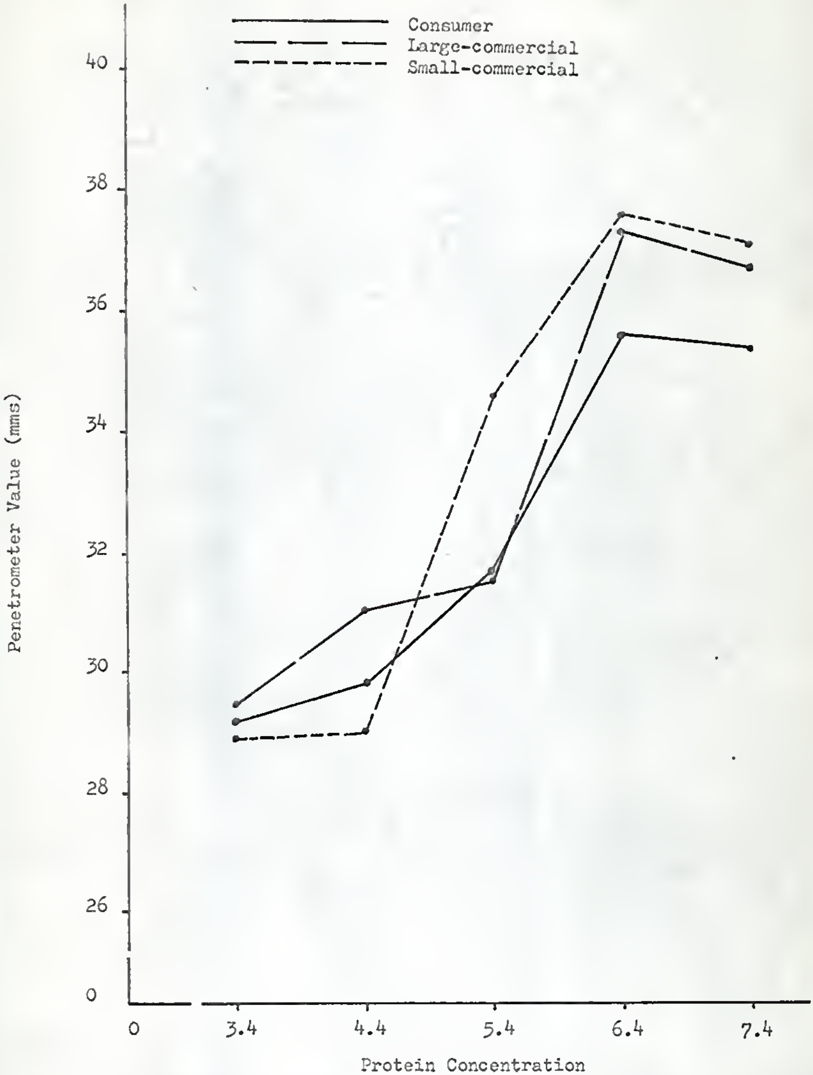


Fig. 8 The effect of dilution of flour protein with wheat starch on the penetretion value.

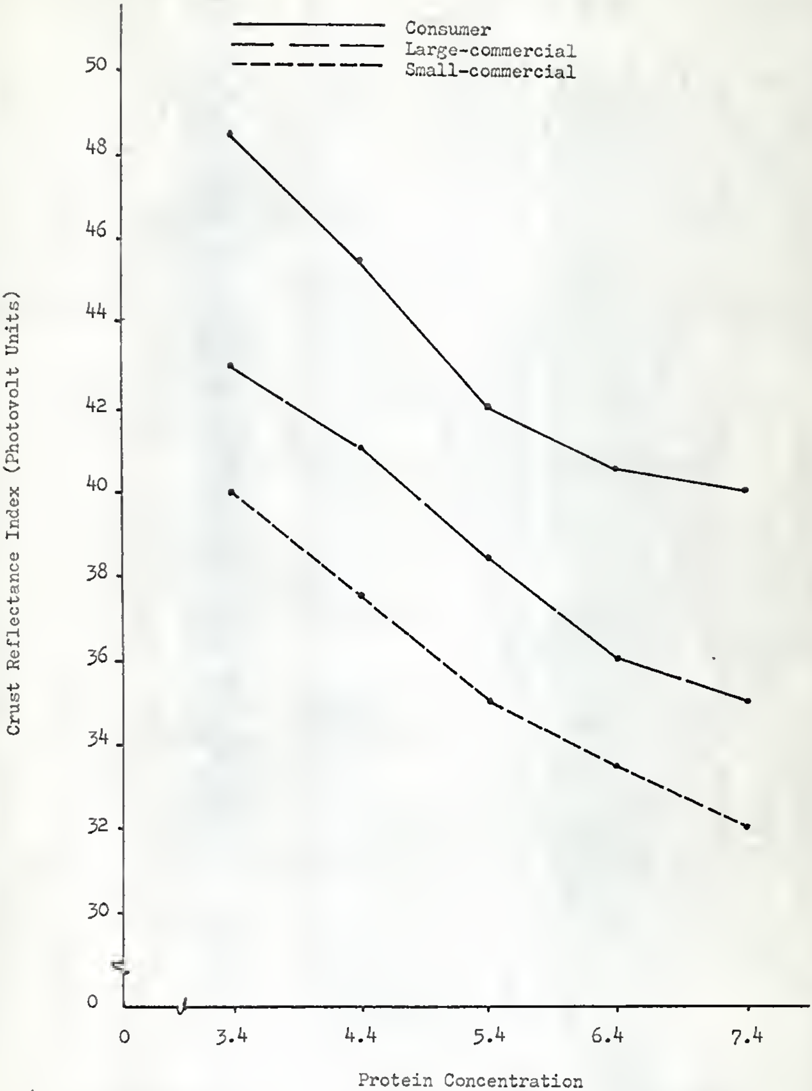


Fig. 9 The effect of dilution of flour protein with wheat starch on the crust reflectance index.

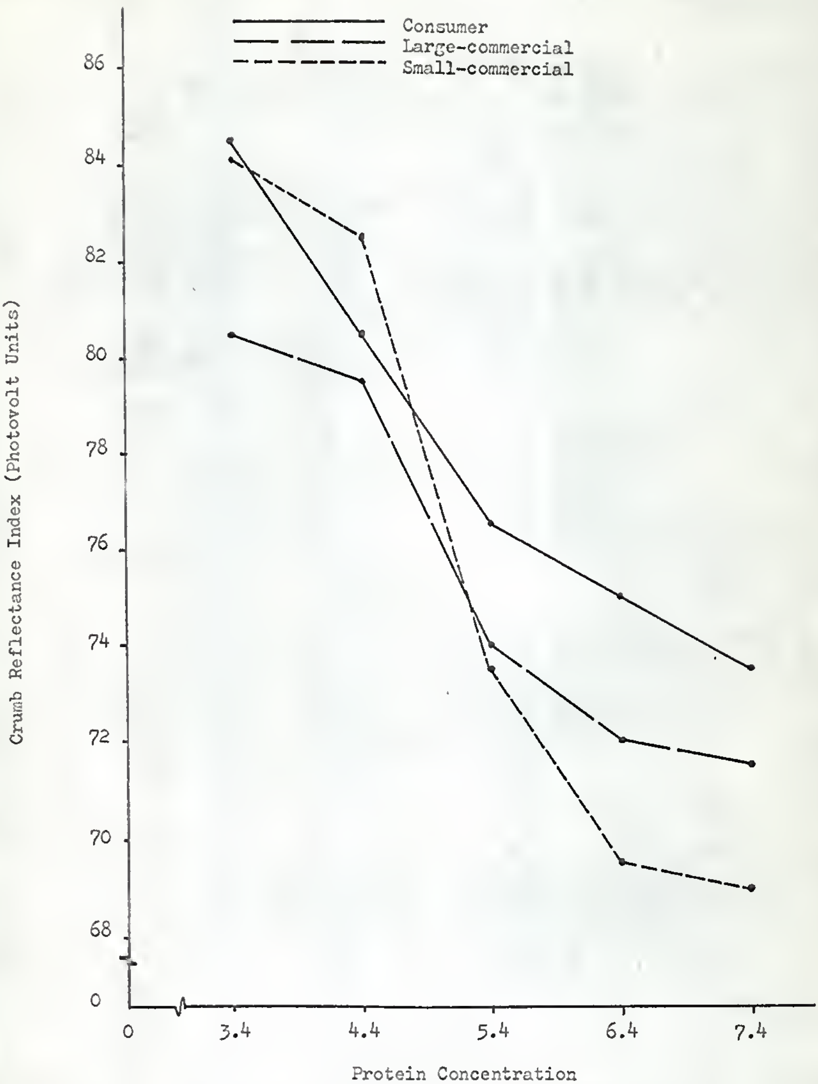


Fig. 10 The effect of dilution of flour protein with wheat starch on the crumb reflectance index.

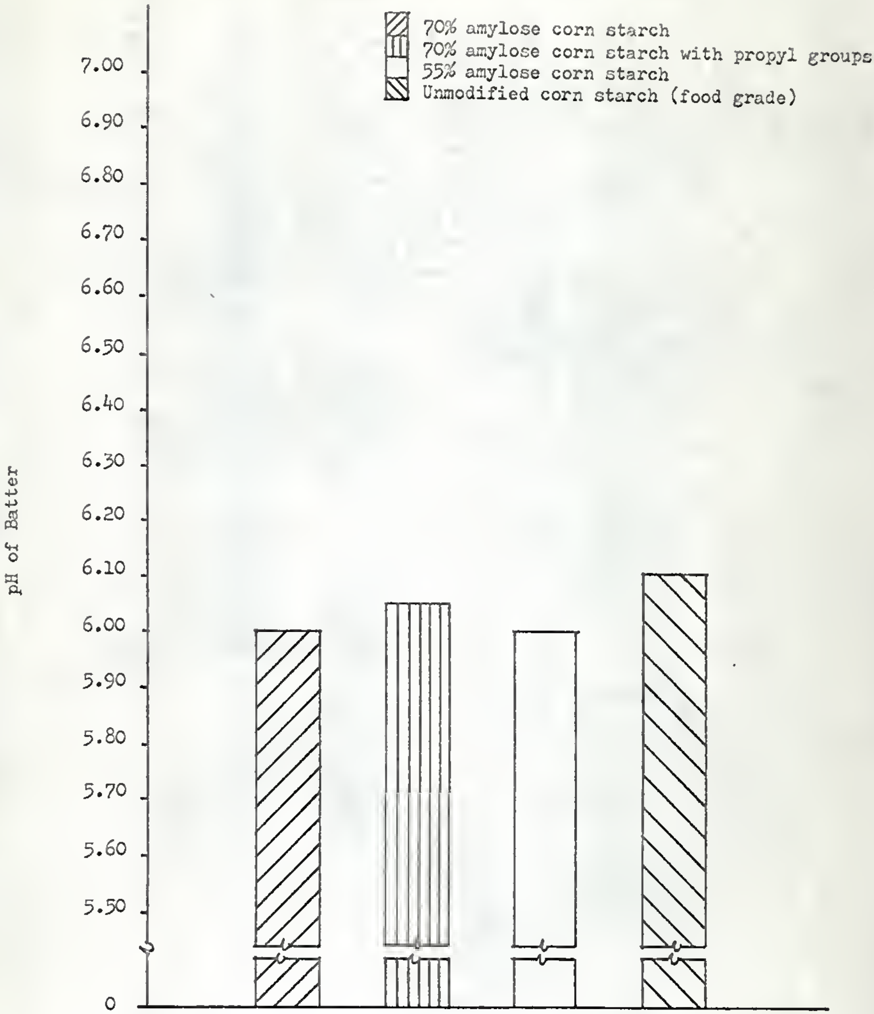


Fig. 11 The effect of dilution of flour protein with corn starches on the pH of the batter.

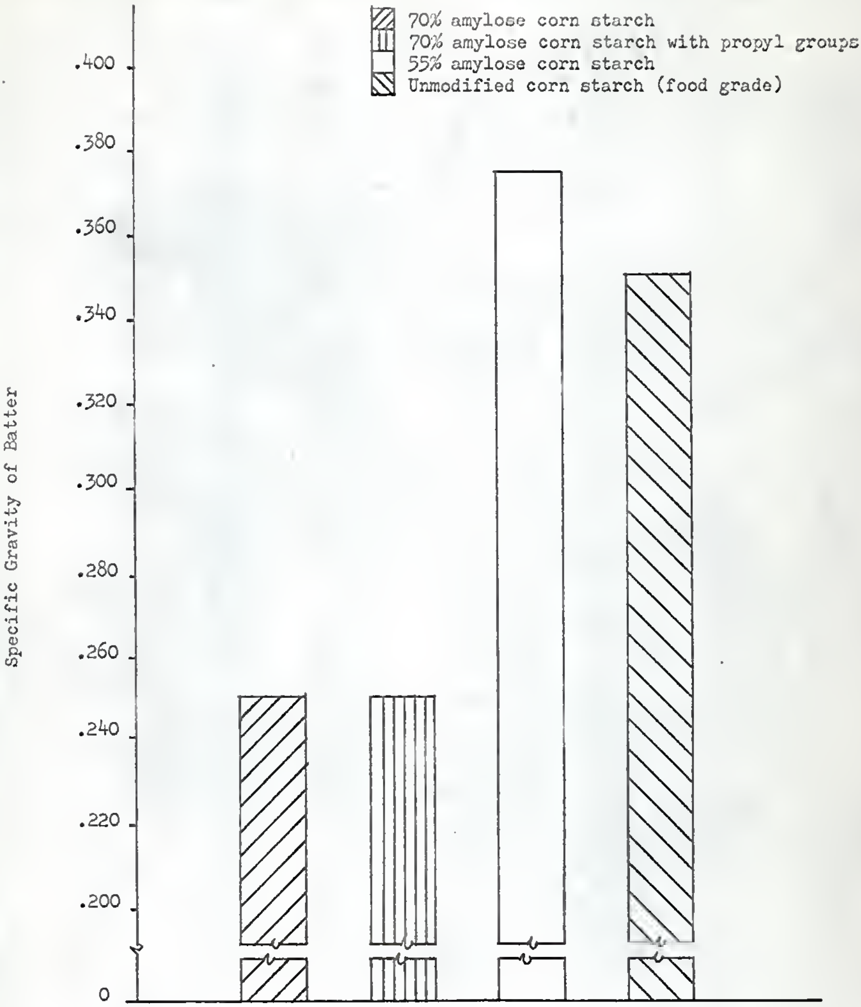


Fig. 12 The effect of dilution of flour protein with corn starches on the specific gravity of the batter.

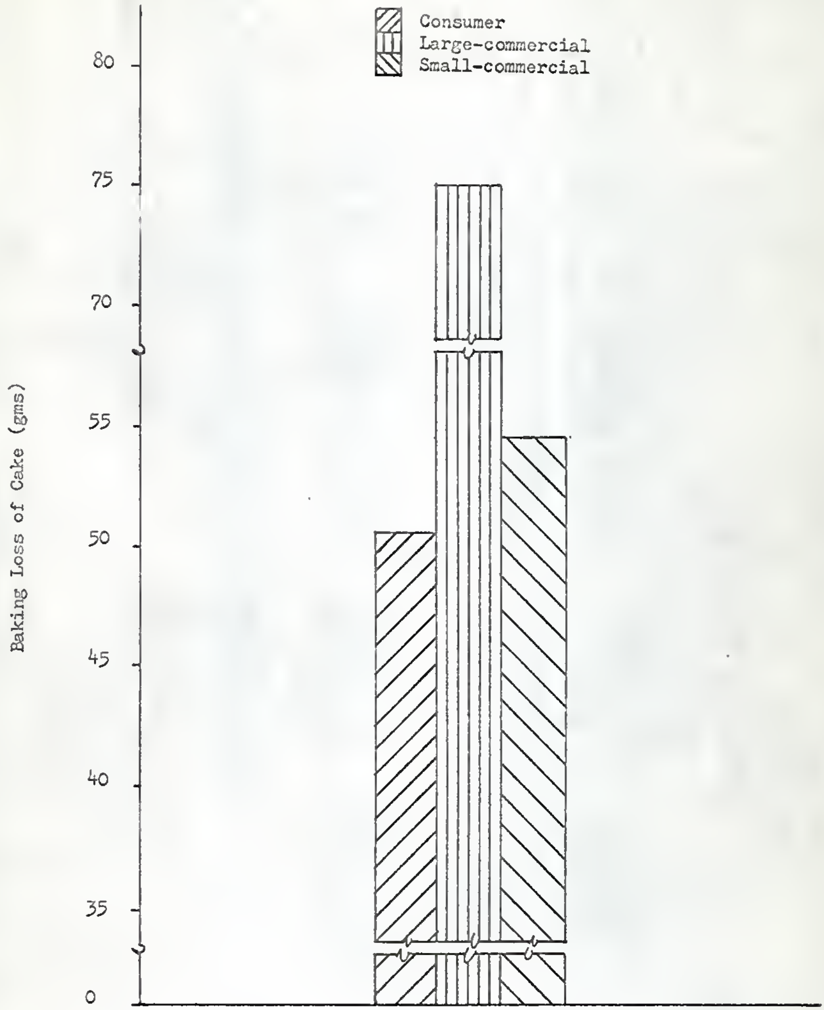


Fig. 13 The effect of dilution of flour protein with 70% amylose corn starch on the baking loss of the cake.

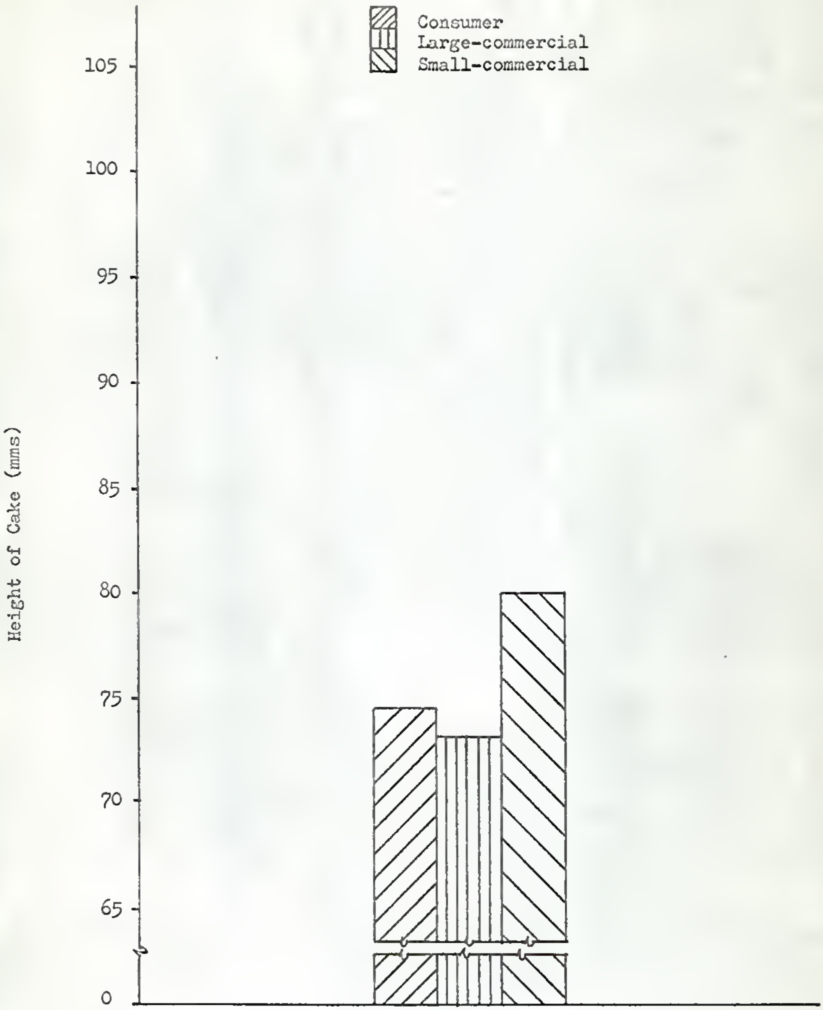


Fig. 14 The effect of dilution of flour protein with 70% amylose corn starch on the height of the cake.

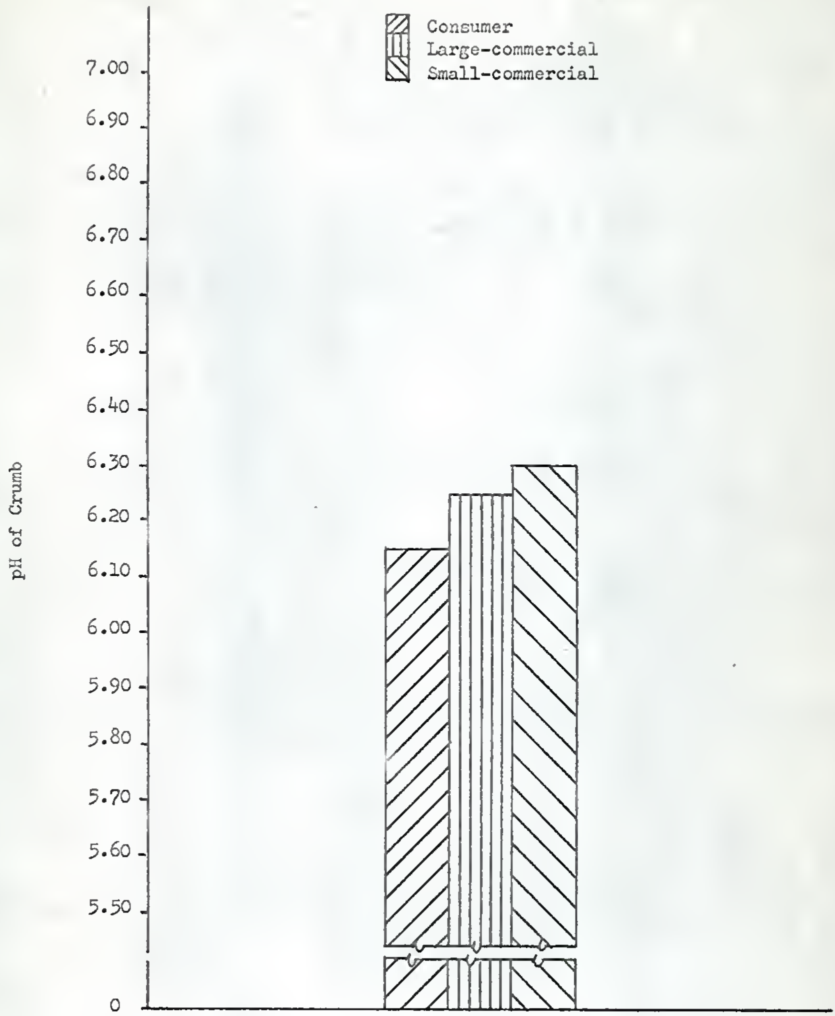


Fig. 15 The effect of dilution of flour protein with 70% amylose corn starch on the crumb pH.

