ABSTRACT

EFFECT OF HEAT TREATMENTS ON THE PHYSICAL AND FUNCTIONAL PROPERTIES OF LIQUID AND SPRAY-DRIED ALBUMEN

by Susan Layton Brown

This investigation was designed to determine the effect of preheating albumen at 130°F (54.4°C) for approximately 3 minutes prior to spray-drying, and the effect of high temperature storage at 128°F (53.3°C) for 5 days following preheating and drying of the albumen on its physical and functional properties. In order to examine the effect of these heat treatments, singly and in combination, the following five types of albumen from each stage of processing were included in the study: (1) liquid albumen, not preheated; (2) liquid albumen, preheated; (3) spray-dried albumen, not preheated; (4) spray-dried albumen, preheated; (5) spray-dried albumen, preheated and stored at high temperature.

The investigation included the study of the physical properties and foaming ability of the albumen, and the evaluation of the functional properties of the albumen through a comparison of angel cakes prepared with the five types of albumen. Five replications of each of the five variables were tested.

The results indicated exposure of albumen to any of the three types of heat treatments brought about the

following significant changes in the physical and functional properties of the albumen: decrease in apparent surface tension; increase in specific gravity of both albumen foam and angel cake batter; decrease in stability of albumen foam; and decrease in volume of angel cakes. Of the three heat treatments, the preheating treatment had the most adverse effect and caused the greatest modifications in albumen properties. These modifications included: increase in relative viscosity; increase in specific gravity and decrease in stability of albumen foams; and decrease in volume and compressibility of angel cakes.

Spray-drying the albumen brought about a significant increase in specific gravity of batters and decrease in volume of angel cakes prepared with reconstituted albumen which had been spray-dried. However, no significant change was observed in relative viscosity of reconstituted albumen which had been spray-dried or in compressibility of angel cakes prepared with this albumen.

Although significant differences were found in volume and compressibility of cakes prepared with the five types of albumen, no significant differences in tenderness or tensile strength were recorded. It was possible there were no significant differences among the cakes. It was also possible the explanation lay in the extremely low readings which may not have recorded subtle changes in cake tenderness and tensile strength. These low readings were due to the lack of an optimum range on the shear press for testing either tenderness or tensile strength. Another factor which might have affected tensile strength readings was damage to the cake samples as they were placed in the testing apparatus.

Evaluation of the results suggested the effects of the three heat treatments on the albumen were not additive, but there was a significant interaction among them. Significant correlations indicated both angel cake volume and compressibility were closely related to albumen foam structure. These findings led to the following suggestions for additional study: an investigation to examine the causes for the observed interaction among the three heat treatments; further refinement of the technique for determination of tensile strength on the shear press; and a study to discover any possible relationships between cake tenderness or tensile strength and albumen foam structure.

EFFECT OF HEAT TREATMENTS ON THE PHYSICAL AND FUNCTIONAL PROPERTIES OF LIQUID AND SPRAY-DRIED ALBUMEN

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INTRODUCTION

Although Ayres and Slosberg (1959) have reported pasteurization effectively reduced the bacterial count of egg albumen without affecting the functional properties of the albumen, some investigators have reported pasteurization of albumen adversely affected its physical and functional properties. These contradictory reports leave some doubt as to the way in which, and the extent to which, pasteurization may affect the characteristics of both liquid and spray-dried albumen. Clinger et al.(1951) and Siedeman et al. (1963) recorded a decrease in whipping rate and angel cake-producing ability of liquid albumen after pasteurization at 134-136°F (56.7-57.8°C) for 3-4 minutes. Other researchers found flash pasteurization at temperatures up to 139°F (59.4°C) did not significantly affect solubility or whipping rate of liquid and reconstituted albumen, or affect the volume of angel cakes prepared with this albumen (Slosberg et al., 1948; Ayres and Slosberg, 1949).

In order to minimize heat coagulation of albumen, many commercial processors reduce the bacterial count prior to drying by subjecting the albumen to preheating rather than pasteurization. Kline (1964) and Eggleston

(1964) reported some processors preheat albumen at 128-130°F (53.3-54.4°C) for approximately 3 minutes in a plate-type or other pasteurizer. To insure a Salmonella-free product, the dried albumen is then exposed to high temperature storage at 128-130°F (53.3-54.4°C) for 4-5 days. Banwart and Ayres (1956) and Ayres and Slosberg (1949) found dried albumen which had been treated with high temperature storage at 122°F (50°C) for 90 days, 130°F (54.4°C) for 8 days, or 135°F (57.2°C) for 4 days retained satisfactory solubility and whipping rate. In addition, angel cakes prepared with this albumen had satisfactory volume. Although several research groups have investigated the effect of heat treatments or high temperature storage on the physical and functional properties of dried albumen, the effect of preheating and subsequent high temperature storage has not been reported in the literature.

This study was initiated to determine the effect of preheating the albumen at 130°F (54.4°C) for approximately 3 minutes prior to spray-drying, and the effect of high temperature storage at 128°F (53.3°C) for 5 days following preheating and drying of the albumen on its physical and functional properties. The writer will examine the results of the study in an attempt to determine whether the effects of preheating, spray-drying and high temperature storage were additive, or if an interaction occurred between the three heat treatments.

REVIEW OF LITERATURE

Composition of Albumen

Several research groups have analyzed the chemical and protein composition of albumen. From studies of the chemical composition of egg, Cruickshank (1940) reported albumen to be 87.77% water, 10.00% protein, 0.82% ash, and 0.05% fat. The total protein of albumen is composed of several fractions. Romanoff and Romanoff (1949) reported albumen contained the following fractions and percentages:

Ovalbumin	75%	Conalbumin	3%
Ovomucoid	13%	Ovoglobulin	2%
Ovomucin	7%		

In a more recent study Evans and Bandemer (1956) separated the protein fractions by paper electrophoresis. Using this method they found albumen consisted of these fractions and percentages:

Ovalbumin	65.2%	Ovomucoid Plus Ovoglobulin	11.2%
Conalbumin	17.0%	Nonmobile Protein	2.1%

Albumen consists of three layers as it occurs in the shell egg. One layer of thin white lies adjacent to the shell, and another layer of thin white surrounds the yolk. In between these two is a layer of thick white which comprises more than half of the total albumen. By examination of the three layers, Forsythe and Foster (1949) found each protein fraction was common to both thick and thin albumen except ovomucin which occurred only in the thick portion and which they reported to be responsible for the structural characteristics of this layer.

Bacterial Aspects of Albumen

Food poisoning occasionally resulting from Salmonellae contamination of albumen has caused concern for many years. The Genus Salmonella is composed of non-sporing bacilli which produce toxins pathogenic to man. The mortality rate in Salmonellae food poisoning is low. However, if a person ingests a large number of these bacilli, the bacilli can produce and release sufficient toxins to cause symptoms of fever and gastrointestinal disturbance, if they are allowed to multiply in the gastrointestinal tract.

In several outbreaks of Salmonellae food poisoning, investigators have traced the source of the infection to frozen egg albumen. Dack (1956) cited Baked Alaska, a dessert prepared using whipped frozen albumen which was only superficially browned on the surface, as responsible for one outbreak. In another reported incidence, soft meringue prepared with frozen albumen was the source of an outbreak of *S. typhimurium* poisoning (Beckett *et al.*, 1960).

Subjecting the food product to sufficient heat to destroy the organisms will largely prevent Salmonellae food poisoning. The two most prevalent species, *S. typhimurium* and *S. manhattan*, are more heat sensitive than the less common species *S. senftenberg*.

The thermal-death-time of each species varies with the medium, the pH and the chemicals present. Solowey *et al.* (1948) found holding liquid whole egg for 30-60 seconds at 58°C was sufficient to eliminate 1 to 3 million cells of *S. typhimurium*. Using egg custard as a medium, Angelotti *et al.* (1961) reported 10 million organisms of *S. manhattan* were reduced to an undetectable level by a holding treatment at 60°C for 19 minutes. Under similar conditions an equal number of *S. senftenberg* cells were destroyed in 78 minutes. Osborne *et al.* (1954) studied the death rate of *S. senftenberg* cells at various pH levels. In a phosphate buffer solution containing 200,000 cells of *S. senftenberg*, holding the solution at 60°C completely destroyed the bacilli in 16 minutes at pH 5.3; while 7 minutes were required at pH 7.0, or 1 minute at pH 8.2. In an egg albumen medium at pH 9.0, all bacilli were eliminated in 3.5 minutes.

Lategan and Vaughn (1964) reported the addition of certain chemicals to liquid whole egg inoculated with *Salmonella typhimurium* significantly reduced the heat resistance of the organisms. These investigators added one thousand ppm of the selected chemicals to liquid whole egg inoculated with 2 million cells of *S. typhimurium* per milliliter of egg and adjusted to pH 5.5. Then they heated this egg mixture at 55°C for 10 minutes. The most effective chemicals of those tested were β-propiolactone, butadiene dioxide, and ethylene oxide, decreasing the thermal-death-time of the *S. typhimurium* organisms by 85%, 80%, and 50%, respectively. Lategan and Vaughn found ethylene oxide and β-propiolactone were also effective in reducing the number of viable bacteria present during frozen storage of liquid whole egg, and in increasing the lag phase of growth of the organisms during incubation of the whole egg at 30°C.

Processing of Albumen

Preparing albumen for experimental or commercial use involves exposing it to several treatments which may or may not affect the physical and functional properties of the albumen. The most common processes include freezing, fermentation, spray-drying, pasteurization, and high temperature storage.

Freezing

Commercial freezing of albumen is very common. Swift and Company (pre-1940) recommended a quick method of freezing to prevent growth of large ice crystals in the albumen and to keep the bacterial count low. The method involved feeding a homogeneous emulsion prepared from the albumen onto a refrigerated roller which froze the liquid in 7 seconds. The frozen albumen was packed into sterile cans and placed in a sub-zero freezing room. LeClerc and Bailey (1940) also stressed the advantages of quick freezing. They stated slow freezing caused the formation of large ice crystals and the resulting liquid remained separated from the albumen upon subsequent thawing. However during rapid freezing, small crystals which were capable of being reabsorbed were formed. LeClerc and Bailey (1940) reported at that time commercial processors quick froze large quantities of albumen at -23°C to -12°C.

Several investigators have studied the effect of freezing on the bacterial count of albumen. LeClerc and Bailey (1940) reported temperatures of -23.3°C and below prevented growth of bacteria in albumen. Hinshaw and McNeil (1951) stated freezing prevented further growth of Salmonellae and further production of any toxic material, but did not destroy the virulence of Salmonellae toxin already present.

Fermentation

Fermentation is the process of removing free glucose naturally present in the albumen. Removal of this free glucose is necessary to produce dried albumen which will retain its physical properties during storage. Throughout the early stages of commercial drying, spontaneous fermentation, brought about by any bacteria already present in the albumen, removed the free glucose. This spontaneous fermentation required a relatively long period of 2 to 7 days, and produced objectionable odors, proteolysis, and a significant increase in the Salmonellae organisms present in the albumen. Later experimentation proved inoculation of the albumen with controlled numbers of fermentation-inducing bacteria greatly reduced both the time period and the unsatisfactory by-products of spontaneous fermentation.

Stuart and Goresline (1942) reported Aerobacter and Escherichia types of bacteria were widely used in commercial fermentation of albumen. Fermentation with 1 billion cells of these bacteria per milliliter of albumen over a period of 72 hours significantly reduced the glucose level without digestion of the protein fractions. Fermentation for 72-96 hours caused proteolysis without further reduction in glucose content. These investigators obtained equally effective results in the fermentation process using either Aerobacter or Escherichia organisms.

A more recent study by Ayres (1958) reported Aerobacter and Streptococci organisms were then in common use for commercial bacterial fermentation of albumen. Ayres compared the activity of two of these organisms, *Aerobacter aerogenes* and *Streptococcus lactis*. He found albumen injected with a 2% inoculum of *Aerobacter aerogenes* (about 20 million organisms per milliliter of albumen) was freed of glucose after a 30-hour fermentation period. A 10% inoculum of *Aerobacter aerogenes* (about 100 million organisms per milliliter of albumen) eliminated free glucose in 16 hours. An inoculum of 5 billion *Streptococcus lactis* "resting cells" per milliliter of albumen eliminated free glucose after 3.5 to 4 hours of fermentation.

Enzymatic fermentation has also been used to remove free glucose from albumen. Carlin and Ayres (1953) reported the use of an enzyme complex composed of glucose oxidase and catalase to ferment albumen. A 0.1% level inoculum of the enzyme solution removed free glucose from albumen adjusted to pH 7.0 over a 10-hour fermentation period.

Spray-drying

Eggs have been dried by three methods: drum-drying, pan-drying, and spray-drying; however, spray-drying has been the most commonly used for albumen. Although the first spray-drying machine was developed in 1903-04, the technique did not come into widespread use until after World War II. Mulvany (1941) listed two main types of spray-drying machines, one which passed heated air through a chamber containing the spray nozzles, and another which sprayed liquid egg into a whirling current of air in a tower. In both types of driers the liquid egg dried instantly and fell to the bottom for removal.

To prevent denaturation by shear stress forces or by heat, the pressure at which the albumen is sprayed, and the temperatures of the drying air are rigidly controlled. Because albumen is more sensitive to damage by these forces than whole egg or yolk, both pressure and temperatures for the drying of albumen must be lower. Lineweaver and Feeney (1950) recommended pressures of less than 1,000 psi for spraying of albumen, as compared to 2,000 to 6,000 psi for whole egg and yolk. They also suggested the use of temperatures below those of 121-149°C inlet and 60-82°C outlet employed for whole egg and yolk. Eggleston (1964) reported commercial use of inlet and outlet temperatures of 113°C and 71°C, respectively, for spray-drying of albumen.

Bergquist and Stewart (1952) studied the effects of spraying albumen at several pressures. For this study they used two-fluid nozzles which they felt brought about the least possible shear damage of the types of nozzles commonly used. The researchers reported a significant and progressive loss in meringue-producing ability of the albumen following spraying at increasing levels of pressure between

25 and 60 psi. They found fermentation before or drying after spraying had no effect on the damage from spraying. Albumen which had been commercially frozen was found to be more susceptible to shear denaturation than fresh albumen. Bergquist and Stewart developed a unique nozzle and a new procedure for drying albumen foam rather than albumen liquid. Spraying foam made possible the use of lower pressures which resulted in significantly less shear damage to the albumen.

Pasteurization and high temperature storage

Winter et al. (1946) conducted one of the earliest research studies on the pasteurization of liquid egg. The pasteurization technique which they developed has been used in many research studies. The technique involved warming the liquid egg as quickly as possible to the specified pasteurization temperature by regulated flow of the albumen through eight feet of bent glass tubing submerged in a constant temperature bath. The investigators used air pressure to initiate and control the flow of the egg. After pasteurization the egg was rapidly cooled to 21.1°C as it flowed down the inside of a glass tube immersed in a beaker of ice water. To cite an example of pasteurization by this technique, Winter et al. stated liquid egg could be warmed from 21.1°C to 62.8°C in 4 seconds by passage through the tubing submerged in a constant temperature bath held at 65°C. They varied the pasteurization temperature and the time required to reach it by regulating the temperature of the constant temperature bath, length of the glass tubing, and the rate of flow of the egg. Liquid whole egg containing 1.5 million bacteria per gram of egg was pasteurized at 62.8°C for 1 minute to eliminate 99% of the bacteria. Further investigation by Wilkin and Winter (1947) with albumen containing 245,000 bacteria per milliliter of albumen demonstrated pasteurization at 56.7°C for 1.6 minutes would destroy 99% of the bacteria.

