EFFECT OF CHEMICAL ADDITIVES ON THE FUNCTIONAL PROPERTIES OF COMMERCIAL AND 0.05 % YOLK-CONTAMINATED SPRAY DRIED ALBUMEN

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ABSTRACT

EFFECT OF CHEMICAL ADDITIVES ON THE FUNCTIONAL PROPERTIES OF COMMERCIAL AND 0.05% YOLK-CONTAMINATED SPRAY DRIED ALBUMEN

by Carolyn McDonald Anderson

This study determined the effect of two types of chemical additives on the functional properties of commercial spray dried albumen, plain and with the addition of yolk. Two anionic type additives (sodium oleate and sodium lauryl sulfate) and an ester type additive (triethyl citrate) were added to the reconstituted albumen in 0.1% and 0.2% concentrations (based on the albumen solids' weight). The two controls were the plain and the 0.05% yolk-contaminated albumen without an additive.

The action of the chemical additive on the foaming ability of the albumen was determined through a comparison of angel cakes, including a study of the specific gravity of the foam and batter, cake volume, and shear press tests for cake compressibility, tenderness, and tensile strength.

The results indicated that the 0.05% yolk-contamination alone significantly reduced the foaming properties of the spray dried albumen as evidenced by

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increased specific gravities and decreased cake volume, compressibility, and tensile strength. The addition of triethyl citrate and sodium lauryl sulfate significantly improved the functionality of the 0.05% yolk-contaminated albumen. Both concentrations of triethyl citrate decreased the specific gravities and increased angel cake volume, compressibility, and tenderness in the 0.05% yolk-contaminated albumen system. The addition of sodium lauryl sulfate improved the 0.05% yolk-contaminated albumen to such an extent that the resulting cakes had similar desirable properties to those made from the plain albumen control.

The addition of sodium oleate further impaired the quality of the albumen with yolk added. Its use increased the specific gravities and decreased cake compressibility and tensile strength.

The addition of a chemical additive did not significantly improve the function of the commercial (plain) spray dried albumen. Sodium oleate additions were likewise detrimental to the plain albumen. The 0.2% concentration of sodium oleate reduced the function of the plain albumen as apparent in all objective evaluations except those for tenderness and pH of the batter.

In conclusion, the results of this study indicated that the role of triethyl citrate and sodium lauryl sulfate was to improve the functional properties of albumen, severly impaired by yolk-contamination. The additive sodium oleate was not of benefit to either the plain or 0.05% yolk-contaminated albumen, but reduced the foaming properties of both egg white systems.

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By

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INTRODUCTION

Spray drying and yolk-contamination are both detrimental to the functional properties of albumen. The atomization and homogenization processes used in spray drying reduce the functional performance of albumen (Bergquist and Stewart 1952A, 1952B); while yolk-contamination is the greatest single reason for albumen failing to perform in angel cake tests. In frozen albumen, as little as 0.01% yolk is harmful; and 0.1% causes angel cake failures (Smith, 1959; Cotterill *et al.*, 1963).

Bergquist (1964) suggested adding certain chemical additives to albumen to preserve and enhance its foaming ability which is damaged during spray drying. The use of chemical additives to improve the functional performance of albumen dates back to Mink's patent in 1939. He advocated the addition of several anionic surface active compounds; one of which was sodium oleate. However, not until Kothe's patent in 1956 for the use of the ester type additive, triethyl citrate, were such additives known to be beneficial to improve yolk-contaminated albumen. The Food and Drug Administration has now approved the addition

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of various chemical additives to egg white in a 0.1-0.2% concentration, based on the egg white solids.

Cotterill et al., (1963) and Gardner (1960) have studied the effect of several of these chemical additives on the functional properties of frozen albumen. These researchers reported that the addition of triethyl citrate, an ester type additive, did not significantly alter the volume of angel cakes made from the frozen albumen; however, the anionic type additives did slightly increase these cake volumes. In a study using frozen albumen with 0.1% yolk added, Cotterill et al., (1963) found both the ester and the anionic chemical additives effective in improving angel cake volumes. In contradiction to Cotterill's findings, Harrel (1959) reported that the use of whipping aids is only beneficial to high quality albumen; and that, they further impair the functional properties of yolk-contaminated albumen.

Although a study of the effect of yolk-contamination in spray dried albumen has not been reviewed in the literature, Cotterill et al., (1965) and Smith (1959) reported that yolk-contamination has a ten-fold effect in egg white after drying. Thus, this study was initiated to determine the effect of three chemical additives on the functional performance of commercial spray dried albumen and commercial spray dried albumen with yolk added. The writer examined the results of this study in an attempt to dete

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to determine the effect of two anionic chemical additives (sodium lauryl sulfate and sodium oleate) and an ester type (triethyl citrate) on the foaming properties of spray dried albumen through an evaluation of angel cakes. The additives were used in two concentrations--0.1% and 0.2%, based on the albumen solids.

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REVIEW OF LITERATURE

Composition of Albumen

Griswold (1962) stated that the structure of albumen consists of three layers; an inner layer of thin white, surrounded by thick white, and an outer layer of thin white. The thick white, or albuminous sac, adheres to the shell at each end of the egg and surrounds the inner thin albumen.

Several researchers have described the chemical composition of the egg white. Cruickshank (1940) reported that the chemical composition of the white is 87.77% water, 0.05% fat, 10.00% protein, and 0.82% ash. Albumen is composed of eight identified proteins which are ovalbumin, conalbumin, ovomucoid, lysozyme, globulins G_2 and G_3, ovomucin, and avidin (Feeny and Hill, 1960; Fevold, 1959).

Composition of Egg White Solids

Ovalbumin	54.00%
Conalbumin	13.00
Ovomucoid	11.00
Lysozyme	3.50
Ovomucin	1.50
Flavoprotein	0.80
Proteinase inhibitor	0.10
Avidin	0.05
Unidentified proteins (mainly globulins)	8.00
Nonprotein (primarily half glucose and salts)	8.00

Processing of Albumen

Eggs are pasteurized to insure a product of high sanitary quality. Glucose is removed to prevent browning due to the Maillard reaction. After the pasteurization and desugarization, the eggs are then ready for drying.

Pasteurization

The primary purpose of pasteurization of eggs is to eliminate any pathogenic organisms present in the eggs. Of major importance is the elimination of Salmonella, a microorganism causing severe food poisoning.