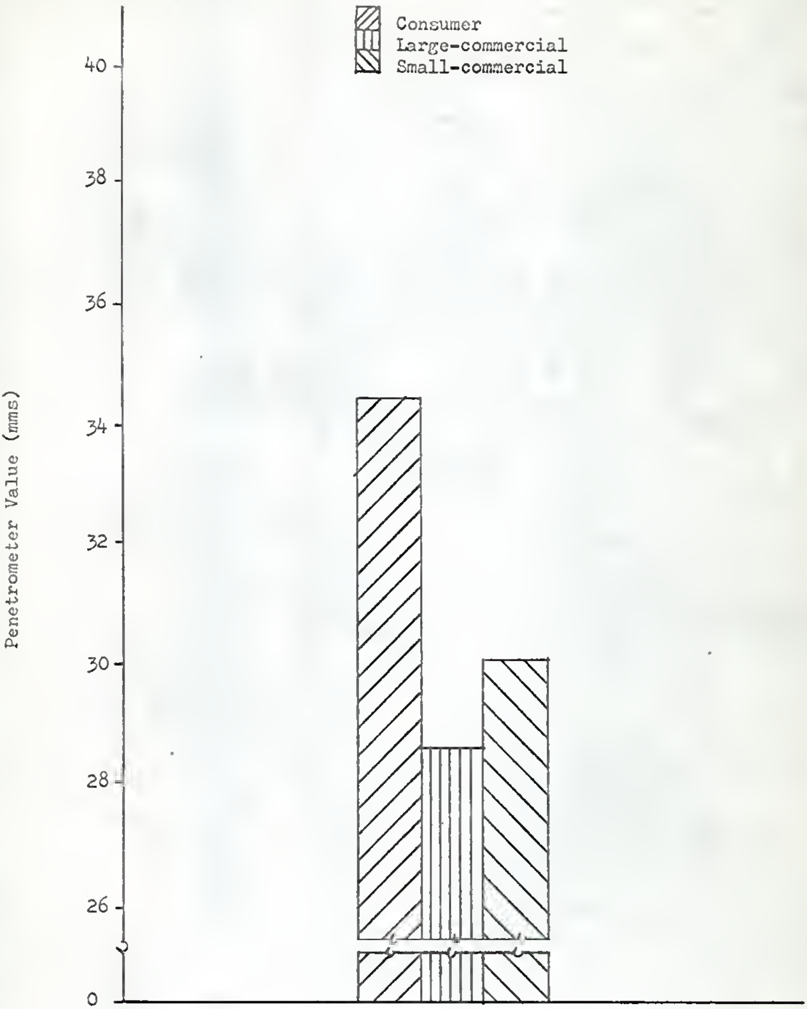


Fig. 16 The effect of dilution of flour protein with 70% amylose corn starch on the penetrometer value.

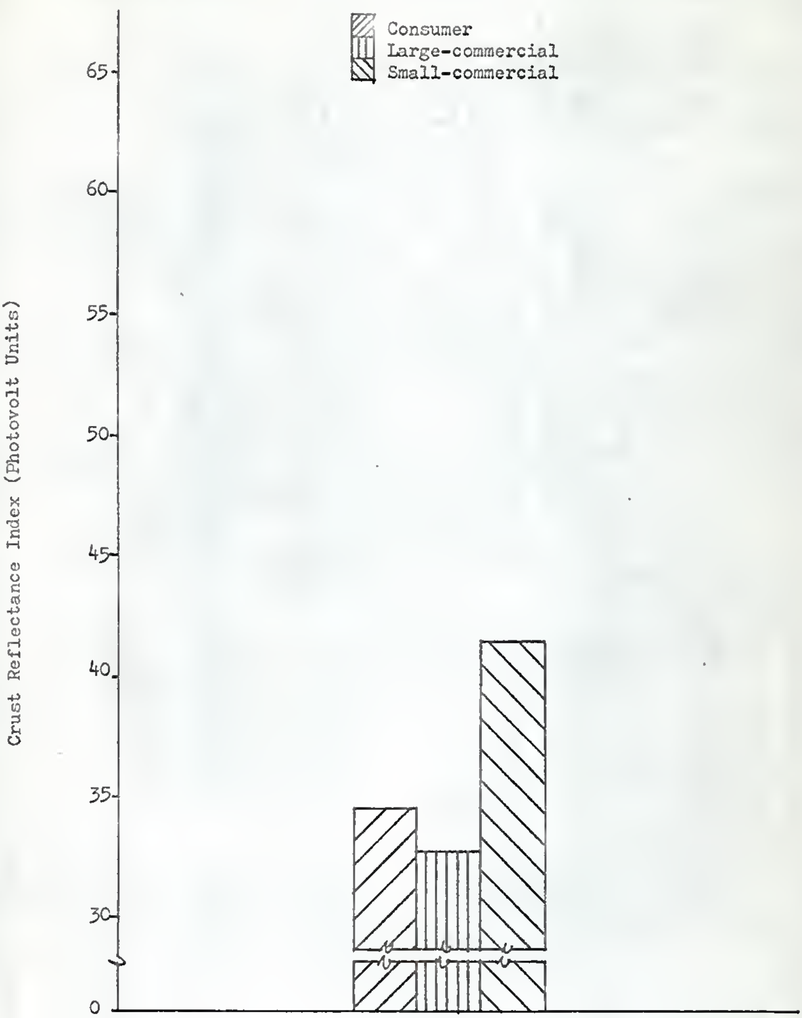


Fig. 17 The effect of dilution of flour protein with 70% amylose corn starch on the crust reflectance index.

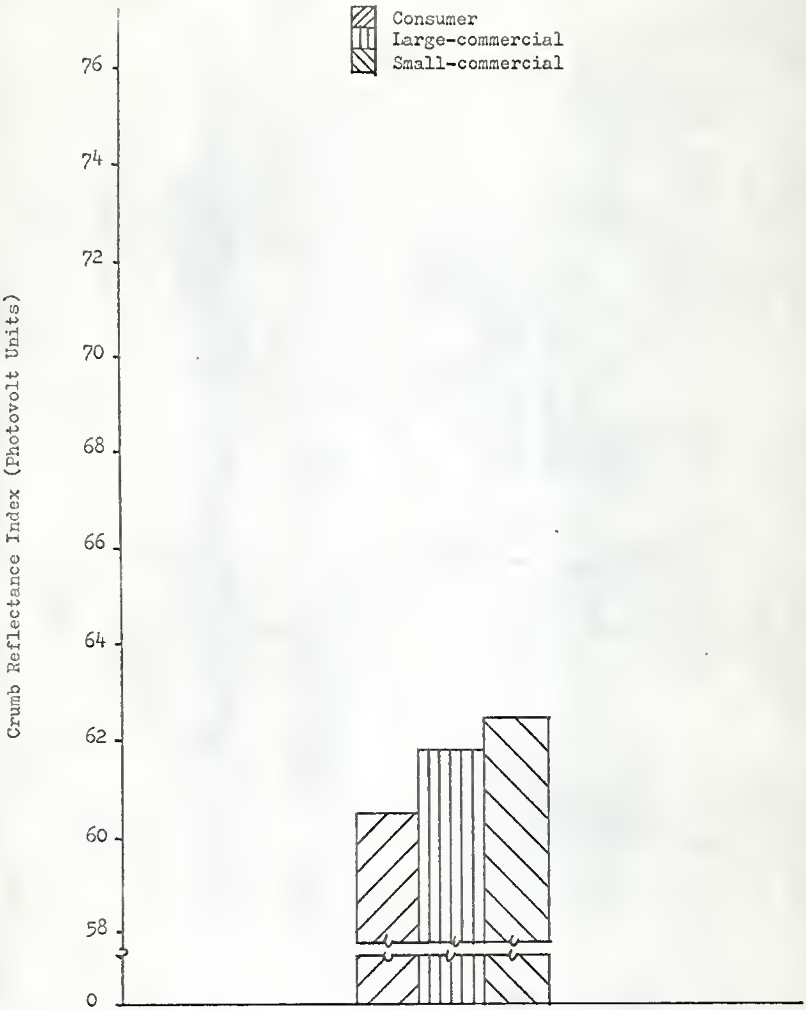


Fig. 18 The effect of dilution of flour protein with 70% amylose corn starch on the crumb reflectance index.

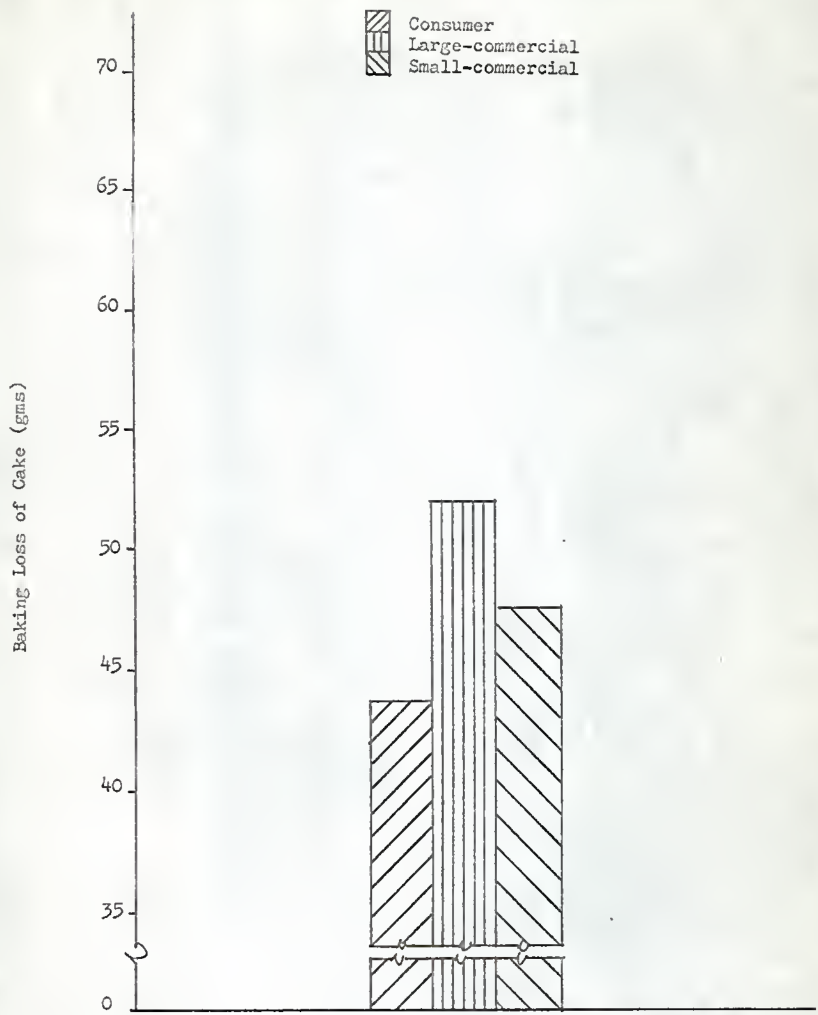


Fig. 19 The effect of dilution of flour protein with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups on the baking loss of the cake.

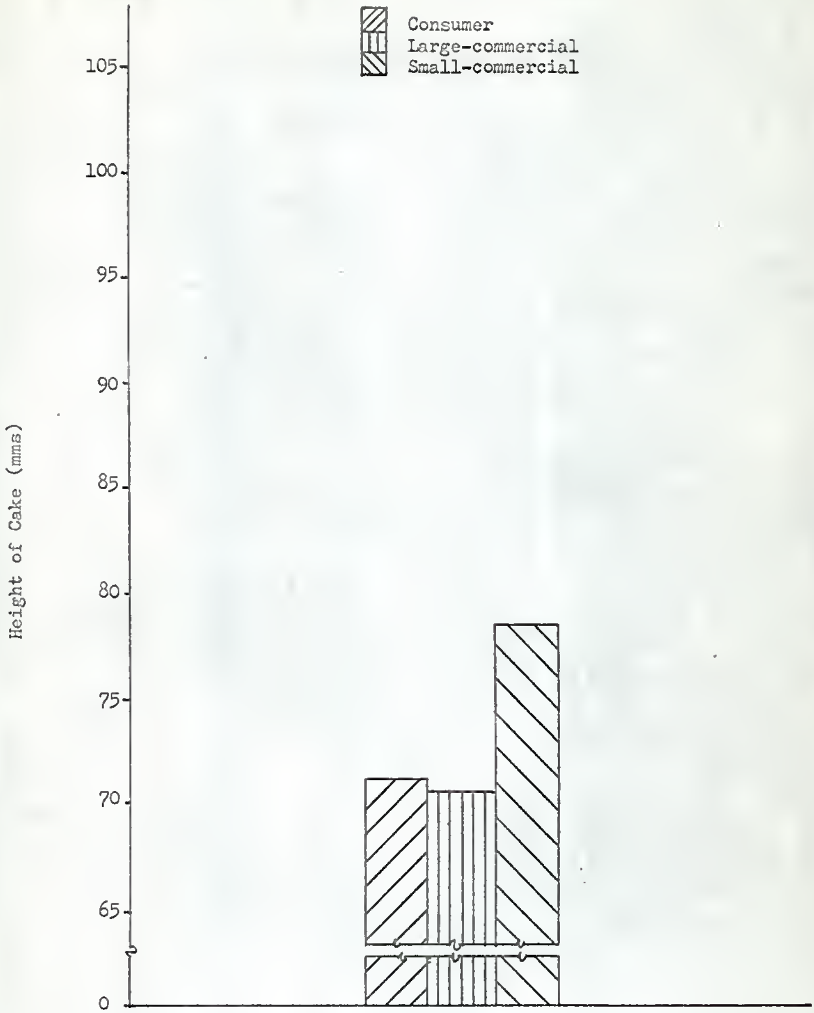


Fig. 20 The effect of dilution of flour protein with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups on the height of the cake.

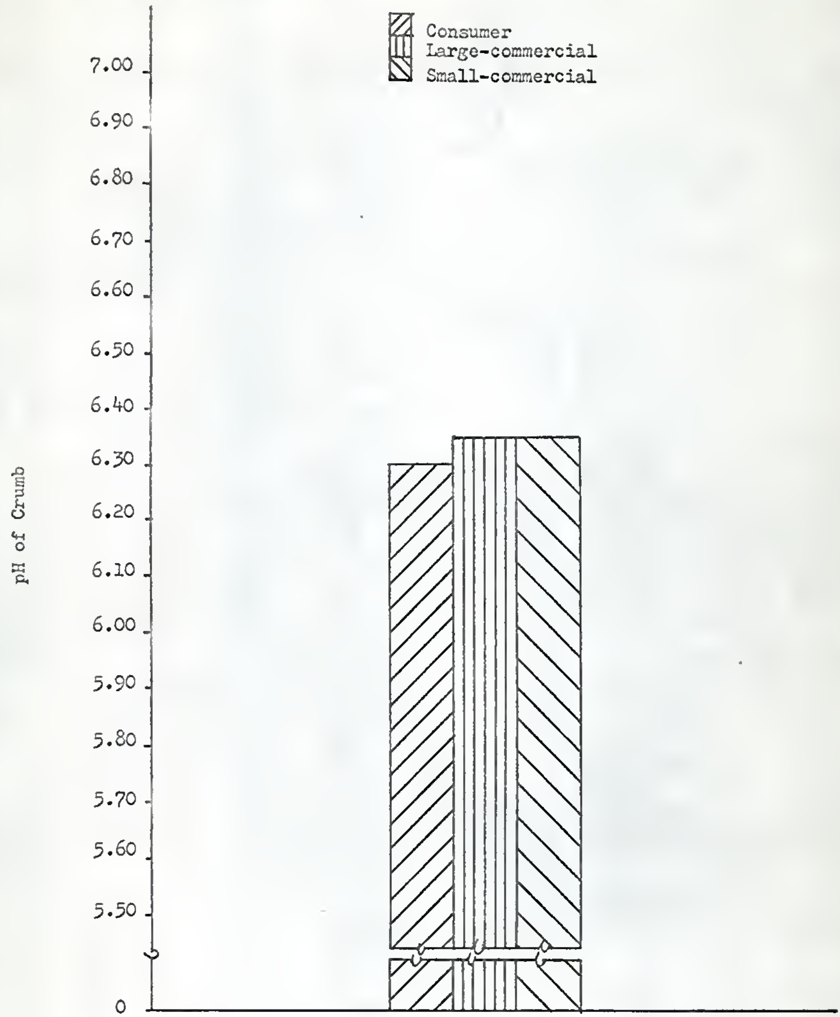


Fig. 21 The effect of dilution of flour protein with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups on the crumb pH.

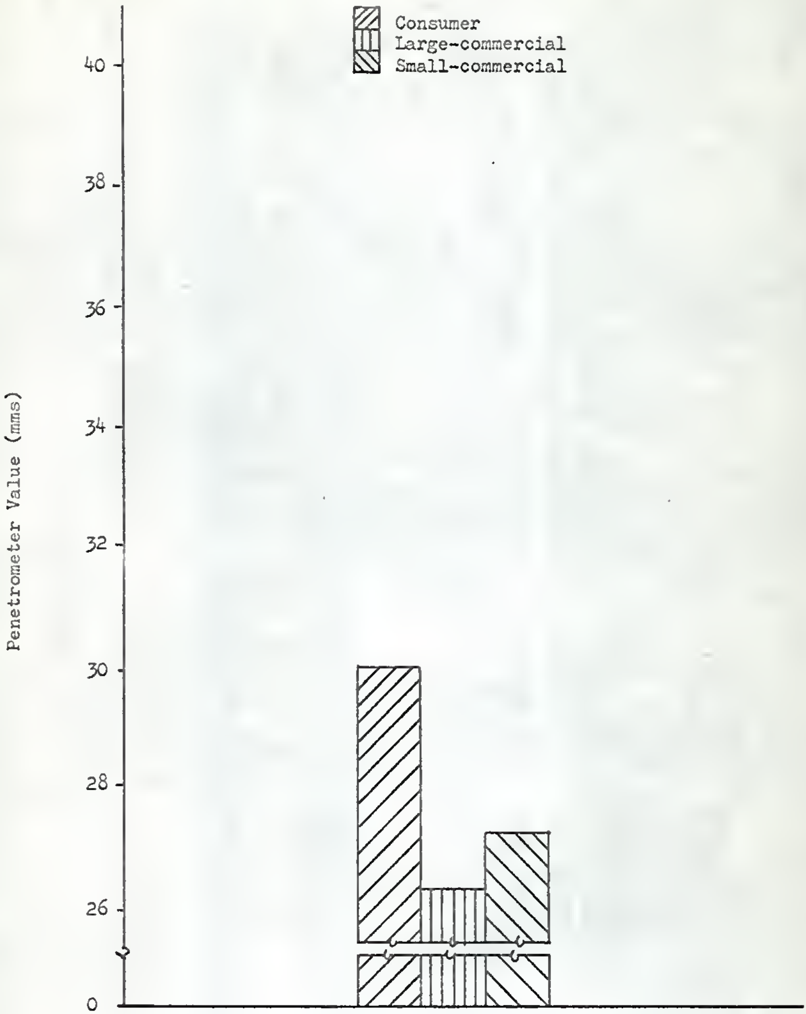


Fig. 22 The effect of dilution of flour protein with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups on the penetrometer value.

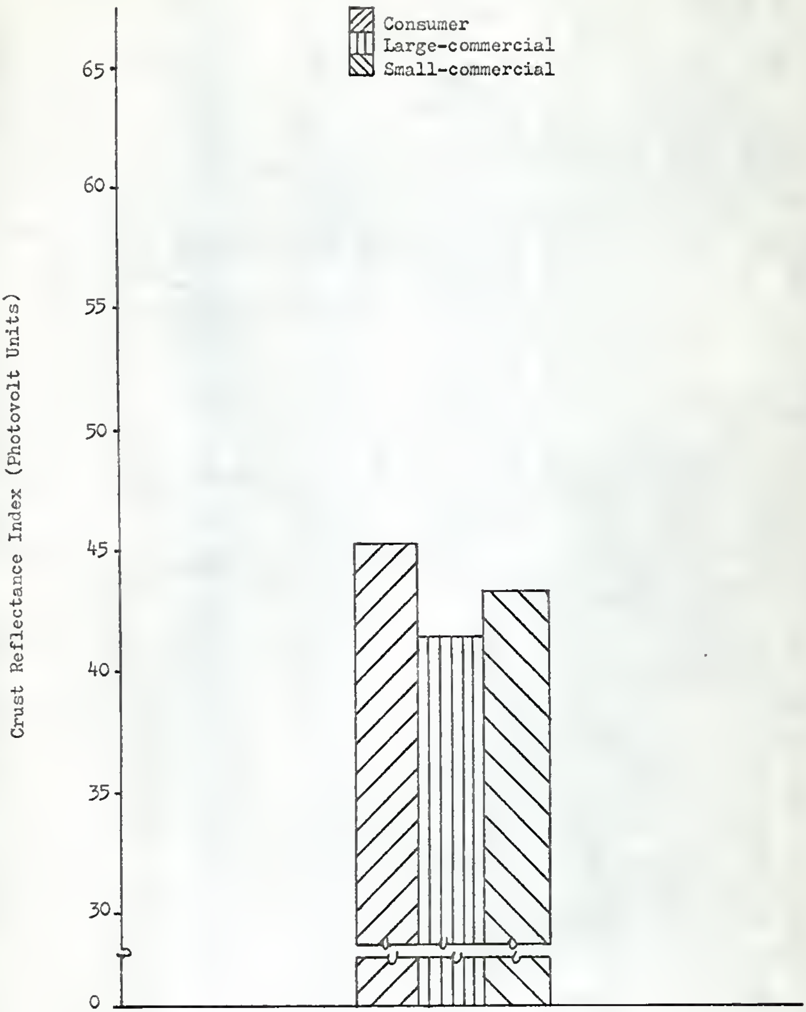


Fig. 23 The effect of dilution of flour protein with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups on the crust reflectance index.