Other research studies have used the pasteurization technique developed by Winter et al. (1946). Clinger et al. (1951) found pasteurization at 56.7°C for 4 minutes killed 90% of the bacteria present in albumen. However, albumen which had been pasteurized under these conditions required longer whipping time and faster whipping speeds than those required by unpasteurized albumen to produce satisfactory angel cakes. Siedeman et al. (1963) also employed this pasteurization method to study the relationship between pH and pasteurization. They found heating albumen at 58°C for 3 minutes with pH varying between 7.0 and 9.5 caused a decrease in the whipping rate of albumen and a reduction in the volume of angel cakes prepared from this albumen. Albumen with a pH near 8.75 and heated under similar conditions whipped faster and produced angel cakes with larger volume than the heated albumen with higher or lower pH. Raising the pasteurization temperature to 60°C brought about a decrease in whipping rate and cake volume regardless of which pH level was used.

Two studies have reported high temperature storage effectively destroyed Salmonellae organisms in dried albumen. Ayres and Slosberg (1949) found storage at 48.9°C for 20 days, 54.4°C for 8 days, or 57.2°C for 4 days eliminated Salmonellae from dried albumen. These investigators reported satisfactory solubility and whipping rates were obtained from albumen held under these storage conditions. Banwart and Ayres (1956) also reported a high death rate of Salmonellae during storage of albumen at 50°C for up to 120 days without loss of functional properties or solubility.

Physical Properties of Albumen

Several investigators have reported the physical properties of albumen relate to its functional performance, and these properties are affected in various ways by processing of the albumen. The physical properties of albumen include viscosity, surface tension, solubility and dispersibility, all of which are defined and discussed in this section.

Viscosity

All liquids possess a resistance to flow or a viscosity which results from an attraction between molecules of the liquid. This attraction is greater between large or well-hydrated molecules than between small ones; thus, a liquid composed of large or well-hydrated molecules is more viscous than a liquid containing a high percentage of small molecules.

Viscosity is commonly measured as relative viscosity. For example, the flow of a test liquid is compared with the flow of a reference liquid, often distilled water. The term poise is used to designate a unit measurement of viscosity. A liquid with a viscosity of 1 poise flows at the rate of 1.00 gram per centimeter per second. However, the majority of liquids have viscosities which register in fractions of a poise, such as centipoise or 1/100 poise. Cunningham and Cotterill (1964) reported the viscosity of albumen averaged between 4.8 and 5.2 centipoise.

Measurement of viscosity. Viscosity may be determined by several methods. Cunningham and Cotterill (1962) measured viscosity with the Ostwald viscosimeter by comparing the time required for the test liquid to pass through the capillary U-tube with that required for the standard liquid. Jordan and Whitlock (1955) used the MacMichael viscosimeter which suspends a horizontal disc in the test liquid by means of a steel wire. Measurement of the angle of torque of the disc as the cup was rotated at a constant speed gave an indication of viscosity. Jordan and Whitlock also determined viscosity by comparison of the rate of flow of the test liquid through a graduated 10-milliliter Mohr pipette with the rate of flow of the standard liquid.

Effect of processing. Both sub-zero and pasteurization temperatures affect subsequent albumen viscosity. LeClerc and Bailey (1940) found an increase in the relative viscosity of albumen followed freezing of the albumen. Examination of shell eggs subjected to five months storage at below freezing temperatures showed the relative viscosity had increased (Musil and Orel, 1957). Siedeman *et al*. (1963) found pasteurization for 3 minutes at 58°C did not affect the viscosity of albumen; however, pasteurization for 3 minutes at 60°C and above brought about a significant increase in viscosity. Stuart and Goresline (1942) reported removal of free glucose by bacterial fermentation decreased the viscosity of albumen.

Surface tension

Surface tension is another of the characteristic physical properties of a liquid. Under all environmental conditions, the molecular attractions within a drop of the liquid cause the drop to form a minimum surface or spherical shape. Within the liquid, the molecules are equally attracted in all directions by the surrounding molecules. However, those molecules on the surface of the liquid are subjected to an unbalanced attraction directed primarily downwards and sideways. Surface molecules receive only a very slight upward pull as there are relatively few molecules above the surface of the liquid to counteract the effect of those below the surface. This unequal attraction concentrates the surface molecules and creates a thin film or membrane on the surface of the liquid.

To break through this membrane and produce a new surface, work is required. Surface tension is a measure of the amount of work necessary to form the new surface. This measurement is defined as the force in dynes perpendicular to a line one centimeter long in the surface of the liquid.

Measurement of surface tension. Surface tension of liquids can be measured objectively. Both Cunningham and Cotterill (1962) and Siedeman et al. (1963) determined surface tension of albumen with the Du Nuoy Tensiometer which measured the force required to pull a platinum ring out of the surface of the liquid.

Effect of processing. Siedeman et al. (1963) reported pasteurization for 3 minutes at 58°C had no effect on surface tension of albumen. However, increasing the pasteurization temperature to 60°C and above brought about an increase in surface tension.

Solubility or dispersibility

Before dried albumen can be utilized, it must be reconstituted. Therefore, the degree to which the albumen solids are solubilized or dispersed affects the resulting performance of the albumen.

Solubility and dispersibility are generally used interchangeably throughout the literature. Webster's dictionary defines solubility in terms of a compound being dissolved and dispersibility in terms of a compound being diffused or scattered. Miller *et al*. (1959) stated they used the term dispersibility to stand for the relationship of dried egg solids to water in the rehydration process.

Measurement of solubility and dispersibility. Methods are available for objective measurement of both solubility and dispersibility. Bishov and Mitchell (1954) measured solubility in terms of the protein content which was in colloidal or in true solution. Their technique involved determination of the solubility index by precipitation of the protein particles with Esbach reagent and volumetric measurement of the precipitate following centrifuging. Miller *et al*. (1959) determined the dispersibility of albumen samples which had been reconstituted according to a standard technique by straining the liquid through fine aluminum-wire screening. Then they calculated the mean per cent residue from the dried weight of the residue which had collected on the screen.

Effect of processing. Solubility and dispersibility of dried egg solids may be affected by fermentation, method of reconstitution, pasteurization, or high temperature storage. Removal of free glucose in albumen significantly increased the solubility of dried albumen (Stewart and Kline, 1941). Miller et al. (1959) found the temperature of the water and the method of mixing used for reconstitution influenced the dispersibility of whole egg solids. The solids dispersed equally well when the following methods of mixing were used with water temperatures between 21°C and 41°C: incorporation of the water in two equal portions; addition of the total amount of water to the solids; and addition of the solids to the total quantity of water. These researchers also reported aeration of the whole egg solids before rehydration did not affect dispersibility. Ayres and Slosberg (1949) found albumen pasteurized momentarily at 59.4°C and then dried retained satisfactory solubility. They also reported high temperature storage at 48.9°C for 20 days, 54.4°C for 8 days, or 57.2°C for 4 days had little or no effect on solubility of dried albumen. Banwart and Ayres (1956) stated storage at 50°C of dried albumen containing 3% or 6% moisture for 120 days or 90 days, respectively, did not affect solubility.

Effect of added ingredients. The addition of table salt or sugar to dried egg solids before reconstitution may influence dispersibility or solubility. Sechler et al. (1959) reported the addition of 0 to 4.5 grams of table salt per egg white to dried albumen just prior to reconstitution had no effect on solubility of the albumen. Miller et al. (1959) found dispersibility was not affected by blending dry sucrose with whole egg solids before reconstitution of the solids.

Functional Properties of Albumen

The unique composition and physical properties of albumen enable it to be whipped into stable foams. Some of the contributing factors and interrelationships of foam formation from albumen to angel cake production from the albumen foams are discussed in the following section.

Foam formation

An egg albumen foam is a colloidal dispersion composed of air bubbles as the dispersed gaseous phase and liquid albumen as the dispersing medium. Each air bubble is surrounded by denatured albumen. This denaturation results from the dividing, stretching, and drying of the albumen which occurs during whipping.

According to Lowe (1959) and Griswold (1962), a liquid must have the following characteristics in order to produce a stable foam: low surface tension; low vapor pressure; and the ability to form a semi-rigid surface film. The surface tension of a liquid naturally causes it to form a minimum surface area. Thus, to allow for the great expansion in volume which must occur during foam production, the surface tension of the albumen must be low. Low vapor pressure is necessary to allow for slow evaporation, because too rapid evaporation during foam formation would cause drying before the liquid albumen could be divided and stretched into large foam volume. Finally, the ability to form a semi-rigid surface film is necessary for the incorporation of air bubbles. The particles of denatured protein which are adsorbed at the liquid/gas interface form this semi-rigid surface film in the albumen foam.

Function of proteins. MacDonnell et al. (1955) undertook a study designed to test the foaming ability of each protein fraction alone and in combination with other fractions. These experimenters had noted the liquid which drained from albumen foam did not have the same foam-producing properties as the original albumen. Chemical analysis of the two liquids showed both ovomucin and ovoglobulin were progressively removed by whipping. A reduction in ovomucin content caused an increase in whipping time and a decrease in foam stability. Partial removal of ovoglobulin significantly reduced foam volume. MacDonnell et al. reported the following functional roles for all of the protein fractions in foam formation: ovomucin decreased the whipping time of foam and contributed to its stability; ovoglobulin was responsible primarily for foam volume; ovalbumin, ovomucoid, and conalbumin formed a supporting matrix during baking, but imparted no unique properties to foam formation.

Effect of physical conditions. Several research groups have reported whipping temperature of albumen affected its functional performance. Both St. John and Flor (1930) and Miller and Vail (1943) found albumen whipped at 21.1°C produced greater foam volume than albumen whipped at lower temperatures. Although albumen whipped at 30°C gave greater foam volume than at 21.1°C, St. John and Flor reported a significant decrease in foam stability.

Effect of processing. Freezing, pasteurization and high temperature storage have been reported to affect albumen foam formation. Miller and Vail (1943) reported albumen which had been frozen whipped more rapidly and produced a more stable foam than fresh albumen. After examination of shell eggs subjected to five months storage at below freezing temperatures, Müsil and Orel (1957) reported the volume and stability of foams prepared with defrosted samples had not been affected.

In an early study Barmore (1934) reported heat treatment of albumen at temperatures up to 50°C for 30 minutes did not significantly affect foam formation. Exposure to higher temperatures caused a decrease in foam stability. Employing the method developed by Winter et al. (1946) to flash pasteurize albumen at temperatures of 58°C to 59.4°C, Slosberg et al.(1948) and Ayres and Slosberg (1949) found the albumen retained a satisfactory whipping rate. Clinger et al. (1951), using the same pasteurization method, reported albumen heated at 57°C for 4 minutes required a significant increase in both whipping speed and time to produce foams comparable to those from fresh albumen. Siedeman _et al_. (1963), also employing the pasteurization technique of Winter _et al_., studied the relationship between pasteurization and pH. They found heating albumen at 58°C for 3 minutes with pH varying between 7.0 and 9.5 brought about a significant increase in the whipping time of the albumen. Albumen with a pH near 8.75 and heated under similar conditions whipped faster than the heated albumen with higher or lower pH. After pasteurization for 3 minutes at 60°C and above, Siedeman _et al_. noted a decrease in whipping rate of the albumen regardless of the pH level used.

Ayres and Slosberg (1949) reported a satisfactory whipping rate for foams prepared using dried albumen which had been held under high temperature storage at 48.9°C for 20 days, 54.4°C for 8 days or 57.2°C for 4 days. Storage of dried albumen containing 3% to 6% moisture at 50°C for periods up to 120 days had no significant effect on its whipping properties (Banwart and Ayres, 1956).

Effect of added ingredients. Sechler _et al_. (1959) reported table salt increased the whipping time of the reconstituted albumen when it was added to dried albumen up to the limit of flavor acceptability, 0 to .75 grams per egg white. These researchers also noted decreased volume and stability in foams prepared with salted albumen.

Angel cake production

Albumen foam formation and angel cake production are closely related. The textural characteristics and volume of the angel cakes result from the air incorporated in the albumen during the whipping and folding processes and maintained during the baking period.

Function of proteins. MacDonnell et al. (1955) investigated the functional role of the protein fractions of albumen in foam formation and angel cake production. They found ovoglobulin plus ovomucin, used in the concentrations normally found in albumen, when combined with the other ingredients of angel cake produced a normal batter which increased in volume as usual during baking but then collapsed. These researchers felt this collapse was due to the inability of the expanded protein fractions to support the flour and sugar. Ovalbumin alone produced an angel cake, but the cake lacked many of the qualities of a cake made from whole albumen. A long whipping time was required to produce a foam from ovalbumin, and the resulting cake had coarse texture and small volume. When ovalbumin and ovoglovulin were combined, the cakes prepared with the two fractions had satisfactory volumes, but the investigators found no significant change in the long whipping time required to produce a foam. Cakes prepared with ovalbumin blended with ovomucin had small volumes, but a significant decrease was observed in the whipping time required for foam formation. Cakes prepared from a combination of ovalbumin, ovoglobulin and ovomucin were comparable to the control cakes. MacDonnell et al. reported the following functional roles for all of the protein fractions in angel cake production: ovomucin decreased the whipping time of the basic foam and contributed to its stability; ovoglobulin was responsible primarily for cake volume; ovalbumin, ovomucoid, and conalbumin formed a supporting matrix in the angel cake during baking.

Function of other ingredients. The ingredients other than albumen which are used in angel cake preparation are also important. Gluten from cake flour aids in maintaining the structure of the cake. Sugar tenderizes the egg and flour proteins, but its main function is the production of a more plastic, stable foam.

Cream of tartar has several functions in angel cake preparation. It has a peptizing or tenderizing effect on the egg and flour proteins. It produces an acid medium. Flavone pigments in flour are colorless at neutral or acid pH, but are yellow-green in an alkaline medium. Addition of sufficient cream of tartar insures a white cake. Grewe and Child (1930) stated cream of tartar also guarantees a whiter cake by preventing the browning reaction between amino acids and reducing sugars which might take place at a higher pH.

Effect of pH. Foam stability and angel cake volume are related to pH of foams and cake batters. Miyahara and Bergquist (1961) obtained optimum foam stability and cake volume from foams and batters with a final pH between 5.8 and 6.4. Carlin and Ayres (1953) reported cakes with optimum volume and texture were produced from batters with a final pH of 5.3.

Effect of manipulation. The stage to which the albumen is whipped greatly influences acceptability of angel cakes. If the albumen is underwhipped, too little air is incorporated. Cell membranes of an underwhipped foam are not stretched to their capacity during baking, and the resulting cake has small volume and thick cell walls. Overwhipping incorporates too much air, stretching the cell membranes beyond their normal capacity and reducing their elasticity. As the air expands during baking, many of these inelastic cell walls break, thereby preventing the development of a large cake volume. Optimum whipping of an albumen foam incorporates enough air to expand the cell walls to their limit before oven heat coagulates the albumen. This produces a cake with large volume and thin cell walls. To prevent loss of air and reduction in the volume of the angel cake which might occur during addition of the dry ingredients, Lowe (1959) and Griswold (1962) recommended gently folding the flour sifted with part of the sugar into the foam using a wire whip.