Effect of heat.--Forsythe (1964) found pasteurization of albumen had caused many problems because of albumen's sensitivity to temperatures required for effective pasteurization. Wilkin and Winter (1947), Slosberg (1946), and Payaval *et al.*, (1946) reported several deleterious effects including requiring a prolonged beating time, having decreased stability, loss of leavening power, and change in vicosity occurred when albumen was subjected to temperatures as low as 105°F for sufficient periods of time. Slosberg *et al.*, (1948) have attributed these changes in the functional properties of albumen, which has been subjected to heat, to protein denaturation.

Recent methods of pasteurization.--Much research has been conducted to find a method of pasteurization that would yield an albumen of low bacterial count, yet retain all the albumen's functional properties. Researchers have developed methods of pasteurization especially for dried albumen. Banwart and Ayres (1956) found the holding dried albumen at a temperature of 125-128°F for 7-10 days destroyed Salmonella and improved the beating performance of the dried albumen. Bergquist (1961) patented a process utilizing combination heat treatments before and after spray drying. Liquid albumen was preheated at 130°F for 80 seconds. The dried albumen produced from this liquid was then subjected to a dry heat treatment at 120°F for 7 days.

Cunningham and Lineweaver (1965) stated that heat damage primarily affects the egg white protein conalbumin and is less in the presence of iron and aluminum salts. Addition of 0.003% aluminum sulfate-lactic acid solution stabilized the albumen so that it could be heated at 140°F for 3 1/2 minutes. These researchers reported that adjusting the egg white to pH 7 increased the heat stability of the ovalbumin, lysozyme, and ovomucoid proteins; producing angel cakes with normal volume and texture, however, the whipping time of the albumen was increased. The authors added triethyl citrate to decrease the whipping time.

Glucose removal or conversion

Unless the 0.38% glucose naturally occuring in raw egg albumen is removed or converted to an acid, a browning reaction which is called the Maillard reaction will occur during the drying and storage of albumen (Bergquist, 1964). In this reaction the aldehyde group of the glucose reacts with the amino acids in the proteins of the egg white, forming a brown insoluble product. Blomberg (1932) stated that an albumen dried without fermentation of the glucose results in a dried product that will not produce a stable froth. Such a product is of little value, even if it is soluble. Rolfes *et al.*, (1955) reported that removal of glucose before drying improves the functional properties and increases the storage life of the dried product so that it will keep almost indefinitely without deterioration.

Methods of removal.--Enzyme treatment, yeast fermentation, and bacterial treatment are three commercially common methods for glucose removal in albumen. Carlin and Ayres (1953) reported that fermentation of albumen with an enzyme complex of glucose oxidase and catalase at 77°C for 10 hours to be superior to other methods of glucose fermentation since there was no excessive growth of organisms, no development of off flavors

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In a subsequent paper, Carlin and Ayres (1951) found yeast-fermented albumen with 0.3% dry yeast pellets and 0.1% yeast extract added held at 32.2°C for 7 hours retained all its functional properties and had no off odors. However, angel cakes prepared from yeast-fermented albumen had a yeasty odor and upon eating, left an after-taste.

In studying several commercial bacterial fermentations of albumen, Stuart and Goresline (1942A) found the organisms to be predominately Aerobacter and Escherichii. In a subsequent paper, they stated that cultures of *Aerobacter aerogenes*, *Aerobacter cloacae*, and *Escherichii freunii* produced normal egg white fermentations (Stuart and Goresline, 1942B). On the other hand, albumen fermented with Serratia and Proteus species and with *Pseudomonas serugenosa* lost much less glucose and showed extensive fermentation.

Spontaneous fermentation is caused by the organisms, usually of the Aerobacter and Escherichii species, naturally present in the albumen. Carlin and Ayres (1951) found that the albumen produced from this method of fermentation had poor leavening power, making it unsuitable for use in angel cakes. Today, spontaneous fermentation has alm

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has almost completely been replaced by the other three methods of fermentation.

Spray drying

Albumen was first dried in China in the early 1900's by German engineers. In the United States processors began drying eggs in the 1920's, but processing development did not receive much attention until World War II. The dried eggs produced during World War II were of inferior quality; however, after World War II extensive research was begun to improve the quality of dried eggs (Bergquist, 1964).

In recent years, the increase in consumption of prepared mixes, especially angel cake mixes, has resulted in a strong demand for dried eggs. The increasing popularity of dried albumen is due to its two advantages over frozen eggs: (1) freezer space is not required and (2) only one eighth as much storage space is required. Today a high percentage of the egg white solids are spray dried.

Pretreatment of albumen.--Prior to spray drying, the liquid albumen must be treated to assure satisfactory drying. The egg white is strained or centrifuged to remove all the extraneous material such as pieces of shell and chalazae. Before the albumen is dried, it must be

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fluid and uniform. High pressure homogenization breaks down the thick portion of the albumen, which is difficult to dry and when dried, is insoluble in water.

Atomization.--Atomization converts the spray of albumen into many fine particles. Three types of atomization devices are used commercially: (1) pressure (2) centrifugal and (3) two fluid nozzles. Under pressures ranging from 1500-3000 lbs. per sq. in., the liquid albumen is pumped into the atomizing device of the spray drier, preheated to 58.9°C (Blomberg, 1932). Air heated to 93.3-104.4°C and kept in rapid motion removes the moisture from the albumen before it reaches the collection filter bags at the floor of the dryer. The final product contains a moisture level between 6-12%.

Functional Properties of Albumen

Albumen is an extremely sensitive product. Its functional properties are easily changed by many factors; these changes in functional properties are revealed in the angel cake quality.

Foam formation

Griswold (1962) defined an egg white foam as a colloid composed of air bubbles surrounded by denatured egg white. Both Lowe (1955) and Griswold (1962) named the three requirements for production of a stable foam:

(1) low vapor pressure (2) low surface tension and (3) tendency for the substance in the surface to solidify, creating a rigid film. Part of the rigidity results from the denaturation of some of the protein surrounding the air bubbles in the foam. During the process of protein denaturation, there is an unfolding of the peptide chains with new linkages being formed. Denaturation of a protein solution can result from a mere agitation, causing the rapid formation of vicous coatings on all free protein surfaces (Barmore, 1934). In egg white foam formation, Romanoff and Romanoff (1949) reported surface denaturation of the albumen protein at the liquid-air interface. The stretching and drying of the albumen during the beating process causes this denaturation. The denatured albumen forms a viscous, plastic film around the air bubbles, keeping them from coalescing and thus stabilizing the albumen foam. This viscous interfacial film is a requirement for a stable egg white foam (Rohn, 1932).