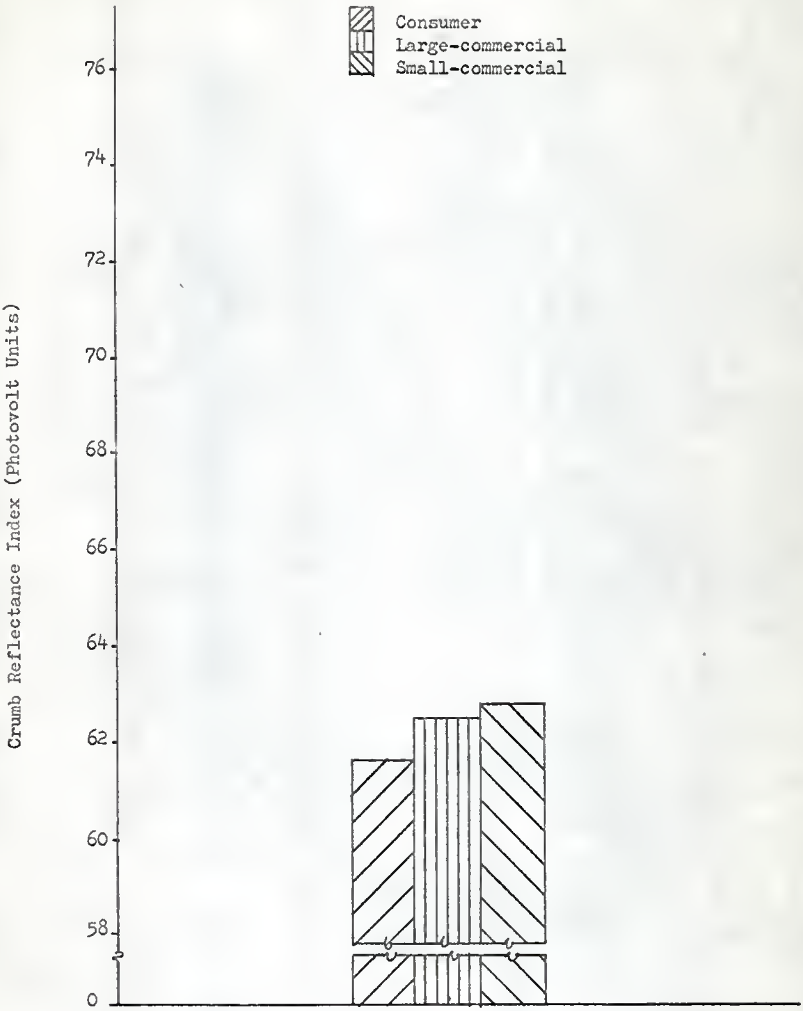


Fig. 24 The effect of dilution of flour protein with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups on the crumb reflectance index.

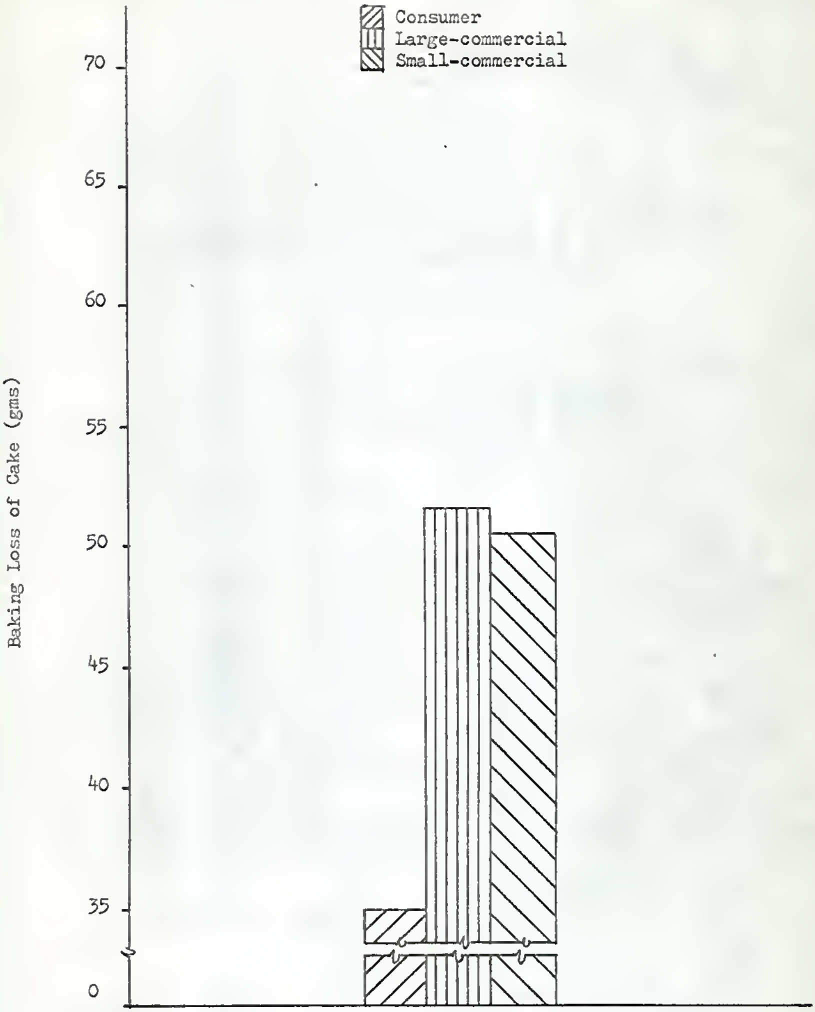


Fig. .25 The effect of dilution of flour protein with 55% amylose corn starch on the baking loss of the cake.

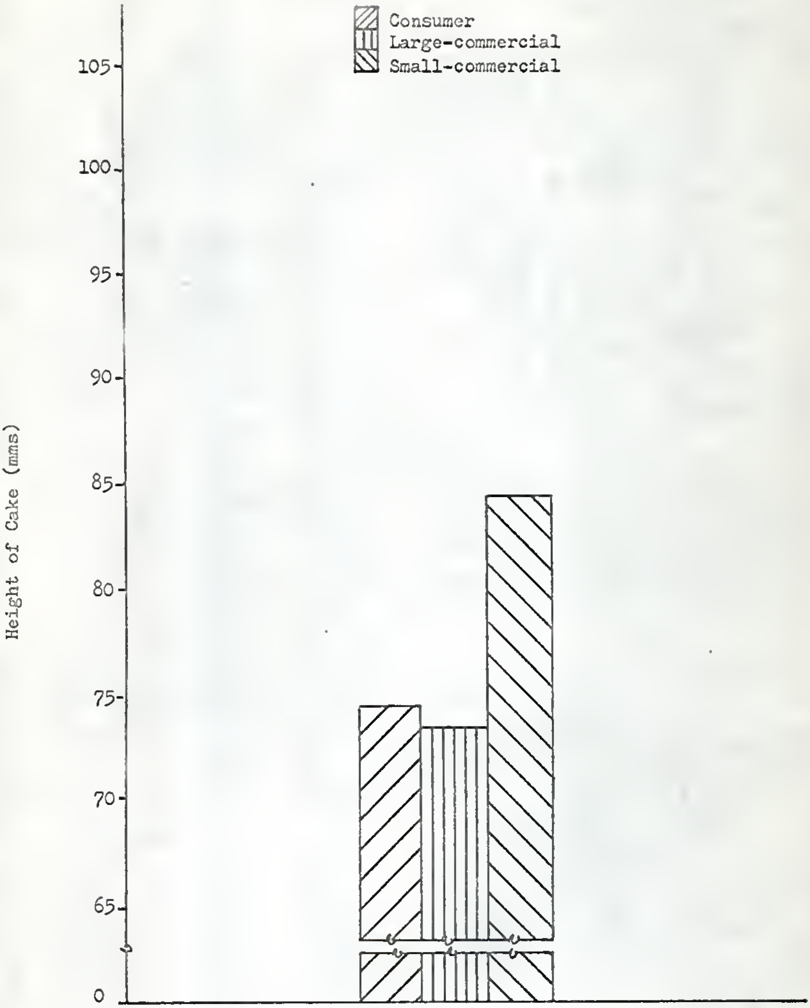


Fig. 26 The effect of dilution of flour protein with 55% amylose corn starch on the height of the cake.

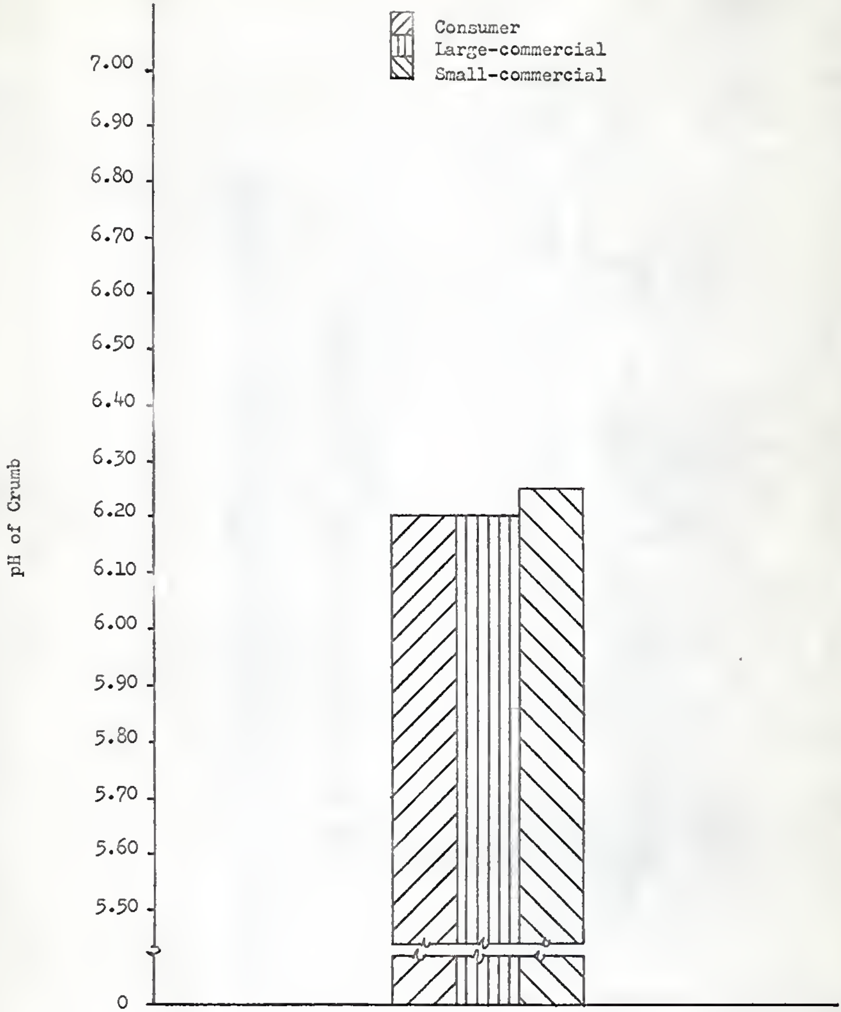


Fig. 27 The effect of dilution of flour protein with 55% amylose corn starch on the crumb pH.

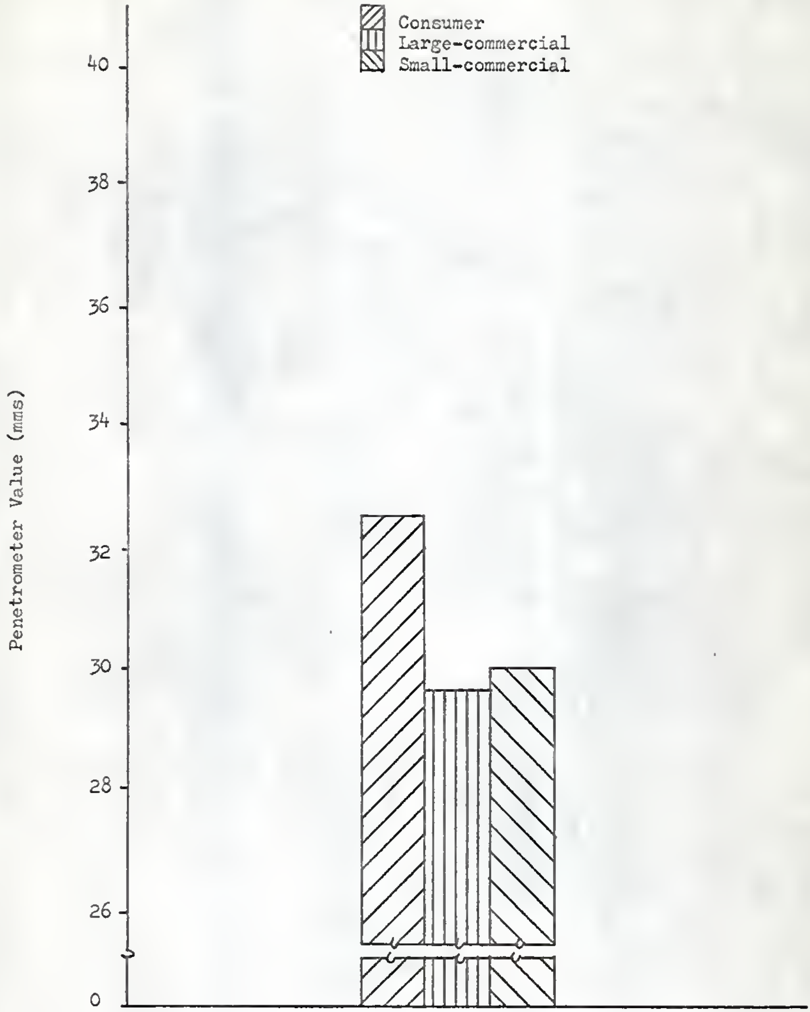


Fig. 28 The effect of dilution of flour protein with 55% amylose corn starch on the penetrometer value.

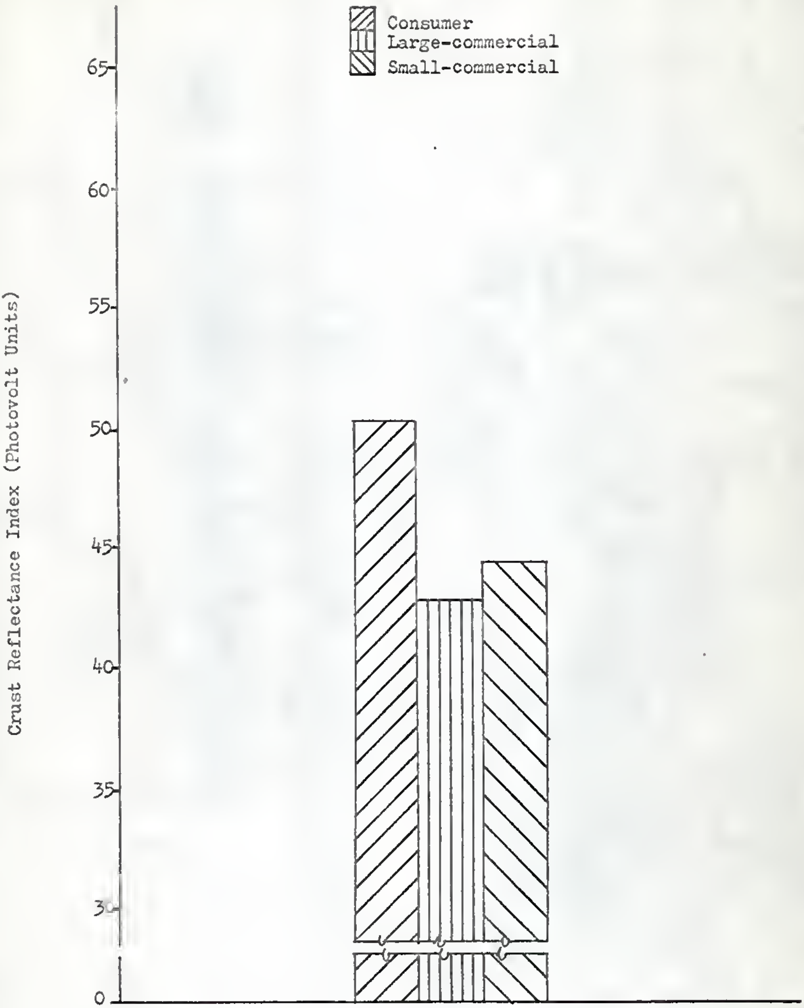


Fig. 29 The effect of dilution of flour protein with 55% amylose corn starch on the crust reflectance index.

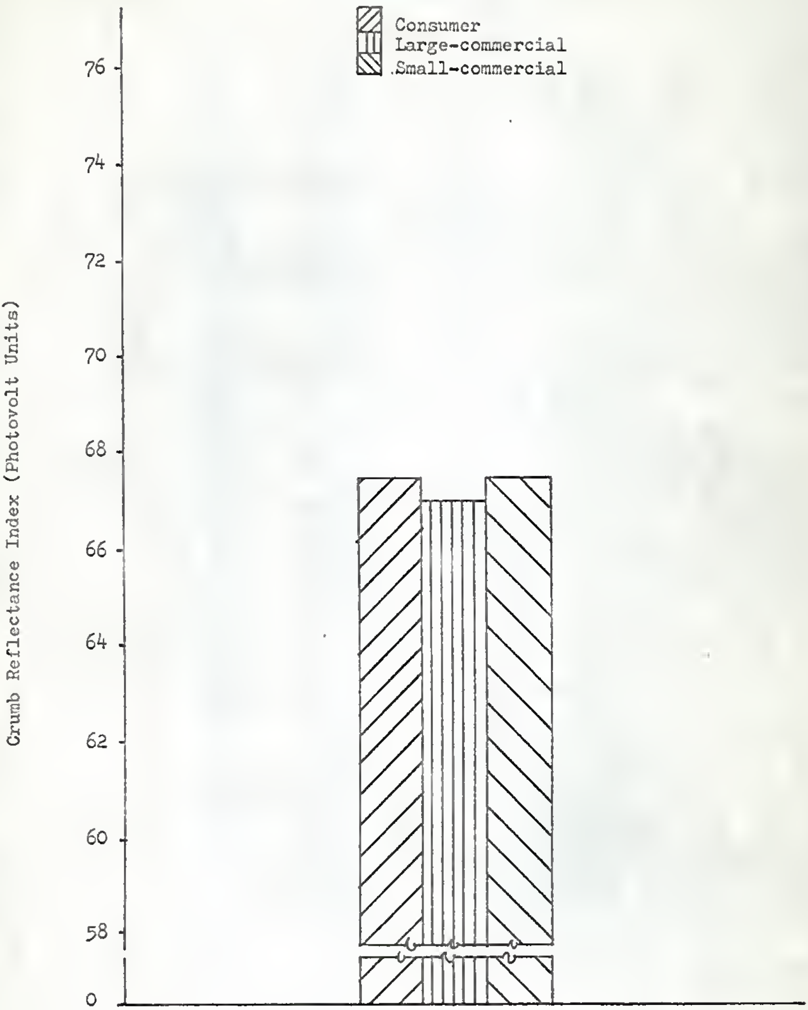


Fig. 30 The effect of dilution of flour protein with 55% amylose corn starch on the crumb reflectance index.

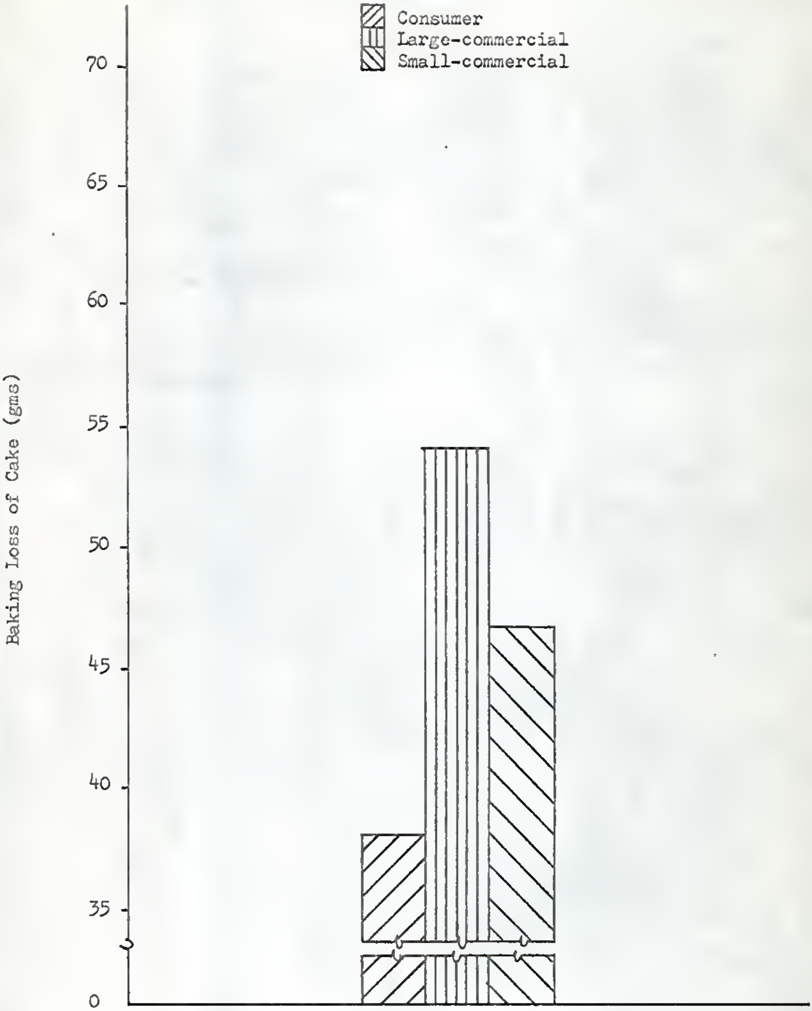


Fig. 31 The effect of dilution of flour protein with corn starch on the baking loss of the cake.