Effect of processing. Freezing, fermentation, pasteurization, and high temperature storage have been reported to affect functional properties of albumen. Miller and Vail (1943) and Clinger et al. (1951) reported no significant differences in volume of cakes prepared with fresh or frozen albumen. Angel cakes prepared with enzyme-fermented albumen had significantly smaller volumes than control cakes prepared from frozen albumen (Carlin and Ayres, 1953). However, Ayres (1958) reported cakes prepared with albumen fermented by *Aerobacter aerogenes* or *Streptococcus lactis* had satisfactory volumes.

Slosberg et al. (1948) found the volumes of angel cakes prepared with albumen which had been momentarily pasteurized at 58°C were not significantly different from the volumes of control cakes. However, cakes prepared with albumen pasteurized at temperatures over 58.9°C had significantly smaller volumes. Clinger et al. (1951) reported albumen pasteurized at 57°C for 4 minutes produced unacceptible angel cakes unless both whipping speed and time of foam production were significantly increased. Even after these increases, satisfactory but not optimum cakes were produced from the pasteurized albumen. Banwart and Ayres (1956) reported angel cakes comparable to the control cakes were prepared from dried albumen subjected to high temperature storage at 50°C for up to 120 days. Siedeman et al. (1963) reported heating albumen at 58°C for 3 minutes with pH varying between 7.0 and 9.5 caused a decrease in volume of angel cakes prepared from this albumen. Albumen with pH near 8.75 and heated under similar conditions produced angel cakes with greater volumes than the heated albumen with higher or lower pH. Cakes prepared with albumen pasteurized at temperatures of 60°C and above had significantly smaller volume regardless of the pH level used.

Objective tests

In order to evaluate differences among several angel cakes, many investigators subject them to a series of objective measurements. The most commonly used include determinations of cake tenderness, compressibility and tensile strength.

Methods used for measurement of compressibility and tensile strength. Platt and Kratz (1933) and Paul *et al.* (1954), using a universal penetrometer fitted with a flat disc, determined compressibility of cake from the distance the crumb was flattened by the known weight of the disc over a specified time period. Platt and Kratz also developed one of the first and most widely used procedures for determination of tensile strength of cake. In this procedure they suspended an hourglass-shaped sample, which measured 3.8 centimeters across the center, from one end by a clamp. A small container was hung from a clamp on the opposite end of the cake. The investigators allowed water to flow into the container at a constant rate of 200 grams per minute until the total weight caused the cake to break or tear across the center section. The total weight consisted of the weights of the container plus water, the lower clamp, and the attached piece of cake. Tensile strength was calculated from the total weight divided by the area of the break. Pyke and Johnson (1940) determined tensile strength by a similar procedure, but modified the apparatus slightly to reduce the danger of accidental damage to the cake sample. In the modified version, they used flat pieces of wood rather than metal clamps to grip the cake sample.

Shear press measurement of tenderness, compressibility, and tensile strength. Kramer et al. (1951) developed the shear press to measure the tenderness of fruits and vegetables. Since that time researchers have used it to test meats and a variety of baked products (Kramer, 1961).

Kramer (1961) stated the basic unit of the shear press consisted of a piston moving at a pre-determined rate powered by a hydraulic drive system. The applied force was measured by compression of a proving ring dynamometer. Proving rings, in a range between 100 and 5,000 pounds, were available for use with cells such as the standard shear-compression cell or the succulometer cell. A sensitive pressure gauge, which was connected to the proving ring and also through an amplifier to a recording device, made it possible to transcribe a continuous recording on chart paper in the form of time-force curves of the force required to shear or compress each food product.

In a review article of the Kramer shear press's current and potential uses, Kramer (1961) stated the shear press could be used to evaluate quality characteristics of baked products, such as tenderness and compressibility. In a very recent investigation Funk (1964) appraised the suitability of the use of the shear press to evaluate tenderness, compressibility, and tensile strength of angel cake. To do this angel cakes were produced to have three different degrees of acceptability, and were subjected to taste panel evaluation as well as to the objective testing. The researchers used the standard shear-compression cell to determine tenderness; both the fixed blade upper assembly of the standard shear-compression cell and the plunger of the succulometer cell to determine compressibility; and a specially designed clamp system to determine tensile strength. The very highly significant correlations between all shear press evaluations based on maximum force and sensory evaluations for tenderness, moistness, cell size, and thickness of cell walls led the investigators to conclude that the Kramer shear press, with appropriate techniques, could be used to evaluate quality characteristics of angel cakes with sufficient precision to show significant differences among variables.

EXPERIMENTAL PROCEDURE

This study was initiated to determine the effect of preheating albumen at 130°F (54.4°C) for approximately 3 minutes prior to spray-drying and the effect of high temperature storage at 128°F (53.3°C) for 5 days following preheating and spray-drying on the physical and functional properties of the albumen. In order to examine fully the effect of preheating and high temperature storage, the following albumen types from each stage of processing were included in the study: (1) liquid albumen, not preheated; (2) liquid albumen, preheated; (3) spray-dried albumen, not preheated; (4) spray-dried albumen, preheated; (5) spray-dried albumen, preheated, and subjected to high temperature storage. Each of the five variables was replicated five times. The investigation was divided into two phases: (1) a study of the physical properties and foaming ability of the albumen; and (2) an evaluation of the functional properties of albumen through a comparison of angel cakes produced from the five types of albumen.

Preliminary Investigations

To compare the effect of heat treatments on the foaming and angel cake-making ability of the five types of albumen, it was necessary to develop methods to control all variables except the processing of the albumen. The whipping time, whipping speed and ingredients in the angel cakes were controlled by following a standard cake formula adapted from KitchenAid Recipes.[1] The whipping time and whipping speed for foam formation were identical to those used for producing the foams of the angel cakes.

Researchers have reported final pH of cake batter affected the qualities of the angel cake produced from this batter. In a study on the preparation of foams and angel cakes from frozen and dried albumen, Miyahara and Bergquist (1961) reported optimum foam stability and cake volume were obtained from foams or batters with a final pH between 5.8 and 6.4. After preparation of angel cakes from albumen which had been frozen, Carlin and Ayres (1953) reported obtaining optimum texture and volume from batters with a final pH of 5.3. The final pH of 5.60-5.80 for both foams and cake batters prepared during this study was selected after reviewing the optimum pH levels reported in the literature. To insure any differences among the angel cakes in this study were due to processing of the albumen, it was necessary to control the final pH of foams and batters.

Two methods have been reported in the literature for control of final foam or batter pH. Miyahara and Bergquist

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[1]KitchenAid Recipes, Hobart Manufacturing Co., Troy, Ohio (1962), page 12.

(1961) reported the initial pH of albumen was adjusted to a predetermined level before the production of foam or angel cake by addition of cream of tartar or sodium hydroxide. The adjusted pH was one which, upon addition of the constant amount of cream of tartar specified in the foam or cake formula, would bring the final pH of the foam or batter to a fixed level. The writer attempted to control the final foam and batter pH using this method of Miyahara and Bergquist; however, she rejected the method because the dried and liquid albumen reacted differently to initial pH adjustment. Although samples of both liquid and reconstituted albumen were adjusted to the same initial pH, addition of a constant amount of cream of tartar did not consistently bring the final pH of foams and batters to a fixed level.

Carlin and Ayres (1953) reported another method for controlling the final pH of angel cake batter. They suggested varying the amount of cream of tartar specified in the cake formula according to the initial pH of the albumen. The writer found this method to be satisfactory for control of final pH of foams and batters prepared using both liquid and reconstituted albumen during the preliminary investigations, and selected it for use in this study.

The following table shows the relative amounts of cream of tartar which were required to produce foams and angel cake batters with a final pH between 5.60 and 5.80 when liquid and reconstituted albumen of known initial pH were used. The writer developed this table through trial and error during the preliminary production of angel cakes and foams.

Table 1. Cream of Tartar Required to Produce Foams and Angel Cake Batters With a Final pH Between 5.6 and 5.8 When Liquid and Reconstituted Albumen of Known Initial pH Were Used.

Albumen Type	Initial pH of Albumen	Cream of Tartar grams
Liquid albumen	6.4 and below	1.4
	6.4-6.6	1.5
	6.6-6.7	1.6
	6.7-6.8	1.7
Reconstituted albumen	8.4-8.7	1.5
	8.7-8.9	1.6

Processing of Albumen

In order to simulate commercial production to obtain products comparable to spray-dried albumen commercially available and yet control the source and processes so that any differences would be due to type and/or extent of heat treatment and not to differences in individual processes, all types of albumen were specially processed in a pilot laboratory of a commercial producer.[2] The processing of the albumen included subjecting it to freezing, fermentation, preheating, spray-drying, and high temperature storage.

Source

The albumen was obtained from a common source of eggs, commercially broken and separated. It was stored in a frozen state at -23.3°C until processed.

Fermentation

Bacterial fermentation was used to remove the free glucose naturally in the albumen. Eggleston (1964) stated the albumen was warmed to 35°C and transferred to a stainless steel vat. A whipping agent, sodium lauryl sulfate, was added on a 0.1% solids basis. To this mixture a "starter culture" composed of liquid albumen containing a glucose-fermenting organism was introduced. Fermentation was completed after approximately 16 hours. Following fermentation approximately one-fifth of the albumen was packaged in one-pound samples and frozen at -23.3°C. The rest was frozen and held at -23.3°C in 30-pound tins until needed for additional processing.

Preheat treatment

Three-fourths of the remaining liquid albumen was preheated at 54.4°C for 3 minutes and then cooled to 35.6°C.

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[2]Henningsen Foods, Inc., Springfield, Missouri.

A quantity was packaged in one-pound samples and frozen at -23.3°C. The remaining portion was frozen and held at -23.3°C in 30-pound tins until needed for drying.

Spray-drying

Quantities of both the control albumen and the preheated albumen were dried separately in a laboratory spray-dryer equipped with a 2-fluid atomization nozzle at temperatures of 112.8°C inlet and 71.1°C outlet. The control spray-dried albumen was packaged as a unit and frozen. The preheated spray-dried albumen was divided in half. Each half was packaged as a unit and frozen and held at -23.3°C.

High temperature storage

One of the packages of preheated spray-dried albumen was subjected to high temperature storage at 53.3°C for 5 days. Following this treatment it was frozen and held at -23.3°C.

Packaging and shipment

The two types of liquid albumen were packaged in one-pound lots in plastic bags protected on the outside by plastic-lined paper cartons. Each of the three types of dried albumen was packaged in a large plastic bag. To retain its original quality, each of the five types of albumen was stored in a frozen state at -23.3°C both before and after processing.

All five types of albumen were shipped by air freight. Because the processor recommended keeping the liquid albumen frozen to protect it from loss in quality during shipping, all cartons containing liquid albumen were shipped packed in dry ice. The bags of spray-dried albumen were not shipped in dry ice as the processor felt spray-dried albumen would retain its quality during the short shipping period. Upon arrival the bulk dried albumen was subdivided into appropriate sample sizes and packaged in closed polyethylene bags. All extra dried albumen was retained in the original plastic bags. Then all samples of both liquid and dried albumen were held at -23.3°C until just prior to testing.

Physical and Functional Properties of Albumen

Before reconstitution of the dried albumen or testing of the liquid albumen each sample was allowed to defrost at 4°C in a refrigerator for approximately 22 hours. Following reconstitution or defrosting the pH of each sample was determined using a Beckman Zeromatic pH meter. The room temperature and humidity were recorded on a Hygro-Thermograph, Model 594, for each day of testing.

Reconstitution of dried albumen

Just prior to reconstitution each sample of dried albumen was allowed to warm to room temperature over a period of approximately 45 minutes. The mixer bowl and paddle attachment to be used for reconstitution were coated with Silicone to reduce the tendency of dried albumen particles to adhere to the metal parts.

All dried albumen samples were reconstituted according to a technique developed by Downs (1964). In this technique, 54.9 (50.7) grams of dried albumen were placed in the bowl of a 5-quart Hobart KitchenAid mixer, Model K-5, and 64 (59) milliliters of distilled water at 25°C was added through a funnel held just above the surface of the albumen to minimize foaming during the addition of the water.[3] The albumen and water were blended for 30 seconds at a speed of 96 planitary revolutions per minute. A powerstat connected to the mixer was used to reduce the rpm to this level. Following this the bowl was scraped and blending was continued for another 30 seconds. At this time 320 (296) milliliters of distilled water at 25°C was added through the funnel. The planitary revolutions of the paddle were further reduced to 68 per minute and the mixture was blended for 30 seconds. The sides of the bowl were again scraped and blending was continued for an additional 15 seconds. After removal of the bowl from the mixer, the reconstituted albumen was poured through a fine gauge

[3]The first set of numerals refers to the ingredient amounts used in reconstitution of albumen to be used for foam production. The second set in parentheses refers to amounts for use in angel cake production.

strainer to remove any lumps of undissolved albumen before the testing period.

Production of albumen foam

The appropriate grams of cream of tartar to be used for each foam were based on the initial pH of the albumen and were selected according to Table 1. The cream of tartar was weighed on a 120-gram capacity Torsion balance just prior to the production of each foam.

Foams were produced from 405 grams of reconstituted or defrosted albumen in a 5-quart Hobart KitchenAid mixer, Model K-5, equipped with a constant temperature bath held at 30-32° C. Each liquid sample was poured into the bowl and warmed to 25°C. Using the whip attachment of the mixer, the albumen was whipped for 35 seconds at speed 4 (132 rpm). The cream of tartar was then added and the two ingredients were whipped for 60 seconds at speed 6 (168 rpm) to produce the albumen foam.

Objective measurements

Objective tests were performed on the dried albumen, on the defrosted or reconstituted albumen, and on the foams produced from the defrosted or reconstituted albumen. These tests included: moisture, dispersibility, and solubility of the spray-dried albumen; relative viscosity and apparent surface tension; specific gravity and stability of the foams.

Moisture of spray-dried albumen. The moisture content of the spray-dried albumen was determined according to the AOAC method 16.3 (b) (1950). Three 2-gram samples of each replication of all three spray-dried variables were weighed into tared aluminum dishes on a Mettler balance, Model H15. The samples were dried to a constant weight (approximately 5 hours) in a vacuum oven at 90-100°C using 28 inches of pressure. Each dried sample was weighed following a cooling period of at least 30 minutes in a dessicator. The percentage moisture listed for each replication represents an average of the percentages from three trials.

Dispersibility of spray-dried albumen. The total dispersion of each preparation of reconstituted albumen was determined according to the technique developed by Downs (1964). Three 5-gram aliquots for each replication of reconstituted albumen were weighed onto tared watch glasses using a Mettler balance, Model H15, and dried to a constant weight (approximately 18 hours) in a vacuum oven at 40-50°C using 28 inches of pressure. Following a 30-minute cooling period in a dessicator, each dried aliquot and watch glass was weighed. The percentage dispersibility was based on the dry weight of the albumen corrected for loss of moisture originally in the product divided by the theoretical weight per 5-gram sample times 100. Each percentage listed represents an average of three readings.

Solubility of spray-dried albumen. The solubility of all types of spray-dried albumen was determined according to the method of Bishov and Mitchell (1954). A 1.0-gram sample of the dried albumen was placed in a 125-milliliter Erlenmeyer flask containing 50 milliliters of 0.90% salt solution. The flask and its contents were agitated for 2 minutes at 240 cycles/minute in a New Brunswick shaking machine, Model 46146-A. After a 5-minute rest period the sample was shaken again for 2 minutes. The mixture was poured into a 40-milliliter thick-walled calibrated centrifuge tube and centrifuged at 2,000 rpm for 30 minutes. Three 5-milliliter aliquots of the supernatent liquid were pipetted into 15-milliliter graduated centrifuge tubes. Each tube was then filled with 10 milliliters of Esbach reagent and the contents were stirred with a glass rod. Following stirring the tubes were centrifuged at 2,000 rpm for 15 minutes. The volume of the precipitate was then read to the nearest five-hundredth milliliter and was recorded as the solubility index. Each recorded solubility index represents an average from three trials.