Role of proteins.--In their study of the function of the various proteins in egg white, MacDonnel *et al.*, (1955) found ovomucin and the globulins both have important roles in foam formation. Globulins, which were good foamers, were responsible for obtaining a foam of large volume, small bubbles, and smooth texture. On the other hand, the ovomucin fraction was not a good foamer, but served to stabilize the albumen foam. The stabilizing effect was due to the rapid insolubilization of ovomucin at the surface of the bubbles. Overwhipping damage to a foam is caused by the insolubilization of too much ovomucin in the bubble surface; thus decreasing the bubble elasticity. Removal of both the globulins and ovomucin from egg white, greatly increases the whipping time of the albumen, and reduces the foam stability and volume.

Effect of physical factors.--The quality and quantity of albumen foam produced is dependent on many factors. Varying one factor can make a significant difference in the resultant foam.

The season and age of the egg are two important factors to consider in foam production. Lowe (1955) reported a study of Nemetz's (1929) in which the author found that eggs laid in April produced sponge cakes with 15% greater volume than eggs laid in July and 5% greater volume than eggs laid in September. The age of the egg can markedly affect the resulting foam. Barmore (1934) concluded that the older the eggs, the less stable the foam; however, the older the eggs, the lighter the specific gravity of the foam.

The temperature of the albumen when beaten affects the volume and stability of the resultant foam. Most researchers agree that for the most desirable foam, egg white should be beaten at room temperature. Barmore (1935) stated that when eggs are cold they will not whip up as easily or to as large a volume. Lowe (1955) attributed this fact to the phenonomen of decreasing surface tension with increasing temperature. Henry and Barbour (1933) discovered that beating egg whites at temperatures from 15° to 25°C had no effect on the stability of the foam; while at 10°C, the stability of the foam was only slightly less.

The length of beating of the egg white contributes to the characteristics of the foam produced. Henry and Barbour (1933) found that the volume and stability of the albumen foam increase first with the beating time, then decrease as the beating time is further increased. Maximum foam stability is reached before maximum foam volume; therefore, maximum foam volume is obtained only with a decrease in foam stability.

Effect of pH.--Henry and Barbour (1933) reported that an albumen foam of greater volume could be formed when the pH of the albumen was above pH 8. Bailey (1935) also found that untreated egg white, pH 9, had a greater foaming power; however, she reported that the stability of the resultant foam was greater when the pH of the egg white was first adjusted with acid to pH 6 or 7. Barmore (1936) attributed the foam stabilizing effect of acid to a change in the physical properties of the denatured protein film formed at the air/liquid interface of the foam.

Effect of added ingredients.--The addition of various substances to egg white can effect the volume and stability of the resultant foam. Several researchers found common table salt had an adverse effect on foam volume and quality, decreasing the stability and increasing the whipping time required to reach a characteristic foam (Griswold, 1962; Sechler, 1959; and Hanning, 1945).

The addition of sugar increases foam stability. Hanning (1945) characterized an albumen foam with sugar as one that is less stiff, more plastic, and more stable than one without sugar. When sugar is added to egg white, the beating time must be increased to achieve a foam of desired volume. Griswold (1962) attributed this delay in foam formation to the action of sugar in retarding the denaturation of the egg white.

The addition of small amounts of fat to egg white seriously impairs its foaming power. Bailey (1935) found the presence of 0 to 1% yolk or a quantity of olive oil containing the same amount of fat in egg white greatly decreased foam volume.

Angel cake production

One of the most critical tests of the functional properties of albumen is its ability to perform in an angel cake. Romanoff and Romanoff (1949) stated that the tenderness, volume, elasticity, texture, and compressibility of an angel cake depend upon the quality of the egg white foam.

Role of the proteins.--MacDonnell *et al.*, (1955) reported that the functional performance of egg white in angel cake was largely dependent on ovomucin, globulins, and ovalbumin. Ovomucin functioned to stabilize the egg white foam which was essential for the production of a high quality angel cake.

The authors found the globulins were responsible for the rapid foaming of egg white. The globulins are essential for the production of a meringue and batter with a large volume, small bubbles, and very smooth texture. Removal of the globulins and ovomucin from egg white produced angel cakes of poor volume. Without these two proteins, the whipping time of the egg white was also increased. The globulins and ovomucin alone produced an excellent meringue and batter. However, upon baking, the cake collapsed because of the absence of the heat-denaturable protein.

Thus the structure of the angel cake is dependent upon the presence of heat-denaturable protein, which is ovalbumin in egg white. The authors found ovalbumin alone made an angel cake of satisfactory volume; however, the cake did not have the unique quality and texture of an angel cake.

Effect of pH.--The pH of the meringue and batter influences the final texture and volume of an angel cake. For optimum beating performance, Miyahara and Bergquist (1961) suggested a meringue pH in the range of pH 6.5-7.0. For maximum foam stability and angel cake volume, the authors recommended that the batter pH be between pH 5.8 to 6.4; while Finucane (1954) thought the batter pH should range between pH 5.4-5.9.

Effect of other ingredients.--The level of cream of tartar can be used to adjust the meringue and batter pH to the desired level. Cream of tartar, an acid salt, serves to lower the pH and increase the stability of the egg white foam. Grewe (1930) recommended the addition of cream of tartar for a white and fine-grained angel cake; without it, the cake would be yellow and coarse-grained.

The gluten in the cake flour forms the structure of the cake; however, overdevelopment of the gluten causes toughness. The sugar has a tenderizing effect, functioning to produce a plastic, stable egg white foam. Barmore

(1936) reported that the addition of sugar during the beating period helped to maintain the volume of the foam and to have less foam shrinkage when the flour was added.

Effect of manipulation.--Egg white acts as a leavening agent in the angel cake batter. In the whipping process, air is incorporated into the egg white in a finely divided state. When the cake is baked, the finely incorporated air expands with the steam and heat causing the cake to rise. The degree to which the egg white is whipped is important in the preparation of an angel cake of good volume and texture. Overwhipping the egg white overstretches the cells, producing an unstable foam. The cell walls collapse during baking forming large holes in the cake and causing a loss in cake volume. Underwhipping egg white incorporates too little air; the cell walls are not stretched to their full capacity. As a result, the cake has poor volume and thick, tough cell walls.