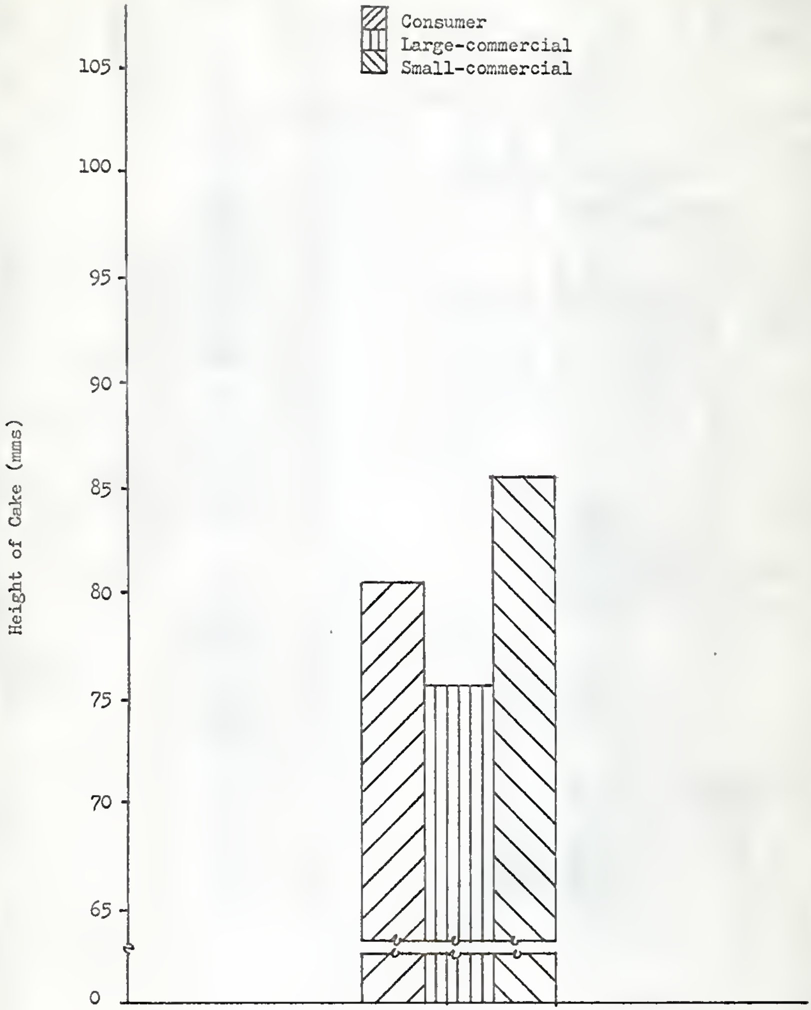


Fig. 32 The effect of dilution of flour protein with corn starch on the height of the cake.

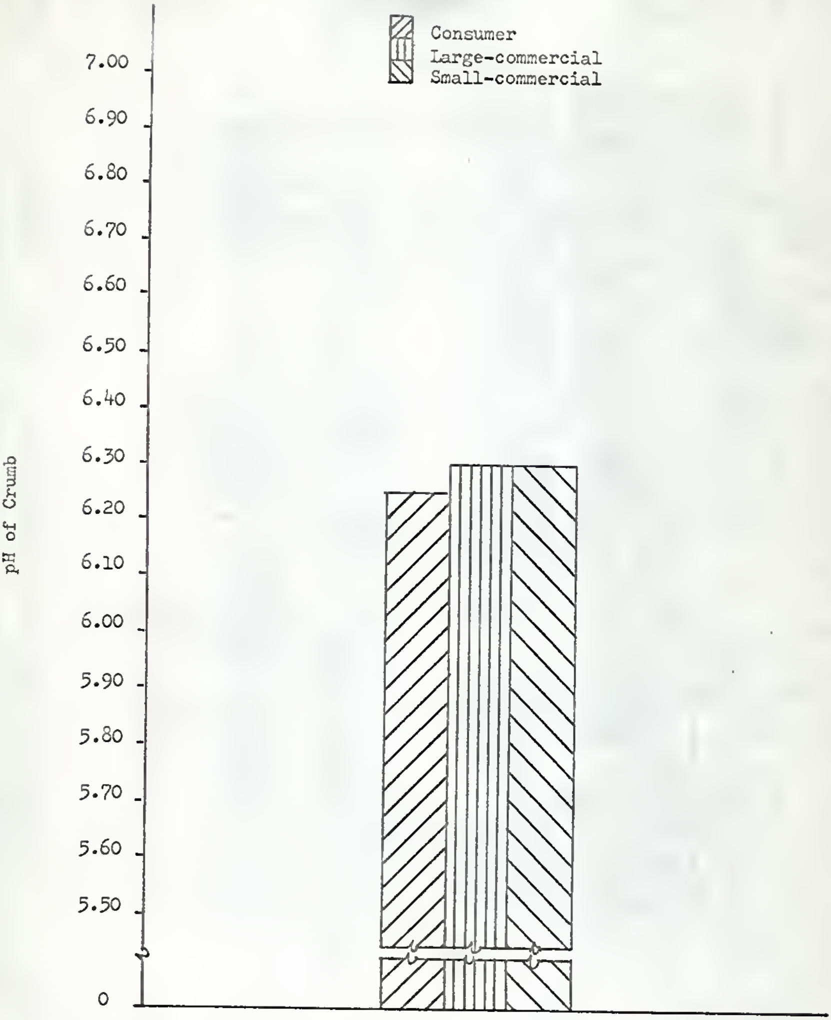


Fig. 33 The effect of dilution of flour protein with corn starch on the crumb pH.

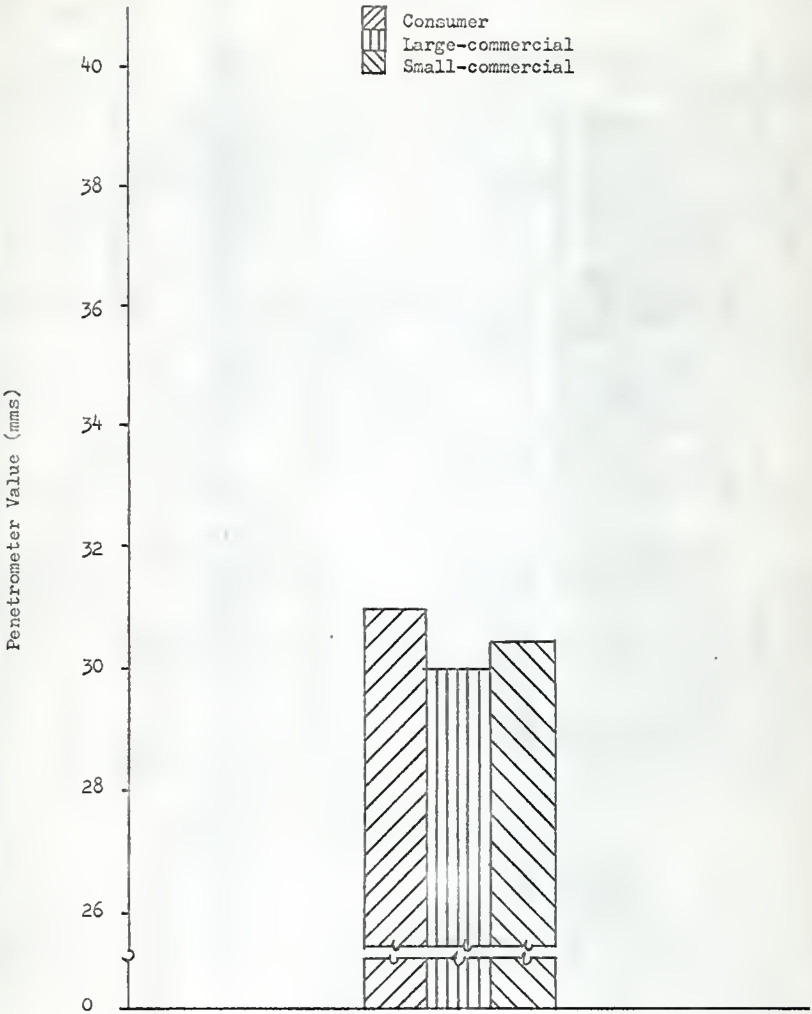


Fig. 34 The effect of dilution of flour protein with corn starch on the penetrometer value.

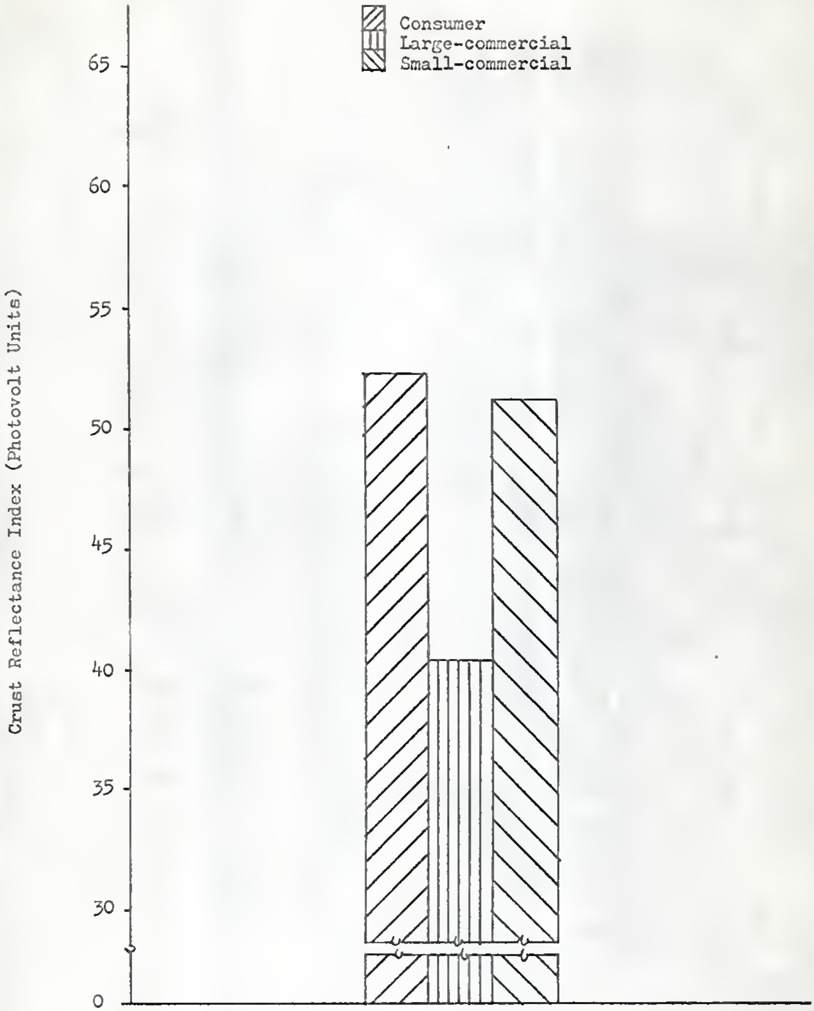


Fig. 35 The effect of dilution of flour protein with corn starch on the crust reflectance index.

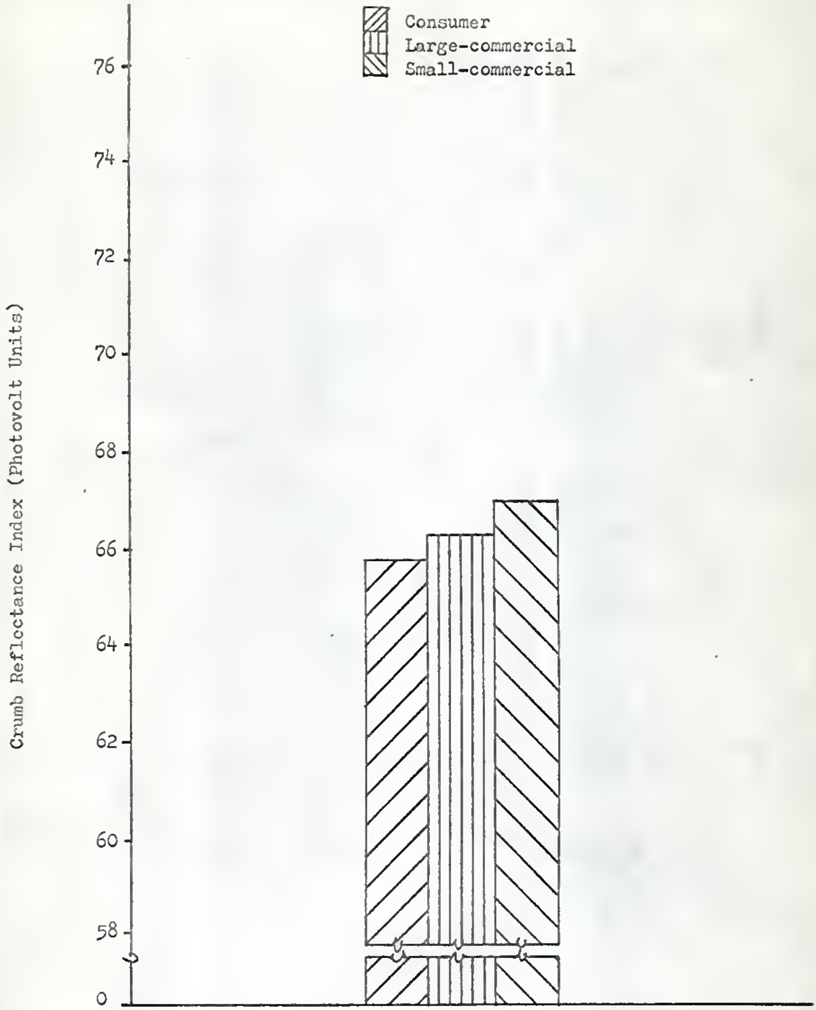


Fig. 36 The effect of dilution of flour protein with corn starch on the crumb reflectance index.

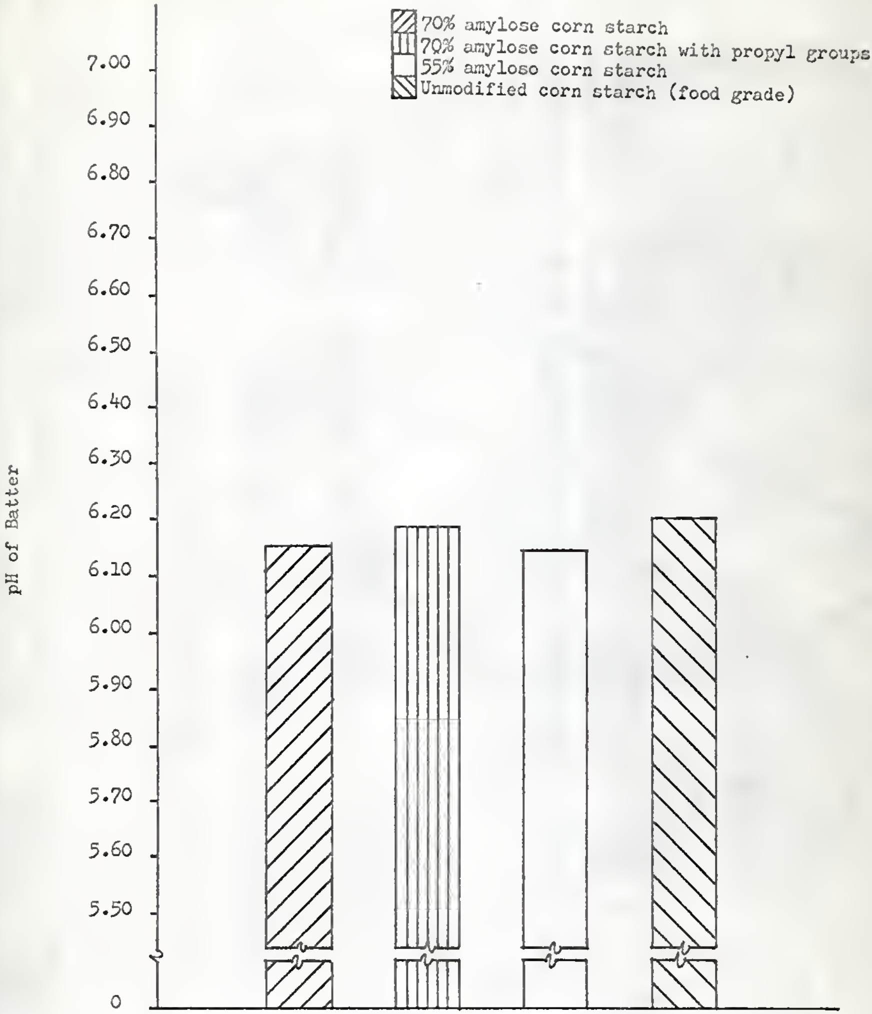


Fig. 37 The effect of dilution of flour protein to 6.4% with corn starches, plus the normal amount of wheat starch in the formula, on the pH of the batter.

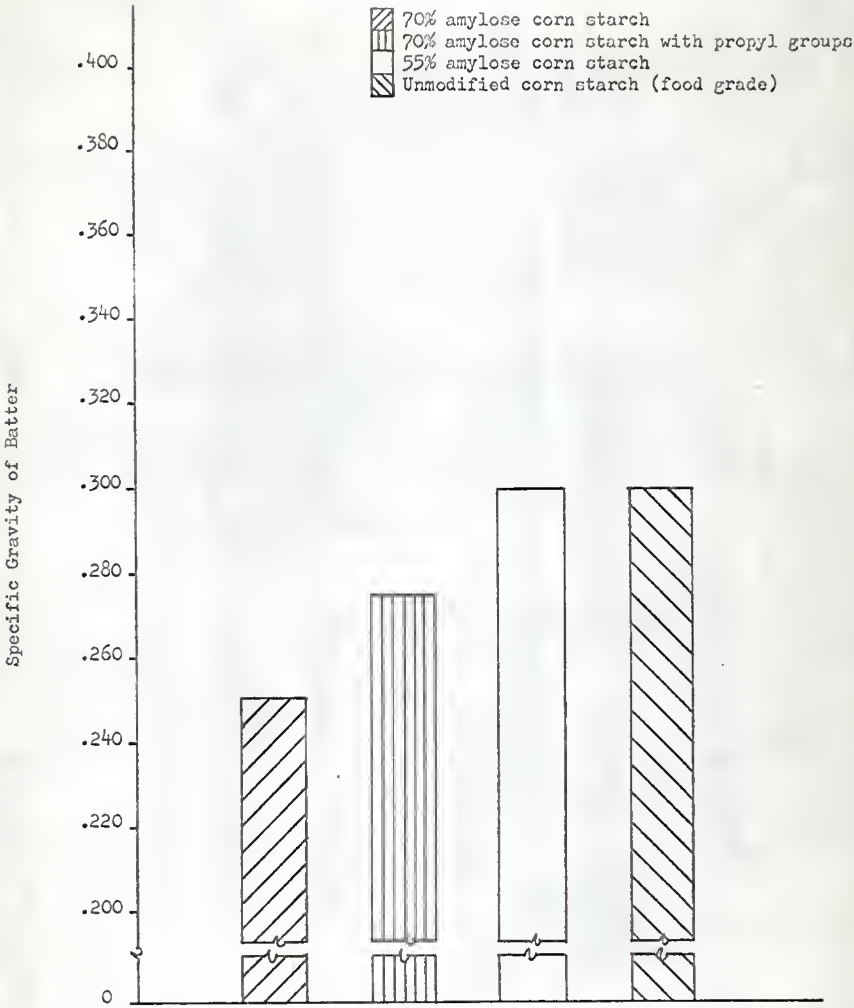


Fig. 38 The effect of dilution of flour protein to 6.4% with corn starches, plus normal amount of wheat starch in formula on the specific gravity of the batter.

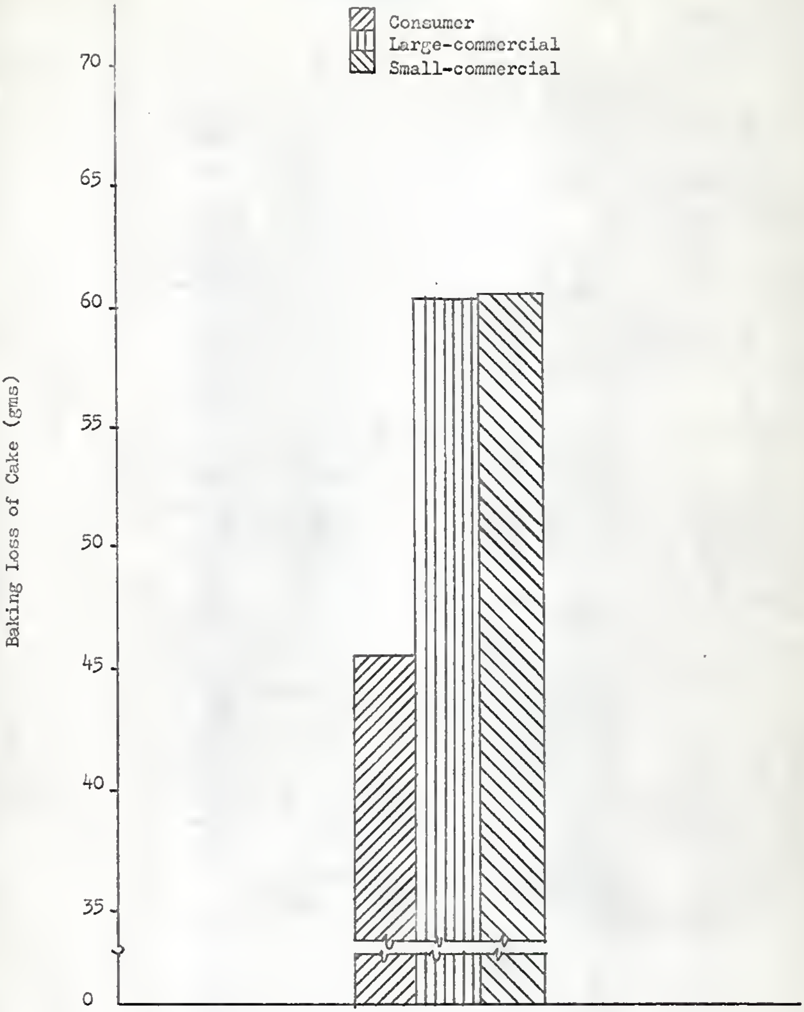


Fig. 39 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch, plus normal amount of wheat starch in formula, on the baking loss of the cake.