Viscosity. Relative viscosity was determined by comparing the timed flow of liquid or reconstituted albumen at 25°C with the timed flow of triple distilled water at 25°C through a Mohr pipette. This technique was developed by Jordan and Whitlock (1955). The same pipette, with the orifice enlarged by cutting off part of the tip, was used for all determinations. It was rinsed with distilled water, thoroughly dried by unheated forced air, and allowed to return to room temperature between each reading. Timing was done with a stop watch calibrated to one-hundredths of a second. The relative viscosity was calculated from the timed flow in seconds of the albumen divided by the average timed flow in seconds of distilled water. The final quotient represents an average of the quotients from three trials.

Surface tension. The apparent surface tension of each variable was measured with a Fisher Surface Tensiometer, Model 20. All albumen samples were tested at 25°C. Between each of the three readings for a single sample of albumen, the platinum ring of the tensiometer was rinsed with distilled water and blotted. Between replications the ring was rinsed in both benzene and acetone. After blotting it was flamed using a bunsen burner. The three readings taken for each sample were averaged for the final reading.

Specific gravity of foam. The specific gravity of each foam was determined according to the method of Platt and Kratz (1933). Their technique involved a comparison of the average weight of one-half cup of foam to the average weight of one-half cup of water at 25°C. The foam was removed from the bowl at the points of an equilateral triangle 1 1/2-2 inches from the sides of the bowl. An ice cream scoop was used to dip out the foam samples. As each half-cup was filled with foam and was leveled with a metal spatula, care was taken not to destroy the foam structure. The specific gravity was computed by dividing the weight of the foam by the average weight of the water. Three quotients were averaged to obtain the final reading.

Foam stability. Foam stability was measured according to the technique described by Lowe (1959). The same half-cup of foam used in determination of specific gravity was inverted into a 100-millimeter diameter funnel placed in a 100-milliliter graduated cylinder. The funnel was tightly covered with Saran to prevent loss of any liquid through evaporation. The milliliters of drainage were read after 30 minutes. The drainage value for each replication represents an average of three readings. During the drainage period an additional half-cup of foam was removed from the mixer bowl for measurement of final pH of the foam using a Beckman Zeromatic pH meter.

Product Formation Using Albumen

A second phase of this study evaluated the foaming ability of the five types of albumen in actual product formation. The writer selected angel cake as representative of products commonly prepared using albumen foams.

Basic formula

The basic formula for angel cake contained constant proportions of liquid or reconstituted albumen, sugar, cake flour and salt:

Ingredients	Gram Amounts
Liquid or Reconstituted Albumen	405
Sugar	310
Cake Flour	120
Salt	1.9

The appropriate grams of cream of tartar for each cake batter were based on the initial pH of the albumen and were selected according to Table 1.

Sufficient amounts of the original five types of albumen had been procured for this phase of the study. The remainder of the ingredients were secured from Michigan State University Stores. At the start of the experiment the sugar was blended in a Hobart mixer, Model A-200, to produce a homogeneous lot. It was packaged in two series of polyethylene bags, one containing 250 grams, and the other 60 grams. The original quantity of cake flour was thoroughly mixed by hand. The entire 120 grams of flour for each cake was packaged in the same polyethylene bag as the 60 grams of sugar. Both sugar and flour were weighed on a 5-kilogram capacity Toledo scale. All bags were securely tied and stored at room temperature. The salt and cream of tartar were weighed individually on a 120-gram capacity Torsion balance just prior to the production of each cake.

Method of preparation

The liquid or reconstituted albumen was weighed into the bowl of a 5-quart Hobart KitchenAid mixer, Model K-5, equipped with a constant temperature bath held at 30-32°C, and warmed to 25°C. Using the whip attachment the albumen was then whipped for 35 seconds at speed 4 (132 rpm). The salt and cream of tartar were added and whipping was continued for 60 seconds at speed 6 (168 rpm). At this time 250 grams of sugar were added gradually over a 35-second interval during which the mixer was operating at speed 2 (92 rpm). After the sides of the bowl had been scraped, the mixture was whipped for an additional 5 seconds at speed 6. The bowl was then removed from the mixer.

The sugar-flour mixture had been previously sifted together 3 times. This mixture was divided into four portions of approximately one-third cup each. Using a large wire whip, each portion was folded into the batter by hand. A total of 12 strokes, with a quarter turn of the bowl after each stroke, was used in folding each portion. At the completion of the folding period, the specific gravity of the batter was determined. This test batter was saved for later measurement of batter pH.

Following determination of specific gravity, 700 grams of batter was weighed into a 15 1/2 x 4x4-inch aluminum loaf pan, and cut through with a metal spatula to reduce large air bubbles. Each cake was individually baked at 350°F for 40 minutes in an Etco forced air oven, Model 186-A, equipped with a Minneapolis-Honeywell Versatronic Controller. After baking the pan was inverted and the cake was allowed to cool for 90 minutes before a determination of cake volume was made.

Preparation of samples

After volume determination, each cake was removed from the pan, wrapped in Saran, placed in a closed polyethylene bag, and frozen and stored at -23.3°C. The preparation of cakes from the albumen variables was randomized so the total frozen storage of all cakes prepared from each variable was 16-18 days.

Prior to testing the frozen cake was sliced on a Hobart electric slicer, Model 410, set at 70. Each cake slice was designated for use according to the predetermined sequence described in Figure 1. After the removal of crust slices, one slice between the center and an end, one center slice, and one end slice were reserved for each of the three shear press measurements. Also one end and one inner slice were selected for determination of cake moisture, and observation and photographic recording of cell structure if visible differences were noted. In addition there were three extra slices.

Figure 1. Sequence for Cutting and Testing the Slices of Angel Cakes Prepared with Liquid and Reconstituted Albumen.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Crust	Compressibility	Tensile Strength	Extra	Moisture	Tenderness	Extra	Cell Structure	Compressibility	Tenderness	Tensile Strength	Extra	Compressibility	Tensile Strength	Cell Structure	Moisture	Tenderness	Crust

Those slices which were to be tested by the shear press were cut by specially designed stainless steel cutters. Each sample was then wrapped in Saran and allowed to thaw for at least 30 minutes at room temperature before testing.

Objective measurements

Several objective tests were used to evaluate the cake batters and angel cakes prepared with the five types of albumen. These measurements included determination of specific gravity of batters, as well as volume, moisture, tenderness, compressibility, and tensile strength of the angel cakes.

Specific gravity of batter. The technique for measurement of specific gravity of each cake batter was identical to the one used for specific gravity of each foam. One determination of specific gravity was made for each batter.

Volume of cake. Volume was measured by modification of the method used by King et al. (1936). The surface of the cake was covered with Saran while the cake was still in the pan. The Saran was eased in places to follow the contour of the surface. The cake, still in the pan, was placed in the bottom of a large roasting pan. Rape seed was poured onto the covered surface of the cake. As the amount of rape seed was leveled with the top of the cake pan, any extra seed fell into the roasting pan. After removal of the extra seed, the pan containing cake and seed was inverted into the roasting pan which collected the rape seed. This seed was then transferred from the roasting pan into a 1000-milliliter graduated cylinder for measurement. The volume of the cake was recorded as the difference between the milliliters of seed measured by the above method and the milliliters of seed which the empty loaf pan would hold. One determination of volume was made from each cake.

Moisture of cake. Cake moisture was determined by drying 2.0-gram shredded samples of cake to a constant weight. The equipment, time, and procedure were the same as those used for determination of spray-dried albumen moisture content.

Tenderness of cake. The standard shear-compression cell of the Allo-Kramer shear press, Model SP-12, equipped with an electronic recorder was used to measure tenderness. For this measurement the 3000-pound proving ring, a range of 300 pounds, and a pressure of 20 pounds were used. In a predetermined randomized order, the cake samples, 5.72 centimeters square and 2.02 centimeters thick, were weighed just prior to testing. Each weighed sample was placed individually in the lower half of the cell. The upper assembly of the cell sheared the sample during a 30-second downstroke. Between all tenderness determinations both sections of the cell were thoroughly washed with lukewarm water and dried with unheated forced air.

The peak of the graphed curve drawn by the electronic recorder was used to compute the maximum force needed to shear the sample. Tenderness was calculated as: peak reading times range divided by sample weight. Each final reading of tenderness based on maximum force represents an average of three trials.

The area of the complete graph curve was also used as an indication of cake tenderness. Each tenderness curve was carefully cut out and weighed on a Mettler balance, Model H15. A conversion factor of 174.2 for changing gram weight to area had been determined by weighing multiple squares of varying known area from random locations on similar chart paper. The numerical data and calibration curve for derivation of this factor appear in the Appendix. The area of each curve was obtained from multiplication of the curve weight times the conversion factor. The area-under-the-tenderness-curve value was calculated as: area-under-the-curve divided by the original sample weight. Each value represents an average of three trials.

Compressibility of cake. Compressibility was measured with a round, flat plunger, 5.73 centimeters in diameter, which is part of the succulometer cell. For this measurement the 100-pound electronic proving ring, a range of 5 pounds, and a pressure of 20 pounds were used. Extra weight was added to the plunger by winding solder around the shaft. This was done to make less adjustment of the shear press necessary during the interchanging of the three attachments used for testing angel cake. A circular sample of cake, 5.08 centimeters in diameter and 2.02 centimeters thick, was depressed on a wooden platform placed on the support plates at the base of the main column of the shear press. The plunger traveled on a downward stroke timed at 30 seconds as it depressed each cake sample to a thickness of 0.72 centimeters (see Figure 2). Each cake sample was depressed three consecutive times to measure the recovery and continuation of compressibility. The peak of the graphed curve was used to compute the maximum force needed to compress the sample. Compressibility was calculated as: peak reading times range. Each final reading of compressibility based on maximum force represents an average of three trials.

The complete graph curve area of the first compression curve was also used to indicate cake compressibility. After carefully cutting out and weighing the curve, the area-under-the-first-compression-curve value was calculated as: weight

Figure 2. Shear Press in Operation During Measurement of the Compressibility of Angel Cake.

of curve times conversion factor. Each value represents an average of three readings.

Tensile strength of cake. Tensile strength was measured by a specially designed attachment for the shear press (Wise, 1964). The ring, range, and pressure were identical to those used for compressibility. Acco clamps, Model 325, modified by substituting a light weight spring to reduce damage to cake samples, were fastened to a U-shaped base plate and an upper plate of size necessary to attach to the proving ring. A set screw in each clamp added further adjustment. The tensile strength apparatus is illustrated in Figure 3. By rewinding the chart drive cable of the shear press it was possible to obtain a graph recording on the upstroke of the piston, when the proving ring was adjusted to give positive graph readings from a negative pull. As illustrated in Figure 4, the samples used for determination of tensile strength were cut in an hourglass shape which measured 2.54 centimeters across the center and 2.02 centimeters thick. The proving ring with the upper tensile strength attachment was run down to almost the end of its stroke. The ends of the cake sample were carefully inserted into the clamps. Figure 5 shows the relative positions of proving ring, tensile strength attachments and cake sample before the start of each trial. As the proving ring and upper attachment started the upstroke, the sample was pulled apart at the center section.

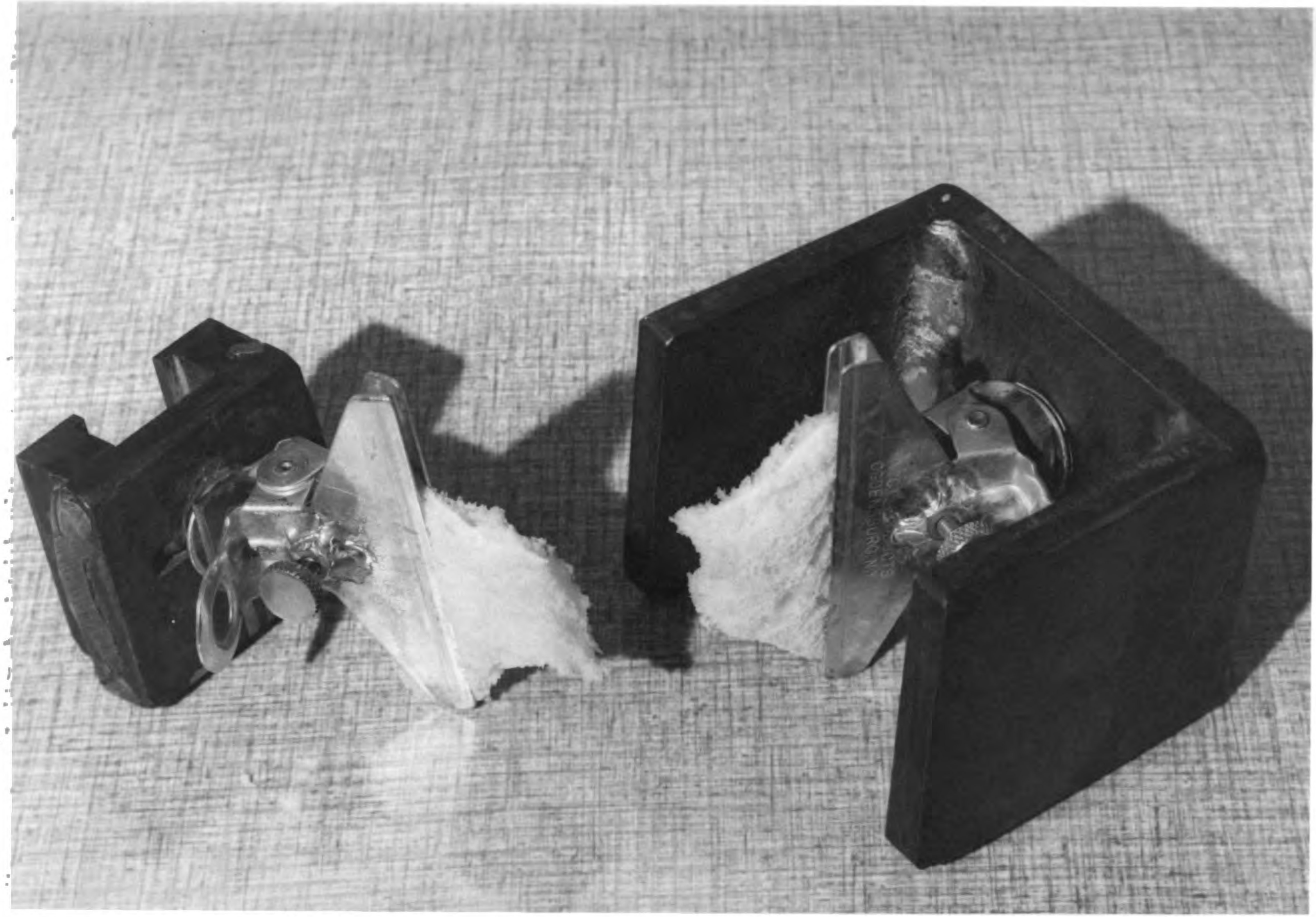

Figure 3. Specially Designed Attachment for the Determination of Tensile Strength of Angel Cake.