As the whipping of egg white continues, two opposite effects are occuring (1) the tendency for increased cake volume due to the increasing amount of air incorporated and (2) the tendency for decreased cake volume because of the reduced foam stability. Barmore (1936) advocated a balance between these two factors for the optimum whipping time.

One of the most important procedures in making an angel cake is to incorporate the flour-sugar mixture into the meringue in such a way as to mix them thoroughly, but without losing the air held in the beaten whites. Griswold (1962) and Lowe (1955) advocate folding in the flour gently using a wire whip. An electric mixer can be used, but there is a danger of overmixing and breaking down the foam structure.

Formula designed for spray dried albumen.--
Miyahara and Bergquist (1961) found that egg white solids performed favorably in angel cakes when compared with frozen albumen, if certain modifications were made in the formulation and mixing techniques. The authors recommended the acid salt level be reduced by one third to one half of that used with the frozen albumen; since the pH of dried albumen (pH 6.5-7.5) is lower than the pH of frozen albumen (pH 8.5-9.5). Replacement of five to twenty percent of the granulated sugar with powered sugar gave the cakes better textural qualities. One third of the flour was replaced with wheat starch, improving cake volume, moistness, and eating quality. The modification in the mixing technique was to whip the dried albumen to a drier, stiffer peak than the frozen albumen.

Effect of spray drying on the functional properties of albumen

The sensitivity of albumen renders its functional properties susceptible to damage caused by the severe treatments employed in the spray drying process. Bergquist (1964) stated that pressure homogenization and atomization are two of the severe treatments used in the spray drying of albumen.

Effect of pressure homogenization.--Several groups of researchers have shown that pressure homogenization was detrimental to the functional properties of albumen. The beating rate, foam stability, viscosity, and angel cake volumes of albumen subjected to pressure homogenization decreased directly with the amount of pressure used (Slosberg, 1946; Forsythe and Bergquist, 1951; MacDonnell et al., 1950). MacDonnell et al., (1950) attributed the damage of the albumen by pressure homogenization to the disruption of the physical structure of the albumen and to the liquid-liquid or liquid-metal shear effect. The authors concluded that static pressure alone did not damage the albumen; however, the shearing forces did destroy the functional properties of the albumen. The mechanism of destruction involved the (1) mechanical rearrangement of the physical structure of the protein molecule and (2) disintegration of the protein molecule.

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Effect of pressure atomization.--Bergquist and Stewart (1952A) reported that the atomization process of spray drying greatly decreased the beating rate of albumen. The degree of damage was a function of (1) the particle size (2) the air pressure and (3) the nozzle design. The authors attributed the major cause of loss of beating power to the shearing forces encountered in atomization. Seltzer and Settlemeyer (1949) found that pressure nozzles and centrifugal atomizers used in spraying exerted shearing effects destructive to the colloidal properties of egg white. Bergquist and Stewart (1952A) designed a two fluid nozzle that helped to minimize the damage due to shear. This atomizing device dried albumen foam instead of the liquid and utilized much lower pressures.

Effect of surface formation.--Bull (1938) stated that the amount of albumen denaturation was a function of the rate of creation of new surfaces and their concentration in the solution. In the spray drying of albumen, there are many new surfaces created. Bergquist and Stewart (1952B) found that if the amount of surfaces formed and the rate of surface formation were excessive, the beating power of the albumen was reduced. Bergquist (1961) found no adverse effects to the albumen unless the surfaces formed were above 4,000 sq. cm. per cc.

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Introduction to Chemical Additives

At the present time, the addition of selected chemicals to improve the functional properties of albumen is an accepted commercial practice. The use of these chemical additives dates back to Mink's patent in 1939 which advocated the addition of the anionic surface active compound sodium oleate to egg white. The search for these chemical additives, or whipping aids, was accelerated in the 1950's; at that time many such additives were patented.

Names and classifications of chemical additives

The Food and Drug Administration approved the addition of certain chemical additives to albumen in 0.1-.2% concentration (based on the egg white solids). Several approved additives are sodium lauryl sulfate, sodium oleate, triethyl citrate, triacetin, and sodium desoxycholate. There are several hundred more known whipping aids.

Putnam (1948) reported that synthetic detergents may be classified as anionic, cationic, and nonionic according to the sign of charge on the hydrocarbon group conferring surface activity. Gardner (1960) similarly grouped known chemical additives into the following six groups.

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Classification of Chemical Additives

Group	Examples
Anionic chemical additives	Sarkosyl NL-30 (sodium l. sarcosinate) Sodium lauryl sulfate, sodium oleate
Cationic chemical additives	Arquad 12-50 (dodecyl trimethyl ammonium chloride) Arquad 18-50 (octadecyl trimethyl chloride)
Nonionic chemical additives	Acetylmethylcarbinol (Acetoin)
Organic and inorganic salts	Sodium desoxycholate
Acids and alkalies	Oleic acid, sodium hydroxide
Miscellaneous	Triethylcitrate, glycerine

Purpose and function of chemical additives

Bergquist (1961) advocated the addition of chemical additives to help preserve and enhance the whipping ability of albumen which would otherwise be impaired during drying. Finucane (1954) stated that such an additive was necessary because the severe treatments used in the spray drying produces a dried albumen that, when reconstituted, is difficult to whip. Harrel (1959) reported that whipping aids, in general, serve three purposes: (1) to shorten the whipping time necessary to make angel cakes (2) to increase tolerance against angel cake failures, and (3) to slightly increase angel cake volumes.

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Sodium oleate.--Sodium oleate $[CH_3(CH_2)_7CH{=}CH(CH_2)_7\overset{\displaystyle O}{\overset{\|}{C}}{-}ONa]$ is a sodium salt of the 18-carbon oleic acid. Mink (1939) included sodium oleate in his study of anionic surface active compounds. He found that the anionic chemical additives improved the quality of the foam which was obtained from whipping the dried egg white by increasing the volume and stability of the foam. As a group, these additives generally decreased the whipping time and increased the angel cake volume, having no adverse effect on cake texture and grain. Gardner (1960) reported sodium oleate, unlike other anionic chemical additives, increased the time required for beating the foam to the desired peak consistency. Gardner (1960) found sodium oleate effective in improving the recipe tolerance to both formulation and manipulation and in improving the function of fat-contaminated albumen. At low concentrations, this additive slightly increased egg white pH and angel cake volumes. At high concentrations of sodium oleate, Gardner (1960) observed decreases in angel cake volumes, excessive cracks in the cake surfaces, and increases in the coarseness of the cakes. The researcher found that sodium oleate significantly decreased the surface tension of the egg white system. Peter and Bell (1930) reported that the addition of sodium oleate yields a whey product of poor foaming properties.