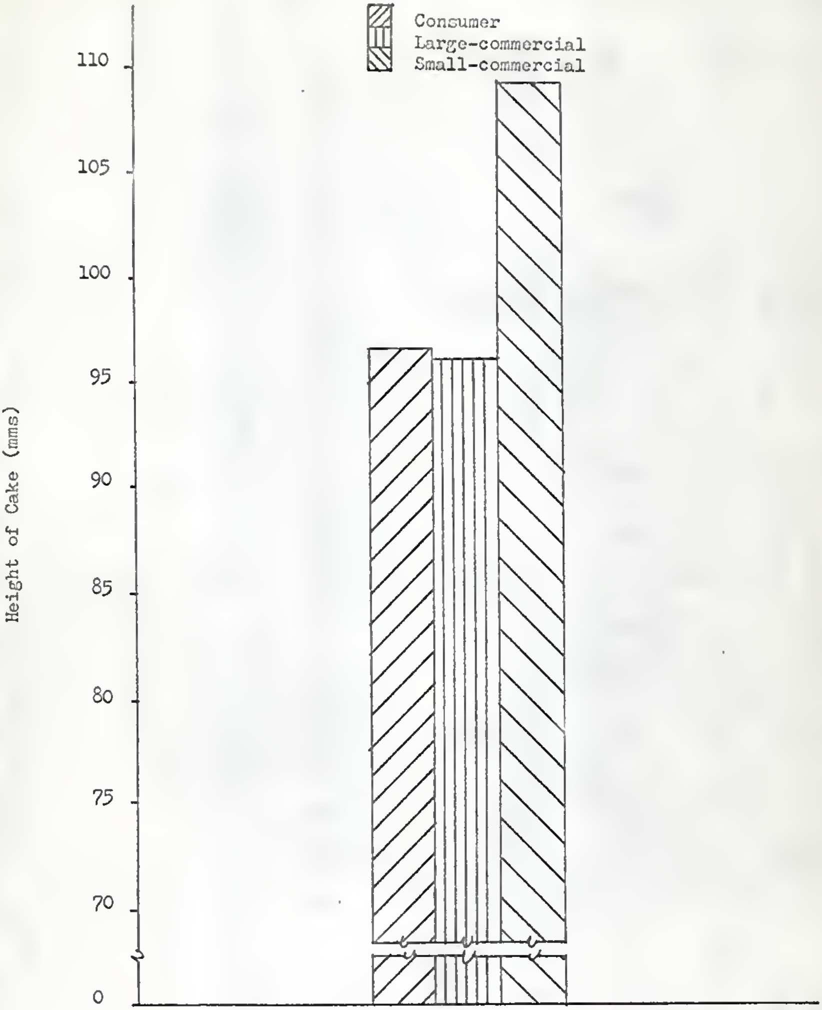


Fig. 40 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch, plus the normal amount of wheat starch in formula, on the height of the cake.

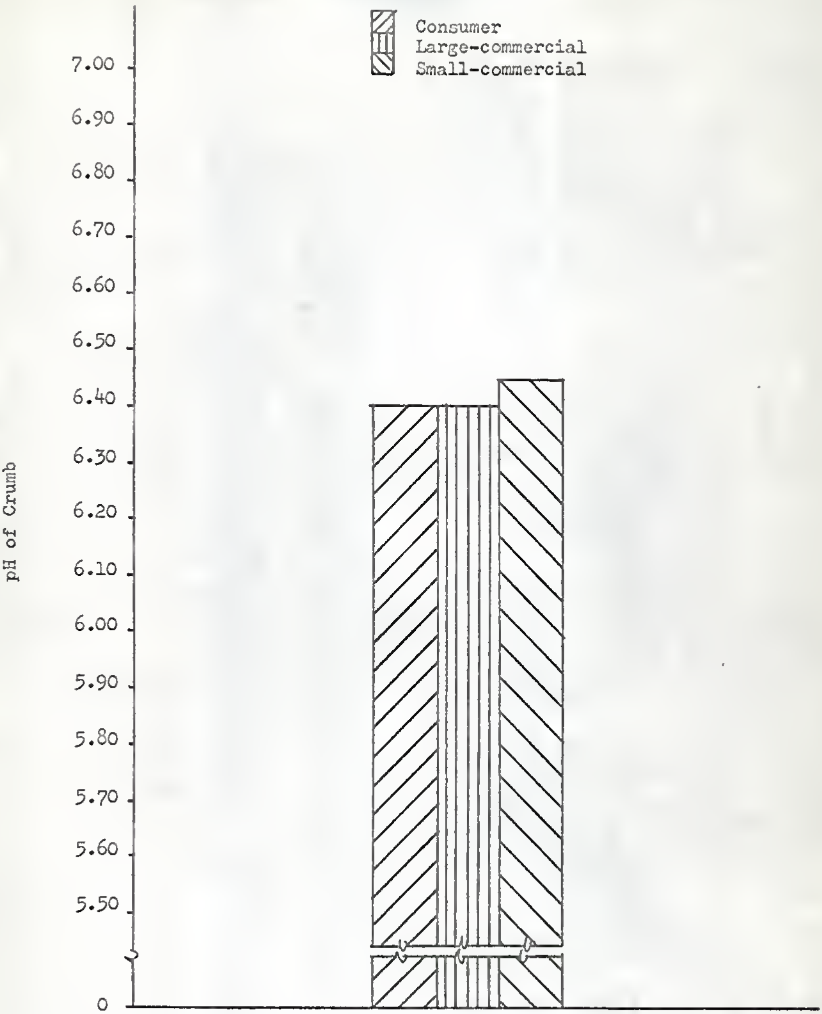


Fig. 41 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch, plus normal amount of wheat starch in formula, on the crumb pH.

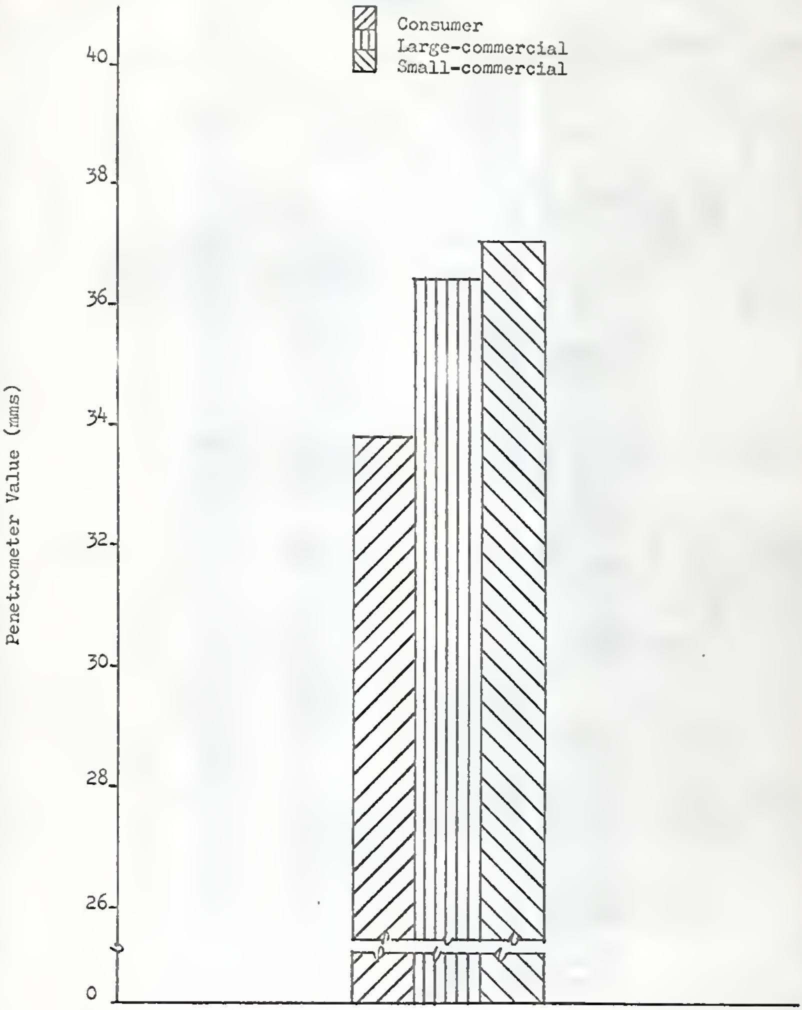


Fig. 42 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch, plus normal amount of wheat starch in formula, on the penetrometer value.

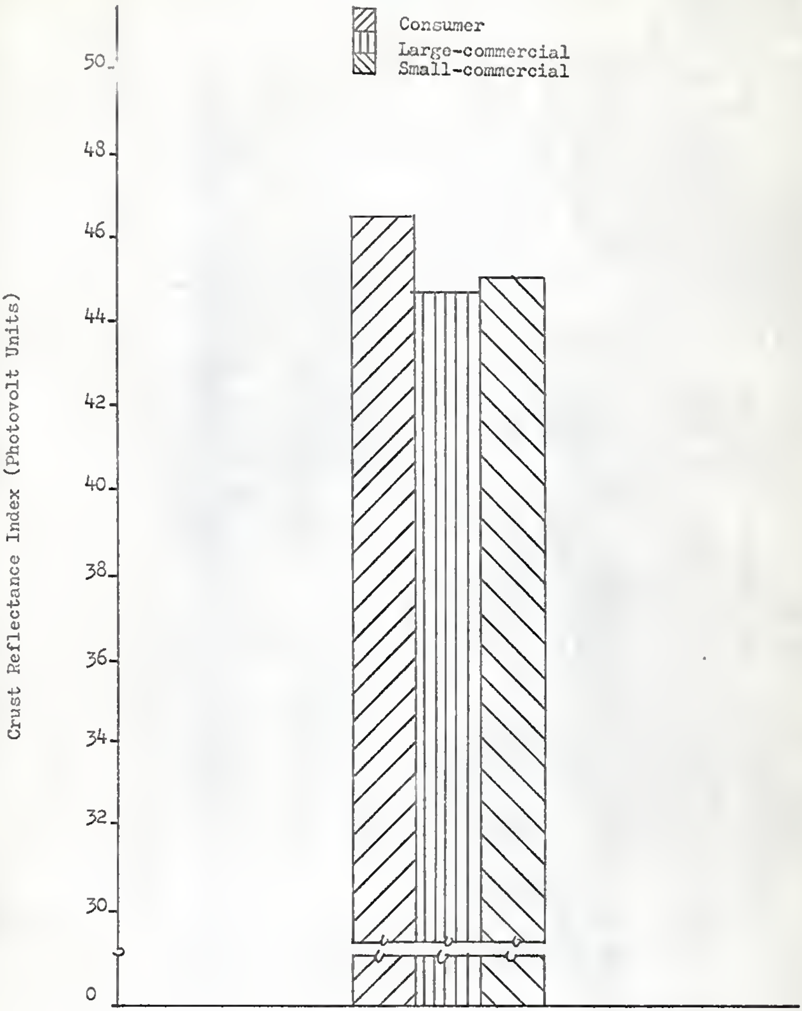


Fig. 43 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch plus normal amount of wheat starch in formula, on the crust reflectance index.

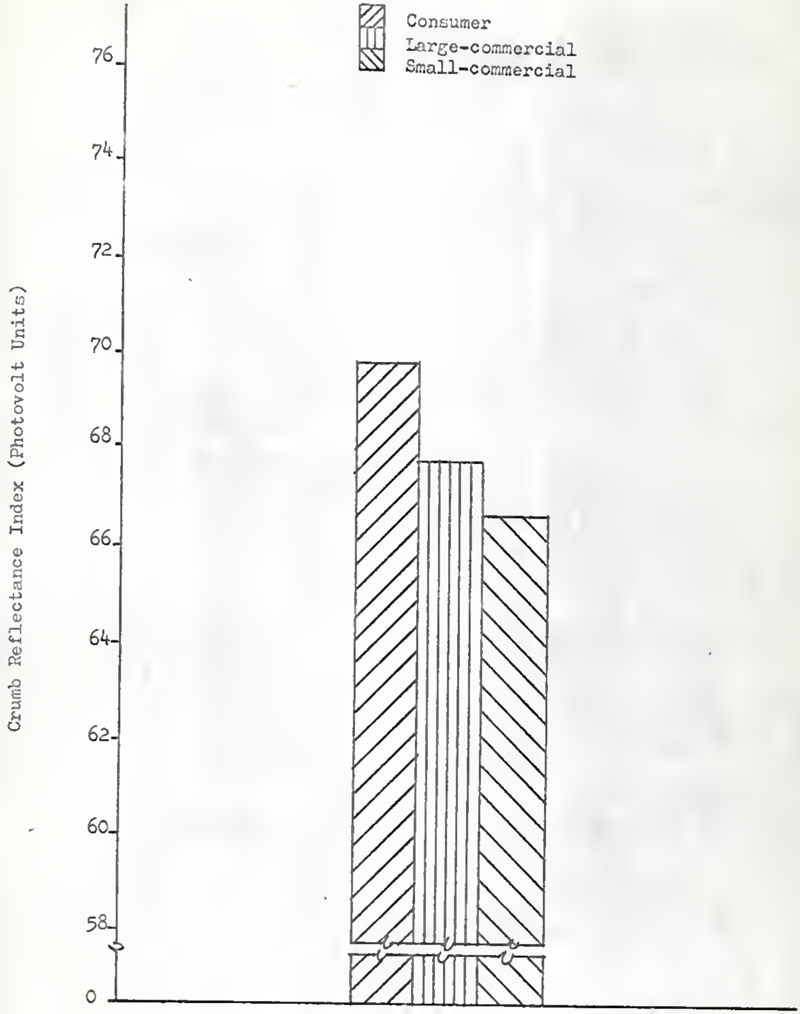


Fig. 44 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch, plus normal amount of wheat starch in formula, on the crumb reflectance index.

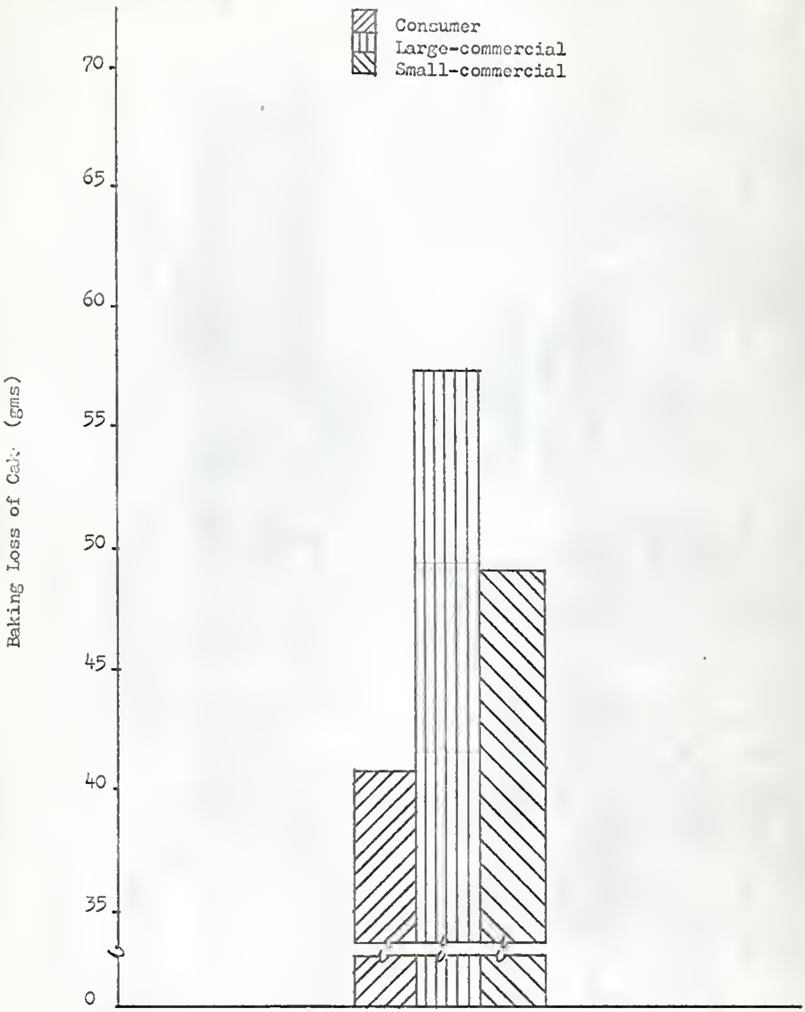


Fig. 45 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups, plus normal amount of wheat starch in formula, on the baking loss of the cake.

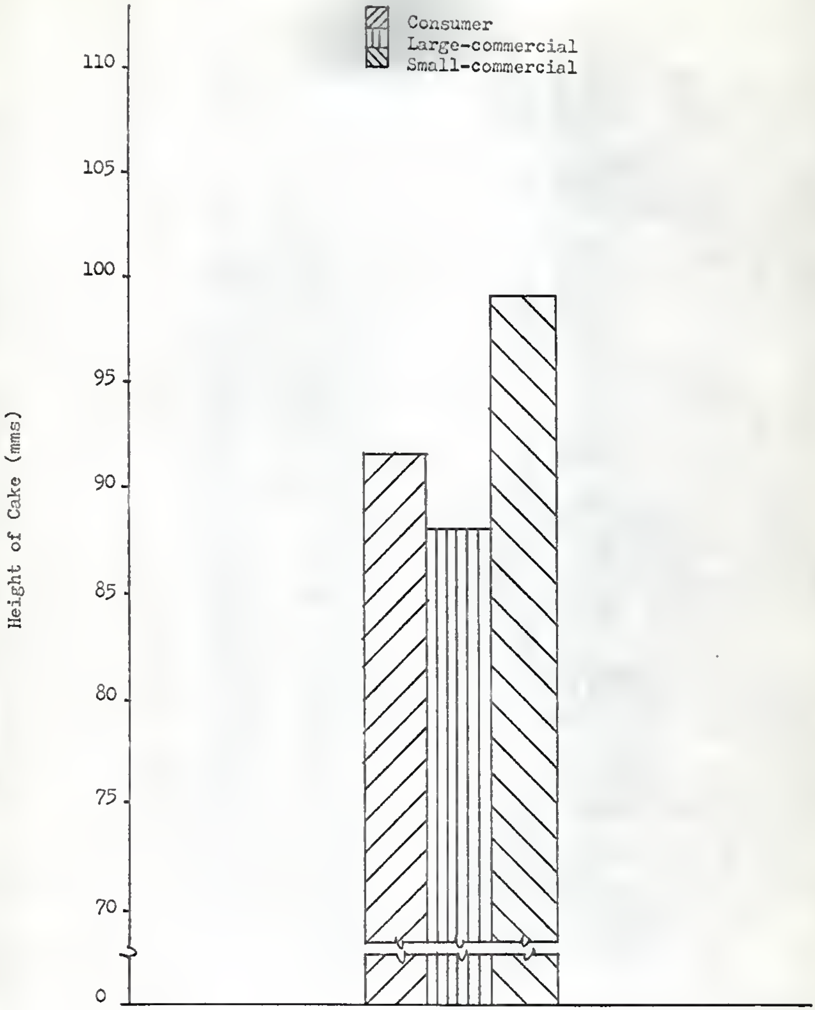


Fig. 46 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups, plus normal amount of wheat starch in formula, on the height of the cake.

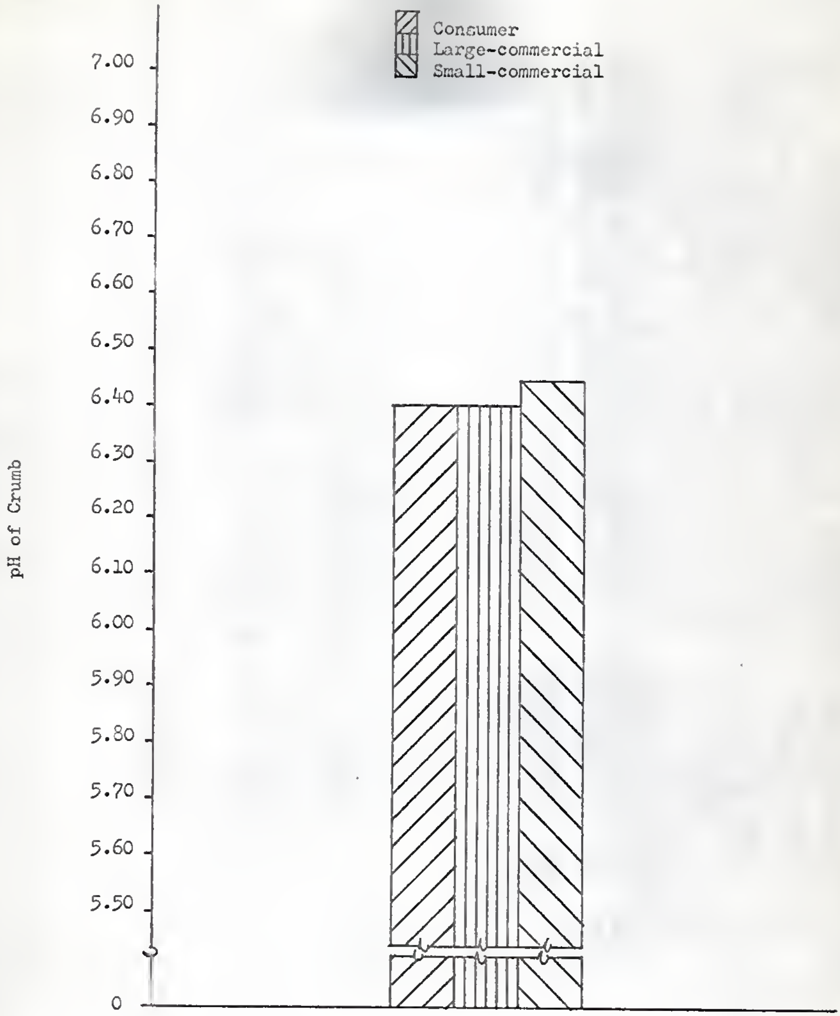


Fig. 47 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups, plus normal amount of wheat starch in formula, on the crumb pH.