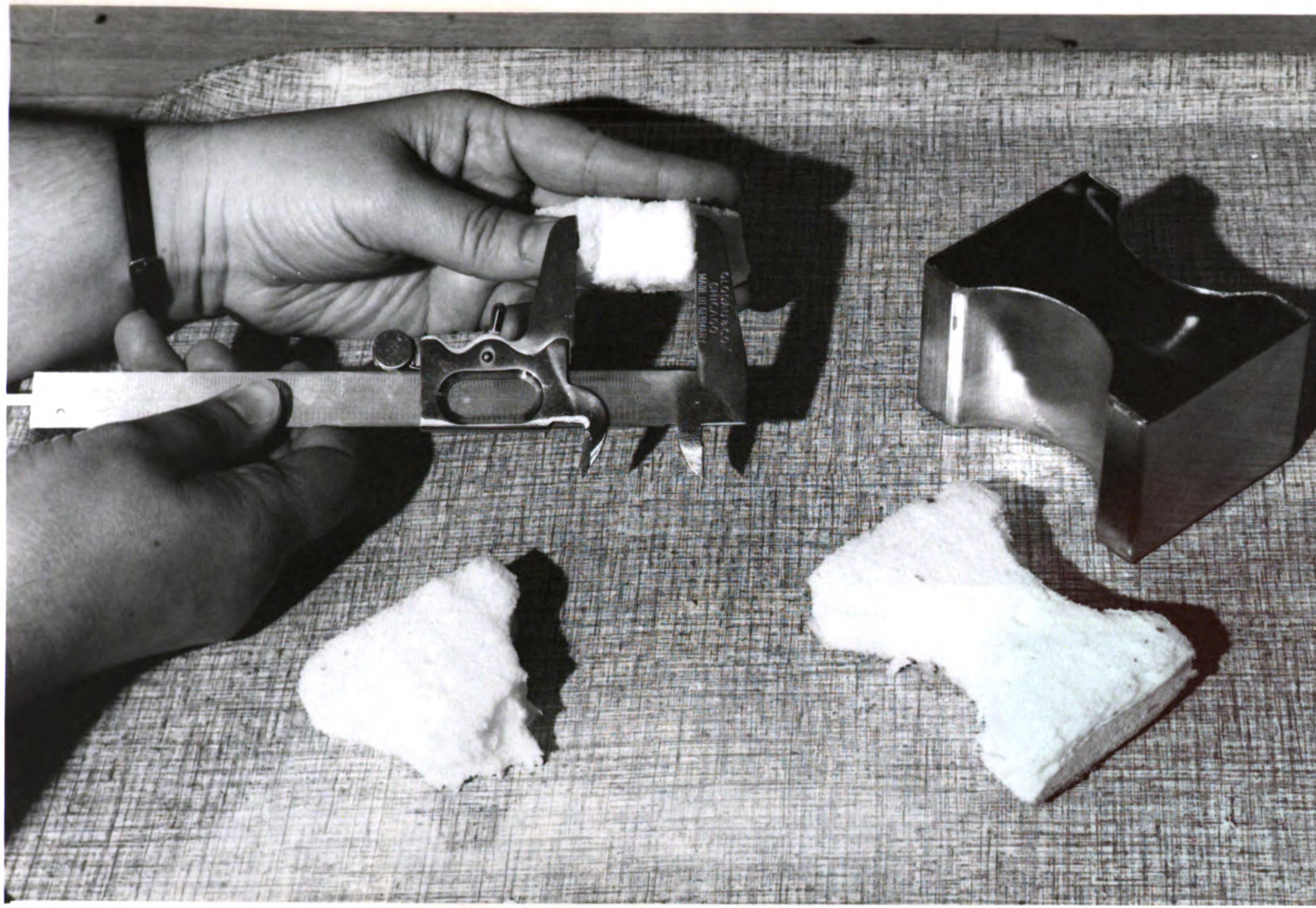

Figure 4. Tensile Strength Sample Cutter and Calipers Used to Measure the Length of the Break Across the Sample.

Figure 5. Measurement of the Tensile Strength of Angel Cake by the Shear Press.

The peak of the graphed curve was used to compute the maximum force needed to pull the sample apart. The length of the break on the bottom half of the sample was measured with calipers. Tensile strength was calculated as: peak reading times range divided by area of break (length of break times width of sample). Each reading represents an average of three trials.

The area of the complete graph curve was also used as an indication of cake tensile strength. After each curve was cut out and weighed, curve area was computed as: weight of curve times conversion factor. The complete area-under-the-tensile-strength-curve value was calculated as: area-under-the-curve divided by area of the break. Each final value represents an average of three trials.

Analysis of Data

The data obtained from all of the tests were evaluated by use of two computer programs on the CDC 3600 Computer at the Michigan State University Computer Center. The RAND Routine (Option 1) was used to calculate analysis of variance and the CORE Routine was used to determine simple correlations. Significant differences among types of albumen were evaluated through the use of the Studentized range tests (Duncan, 1955).

RESULTS AND DISCUSSION

This study was undertaken to determine the effect of preheating per se, and preheating in conjunction with spray-drying and subsequent high temperature storage on the physical and functional properties of albumen. In order to examine fully the effect of the heat treatments, the following albumen types from each stage of processing were included in the study: (1) liquid albumen, not preheated; (2) liquid albumen, preheated; (3) spray-dried albumen, not preheated; (4) spray-dried albumen, preheated; (5) spray-dried albumen, preheated, and subjected to high temperature storage.

The investigation was divided into two phases: (1) a study of the physical properties and foaming ability of the albumen, and (2) an evaluation of the functional properties of albumen through a comparison of angel cakes prepared from the five types of albumen. Methods were developed in the laboratory to control all variables except processing of albumen. The albumen was supplied according to specification by a commercial processor. The results of the study were examined in an attempt to determine whether the effects of preheating, spray-drying, and high temperature storage were additive, or if an interaction occurred among the three processes.

Physical and Functional Properties of Spray-dried, Liquid and Reconstituted Albumen

The numerical data from objective measurements of the physical and functional properties of the albumen were subjected to analyses of variance. Studentized multiple range tests were used to evaluate significant differences disclosed by the analyses of variance (Duncan, 1955). Tables of values which were significant from both analyses of variance and Studentized multiple range tests accompany the discussion of these results.

Objective measurements of spray-dried albumen

The replicate means, albumen type means, and standard deviations for moisture content, dispersibility, and the solubility index of the three types of spray-dried albumen are given in the Appendix.

Moisture, dispersibility, and solubility. Analysis of variance for spray-dried albumen moisture content (Table 2) disclosed highly significant differences which could be attributed to processing of the albumen. Comparison of albumen type means showed albumen which had been preheated and dried possessed a lower moisture content, at the 1 per cent level of probability, than albumen which had been either dried or preheated, dried, and stored at high temperature.[4] The latter two types of treatments were not found to be

[4]Denotes all processes to which a type of albumen had been subjected.

Table 2. Analysis of Variance for Moisture Content Values of Spray-dried Albumen.

Source of Variance	Degrees of Freedom	Mean Square	F Ratio
Types of Albumen	2	1.84	14.72*
Replicates	4	.53	
Error	8	.125	
Total	14		

*Significant at 1 per cent level of probability.

STUDENTIZED MULTIPLE RANGE TEST[a]

1% Level:

Preheated, dried	Preheated, dried, high temp. storage	Dried
1.93	2.69	3.13

5% Level:

Preheated, dried	Preheated, dried, high temp. storage	Dried

[a]Means underscored by the same line are not significantly different (Duncan, 1955).

significantly different. Several theories might be advanced to explain these results. The albumen was dried in two runs: one for the control albumen, and another for the preheated albumen. Slight fluctuations in drying temperatures or in drying end point could have caused the difference in moisture content between albumen which had been dried, and albumen which had been preheated and dried. Moisture could have been absorbed by the albumen which had been preheated, dried, and subjected to high temperature storage during the storage period. It is also possible preheating the albumen before spray-drying caused a greater moisture loss than spray-drying alone. More conclusive evidence on reasons for differences in moisture content must come from further investigation.

Analysis of variance for dispersibility and solubility of the three types of spray-dried albumen revealed no significant differences due to processing. The results of the test for solubility agree with those reported by Ayres and Slosberg (1949) and Banwart and Ayres (1956) who found solubility of spray-dried albumen was not significantly affected by pasteurization before drying or by high temperature storage following drying.

Objective measurements of liquid and reconstituted albumen

The replicate means, albumen type means, and standard deviations for relative viscosity and apparent surface tension of liquid and reconstituted albumen as well as for the specific gravity and stability of foams prepared from this albumen are recorded in the Appendix.

The final pH values of the foams were not analyzed because there were no apparent differences in pH ranges among the albumen types. A complete listing of pH ranges is included in the Appendix. Examination of room temperatures and humidities recorded on the testing days showed no apparent relationship to the results obtained in the study.

Relative viscosity. Analysis of variance for relative viscosity of the five types of albumen, as shown in Table 3, revealed highly significant differences which could be traced to processing of the albumen. At the 1 per cent level of probability, comparison of albumen type means disclosed albumen which had been frozen and reconstituted albumen which had been given any of the three spray-drying treatments had lower viscosities than did albumen which had been preheated.

These results indicate the spray-drying process had no significant effect on albumen viscosity, but preheating liquid albumen at 54.4°C for 3 minutes caused a significant increase in viscosity. However, when the preheating treatment was followed by spray-drying or by spray-drying and storage at high temperature, the adverse effect of preheating on albumen viscosity was negated. The above results differ from those of Siedeman et al. (1963) who found

Table 3. Analysis of Variance for Relative Viscosity Values of Liquid and Reconstituted Albumen.

Source of Variance	Degrees of Freedom	Mean Square	F Ratio
Types of Albumen	4	.004274	12.42*
Replicates	4	.004274	
Error	16	.000344	
Total	24		

*Significant at 1 per cent level of probability.

STUDENTIZED MULTIPLE RANGE TEST[a]

1% Level:

Preheated, dried	Dried	Preheated, dried, high temp. storage	Frozen[b]	Preheated
1.03	1.04	1.04	1.05	1.10

5% Level:

Preheated, dried	Dried	Preheated, dried, high temp. storage	Frozen	Preheated

[a]Means underscored by same line are not significantly different (Duncan, 1955)

[b]Term used interchangeably with liquid albumen, not preheated.

pasteurization at 58°C for 3 minutes had no effect on albumen viscosity. These conflicting results may be attributed to differences in processing temperature, processing technique, method of determining viscosity, or type of albumen, i.e., fermented or unfermented albumen, or a combination of these.

Apparent surface tension. Analysis of variance for apparent surface tension (Table 4) showed highly significant differences among the five types of albumen. Comparison of albumen type means revealed albumen which had been subjected to any of the four types of heat treatments had lower surface tension, at the 1 per cent level of probability, than did albumen which had been frozen. Additional significance at the 5 per cent level of probability disclosed reconstituted albumen which had been preheated and dried possessed lower surface tension than did reconstituted albumen which had been dried.

These results indicate the treatments of preheating, spray-drying and high temperature storage, alone or in combination, caused a significant reduction in the apparent surface tension of the albumen. Of these treatments spray-drying caused the least reduction. The findings of Siedeman et al. (1963), who reported pasteurization at 58°C for 3 minutes had no effect on albumen surface tension, differed from the above results. This divergence in results

Table 4. Analysis of Variance for Apparent Surface Tension Values of Liquid and Reconstituted Albumen.

Source of Variance	Degrees of Freedom	Mean Square	F Ratio
Types of Albumen	4	9.8264	8.90*
Replicates	4	3.9624	
Error	16	1.1039	
Total	24		

*Significant at 1 per cent level of probability.

STUDENTIZED MULTIPLE RANGE TEST[a]

1% Level:

Preheated dried	Preheated, dried, high temp. storage	Preheated	Dried	Frozen
51.4	51.8	52.3	53.0	54.9

(Line under: Preheated dried through Dried)

5% Level:

Preheated dried	Preheated, dried, high temp. storage	Preheated	Dried	Frozen

(Lines under: Preheated dried through Preheated; Preheated, dried, high temp. storage through Dried)

[a]Means underscored by same line are not significantly different (Duncan, 1955).

may be attributed to different processing temperatures, processing techniques, or type of albumen, or a combination of these factors.

Specific gravity of foam. Analysis of variance for specific gravity of foams, as shown in Table 5, revealed highly significant differences attributable to heat processing of albumen. Comparison of albumen type means showed the following differences were significant at the 1 per cent level of probability. Foams prepared from albumen which had been frozen had lower specific gravities than did foams prepared with albumen which had been subjected to any of the four types of heat treatments. Foams prepared with reconstituted albumen which had been given any of the three spray-drying treatments exhibited lower specific gravities than did foams prepared using albumen which had been preheated. In addition, the specific gravity of foams prepared with reconstituted albumen which had been either dried or preheated and dried was lower than the specific gravity of foams prepared with reconstituted albumen which had been preheated, dried, and stored at high temperature.

Thus, although the results indicate heating the albumen brought about a significant increase in the specific gravity of foams prepared using any of the four types of heated albumen, the greatest increase in specific gravity occurred in foams prepared with albumen which had been

Table 5. Analysis of Variance for Specific Gravity Values of Foams Prepared with Liquid and Reconstituted Albumen.

Source of Variance	Degrees of Freedom	Mean Square	F Ratio
Types of Albumen	4	.00117	23.40*
Replicates	4	.00002	
Error	16	.00005	
Total	24		

*Significant at 1 per cent level of probability.

STUDENTIZED MULTIPLE RANGE TEST[a]

1% Level:

Frozen	Preheated, dried	Dried	Preheated, dried, high temp. storage	Preheated
.115	.135	.136	.140	.158

5% Level:

Frozen	Preheated, dried	Dried	Preheated, dried, high temp. storage	Preheated

[a]Means underscored by same line are not significantly different (Duncan, 1955).

preheated, and the second greatest increase occurred in foams prepared with reconstituted albumen which had been preheated, dried, and stored at high temperature. These results agree with those of Clinger et al. (1951) who reported a significant increase in specific gravity of foams prepared with albumen which had been pasteurized.

Foam stability. Analysis of variance for foam stability measured as milliliters of drainage from the foams (Table 6) showed highly significant differences which could be attributed to processing of the albumen. Comparison of albumen type means disclosed stability of foams prepared with albumen which had been frozen was greater, at the 1 per cent level of probability, than was the stability of foams prepared with albumen which had been subjected to any of the four types of heat treatments. Also at the 1 per cent level of probability, foams prepared with reconstituted albumen which had been either dried or preheated, dried, and stored at high temperature were more stable than were foams prepared with albumen which had been preheated. Additional significance at the 5 per cent level indicated stability of foams prepared with reconstituted albumen which had been preheated and dried was greater than was the stability of foams prepared with albumen which had been preheated.

Thus, although the results reveal heating the albumen brought about a significant decrease in stability of foams

Table 6. Analysis of Variance for Milliliters of Drainage Values of Foams Prepared with Liquid and Reconstituted Albumen.

Source of Variance	Degrees of Freedom	Mean Square	F Ratio
Types of Albumen	4	13.1670	18.08*
Replicates	4	.3350	
Error	16	.7282	
Total	24		

*Significant at 1 per cent level of probability.