<u>Sodium lauryl sulfate</u>.--Sodium lauryl sulfate [$CH_3(CH_2)_{11}-O-SO_3Na$] belongs to the anionic class of whipping aids. This additive is one of the newer whipping aids, approved by the Food and Drug Administration in 1960. This fatty alcohol sulfate is prepared by reducing the fatty acid radical of a fatty material by high pressure and catalytic hydrogenation with the formation of the corresponding alcohols which are then sulfated.

Gardner (1960) studied the effects of sodium lauryl sulfate in an egg white system. The additive slightly decreased the surface tension of the liquid albumen. At low concentrations, sodium lauryl sulfate decreased the beating time and slightly increased the angel cake volume. At higher additive concentrations, Gardner (1960) found the additive produced an angel cake of coarse texture. Forsythe (1964) reported that sodium lauryl sulfate is the favorite additive in the egg products industry.

<u>Triethyl citrate</u>.--Triethyl citrate

$$\left[\begin{array}{l} CH_2-\overset{\overset{O}{\|}}{C}-O-C_2H_5 \\ \quad | \\ HO-C-O-C_2H_5 \\ \quad | \\ CH_2-\overset{\overset{O}{\|}}{C}-O-C_2H_5 \end{array}\right]$$

is an ester of an aliphatic alcohol and aliphatic polybasic acid. Kothe, who was credited with patenting the use of triethyl citrate, found the ester to be the most effective in an egg white system in concentrations between 0.01-.05%, based on the weight of the albumen. Kothe (1953) found that triethyl citrate shortened the whipping time of albumen, increased its tolerance to overbeating, and slightly increased the angel cake volume. Cotterill et al., (1963) stated that the most outstanding effect of triethyl citrate was to reduce the whipping time of egg white. However, these investigators found that triethyl citrate had little or no effect on the physical properties of albumen. In a later study, Forsythe (1964) observed that triethyl citrate appeared to repair the heat-induced damage to egg white, whereas sodium lauryl sulfate appeared unable to do this.

Mode of action

The mode of action of these chemical additives on egg white is not completely understood. Probably more is known about the action of the anionic type derivatives than of the other types. Stirton (1964) observed that the effect of these surface active compounds in promoting and stabilizing foam appeared to be due to their concentration in the interfacial film of the foam and to their action in the concentrated surface film rather than their effect on the surface itself. Karush et al., (1949) believed that there is an electrostatic interaction between a positively charged

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charged group on the protein and the negative group of the anion. Gardner (1960) postulated that this complex between egg white protein and anionic additive increased the functional efficiency of the egg white system through a specific combination of lowered surface energy and protein complexing. Cunningham and Cotterill (1964) thought that there was more to the action of the chemical additive than a complex formed with the lysozyme fraction; however, they made no postulation because of incomplete evidence.

Yolk-Contamination in Albumen

Harrel (1959) proclaimed that the greatest single reason for egg white failing to perform in angel cake is yolk-contamination. In commercial operations yolk-contamination is usually a result of the mechanical separating operations or the condition of the egg. In the commercial egg breaking and separating operations, it is impossible to prevent minute quantities of yolk from getting into the egg white. Bergquist and Wells (1956) found that the amount of yolk-contamination usually ranged from 0.01% in an efficient operation to as high as 0.20% in an inefficient operation. Yolk-contamination can occur when shell eggs are subjected to an environment promoting a rapid loss of moisture, yolk lipids diffuse through yolk membranes into the albumen.

Effect of yolk on the functional properties of albumen

A minute quantity of yolk can greatly decrease the functional performance of albumen. Cunningham and Cotterill (1964) named this quantity as 0.01%. St. John and Flor (1931) stated that a single drop of yolk in 30 grams of albumen would reduce the quantity of foam from 135 c.c. to 40 c.c. While Harrel (1959) reported that 0.15% yolk in egg white produced no foam at all. Cunningham and Cotterill (1964) found that foam stability was decreased in direct relation to the amount of yolk. The whipping time of albumen was increased by the yolk in concentrations as low as 0.001%; while, angel cake volume was decreased by all concentrations of yolk above 0.001%. The researchers reported that 0.01% yolk-contamination decreased foam volume. Thus, the detrimental effects increase with the amount of yolk present until a point where there is total destruction of the foaming power of albumen.

Effect of yolk in spray dried albumen

It is a well known fact that spray drying magnifies the adverse effects of yolk-contamination in albumen. Cotterill *et al.*, (1965) found that the detrimental effects of yolk on albumen were enhanced by about ten times in the spray drying process. A yolk concentration of 0.02% (on a liquid basis) was as detrimental after drying as 0.2%

yolk before drying. The best explanation for this phenomen is given by Smith (1959). He discovered that the greater the dispersion of yolk throughout the albumen, the more harmful its effect. The blending and atomization in spray drying disperse the yolk throughout the albumen, multiplying its detrimental effects.

The harmful components of yolk

Smith (1959) found that when yolk lipids diffused through the yolk membrane into the albumen they did not have the same ratio of fat constitutents as in whole yolk. These diffused lipids were primarily glycerides instead of containing the amounts of glyceride, cephalin, lecithin, and cholesterol normally found in whole yolk. The author found that the glyceride fractions were the detrimental components; the other lipids in yolk had little or no effect on the functional performance of albumen. The diffused yolk was two to three times more harmful to the functional performance of albumen than whole yolk; a diffused yolk-contamination of 0.03-0.4% (on a liquid basis) would have the same adverse effect as a whole yolk-contamination of 0.09-.12%.

Mechanism of effects

The mechanism of adverse effects caused by the presence of yolk in albumen is not completely understood.

St. John and Flor (1931) thought that yolk retarded foam formation by decreasing the surface tension of the albumen. In a later study, Cunningham and Cotterill (1964) found that yolk did not greatly influence the surface tension of albumen. They attributed the adverse effects of yolk-contamination to an interaction between yolk and two of the egg white proteins. The researchers believed that the increased whipping time of yolk-contaminated albumen was due to the involvement of one of the globular proteins, responsible for the rapid foaming of egg white. The decreased foam stability and reduced amount of ovomucin insolubilized in the foam, led the researchers to conclude that there was a possible lipide-ovomucin complex formed.