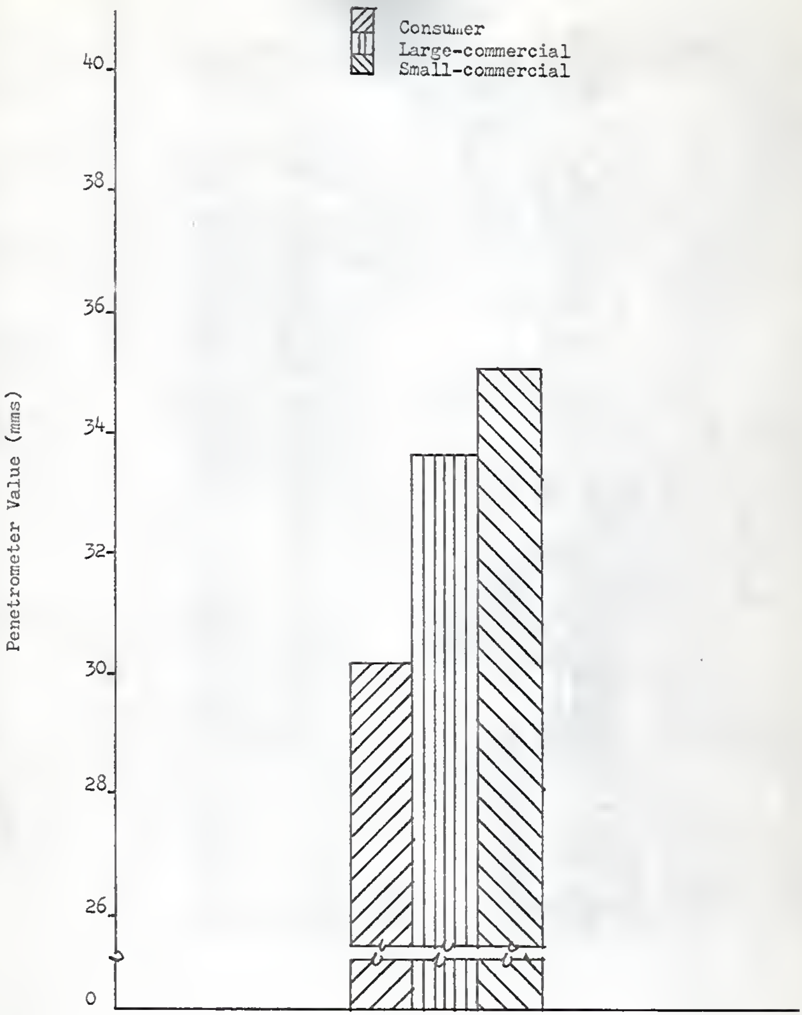


Fig. 48 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups, plus normal amount of wheat starch in formula, on the penetrometer value.

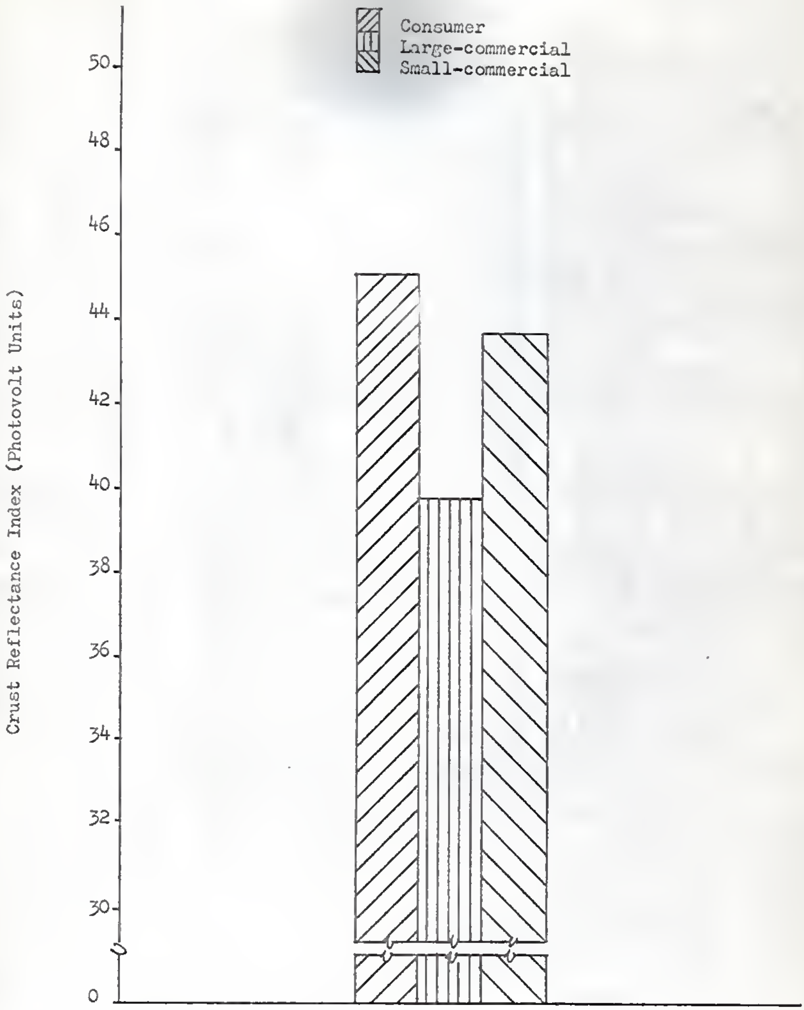


Fig. 49 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch treated to contain 10 percent hydroxymethyl propyl groups, plus normal amount of wheat starch in formula, on the crust reflectance index.

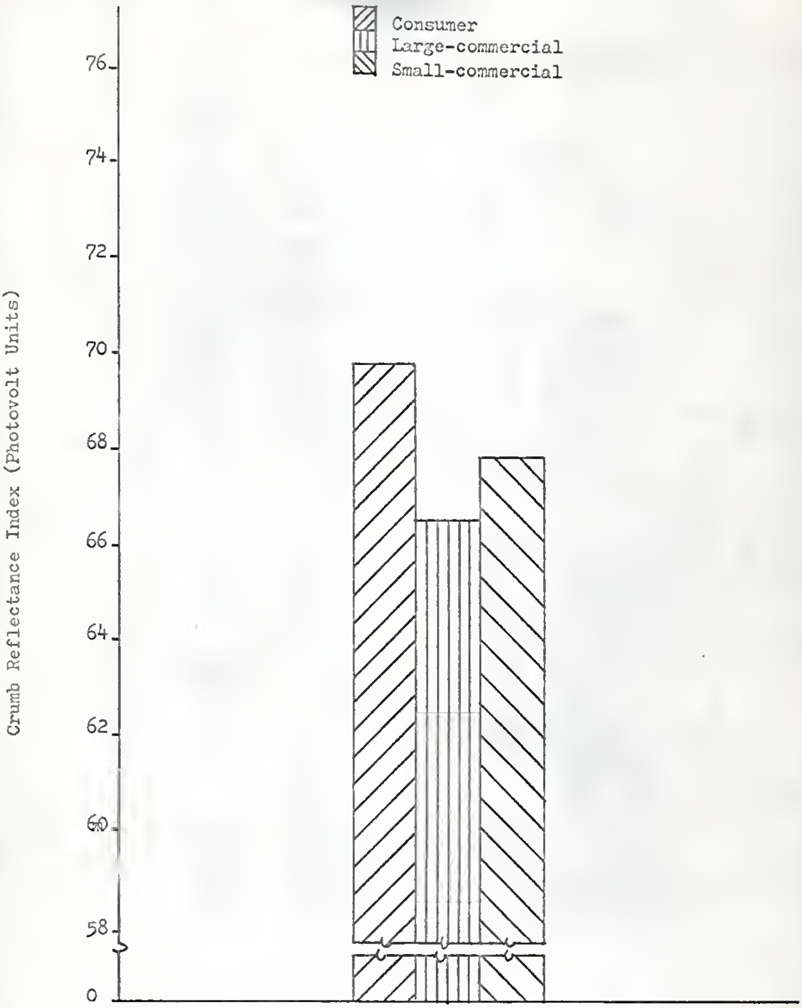


Fig. 50 The effect of dilution of flour protein to 6.4% with 70% amylose corn starch treated to contain 10 per-cent hydroxymethyl propyl groups, plus normal amount of wheat starch in formula, on the crumb reflectance index.

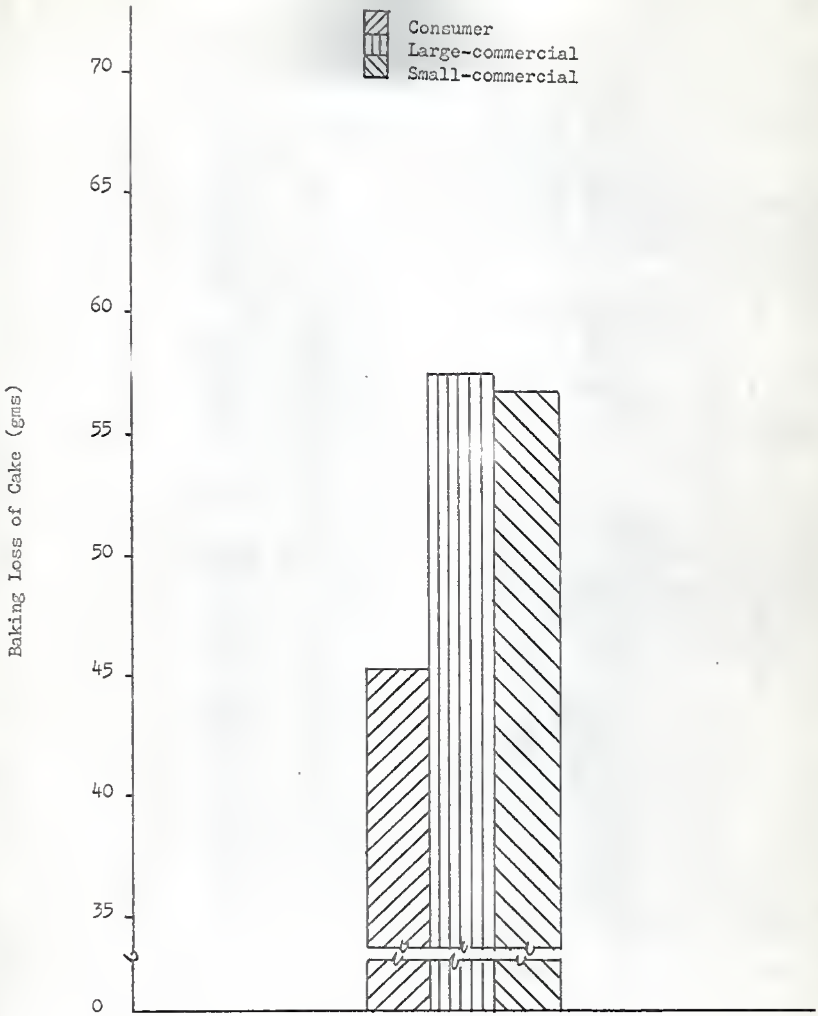


Fig. 51 The effect of dilution of flour protein to 6.4% with 55% amylose corn starch, plus normal amount of wheat starch in formula, on the baking loss of the cake.

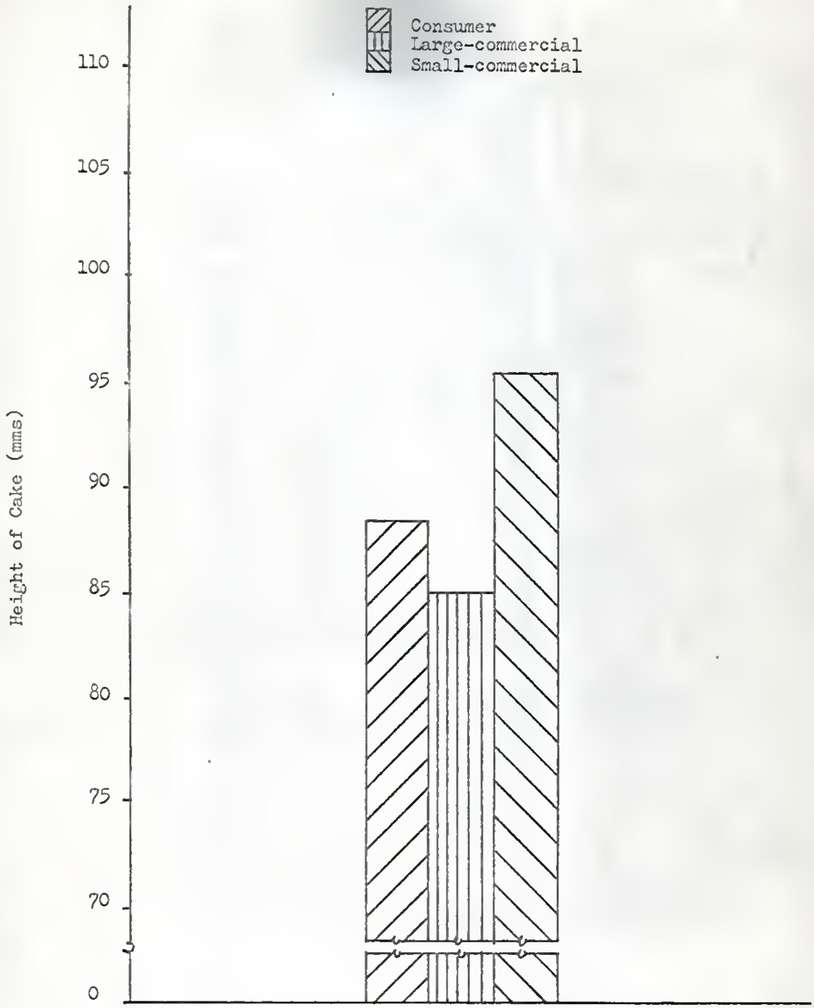


Fig. 52 The effect of dilution of flour protein to 6.4% with 55% amylose corn starch, plus normal amount of wheat starch in formula, on the height of the cake.

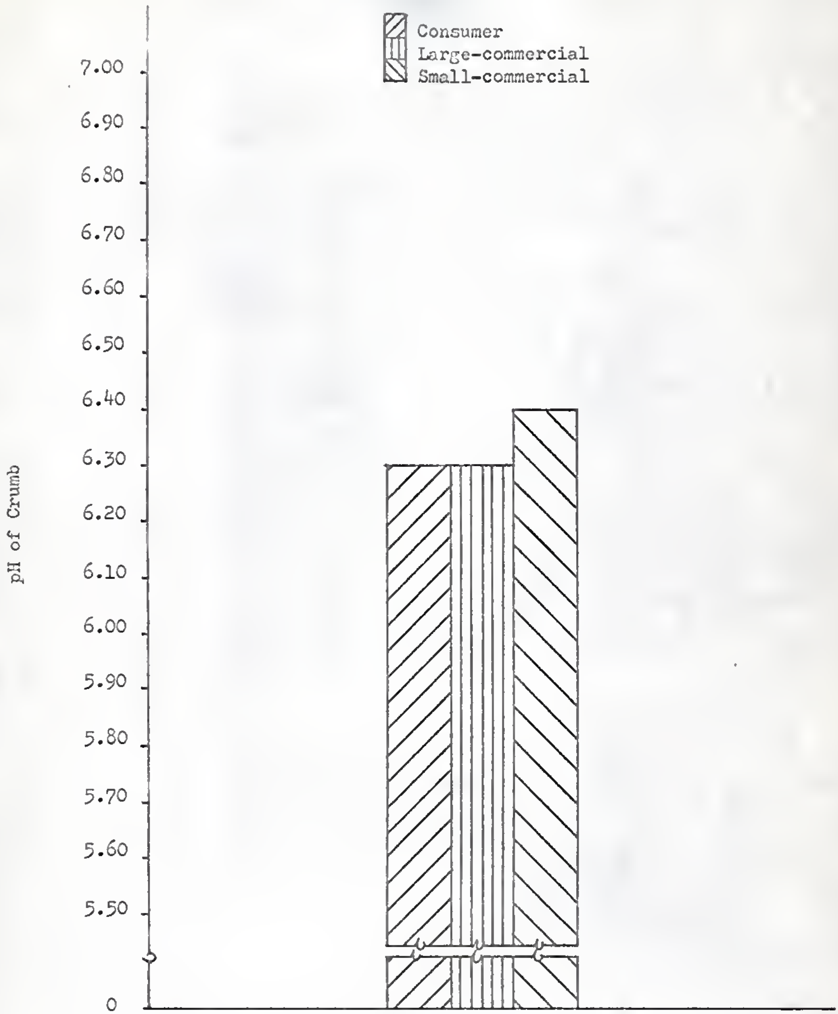


Fig. 53 The effect of dilution of flour protein to 6.4% with 55% amylose corn starch, plus normal amount of wheat starch in the formula, on the crumb pH.

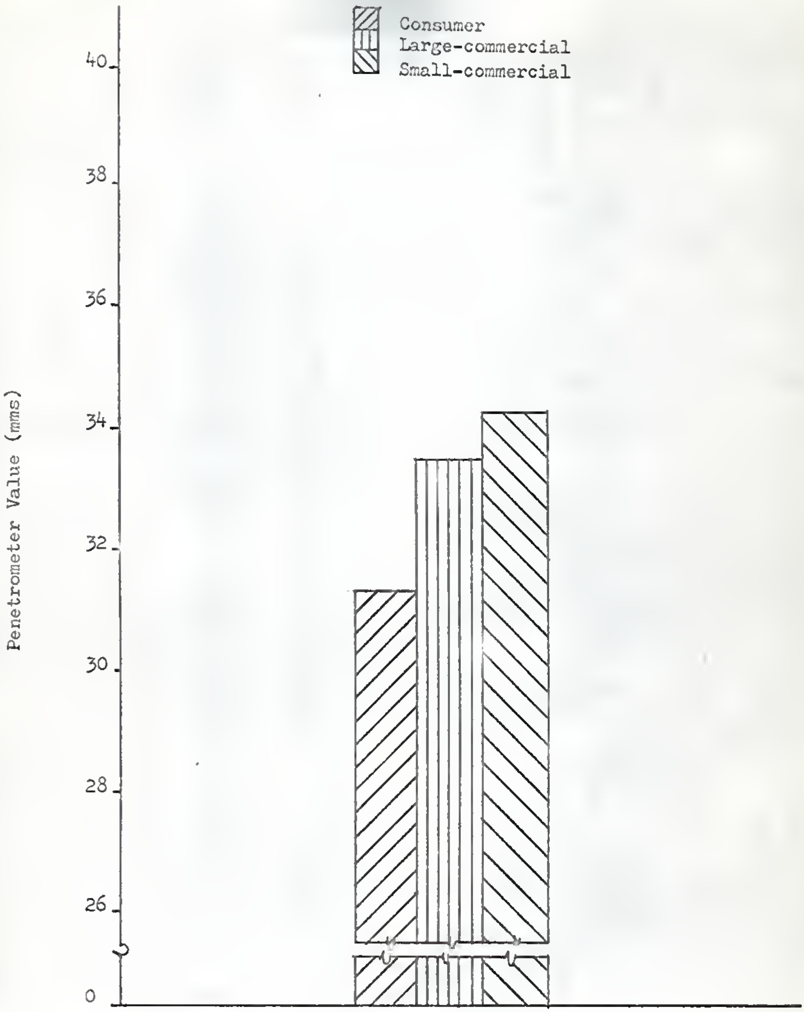


Fig. 54 The effect of dilution of flour protein to 6.4% with 55% amylose corn starch, plus normal amount of wheat starch in formula, on the penetrometer value.

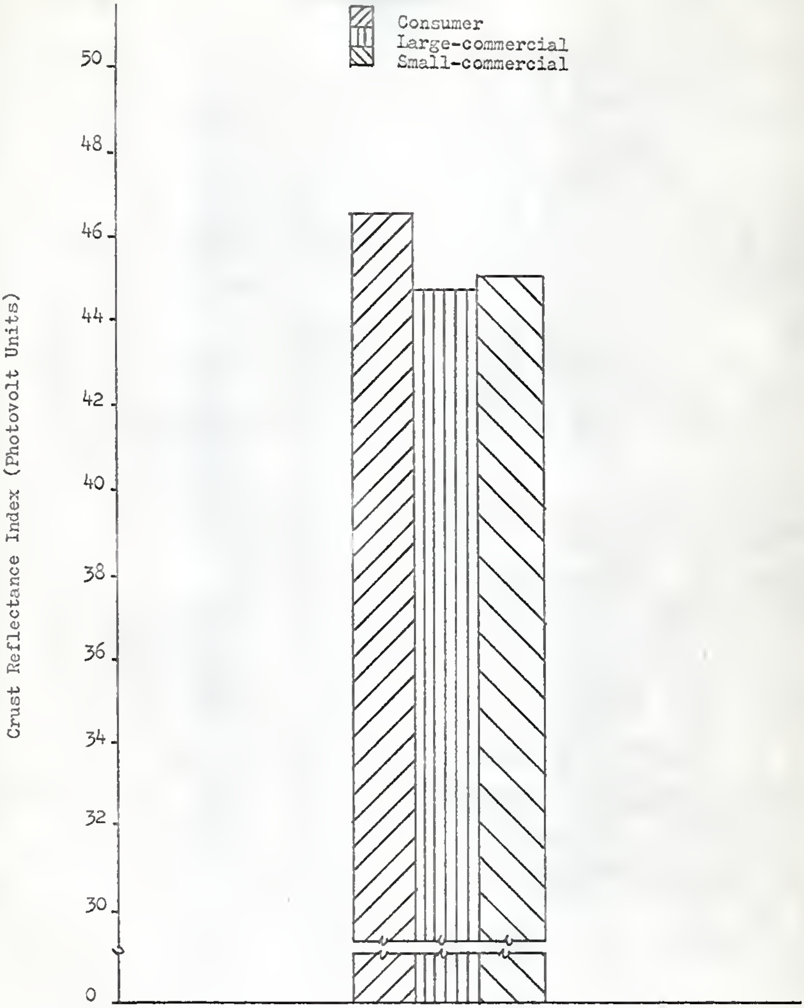


Fig. 55 The effect of dilution of flour protein to 6.4% with 55% amylose corn starch, plus normal amount of wheat starch in formula, on the crust reflectance index.