STUDENTIZED MULTIPLE RANGE TEST[a]

1% Level:

Frozen	Dried	Preheated, dried, high temp. storage	Preheated, dried	Preheated
5.7	7.9	8.5	8.5	10.2

5% Level:

Frozen	Dried	Preheated, dried, high temp. storage	Preheated, dried	Preheated

[a]Means underscored by the same line are not significantly different (Duncan, 1955).

prepared with the heated albumen, the greatest decrease occurred in foams prepared with albumen which had been preheated. This decrease is in accord with a similar decrease in stability of foams prepared with albumen which had been exposed to temperatures over 50°C (Barmore, 1934). Further examination of the above results reveals the adverse effects of preheating were reduced when albumen which had been preheated was subjected to further heat treatments in the form of spray-drying or high temperature storage.

Product Formation Using Albumen

The numerical data from objective measurements during and after preparation of angel cakes using liquid and reconstituted albumen were subjected to analyses of variance. Studentized multiple range tests were used to evaluate significant differences revealed by the analyses of variance (Duncan, 1955). The values which were significant from both analyses of variance and Studentized multiple range tests are given in tables which accompany the discussion of these results.

Objective measurements

The replicate means, albumen type means, and standard deviations for specific gravity of batters, and the volume and moisture content of angel cakes prepared using liquid and reconstituted albumen are recorded in the Appendix. The replicate means, albumen type means and standard deviations for compressibility, tenderness, and tensile strength of angel cakes are also given in the Appendix.

The final pH values of the batters were not analyzed because no differences were apparent. A complete listing of pH ranges is included in the Appendix. Photographs of angel cake cellular structure were not taken because no obvious differences could be observed. Examination of room temperatures and humidities recorded on the testing days showed no apparent relationship to the results obtained in the study.

Specific gravity of batter. Analysis of variance for specific gravity of cake batters (Table 7) revealed highly significant differences due to processing of the albumen. Comparison of albumen type means showed the following differences were significant at the 1 per cent level. Batters prepared with albumen which had been frozen had lower specific gravities than did batters prepared with albumen which had been subjected to any of the four types of heat treatments. Batters prepared with albumen which had been preheated exhibited lower specific gravities than did batters prepared with reconstituted albumen which had been either dried or preheated and dried. In addition, at the 5 per cent level of probability,

Table 7. Analysis of Variance for Specific Gravity of Batter Values of Angel Cakes Prepared with Liquid and Reconstituted Albumen.

Source of Variance	Degrees of Freedom	Mean Square	F Ratio
Types of Albumen	4	.00107	50.35*
Replicates	4	.00006	
Error	16	.00002	
Total	24		

*Significant at 1 per cent level of probability.

STUDENTIZED MULTIPLE RANGE TEST[a]

1% Level:

Frozen	Preheated	Preheated, high temp. storage	dried,	Dried	Preheated, dried
.338	.361	.368		.372	.374

5% Level:

Frozen	Preheated	Preheated, high temp. storage	dried,	Dried	Preheated, dried

[a]Means underscored by same line are not significantly different (Duncan, 1955).

batters prepared with albumen which had been preheated had lower specific gravities than did batters prepared with reconstituted albumen which had been preheated, dried, and stored at high temperature.

Thus, although the results indicate heating the albumen brought about a significant increase in specific gravity of batters prepared with the heated albumen, the greatest increase in specific gravity occurred in the three batters prepared with reconstituted albumen which had been spray-dried. These results are in contrast to those results obtained from analyses of specific gravity of foams for which the greatest increase was noted in foams prepared with albumen which had been preheated. This suggests foams prepared with albumen which had been preheated were more stable to the incorporation of flour and sugar than were foams prepared with reconstituted albumen which had been spray-dried.

Volume of cake. Analysis of variance for volume of angel cakes (Table 8) disclosed highly significant differences which could be traced to processing of the albumen. Comparison of albumen type means showed the following differences were significant at the 1 per cent level of probability. Cakes prepared with albumen which had been frozen, and reconstituted albumen which had been either preheated and dried, or preheated, dried, and stored at high temperature had greater volumes than did cakes prepared

Table 8. Analysis of Variance for Volume Values of Angel Cakes Prepared with Liquid and Reconstituted Albumen.

Source of Variance	Degrees of Freedom	Mean Square	F Ratio
Types of Albumen	4	23880.00	9.44*
Replicates	4	5200.00	
Error	16	2530.00	
Total	24		

*Significant at 1 per cent level of probability.

STUDENTIZED MULTIPLE RANGE TEST[a]

1% Level:

Preheated	Dried	Preheated, high temp.	dried, storage	Preheated, dried	Frozen
3160	3228	3300		3304	3328

5% Level:

Preheated	Dried	Preheated, high temp.	dried, storage	Preheated, dried	Frozen

[a]Means underscored by same line are not significantly different (Duncan, 1955).

with albumen which had been preheated. The volumes of cakes prepared with albumen which had been frozen were greater than were volumes of cakes prepared with reconstituted albumen which had been dried. Additional significance at the 5 per cent level of probability showed cakes prepared with reconstituted albumen which had been dried exhibited greater volumes than did cakes prepared with albumen which had been preheated. Also at the 5 per cent level of probability, cakes prepared with reconstituted albumen which had been either preheated and dried, or preheated, dried and stored at high temperature had greater volumes than did cakes prepared with reconstituted albumen which had been dried.

These results disclose a significant decrease in volume of angel cakes prepared with albumen which had been preheated. This is in accord with the findings of Slosberg et al. (1948), Clinger et al. (1951), and Siedeman et al. (1963). These investigators have reported a reduction in volume of angel cakes prepared with albumen which had been pasteurized at 57-59°C for up to 4 minutes.

The results also reveal a decrease in cake volume was brought about by spray-drying the albumen. It is interesting to note additional heat treatment of the albumen in the form of preheating before drying or high temperature storage following drying negated the effect of spray-drying to the extent that volumes of cakes prepared with reconstituted albumen which had been either preheated and dried, or preheated, dried, and stored at high temperature were not significantly different from volumes of cakes prepared with albumen which had been frozen.

Moisture of cake. Analysis of variance revealed no significant differences in moisture content of angel cakes due to processing of the albumen. Thus, although there were differences in the original moisture content among the three types of spray-dried albumen, these differences were not carried through into moisture content of angel cakes prepared with the three types of albumen.

Shear press measurements of compressibility, tenderness, and tensile strength. Analysis of variance disclosed highly significant differences in compressibility of angel cakes prepared with albumen processed in five different ways (Table 9). Comparison of albumen type means for all three successive compressions indicated that for each compression, angel cakes prepared with albumen which had been frozen were more compressible, at the 1 per cent level of probability, than were cakes prepared with albumen which had been preheated, or reconstituted albumen which had been either preheated and dried, or preheated, dried, and stored at high temperature. Also at the 1 per cent level of probability, cakes prepared with reconstituted albumen which had been spray-dried were significantly more compressible than cakes prepared with reconstituted albumen which had been preheated and dried.

Table 9. Analysis of Variance for Shear Press Maximum Force Values of Compressibility for Each of Three Successive Compressions of Angel Cakes Prepared with Liquid and Reconstituted Albumen.

Source of Variance	Degrees of Freedom	Mean Square	F Ratio
	First Compression		
Types of Albumen	4	25054.51	7.89*
Replicates	4	14985.91	
Error	16	3177.00	
Total	24		
	Second Compression		
Types of Albumen	4	20684.93	7.55*
Replicates	4	16393.14	
Error	16	2738.54	
Total	24		
	Third Compression		
Types of Albumen	4	17827.28	7.44*
Replicates	4	16669.29	
Error	16	2397.05	
Total	24		

*Significant at 1 per cent level of probability.

Table 9 (Continued)

STUDENTIZED MULTIPLE RANGE TEST[a]

1% Level:

Frozen	Dried	Preheated	Preheated, dried, high temp. storage	Preheated, dried
662.39	720.60	773.98	790.61	848.52
601.61	650.60	708.51	720.15	767.02
567.90	617.49	666.48	675.24	724.54

5% Level:

Frozen	Dried	Preheated	Preheated, dried, high temp. storage	Preheated, dried

[a]Means underscored by same line are not significantly different (Duncan, 1955).

These results indicate preheating albumen brought about a significant decrease in compressibility of cakes prepared with albumen which had been preheated, as well as in those prepared with reconstituted albumen which had been either preheated and dried, or preheated, dried, and stored at high temperature. Cakes prepared using reconstituted albumen which had been spray-dried were not significantly different in compressibility from cakes prepared with albumen which had been frozen.

Shown in Table 10, analysis of variance for area-under-the-first-compression-curve values of angel cakes prepared with the five types of albumen revealed significant differences only at the 5 per cent level of probability. Also fewer significant differences among albumen type means were disclosed by the Studentized range test for area-under-the-first-compression-curve values than had been disclosed among the albumen type means for maximum force values. Comparison of albumen type means indicated there were greater values for area-under-the first-compression-curves of cakes prepared with reconstituted albumen which had been preheated and dried than there were for curves of cakes prepared with albumen which had been subjected to the other four types of processing. Thus, these results point out more force was necessary to compress the cakes prepared with reconstituted albumen which had been preheated and dried, and these cakes were therefore less compressible.

Table 10. Analysis of Variance for Area-Under-the-First Compression-Curve Values of Angel Cakes Prepared with Liquid and Reconstituted Albumen.

Source of Variance	Degrees of Freedom	Mean Square	F Ratio
Types of Albumen	4	.10546	4.57*
Replicates	4	.19409	
Error	16	.02310	
Total	24		

*Significant at 5 per cent level of probability.

STUDENTIZED MULTIPLE RANGE TEST[a]

5% Level:

Frozen	Dried	Preheated	Preheated, dried, high temp. storage	Preheated, dried
1.27	1.28	1.42	1.42	1.63

(Underscored together: Frozen, Dried, Preheated, Preheated, dried, high temp. storage)

[a]Means underscored by same line are not significantly different (Duncan, 1955).

Analysis of variance showed no significant differences in the following measurements of angel cakes prepared using the five types of albumen: tenderness values based on maximum force; area-under-the-tenderness-curve values; tensile strength values based on maximum force; and area-under-the-tensile-strength-curve values. Thus, although significant differences were revealed in volume and compressibility of angel cakes prepared with the five types of albumen, no significant differences were disclosed in cake tenderness or tensile strength. It is possible there were no significant differences in either tenderness or tensile strength among the cakes. It is also possible there were significant differences which were not recorded by the shear press due to the lack of an optimum range for use in these measurements. All readings of both tenderness and tensile strength were very low, and any subtle differences among the cakes may not have been recorded. These results differ from those of Funk (1964) who, using the same shear press range for determination of angel cake tenderness and tensile strength, reported high correlations between shear press tenderness and tensile strength readings, and taste panel scores for angel cakes. However, in that study, the differences among the cakes may have been gross enough to have been recorded by the shear press.

The standard deviations for cake tenderness readings were very low, suggesting determination of tenderness by by the shear press was a valid method for testing even though the actual tenderness readings were low. However, the writer feels additional determinations of cake tenderness using more optimum shear press ranges are necessary before conclusive statements can be made regarding differences or lack of differences in tenderness.

The high standard deviations for reading of cake tensile strength indicate the method for determination of tensile strength requires further refinement before valid results can be obtained for a product as fragile as angel cake. Even with maximum care, some cake samples were damaged as they were placed in the testing apparatus. The possibility of damage might be reduced by placing the sample in the frozen state into the testing apparatus and then allowing the positioned sample to thaw before testing.

Relationship Among Effects of Heat Treatments

The results from objective measurement of the physical and functional properties of liquid and spray-dried albumen indicate the effects of the heat treatments were not additive, but there was a significant interaction among them. An interaction was observed when the adverse effect of preheating on relative viscosity and foam stability was negated or reduced by subjecting the preheated albumen to additional heat treatment in the form of either spray-drying or spray-drying and high temperature storage. Another example of an interaction occurred when exposure of albumen which had been preheated or reconstituted albumen which had been spray-dried to further heat treatment negated the adverse effect of the single heat treatments on angel cake volume.

These observations pose a question as to what caused this interaction among heat treatments. There are at least two possible answers. It is possible the increase in relative viscosity resulted from an increase in concentration of the albumen solution due to evaporation during the preheating treatment. An increase in concentration of the solution would not be evident after the albumen had been spray-dried. However, this theory does not explain the second interaction which occurred.

It is also possible the increase in viscosity resulted from the beginning of protein coagulation. Griswold (1962). reported albumen began to thicken into a gel at 60°C. No information is available concerning the lowest temperature at which slight protein coagulation of albumen can be observed. Exposure of albumen to temperatures considerably lower than 60°C, as in this study, could conceivably bring about the start of protein coagulation. Spray-drying appeared to reverse the adverse effect of preheating on the albumen, but the shear of atomization may really have counteracted this adverse effect.

If the various physical and functional properties of albumen are closely related, a significant increase in viscosity may be responsible for other significant modifications in albumen properties. These modifications may include: increase in specific gravity and decrease in stability of albumen foams; decrease in volume and compressibility of angel cakes.

This speculation as to the cause of the observed interaction among the three heat treatments suggests the need for additional research in these areas: (1) an investigation to determine the lowest temperature at which the start of protein denaturation of albumen may be observed, possibly utilizing a programmed rate of heating on a visco-amylograph; (2) a thorough chemical analysis of the protein fractions of albumen at the five stages of processing; (3) determination of the percentage solids of albumen which had been frozen and albumen which had been preheated.

Correlations for Physical and Functional Properties of Spray-dried, Liquid and Reconstituted Albumen

Simple correlations were calculated between the various objective measurements of the physical and functional properties of the albumen. The correlation coefficients which were significant are given in Table 11

Table 11. Significant Correlation Coefficients of Physical and Functional Properties of Spray-dried, Liquid and Reconstituted Albumen[a]

Objective Measurements	Albumen Moisture	Dispersibility	Solubility Index	Viscosity	Surface Tension	Specific Gravity of Foam	Foam Stability
Albumen Moisture					.790**		
Dispersibility					.527*		
Solubility Index							
Viscosity						.398*	-.353*
Surface Tension	.790**	.527*				-.389*	.407*
Specific Gravity of Foam				.398*	-.389*		-.961**
Foam Stability				-.353*	.407*	-.961**	
Specific Gravity of Batter					-.606**	.454*	-.558**
Cake Volume						-.535**	.489**
Cake Moisture							
Tenderness							
Area-Under-Tenderness-Curve Value							

Table 11. (Continued)

Objective Measurements	Albumen Moisture	Dispersibility	Solubility Index	Viscosity	Surface Tension	Specific Gravity of Foam	Foam Stability
Compressibility #1						-.359*	.495**
Compressibility #2						-.357*	.487**
Compressibility #3							.474**
Area-Under-First-Compression-Curve Value							
Tensile Strength							
Area-Under-Tensile-Strength-Curve Value							

[a]Nonsignificant values were purposely omitted to enable the reader to easily see which objective measurements correlated.

*Significant at 5 per cent level of probability.

**Significant at 1 per cent level of probability.

which accompanies the discussion of these correlations. A complete listing of correlation coefficients is included in the Appendix.

Objective measurements of spray-dried albumen

The replicate means for moisture content, dispersibility, and the solubility index of the three types of spray-dried albumen were correlated.

Moisture, dispersibility, and solubility. A highly significant positive correlation was found between moisture content of spray-dried albumen and surface tension of reconstituted albumen. This indicates as the moisture content of dried albumen increased, the surface tension of the albumen when reconstituted also increased. A significant positive correlation was also disclosed between dispersibility and surface tension, suggesting an increase in surface tension followed an increase in dispersibility. No significant correlations were found between solubility index and other measurements of the physical properties of albumen.