Method of detection

At the present time, the quantity of yolk present in egg white can be detected by a film test method. Bergquist and Wells (1956) adapted this test for determining small quantities of yolk, or fat, in egg white from the Heinemann and Rohr method for determining the fat content of skim milk. In the film test method, the fat was extracted from the egg white using ethyl and petroleum ether. The fat, redissolved in petroleum ether, was then spread as a monolayer on the surface of an acetic acid solution. The quantity of yolk present in the albumen was then measured as the area of the spread. The Bergquist and Wells film test method is probably the most accurate and commonly used methods for determining the amount of yolk-contamination in albumen.

Methods to counteract the adverse effects

Four recent studies have been made by researchers from the University of Missouri, suggesting ways of improving the functional properties of yolk-contaminated albumen. Some of these methods have proved more effective than others.

Lipase treatment.--Cotterill and Funk (1963) studied the effect of adding a wheat germ lipase and two pancreatic lipases in 0.03% concentration to 0.02% yolk-contaminated albumen. The wheat germ lipase was not effective in improving the functional properties of yolk-contaminated albumen; whereas, the pancreatic lipases, steapsin and Lipase 150, were effective. The pancreatic lipases decreased the whipping time and improved the angel cake volumes of the yolk-contaminated albumen; however, the cake volumes never equalled those of the control. The flavor and aroma of the cakes made with pancreatic lipase steapsin were undesirable; whereas, that of the cakes made with Lipase 150 was normal. Treating the yolk-contaminated albumen with pancreatic lipases prior to spray drying also produced a magnitude of improvement in the functional performance of the albumen. The researchers suggested using the lipase treatment simultaneously with desugarization. It was not determined whether the improvement due to the lipase treatment results from the destruction of the glycerides in the yolk or from the presence of free fatty acids, byproducts of the hydrolysis of the glycerides.

Centrifugation.--Cunningham and Cotterill (1964) recommended centrifugation as a commercial method to improve the functional properties of yolk-contaminated albumen. They found that centrifuging improved the functional properties of yolk-contaminated albumen provided that the amount of yolk did not exceed 0.2%. By adjusting the pH to pH 5.5 and centrifuging, the maximum amount of yolk lipids appeared as a precipitate.

Heat treatment.--Cotterill *et al.*, (1965) discovered that the functional properties of liquid albumen contaminated with small amounts of yolk (0.05%) could be improved by heat treatments. A short time-high temperature treatment (15 minutes at 130°F) was effective as lower temperatures for longer times. However, the angel cake volumes never equalled those made from the yolk-free albumen. The researchers attributed the improvement in functional performance of the yolk-contaminated albumen to a dissociation of the detrimental complex between the yolk and egg white components. Unfortunately, the beneficial effect of the heat treatments was not apparent after spray drying.

Chemical additives.--Kothe (1953) was the first to be accredited with the discovery of the use of chemical additives to improve the functional properties of yolk-contaminated albumen. He advocated the use of ester type organic chemicals such as triethyl citrate.

In a recent investigation, Cotterill *et al.*, (1963) studied the effects of three surfactants and an ester on the functional performance of yolk-free and yolk-contaminated albumen. The researchers investigated the effect of the chemical additives on angel cake volume, surface tension, and amount of yolk lipids retained in the drainage from the foam in 0.1% yolk-contaminated egg white system.

A 0.03% concentration of Sarkosyl NL (sodium lauroyl sarcosinate), an anionic additive having an effect similar to sodium lauryl sulfate, improved angel cake volumes made from yolk-contaminated albumen to such an extent that the volumes exceeded those made from the yolk-free albumen. The cationic surface active compound Arquad 12 (dodecyl trimethyl ammonium chloride), at 0.03% concentration, also increased angel cake volume of the yolk-contaminated albumen so that it approximately equalled those of the control. The nonionic surfactant Tween 80 (polyoxyethylene sorbitan monooleate) further impaired the quality of the yolk-contaminated albumen. The ester triethyl citrate improved angel cake volume made from yolk-contaminated albumen; however, these angel cakes never equalled the yolk-free in volume.

The anionic additive Sarkosyl NL was the most effective in causing the yolk lipids to remain in the foam, while the cationic surface active coupound did not significantly affect the amount of lipids in the foam or drainage. The ester triethyl citrate slightly decreased the amount of lipids in the foam drainage.

The addition of yolk had little effect on the surface tension of the albumen. The researchers concluded that the role of the chemical additives in improving the functional performance of yolk-contaminated albumen can not be explained on the basis of surface active effects alone; but, the ionic character apparently had some effect in altering the performance of yolk-contaminated egg white. The investigators reported that the action of whipping aids were not solely associated with overcoming the adverse effects of yolk-contamination. On the other hand, Harrel (1959) maintained that the function of such additives was only to improve quality albumen, not to upgrade yolk-contaminated albumen. However, Cotterill _et al_., (1963), Smith (1959), and Kothe (1953) have presented substantial evidence to support the fact that certain additives can partially overcome the effects of yolk-contamination in albumen.

Objective Tests for Angel Cakes

Brown (1964) reviewed several objective tests to measure the quality of the meringue, batter, and final angel cakes. The researcher used the seed displacement method to measure the volume of the cakes, the foam and batter specific gavities to measure the amount of air incorporated, and the pH to determine the acidity of the batter. Both Brown (1964) and Funk *et al.*, (1965) utilized the Allo-Kramer Shear Press to measure the compressibility, tensile strength, and tenderness of angel cakes. Funk *et al.*, (1965) found very highly significant correlation coefficients between shear press values and sensory evaluations of the angel cakes. The researchers suggested that the shear press could be reliably used to evaluate texture in place of a taste panel.

EXPERIMENTAL PROCEDURE

The study was initiated to determine the effects of three chemical additives on the functional properties of commercially (plain) spray dried albumen and commercially spray dried albumen with yolk added. To achieve a detrimental level of yolk in the albumen, 0.05 g spray dried yolk was added to half of the variables; these variables were designated as commercially spray dried albumen with yolk added. The other half of the variables were designated as commercially (plain) spray dried albumen. Three chemical additives--sodium lauryl sulfate, sodium oleate, and triethyl citrate were added to the albumen in 0.1% and 0.2% concentrations based on the egg white solids. Both the albumen with yolk added and the plain albumen controls contained no chemical additive. Thus the fourteen variables consisted of the two concentrations of each of these three additives in the plain series and in the series with yolk added, and the two controls. Each of the fourteen variables were replicated five times. The foaming ability of the spray dried albumen was evaluated through a comparison of angel cakes.