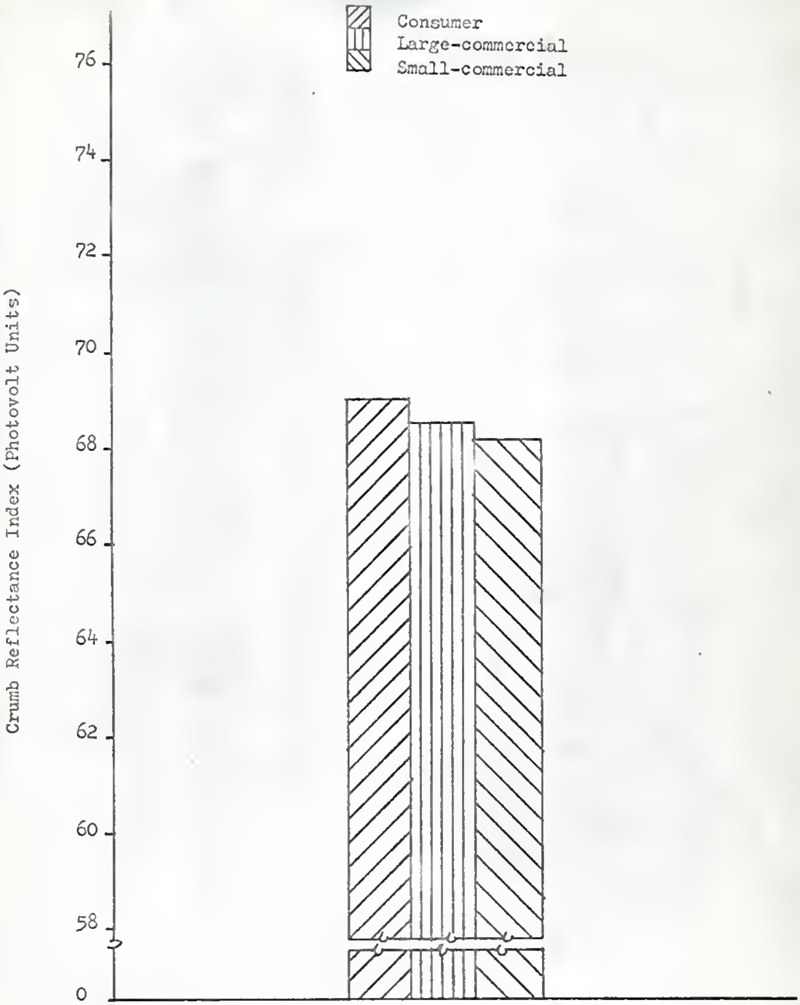


Fig. 56 The effect of dilution of flour protein to 6.4% with 55% amylose corn starch, plus normal amount of wheat starch in formula, on the crumb reflectance index.

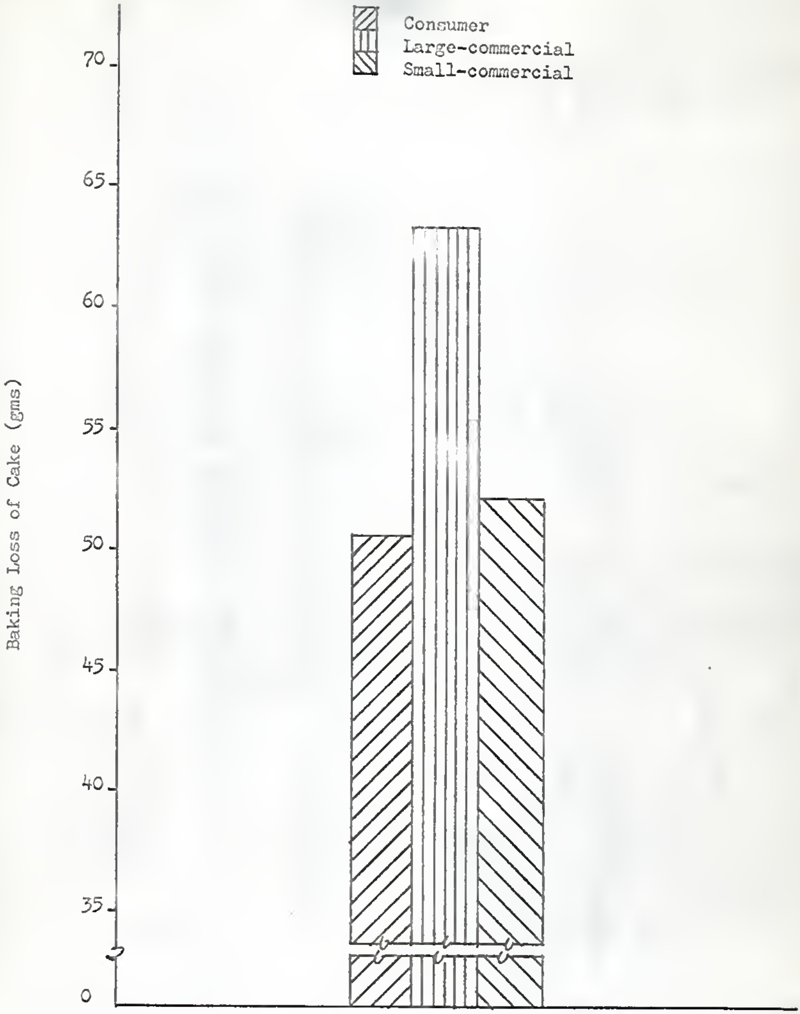


Fig. 57 The effect of dilution of flour protein to 6.4% with corn starch, plus normal amount of wheat starch in formula, on the baking loss of the cake.

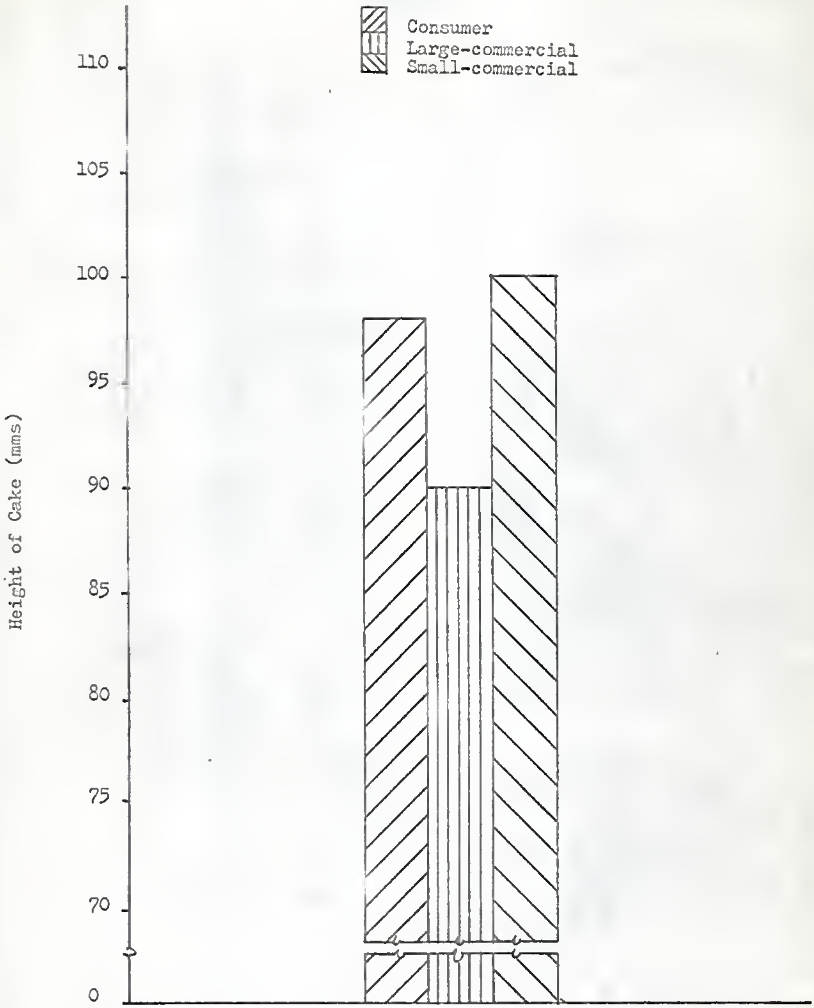


Fig. 58 The effect of dilution of flour protein to 6.4% with corn starch, plus normal amount of wheat starch in formula, on the height of the cake.

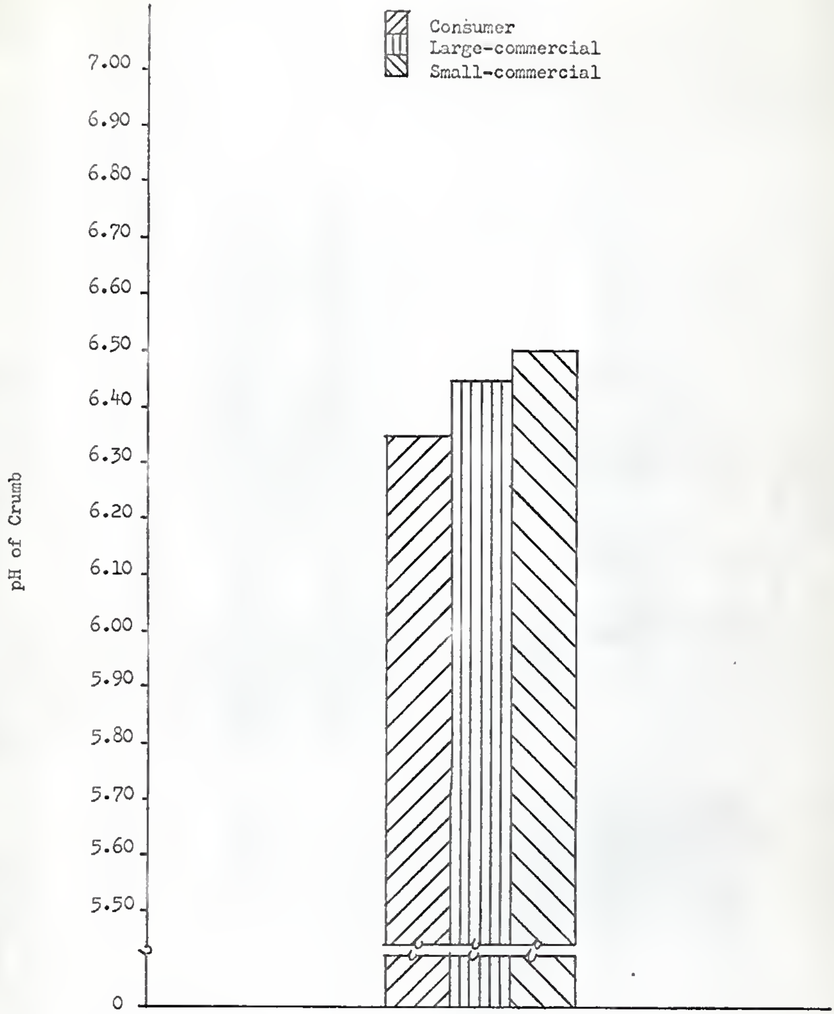


Fig. 59 The effect of dilution of flour protein to 6.4% with corn starch, plus normal amount of wheat starch in formula, on the crumb pH.

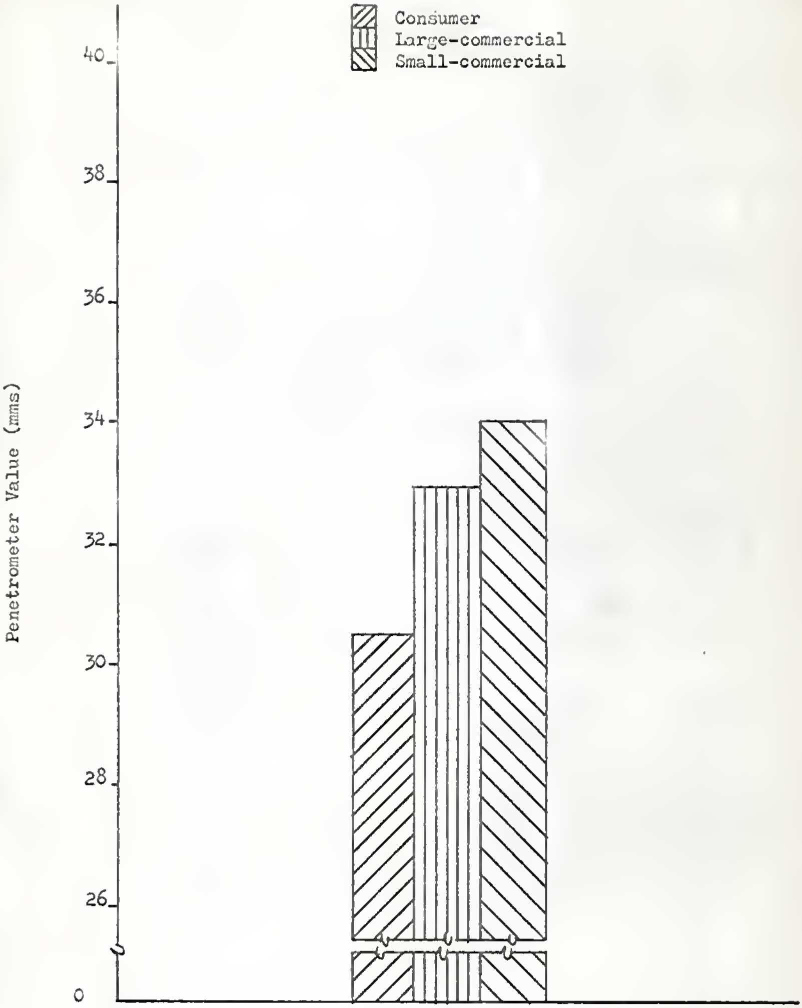


Fig. 60 The effect of dilution of flour protein to 6.4% with corn starch, plus normal amount of wheat starch in formula, on the penetrometer value.

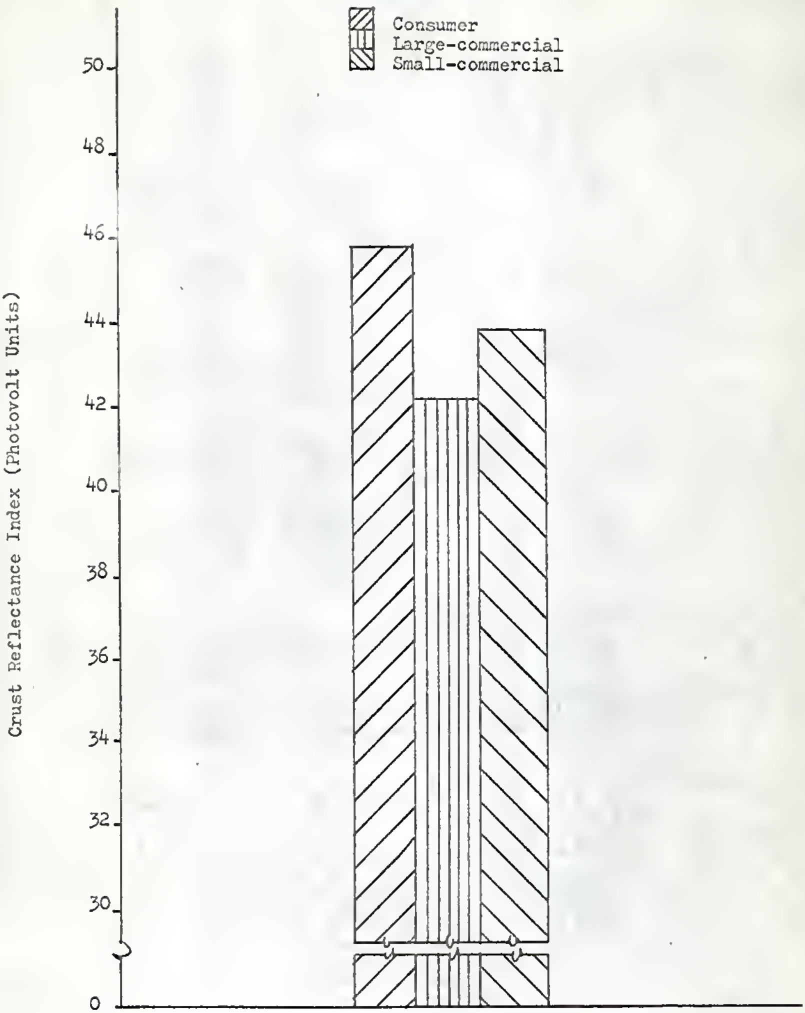


Fig. 61 The effect of dilution of flour protein to 6.4% with corn starch, plus normal amount of wheat starch in formula, on the crust reflectance index.

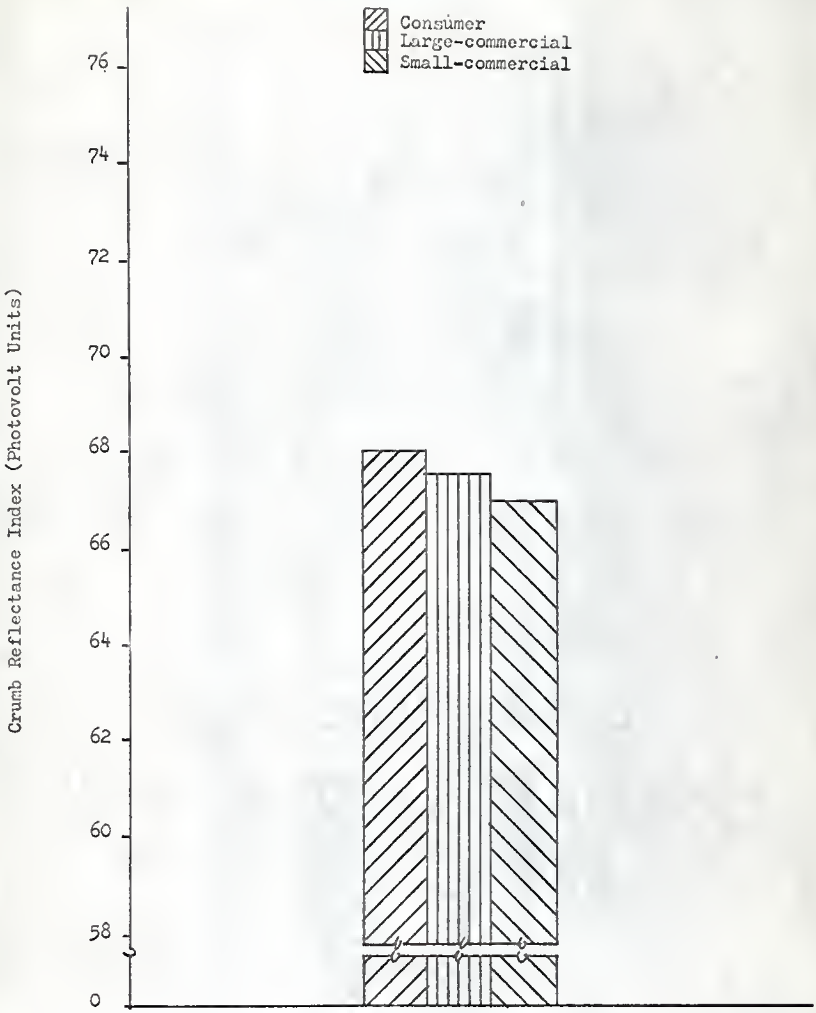


Fig. 62 The effect of dilution of flour protein to 6.4% with corn starch, plus normal amount of wheat starch in formula, on the crumb reflectance index.

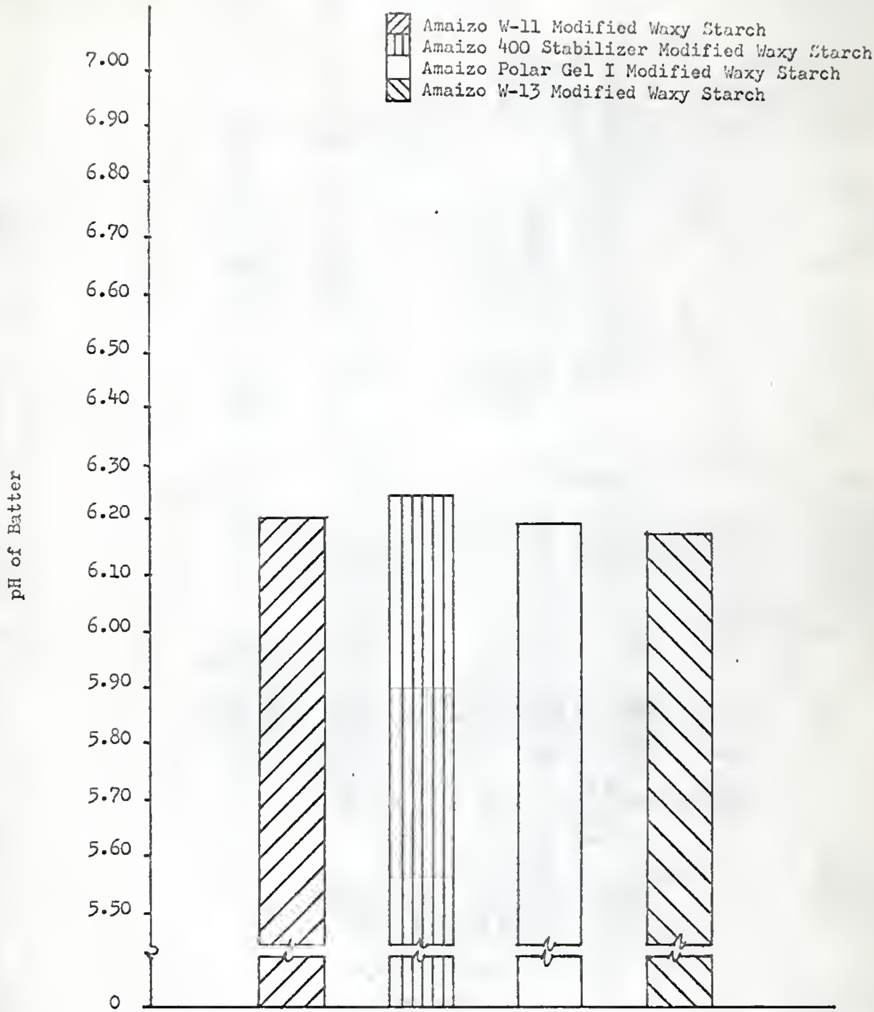


Fig. 63 The effect of dilution of flour protein with modified corn starches on the pH of the batter.