Objective measurements of liquid and reconstituted albumen

The replicate means for relative viscosity and apparent surface tension of liquid and reconstituted albumen were correlated. Additional correlations were calculated among replicate means for specific gravity and stability of foams prepared using the five types of albumen.

Relative viscosity and apparent surface tension. A significant positive correlation was shown between albumen viscosity and specific gravity of foam, while a significant negative correlation was revealed between viscosity and stability of foam. These correlations suggest as the viscosity of albumen decreased, a subsequent decrease in specific gravity and increase in stability of foams was observed.

As previously mentioned, significant correlations existed between surface tension and albumen moisture and disper bility. Additional correlations included a significant negative one between surface tension and specific gravity of foam, a significant positive correlation with foam stability, and a highly significant negative correlation with specific gravity of cake batter. These correlations indicate albumen which had higher surface tension produced more stable foams, and produced both foams and cake batters with lower specific gravities.

Specific gravity and stability of foam. The significant correlations between specific gravity of foam and albumen viscosity and surface tension have been discussed previously. Additional correlations included significant negative ones between specific gravity of foam and foam stability, volume, and compressibility of angel cake. In addition, a significant positive correlation existed between specific gravity of foam and specific gravity of cake batter. Interpretation of these correlations suggests as the specific gravity of foam decreased, the specific gravity of cake batter decreased, the foam stability increased, and an increase was recorded in the volume and compressibility of angel cake.

As previously mentioned, significant correlations existed between foam stability and viscosity, surface tension and specific gravity of foam. Along with these correlations, highly significant positive correlations were revealed between stability of foam and volume and compressibility of angel cake; and, a highly significant negative correlation was shown between foam stability and specific gravity of cake batter. These correlations indicate as the stability of albumen foam increased, the volume and compressibility of angel cake increased, and the specific gravity of cake batter decreased.

Correlations for Product Formation Using Albumen

Simple correlations were calculated between the various objective measurements taken during and after preparation of angel cakes with liquid and reconstituted albumen. The correlation coefficients which were significant are given in Table 12 which accompanies the discussion of these correlations. A complete listing of correlation coefficients is included in the Appendix.

Table 12. Significant Correlation Coefficients of Product Formation Using Liquid and Reconstituted Albumen.

Objective Measurements	Specific Gravity of Batter	Cake Volume	Cake Moisture	Tenderness	Area-Under-Tenderness-Curve Value	Compressibility #1	Compressibility #2	Compressibility #3	Area-Under-First-Compression-Curve Value	Tensile Strength	Area-Under-Tensile-Strength-Curve Value
Albumen Moisture											
Dispersibility											
Solubility Index											
Viscosity											
Surface Tension	-.606**										
Specific Gravity of Foam	.454*	-.535**				-.359*	-.357*				
Foam Stability	-.558**	.489**				.495**	.487**	.474**			
Specific Gravity of Batter						.526**	.507**	.497**			
Cake Volume											
Cake Moisture											
Tenderness					.846**					.538**	-.498**
Area-Under-Tenderness-Curve Value				.846**						.643**	-.602**
Compressibility #1	-.526**						.992**	.989**	.894**		
Compressibility #2	-.507**					.992**	.994**	.994**	.907**		
Compressibility #3	-.497**					.989**	.994** ~~.907**~~		.931**		
Area-Under-First-Compression-Curve Value						.894**	.907**	.931**			
Tensile Strength				-.538**	-.643**						.966**
Area-Under-Tensile-Strength-Curve Value				-.492**	-.602**					.966**	

[a]Nonsignificant values were purposely omitted to enable the reader to easily see which objective measurements correlated.

**Significant at 1 per cent level of probability.

*Significant at 5 per cent level of probability.

Table 12. Significant Correlation Coefficients of Product Formation Using Liquid and Reconstituted Albumen.

Objective Measurements	Specific Gravity of Batter	Cake Volume	Cake Moisture	Tenderness	Area-Under-Tenderness-Curve Value	Compressibility #1	Compressibility #2	Compressibility #3	Area-Under-First-Compression-Curve Value	Tensile Strength	Area-Under-Tensile-Strength-Curve Value
Albumen Moisture											
Dispersibility											
Solubility Index											
Viscosity											
Surface Tension	-.606**										
Specific Gravity of Foam	.454*	-.535**				-.359*	-.357*				
Foam Stability	-.558**	.489**				.495**	.487**	.474**			
Specific Gravity of Batter						.526**	.507**	.497**			
Cake Volume											
Cake Moisture											
Tenderness					.846**					.538**	-.498**
Area-Under-Tenderness-Curve Value				.846**						.643**	-.602**
Compressibility #1	-.526**						.992**	.989**	.894**		
Compressibility #2	-.507**					.992**	.994**	.994**	.907**		
Compressibility #3	-.497**					.989**	~~.907**~~ .994**		.931**		
Area-Under-First-Compression-Curve Value						.894**	.907**	.931**			
Tensile Strength				-.538**	-.643**						.966**
Area-Under-Tensile-Strength-Curve Value				-.492**	-.602**					.966**	

[a]Nonsignificant values were purposely omitted to enable the reader to easily see which objective measurements correlated.

**Significant at 1 per cent level of probability.

*Significant at 5 per cent level of probability.

Objective measurements

The replicate means for specific gravity of batters, and the volume and moisture content of angel cakes prepared with liquid and reconstituted albumen were correlated. Additional correlations were calculated among replicate means for compressibility, tenderness, and tensile strength of angel cakes prepared using the five types of albumen.

Specific gravity of batter, cake volume and cake moisture. Correlations between specific gravity of batter and albumen surface tension, specific gravity and stability of albumen foams have been mentioned previously. Highly significant negative correlations were also found between specific gravity of batter and the three successive compressions of angel cake, suggesting more compressible cakes resulted from batters which had lower specific gravities.

As previously mentioned, significant correlations existed between cake volume and specific gravity and stability of foam. No further significant correlations were revealed. There were no significant correlations disclosed between moisture of angel cakes and other measurements of product formation using the five types of albumen.

Compressibility, tenderness, and tensile strength. Significant correlations between cake compressibility and specific gravity of albumen foams, foam stability and specific gravity of cake batters have been mentioned previously. Further findings include highly significant positive correlations among the three successive compressions, and between all three compressions and the area-under-the-first-compression-curve values. These correlations suggest all measurements of compressibility were closely related and showed the same trends.

A highly significant positive correlation was found between tenderness and area-under-the-tenderness-curve values, indicating as one measurement increased, the other increased also. Negative correlations, at the 1 per cent level of probability, were found between both tenderness measurements and cake tensile strength and area-under-the-tensile-strength-curve values. These correlations suggest cake tenderness increased as the tensile strength of the cake decreased.

As mentioned previously, tensile strength and area-under-the-tensile-strength-curve values were significantly correlated with tenderness and area-under-the-tenderness-curve values. An additional highly significant positive correlation existed between the two tensile strength measurements, indicating as one measurement increased, the other increased also.

Reliability of Objective Measurements

Significant positive correlations were found between the following objective measurements: specific gravity of foam and specific gravity of batter; tenderness of cake and area-under-the-tenderness-curve value; the three successive compressions and area-under-the-first-compression-curve value; tensile strength of cake and area-under-the-tensile-strength-curve value. These positive correlations may indicate the reliability of these objective measurements.

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to determine the effect of preheating per se, and preheating in conjunction with spray-drying and subsequent high temperature storage on the physical and functional properties of albumen. In order to examine the effect of the heat treatments, singly and in combination, the following five types of albumen from each stage of processing were included in the study: (1) liquid albumen, not preheated; (2) liquid albumen, preheated: (3) spray-dried albumen, not preheated; (4) spray-dried albumen, preheated; (5) spray-dried albumen, preheated, and subjected to high temperature storage.

The evaluation of the physical and functional properties of albumen was divided into two phases: (1) an objective examination of the physical properties and foaming ability of the albumen, and (2) an appraisal of the functional properties of the albumen by standardized objective testing of angel cakes prepared from the five types of albumen. Five replications of each of the five variables were tested.

During the study of physical properties and foaming ability of the albumen, objective measurements were used to determine the moisture content, dispersibility, and solubility of the three types of spray-dried albumen; relative viscosity and apparent surface tension of liquid and reconstituted albumen; and specific gravity and stability of foams prepared with liquid and reconstituted albumen. In the second phase of the investigation, angel cakes were prepared using the five types of albumen. During cake preparation the specific gravity of the batters was measured. After the cakes were baked in a forced air oven, volume, moisture, tenderness, compressibility, and tensile strength of the cakes were determined.

The results indicated subjecting albumen to any of the three types of heat treatments, alone or in combination, brought about the following significant changes in the physical and functional properties of the liquid or reconstituted albumen: decrease in apparent surface tension; increase in specific gravity of foams; decrease in foam stability; increase in specific gravity of cake batters; and decrease in volume of angel cakes. Comparison of the three heat treatments showed the preheating treatment had the most adverse effect on the albumen and brought about the greatest modifications in physical and functional properties of the albumen. These modifications included: decrease in moisture content of spray-dried albumen; increase in relative viscosity; increase in specific gravity and decrease in stability of foams; and decrease in volume and compressibility of angel cakes.

Spray-drying the albumen had no effect on relative viscosity of reconstituted albumen which had been dried or on compressibility of angel cakes prepared using this albumen. However, a significant increase was observed in specific gravity of batters and a decrease in volume of cakes prepared with reconstituted albumen which had been spray-dried.

No significant differences among cakes prepared with the five types of albumen were revealed for the following measurements: tenderness values based on maximum force; area-under-the-tenderness-curve values; tensile strength values based on maximum force; and area-under-the-tensile-strength-curve values. It is possible there were no significant differences in tenderness or tensile strength among the cakes. It is also possible subtle differences may not have been recorded by the shear press due to lack of an optimum range for determination of both tenderness and tensile strength, and damage to some of the tensile strength samples prior to testing.

Simple correlations between the various objective measurements of physical and functional properties of the albumen revealed significant correlations between specific gravity of foam, foam stability, specific gravity of cake batter, and compressibility of angel cake. These correlations suggest angel cake compressibility was closely related to the structure of albumen foam. Both specific gravity and stability of albumen foam were significantly correlated with volume of angel cake, suggesting cake volume was also closely related to albumen foam structure. No indication was given of possible relationships between angel cake tenderness or tensile strength and albumen foam structure.

Evaluation of the results from this investigation indicates the need for additional study in these related areas: (1) a search for an explanation for the observed interaction among the three heat treatments, which would include a thorough chemical analysis of the protein fractions of albumen at the five stages of processing; (2) further refinement of the method for determination of tensile strength by the shear press; (3) the verification of the results for tenderness and tensile strength obtained in this study using an optimum range on the shear press; (4) a study of possible relationships between tenderness or tensile strength of angel cakes and albumen foam formation; (5) and an investigation to determine whether the difference in albumen moisture content was caused by preheating the albumen before spray-drying or whether it resulted from slight fluctuations in drying temperature and drying end point.

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APPENDIX

Table 13. Replicate Means, Albumen Type Means and Standard Deviations for Moisture Values, Dispersibility Values and the Solubility Index Values of Spray-dried Albumen.

Objective Test	Albumen Types	Replications					Type Mean	S.D.
		1	2	3	4	5		
Moisture %	Dried	3.80[a]	3.15	2.59	2.63	3.48	3.13±	.53
	Preheated, dried	2.81	1.41	1.58	1.42	2.44	1.93±	.66
	Preheated, dried, high temp. storage	2.90	3.07	2.47	2.47	2.53	2.69±	.28
Dispersibility %	Dried	78.38[b]	79.17	75.70	78.43	75.89	77.51±	1.60
	Preheated, dried	80.66	77.38	75.74	76.22	76.48	77.30±	1.97
	Preheated, dried, high temp. storage	75.38	76.61	75.27	77.47	77.68	76.38±	1.13
Solubility Index	Dried	1.58[a]	1.55	1.57	1.52	1.48	1.54±	.02
	Preheated, dried	1.45	1.60	1.53	1.55	1.57	1.54±	.02
	Preheated, dried, high temp. storage	.167	1.62	1.53	1.55	1.50	1.57±	.05

[a]Figure represents an average of two trials for each replication.

[b]Figure represents an average of three trials for each replication

Table 14. Replicate Means, Albumen Type Means and Standard Deviations for Relative Viscosity Values and Apparent Surface Tension Values of Liquid and Reconstituted Albumen

Objective Test	Albumen Types	Replications					Type Mean	S.D.
		1	2	3	4	5		
Viscosity Centipoise	Frozen	1.06[a]	1.05	1.02	1.05	1.08	1.05±	.02
	Preheated	1.10	1.07	1.05	1.11	1.17	1.10±	.05
	Dried	1.03	1.05	1.00	1.01	1.09	1.04±	.04
	Preheated, dried	1.04	1.06	0.98	1.01	1.04	1.03±	.03
	Preheated, dried, high temp storage	1.03	1.04	1.00	1.04	1.08	1.04±	.03
Surface Tension dynes/cm	Frozen	53.8[a]	53.8	54.4	56.4	56.3	54.9±	1.3
	Preheated	53.2	50.4	53.1	52.3	52.3	52.3±	1.1
	Dried	54.2	52.8	51.4	52.4	54.0	53.0±	1.2
	Preheated, dried	54.0	50.6	49.2	51.1	52.0	51.4±	1.8
	Preheated, dried, high temp. storage	52.9	51.2	50.6	51.7	52.5	51.8±	.9

[a]Each figure represents an average of three trials for each replication.

Table 15. Replicate Means, Albumen Type Means and Standard Deviations for Specific Gravity Values and Drainage Values of Foams Prepared with Liquid and Reconstituted Albumen.

Objective Test	Albumen Types	Replications					Type Mean	S.D.
		1	2	3	4	5		
Specific Gravity	Frozen	.111[a]	.120	.122	.113	.111	.115±	.005
	Preheated	.164	.148	.164	.154	.162	.158±	.007
	Dried	.135	.134	.127	.140	.144	.136±	.006
	Preheated, dried	.137	.129	.145	.135	.130	.135±	.006
	Preheated, dried, high temp. storage	.141	.141	.126	.143	.149	.140±	.008
Drainage ml	Frozen	5.2[a]	6.4	6.0	6.1	4.7	5.7±	.7
	Preheated	11.1	8.9	10.5	9.9	10.5	10.2±	.8
	Dried	8.4	7.9	6.2	8.0	9.1	7.9±	1.1
	Preheated, dried	9.0	8.0	9.2	8.6	7.8	8.5±	.6
	Preheated, dried, high temp. storage	8.5	8.5	7.3	9.1	9.1	8.5±	.7

[a]Each figure represents an average of three trials for each replication.

Table 16. Replicate Means, Albumen Type Means and Standard Deviations for Specific Gravity of Batter Values, Volume Values and Moisture Values of Angel Cakes Prepared With Liquid and Reconstituted Albumen.