Preliminary Investigations

To make a valid comparison of the foaming ability of the albumen, it was necessary to perfect a controlled formula and procedure for producing quality angel cakes with spray dried albumen. Initial experiments were made using the formula developed by Brown (1964); however, no modification of Brown's formula was found to produce angel cakes of acceptable volume and texture with this particular lot of spray dried albumen. Perhaps this failure was due to a difference in the processing of the two lots of dried albumen.

After extensive experimentation, the author found that Miyahara and Bergquist's (1961) formula designed specifically for the use of spray dried albumen, produced angel cakes of acceptable volume and texture. Slight modifications in the ingredients and oven temperature of this formula were made. Cornstarch was used in place of the wheat starch, since the cornstarch was readily available and produced cakes of equally acceptable quality.

The author investigated several oven temperatures and baking times. Using the Ecto forced air oven, Model 186-A, a temperature of 177°C and a time of 33 minutes produced angel cakes with a high degree of tenderness and a high volume. Higher temperatures caused excessive browning and an underdone cake; whereas, a lower temperature produced a tougher cake.

Further testing was carried out to adjust the pH of the cake batter. Brown (1964) found that high quality angel cakes were produced when the pH of the cake batter ranged between pH 5.6-5.8. The level of the cream of tartar in the formula is largely responsible for achieving the desired pH. The amount of cream of tartar to be used depends on the pH of the albumen. Glucose fermentation alters the pH of the albumen; thus spray dried albumen, which is fermented, tends to have a more neutral pH than fresh albumen. Various methods of spray drying produce albumen with different end pH's; thus the pH of spray dried albumen may vary. In the present study, the pH of the spray dried albumen was pH 6.5. The addition of 1.15 grams of cream of tartar per 315 ml reconstituted albumen gave a cake with a final batter pH ranging between 5.6-5.8.

Processing of Albumen

The spray dried albumen was obtained from a commercial processor,[1] so that the albumen was obtained from a common lot. All treatment and spray drying of the egg white was carried out in the processing plant.

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[1]Seymour Foods, Topeka, Kansas.

Source and processing of eggs

The albumen was procured from fresh shell eggs varying in age from 1 to 2 weeks and grades from A to C. The eggs were machine broken and separated according to U.S.D.A. requirements. To remove all shell fragments and membranes, the albumen was strained through stainless steel strainers with 0.024 inch perforations. A homogenous product was achieved by churning the egg white in churns equipped with stainless steel agitators.

Fermentation and freezing

The liquid albumen was desugared with *Aerobacter aerogenes* fermentation carried out at 29°C. Following fermentation, the albumen was frozen in 30-lb metal containers and held until spray dried.

Spray drying

The albumen was thawed, blended, and spray dried with a 12-nozzle Roger's spray dryer, under an atomizing pressure of about 2000 lbs. The intake temperature was 149-163°C and the exhaust temperature 66-71°C. After drying, the albumen was screened through a 80 mesh USBS screen and cooled to 29°C before packaging.

Packaging and shipment

The dried albumen was packaged in large polyethylene bags and held at 20.6°C until ready for shipment. Upon arrival of the shipment of albumen, the bag was immediately stored at -29°C. The dried albumen was then prepackaged in appropriate sized heat sealable bags, heat sealed, and stored at -29°C until preparation of each cake.

Yolk-Contamination in the Albumen

Since commercially processed spray dried yolk[2] was readily available and could serve as a common lot throughout the experiment, it was used to contaminate the albumen. To obtain a thorough yolk disperison in the albumen, the dried yolk was blended with the albumen, sugar, cream of tartar and salt, prior to the preparation of the angel cakes.

Preparation of the yolk

One pound of spray dried yolk was blended on the Hobart mixer, Model K-5, set at Speed 1 (56 rpm) for 5 minutes. The dried yolk was then weighed on a Torsion balance, Model PL800, in 3-gram amounts and packaged in

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[2]Seymour Foods, Topeka, Kansas.

heat sealable bags. The packages were stored at -29°C until ready for use. A single package was used for all the 0.05% yolk-contaminated variables prepared on one day. For each variable with yolk added, 0.05 gram of yolk in the dried form was weighed out on the Mettler balance, Model H15.

Level of yolk-contamination

The addition of 0.05 gram (equivalent to 0.1 gram on a liquid basis) of spray dried yolk produced a 0.028% level of yolk-contamination in the reconstituted albumen. This amount was chosen after preliminary investigations revealed that this level of yolk-contamination gave a serious, yet reversible, impairment to the quality of angel cakes.

The Bergquist and Wells monomolecular film test, conducted by the processor of the albumen, showed that the spray dried albumen had an initial yolk-contamination of 0.022% (based on a liquid basis). Therefore, the total amount of yolk in the variables designated as s.d. albumen with yolk added was 0.05%; the variables designated as plain s.d. albumen had an actual contamination of 0.022%. Bergquist and Wells (1956) reported that the entrance of some yolk into the albumen during commercial mechanical breaking and separating operations was inevitable.

Measurement and Addition of Chemical Additives

The Food and Drug Administration allows the addition of the three commercial "whipping aids"--sodium oleate, sodium lauryl sulfate, and triethyl citrate to egg white in 0.1% and 0.2% concentrations based on the egg white solids. Both the 0.1% and 0.2% concentrations of each of these chemical additives were used in this study.

Sodium lauryl sulfate is a white powder; sodium oleate comes in flake form. The amount of these two additives can be calculated as 0.1% (0.045 grams) and 0.2% (0.09 grams) of the forty-five grams of egg white solids used in the formula. Since triethyl citrate is a liquid and more easily measured volumetrically, the weights were converted to volumes by dividing its specific gravity (1.1369) into the weight required. Thus, 0.1% and 0.2% concentrations of triethyl citrate are equivalent to 0.04 and 0.08 ml, respectively.

The chemical additives were added just before the reconstitution of the albumen. Sodium lauryl sulfate and sodium oleate were weighed to the nearest thousandth of a gram on the Mettler balance, Model H15. Triethyl citrate was measured with a 0.1 ml pipette, calibrated in hundreths of a milliliter. The additive was gently blown from the pipette into the bowl containing the albumen and distilled water. The tip of the pipette was gently tapped on the side of the bowl to capture the last drop.