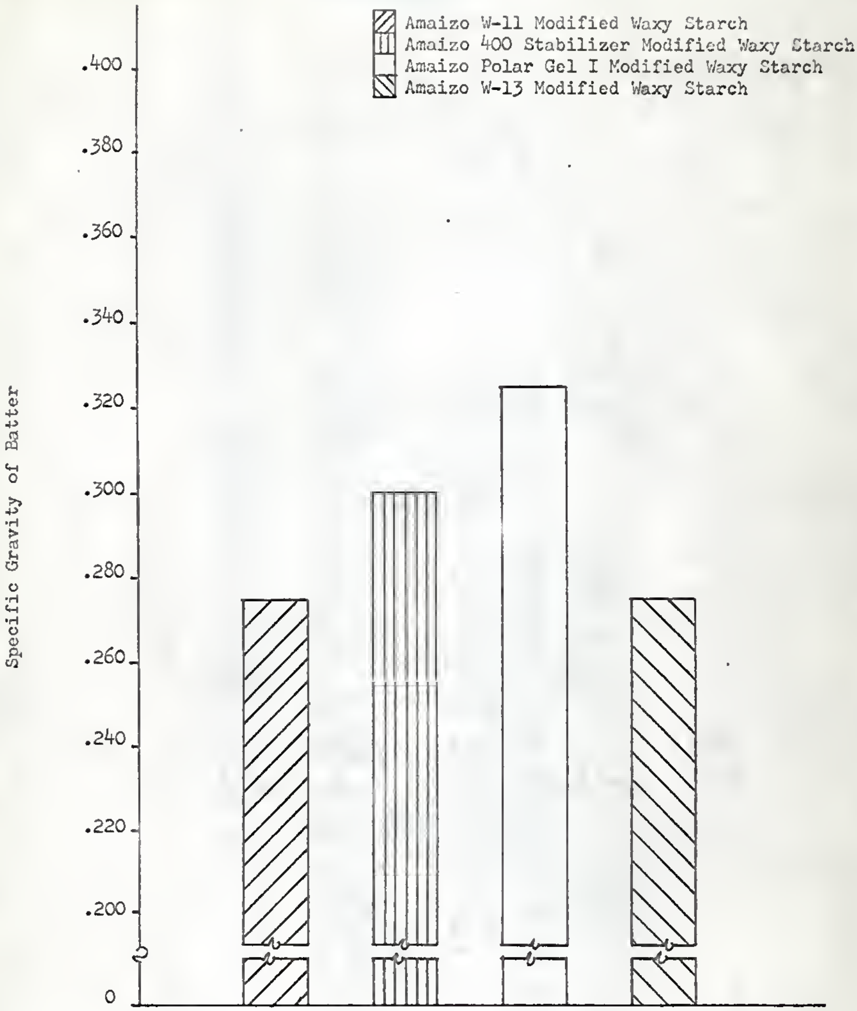


Fig. 64 The effect of dilution of flour protein with modified corn starches on the specific gravity of the batter.

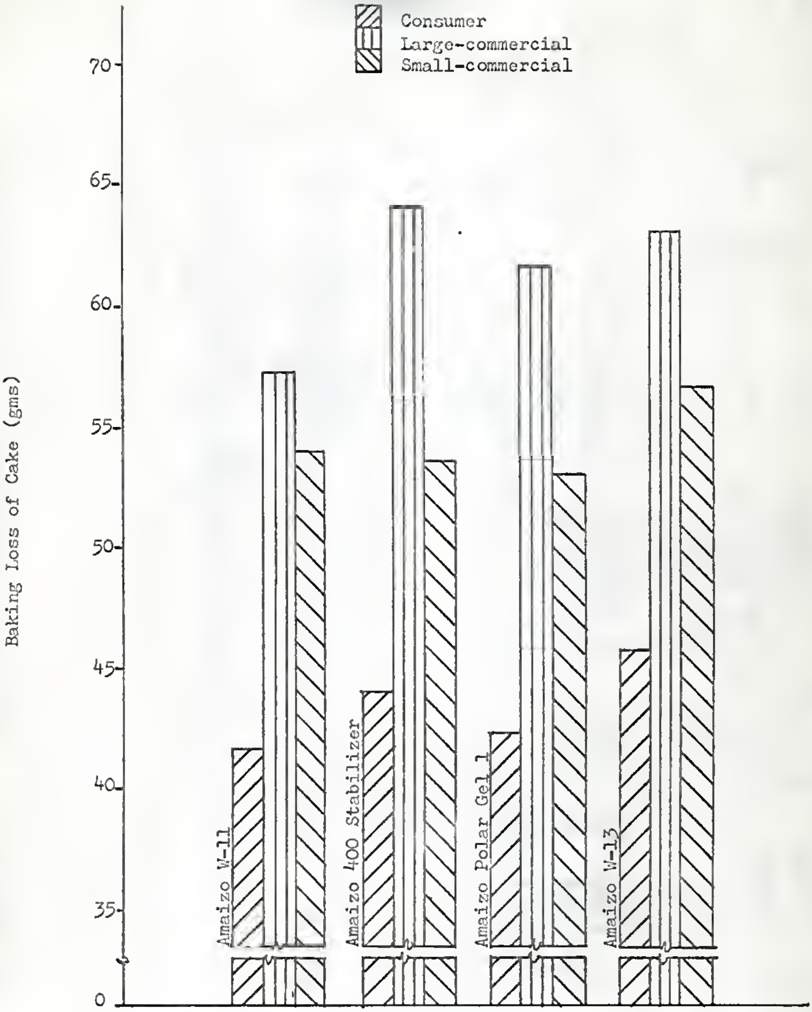


Fig. 65 The effect of dilution of flour protein with modified waxy corn starches on the baking loss of the cake.

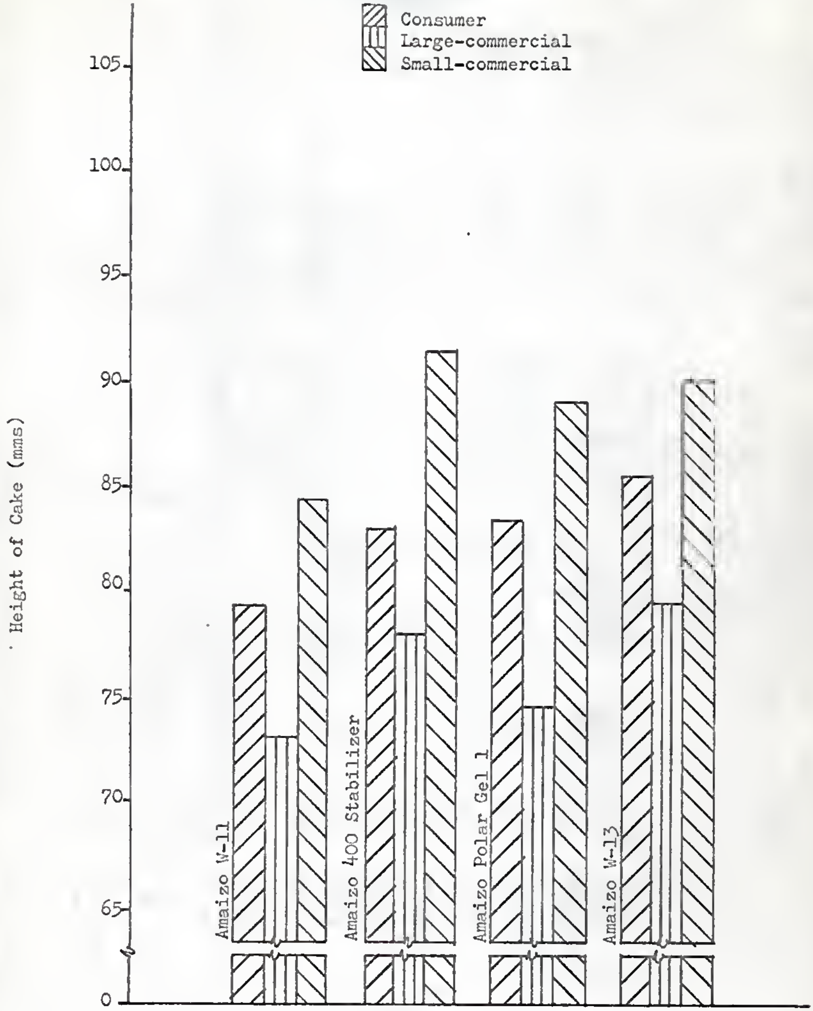


Fig. 66 The effect of dilution of flour protein with modified waxy corn starches on the height of the cake.

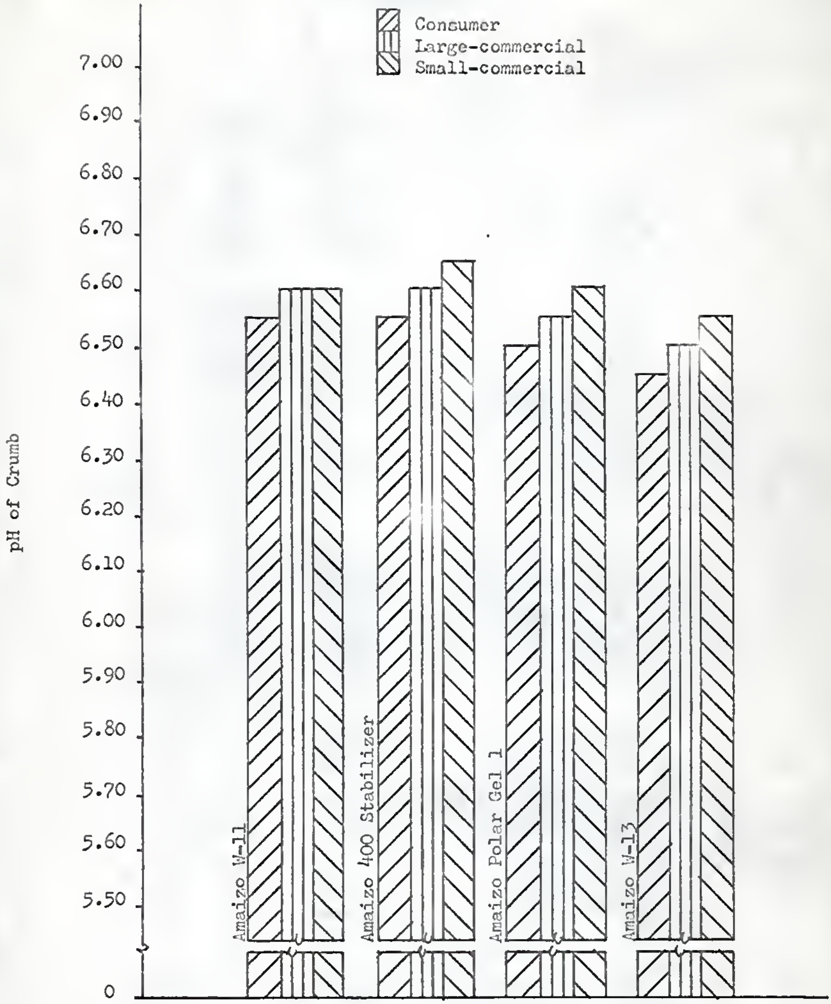


Fig. 67 The effect of dilution of flour protein with modified waxy corn starches on the pH of the crumb.

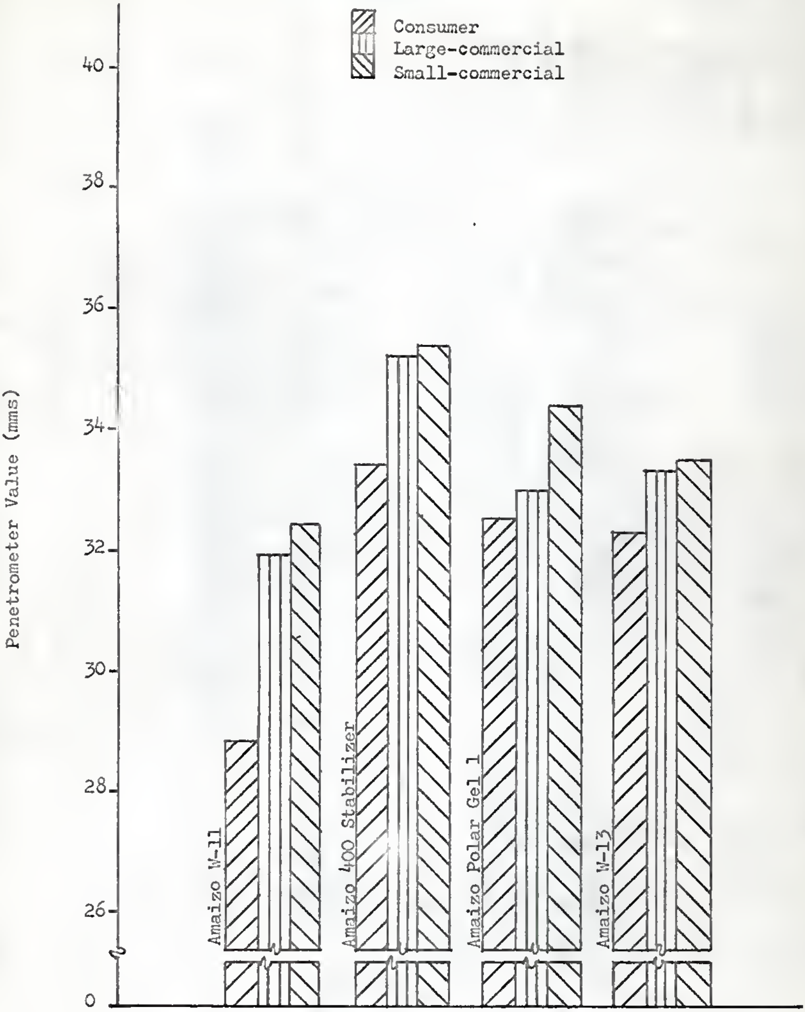


Fig. 68 The effect of dilution of flour protein with modified waxy corn starches on the penetrometer value.

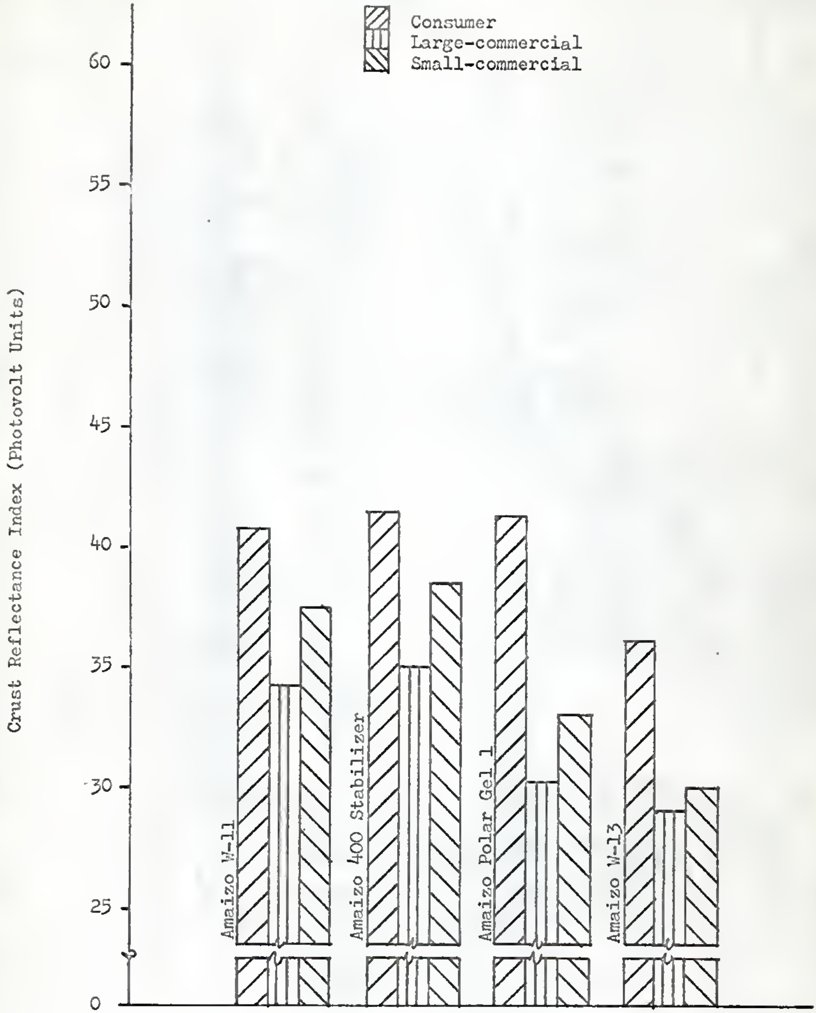


Fig. 69 The effect of dilution of flour protein with modified waxy corn starches on the crust reflectance index.

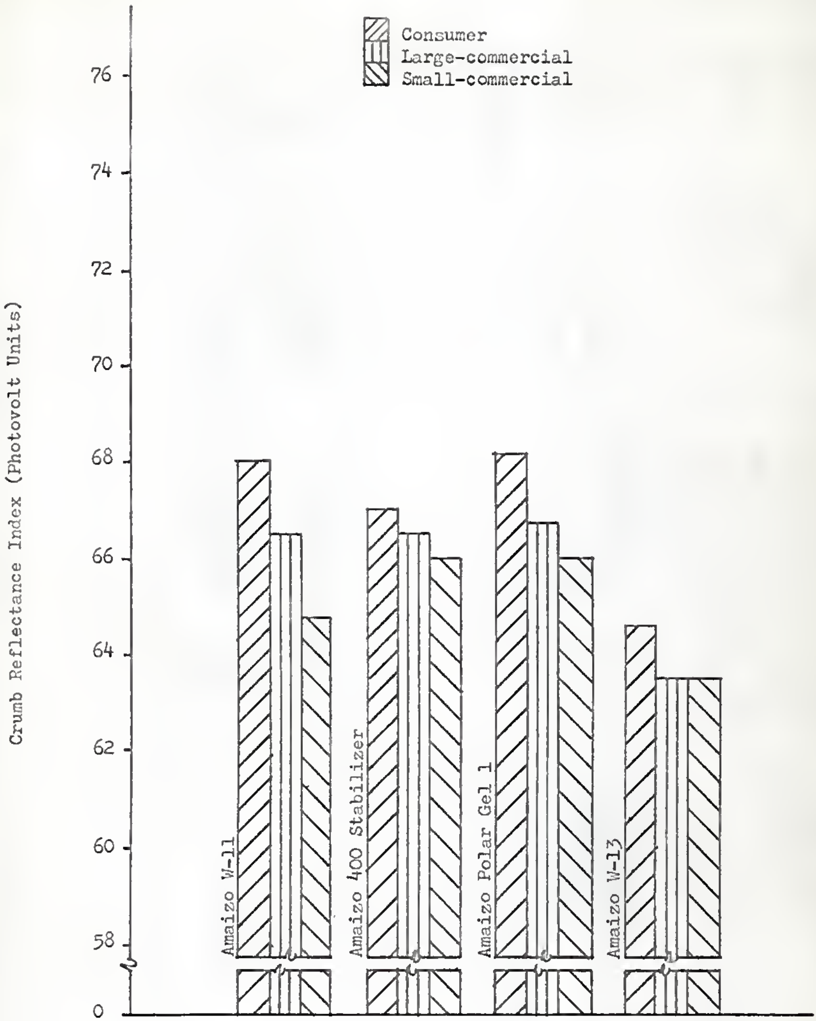


Fig. 70 The effect of dilution of flour protein with modified waxy corn starches on the crumb reflectance index.

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THE RELATIONSHIP OF FLOUR PROTEIN CONCENTRATION, VARIOUS STARCHES AND PAN SIZE TO THE PHYSIOCHEMICAL PROPERTIES OF ANGEL FOOD CAKES USING THE OAKES CONTINUOUS MIXING SYSTEM

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An investigation into the relationship of flour protein content and pan size to the quality of angel food cake was conducted, with primary emphasis on the protein level and type of starch used to dilute the protein.

In this study, nine commercially prepared samples of starch were obtained and used to dilute a commercial cake flour of 7.4% protein content. The starches were: commercial wheat starch, unmodified corn starch (food grade), corn starch of 55% and 70% amylose content, corn starch of 70% amylose content treated to contain 10% hydroxymethyl propyl groups, Amaizo W-11, Amaizo Polar Gel I, Amaizo W-11 and Amaizo 400 Stabilizer. Three different types of pans were used to bake the cakes: consumer or household, large commercial and small commercial.

In conducting this research four experiments were designed to study the various types of starch. The following determinations were used to measure characteristics of batter and cake: pH and specific gravity of the batter, baking loss and height of the cake, pH of the crumb, penetrometer value and crust and crumb color.

In Experiment I the cake flour was diluted with wheat starch in 1% intervals from 7.4% to 3.4% protein content.

Experiment II was designed to study the effects of producing cakes from flour of 7.4% protein content, with corn starch (food grade), corn starch of 55% and of 70% amylose content, and 70% amylose corn starch treated to contain 10% hydroxymethyl propyl groups replacing the wheat starch prescribed in the formulation. The final protein level was 5.7%.

Determinations of characteristics of batter and cake in Experiment I showed that cakes produced from the flour of 6.4% protein concentration were generally superior to those produced from the other dilution levels.

Experiment III was therefore, designed to study the effects of diluting the protein level of the flour from 7.4% to 6.4% using unmodified corn starch (food grade), corn starch of 55% and 70% amylose content, and the last treated to contain 10% hydroxymethyl propyl groups. The normal amount of wheat starch prescribed was also used in the formula. The final protein concentration for a mixture of the flour, corn starch, and wheat starch was 5.0%.

Experiment IV was conducted to determine the effect of various modified waxy maize starches on the quality of angel food cakes. The starches used are sold under the trade names: Amaizo W-11, Amaizo Polor Gel I, Amaizo 400 Stabilizer and Amaizo W-13. In this study, the protein level of the flour was 7.4%. The various modified starches replaced wheat starch in the formulation; and the final protein level for a mixture of the flour and starch was 5.7%.

Changes in the specific gravity of the batter appeared to be closely related to the protein content of the flour in Experiment I. The batter tended to be heavier when the protein concentration decreased. At levels of 4.4% and 3.4% protein, an increased volume of air incorporated into the system was needed to maintain the operating conditions required by the Oakes Unit. From the results, it became evident that the higher the cake (larger volume), the greater the baking loss. Decreasing protein concentration of the flour decreased the baking loss.

The data for all experiments, however, showed substantial evidence that the size and type of pan used were more important variables affecting baking losses and crust color. Increases in baking loss and crust color were most for consumer and least for large commercial pans.

Crumb color appeared to be influenced by the type of starch used. In general, wheat starch produced whiter crumb than did any corn starch when equal flour dilutions were compared.

The crumb pH of the cakes increased as the protein concentration decreased in Experiment I. The pH of the crumb for cakes produced from modified waxy maize starches was higher than for any of the other starches.

Tenderness decreased when the protein concentration was decreased in Experiment I by adding wheat starch. Use of wheat starch together with any of the corn starches in Experiment III generally produced more tender cake than when a corn starch was used alone (Experiment II). Penetrometer values for cakes produced from modified starches also tended to be higher than those for cakes made with any of the corn starches.