Objective Test	Albumen Types	Replications					Type Mean	S.D.
		1	2	3	4	5		
Specific Gravity	Frozen	.330[a]	.339	.340	.344	.336	.338±	.005
	Preheated	.359	.366	.357	.363	.360	.361±	.004
	Dried	.377	.374	.367	.372	.369	.372±	.004
	Preheated, dried	.373	.379	.371	.382	.363	.374±	.007
	Preheated, dried, high temp. storage	.373	.376	.366	.363	.362	.368±	.006
Volume ml	Frozen	3340[a]	3350	3310	3230	3410	3328±	66
	Preheated	3220	3110	3140	3130	3200	3160±	47
	Dried	3170	3270	3170	3260	3270	3228±	53
	Preheated, dried	3290	3230	3350	3290	3360	3304±	53
	Preheated, dried, high temp. storage	3230	3300	3360	3260	3350	3300±	56

Moisture Content %	Frozen	39.68[b]	40.11	36.66	41.31	38.38	39.23±	1.78
	Preheated	39.77	35.76	39.69	40.06	37.30	38.52±	1.90
	Dried	41.95	38.65	40.51	39.89	37.26	39.65±	1.79
	Preheated, dried	41.04	39.88	40.39	40.14	36.54	39.60±	1.79
	Preheated, dried, high temp. storage	40.05	39.22	37.93	40.40	38.38	39.20±	1.05

[a]Each figure represents one trial for each replication.

[b]Each figure represents an average of four trials for each replication.

Table 17. Replicate Means, Albumen Type Means and Standard Deviations for Shear Press Maximum Force Values of Compressibility for Each of Three Successive Compressions and Area-Under-the-First-Compression-Curve Values of Angel Cakes Prepared with Liquid and Reconstituted Albumen.

Objective Test	Albumen Types	Replications					Type Mean	S.D.
		1	2	3	4	5		
First Compression grams	Frozen	735.6[a]	692.5	636.5	581.4	666.0	662.4±	58.1
	Preheated	764.3	768.8	797.6	780.2	759.0	774.0±	15.3
	Dried	947.2	659.2	650.9	607.8	737.8	720.6±	135.1
	Preheated, dried	942.0	874.7	839.9	797.6	788.5	848.5±	62.6
	Preheated, dried, high temp. storage	858.0	782.4	777.2	737.8	797.6	790.6±	43.7
Second Compression grams	Frozen	667.5[a]	631.3	577.6	523.1	608.6	601.6±	54.8
	Preheated	706.8	720.5	715.9	704.6	694.8	708.5±	10.1
	Dried	868.6	585.9	579.8	544.3	674.3	650.6±	131.0
	Preheated, dried	867.1	794.5	732.6	725.7	715.2	767.0±	64.0
	Preheated, dried, high temp. storage	805.1	722.7	695.6	655.4	722.0	720.2±	54.8

Third Compression grams	Frozen	646.4[a]	604.8	547.3	468.7	572.3	567.9±	66.7
	Preheated	680.4	669.1	672.8	659.2	650.9	666.5±	11.6
	Dried	828.6	565.5	541.3	520.9	631.3	617.5±	125.1
	Preheated, dried	815.0	755.2	698.5	685.7	668.3	724.5±	60.1
	Preheated, dried, high temp. storage	755.2	672.1	662.2	620.7	666.0	675.2±	49.1
Area Under Curve cm^2	Frozen	1.6[a]	1.5	1.2	0.9	1.3	1.3±	.3
	Preheated	1.5	1.4	1.4	1.3	1.5	1.4±	.1
	Dried	1.9	1.2	1.0	0.9	1.4	1.3±	.4
	Preheated, dried	1.8	1.8	1.6	1.5	1.5	1.6±	.1
	Preheated, dried, high temp. storage	1.7	1.4	1.4	1.2	1.3	1.4±	.2

[a]Each figure represents an average of three trials for each replication.

Table 18. Replicate Means, Albumen Type Means and Standard Deviations for Shear Press Maximum Force Values of Tenderness and Area-Under-the-Tenderness-Curve Values of Angel Cakes Prepared with Liquid and Reconstituted Albumen.

Objective Test	Albumen Type	Replications 1	2	3	4	5	Type Mean	S.D.
Tenderness lb./gram	Frozen	1.53[a]	1.34	1.64	1.05	1.44	1.40±	.22
	Preheated	1.34	1.50	1.35	1.37	1.27	1.37±	.08
	Dried	1.42	1.41	1.08	1.28	1.19	1.28±	.15
	Preheated, dried	1.49	1.33	1.13	1.28	1.14	1.27±	.15
	Preheated, dried, high temp. storage	1.40	1.40	1.64	1.29	1.49	1.44±	.13
Area Under Curve cm^2/gram	Frozen	.034[a]	.032	.046	.020	.029	.032±	.009
	Preheated	.032	.043	.034	.034	.029	.034±	.005
	Dried	.033	.042	.024	.027	.024	.030±	.007
	Preheated, dried	.033	.036	.029	.027	.022	.029±	.005
	Preheated, dried, high temp. storage	.036	.029	.044	.031	.034	.035±	.005

[a]Each figure represents an average of three trials for each replication.

Table 19. Replicate Means, Albumen Type Means and Standard Deviations for Shear Press Maximum Force Values of Tensile Strength and Area-Under-the-Tensile-Strength-Curve Values of Angel Cakes Prepared With Liquid and Reconstituted Albumen.

Objective Test	Albumen Type	Replications 1	2	3	4	5	Types Mean	S.D.
Tensile Strength / grams/cm^2	Frozen	4.75[a]	10.53	3.83	10.29	10.13	7.91±	3.32
	Preheated	6.55	7.79	3.06	6.45	12.94	7.36±	3.58
	Dried	6.94	5.59	11.67	9.49	11.69	9.08±	2.76
	Preheated, dried	6.87	6.16	5.24	10.94	8.67	± 7.58±	2.26
	Preheated, dried, high temp. storage	6.43	7.30	5.52	5.26	6.60	6.22±	.83
Area Under Curve / Area of Curve/Area of Break	Frozen	.025[a]	.059	.017	.050	.052	.041±	.018
	Preheated	.029	.035	.012	.033	.068	.035±	.020
	Dried	.032	.027	.048	.043	.060	.042±	.013
	Preheated, dried	.031	.028	.030	.058	.042	.038±	.013
	Preheated, dried, high temp. storage	.038	.036	.027	.023	.029	.031±	.006

[a]Each figure represents an average of three trials for each replication.

Table 20. Replicate pH Ranges of Foams and Angel Cake Batters Prepared With Liquid and Reconstituted Albumen.

Objective Test	Albumen Process	Replications 1	2	3	4	5
pH of Foams	Frozen	5.75	5.65	5.74	5.72	5.75
	Preheated	5.78	5.65	5.73	5.78	5.78
	Dried	5.78	5.73	5.68	5.72	5.72
	Preheated, dried	5.70	5.60	5.73	5.62	5.75
	Preheated, dried, high temp. storage	5.60	5.68	5.77	5.80	5.70
pH of Batters	Frozen	5.70	5.65	5.64	5.65	5.67
	Preheated	5.70	5.75	5.72	5.65	5.62
	Dried	5.70	5.70	5.63	5.65	5.65
	Preheated, dried	5.72	5.75	5.75	5.68	5.70
	Preheated, dried, high temp. storage	5.65	5.65	5.60	5.65	5.65

Table 21. Correlation Coefficients of Physical and Functional Properties, and Product Formation Using Spray-dried, Liquid and Reconstituted Albumen.

Objective Measurements	Albumen Moisture	Dispersibility	Solubility Index	Viscosity	Surface Tension	Specific Gravity of Foam	Foam Stability	Specific Gravity of Batter	Cake Volume	Cake Moisture	Tenderness	Area-Under-Tenderness-Curve	Compressibility #1	Compressibility #2	Compressibility #3	Area-Under-Compressibility-Curve	Tensile Strength	Area-Under-Tensile-Strength-Curve
Albumen Moisture	1.000	.264	-.027	.366	.790**	.147	.007	-.141	-.331	-.043	.241	.059	-.039	.022	.014	-.028	.077	.030
Dispersibility	.264	1.000	-.420	.290	.527*	.093	.238	.173	-.142	.330	.324	.208	.154	.156	.177	.070	-.240	-.368
Solubility Index	-.027	-.420	1.000	-.162	-.235	-.215	-.287	.296	-.360	.142	-.065	.098	.087	.130	.131	.205	-.159	.077
Viscosity	.366	.290	-.162	1.000	.280	.298*	-.353*	-.239	-.263	-.311	.039	-.045	-.008	.043	.021	.064	.276	.298
Surface Tension	.790**	.527*	-.235	.280	1.000	-.389*	.407*	-.606**	.127	.142	.070	-.179	-.330	-.280	-.295	-.197	-.161	.170
Specific Gravity of foam	.147	.093	-.215	.398*	-.389*	1.000	-.961**	.454*	-.535**	-.093	-.082	.053	-.359*	-.357*	.343	.182	-.117	-.132
Foam Stability	-.007	-.238	.287	-.353*	.407*	-.961**	1.000	-.558**	.489**	-.006	-.116	-.016	.495**	.487**	.474**	.313	.129	.126
Specific Gravity of Batter	-.141	.173	.296	-.239	-.606**	.454*	-.558**	1.000	-.314	.162	-.178	-.025	.526**	.507**	.497**	.304	.030	-.014
Cake Volume	-.331	-.142	-.360	-.263	.127	-.535**	.489**	-.314	1.000	-.153	.170	-.072	-.129	-.155	-.130	.043	-.003	.091
Cake Moisture	-.043	.330	.142	-.311	.142	-.093	.006	.162	-.153	1.000	-.283	-.314	.220	.184	.200	.083	-.072	-.078
Tenderness	.241	.324	-.065	.039	.070	-.082	-.116	-.178	.170	-.283	1.000	.846**	.207	.241	.270	.282	-.538**	-.492**
Area-Under-Tenderness-Curve	.059	.208	.098	-.045	-.179	.053	.016	-.025	-.072	-.314	.846**	1.000	.160	.172	.209	.227	-.643**	-.602**
Compressibility #1	-.039	.154	.087	-.008	-.330	-.359*	.495**	.526**	-.129	.220	.207	.160	1.000	.992**	.989**	.894**	-.300	-.247
Compressibility #2	.022	.156	.130	.043	-.280	-.357*	.487**	.507**	-.155	.184	.241	.172	.992**	1.000	.994**	.907**	-.261	-.208
Compressibility #3	.014	.177	.131	.021	-.292	.343	.474**	.497**	-.130	.200	.270	.209	.989**	.994**	1.000	.931**	-.295	-.236
Area-under-Compressibility-Curve	-.028	.070	.205	.064	-.197	.182	.313	.304	.043	.083	.282	.227	.894**	.907**	.931**	1.000	-.253	-.141
Tensile Strength	.077	-.240	-.159	.276	-.161	-.117	.129	-.030	-.003	-.072	-.538**	-.643**	-.300	-.261	-.293	-.253	1.000	.966**
Area-Under-Tensile-Strength-Curve	.030	-.368	.077	.298	.170	-.132	-.126	-.014	.091	-.078	-.492**	-.602**	-.247	-.208	-.236	-.141	.966**	1.000

**Significant at 1 per cent level of probability.
*Significant at 5 per cent level of probability.

Table 22. Derivation of a Factor for Converting Weights of Graph Curves into Areas for Allo-Kramer Shear Press Chart Graph Paper Using the Weights of Known Areas[a] of Chart Paper.

Known Areas cm^2	Weights Grams	Factor Calculation cm^2/gram	Factor Check cm^2
1	.0058	172.414	1.01
4	.0230	173.913	4.01
9	.0531	169.492	9.25
16	.0913	175.264	15.90
25	.1415	176.678	24.65
36	.2061	174.672	35.90
49	.2760	177.536	48.08
64	.3689	173.489	64.26
	Factor Mean	174.216	

[a]Each figure represents an average of readings obtained from five areas cut from randomly selected portions of similar chart paper.

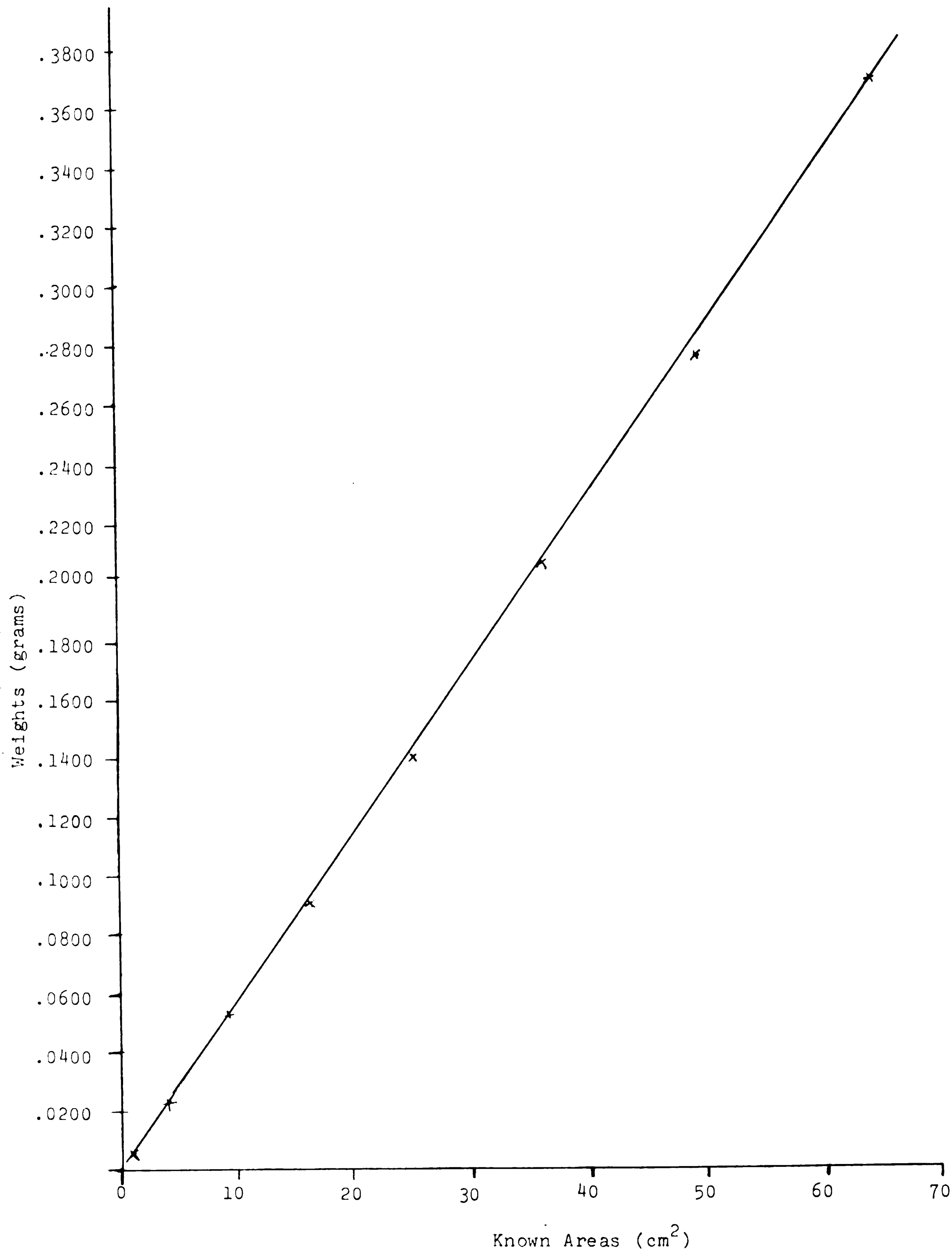

Figure 6. Calibration Curve for Derivation of a Factor for Converting Weights of Graph Curves into Areas for Allo-Kramer Shear Press Chart Graph Paper Using the Weights of Known Areas of Chart Paper.