Angel Cake Formulation Using Albumen

To evaluate the effects of chemical additives on commercially s.d. albumen and commercially s.d. albumen with yolk added, angel cakes were prepared. Researchers have commonly used angel cakes to study the functional properties of albumen.

Blending and packaging of ingredients

All ingredients, with exception of the albumen, yolk, and chemical additives, were purchased from Michigan State University Stores. The cake flour, granulated sugar, cornstarch, and powdered sugar were blended separately on the Hobart mixer, Model A-200, using the paddle attachment.

Ninety grams of cake flour and 150 grams granulated sugar were weighed on the 5-kilogram capacity Toledo scale. Forty-five grams of cornstarch and 59.4 grams of powdered sugar were weighed to the nearest tenth on a Torsion balance, Model PL800. All four ingredients were then placed in a one quart polyethylene bag, tied securely, and stored at room temperature.

Seventy-four hundreths of a gram of salt and 1.15 grams of cream of tartar were weighed on the Mettler balance, Model H15, and packaged with an additional

150 grams granulated sugar. The polyethylene bags were tied securely and also stored at room temperature.

Basic formula

The basic formula contained constant amounts of the following ingredients for every variable:

TABLE 1. Basic formula for angel cakes

Ingredients	Amounts	
	Grams	Milliliters
Distilled water		315
Egg white solids	45.00	
Salt	0.74	
Cream of tartar	1.15	
Cake flour	90.00	
Cornstarch	45.00	
Powdered sugar	59.40	
Granulated sugar	300.00	

Yolk and chemical additives were the varying ingredients.

Method of preparation

The method of preparation was standardized to prevent any variation in the mixing. Five cakes were baked daily. The plain albumen cakes were made first, completing an entire series and then the next one; then the cakes prepared from the 0.05% yolk-contaminated albumen were prepared in the same manner.

Mixing of ingredients.--The angel cakes were prepared using the 5-quart Hobart mixer, Model K-5. The flour-sugar mixture was placed in the five quart bowl and blended at Speed 2 (92 rpm) for three minutes. The mixture was sifted onto waxed paper and set aside until ready for use.

The albumen, stored at -29°C, was brought to room temperature before mixing. Then, the albumen, sugar, salt, and cream of tartar were placed in a separate 5-quart bowl and blended for 3 minutes at Speed 1 (56 rpm), also using the paddle attachment of the mixer. If yolk was to be added, it was blended with this albumen-sugar mixture.

Reconstitution of albumen.--Three hundred-fifteen milliliters of distilled water, at room temperature, were poured into a 5-quart mixing bowl. The albumen-sugar mixture was added to the distilled water. Miyahara and Bergquist (1961) suggested adding the egg white solids to the distilled water to increase the ease of reconstitution. Any chemical additive to be included was added just prior to the reconstitution to insure a uniform distribution throughout the albumen.

In reconstituting the albumen, the paddle attachment of the Hobart mixer, Model K-5, was used. The mixture was blended at Speed 2 (92 rpm) for thirty seconds;

afterwards, the bowl and paddle were scraped with a rubber spatula to remove any adhering egg. Another 30 second blending followed. After scraping, the rpm was decreased to Speed 1 (56 rpm); the mixture blended for 30 seconds; and the bowl and paddle scraped again. To insure thorough reconstitution, the mixture was blended another 90 seconds at Speed 1 (56 rpm). The temperature of the albumen was measured with a Centigrade thermometer to assure that the albumen was at room temperature, 25°C. If the temperature was below room temperature, the bowl containing the albumen was placed in a larger bowl of lukewarm water until the temperature of the albumen reached 25°C.

Formation of the meringue.--The whip attachment of the Hobart mixer, Model K-5, was used to whip the reconstituted albumen-sugar mixture to the meringue stage. The mixer was set at the highest speed, Speed 10 (280 rpm) and turned on for two minutes. According to Miyahara and Bergquist (1961) spray dried albumen should be whipped to a stiffer and dryer peak, than either fresh or frozen albumen. Perhaps this is due to damage inflicted to the albumen during the spray drying process.

Addition of the "fold in" ingredients.--The flour-sugar mixture was divided into four approximately equal portions; each portion was sifted over the meringue. After each addition of the "fold in" ingredients, a wire whip was used to execute five folding strokes. Griswold (1962) recommended using a wire whip to fold the flour into the meringue, since there is less destruction of albumen air cells than with a mixer. The flour mixture was folded in with light and gentle strokes to prevent breakdown of the foam.

Preparation of the batter and cake.--Six hundred-fifty grams of batter was weighed into a 15 1/2 x 4x4-inch aluminum loaf pan on the 5-kilogram Toledo scale. A metal spatula was used to spread the batter evenly in the pan. The cakes were baked in the Ecto forced air oven, Model 186-A, at 177°C for 33 minutes. Upon removal from the oven, the cakes were inverted onto cake racks and allowed to cool for 1-1 1/2 hours.

After volume measurements had been made, the cakes were removed from the pans onto Saran-covered cardboard. A cake knife was used to cut around the sides of the pan. Two metal spatulas were used to gently lift the cake from the pan. Care was taken to prevent tearing of the cake. Problems arose when several of the cakes made from the albumen with yolk added stuck to the bottom of the pans; thus, a pancake turner had to be used to lift these cakes from the pan. The cakes were doubly wrapped in Saran and sealed with masking tape to prevent the entrance of moisture. All cakes were stored for 3-4 weeks at -29°C.

Preparation of samples

After the cakes were stored at -29°C for 3-4 weeks, the frozen cakes were sliced on a Hobart electric slicer, Model 410, set at 60. Each slice was designated for use according to the rotation pattern in Figure 1. After each replication, the slices were rotated forward by one slice.

Crust	1
Tenderness	2
Extra	3
Compressibility	4
Tensile Strength	5
Taste Panel	6
Extra	7
Tenderness	8
Extra	9
Cell Structure	10
Compressibility	11
Taste Panel	12
Tenderness	13
Tensile Strength	14
Extra	15
Compressibility	16
Tensile Strength	17
Taste Panel Extra	18
Taste Panel	19
Extra	20
Crust	21

Figure 1. Rotation pattern designating use of angel cake slices.

The slices designated for testing with the shear press were cut with specially designed stainless steel cutters. Three extra slices were cut for tensile strength evaluations. Shear press, taste panel, cell structure, and extra slices were wrapped individually in Saran and stored in sealed cardboard boxes at -29°C until ready for use.

Objective Measurements of Angel Cakes

To determine the effects of chemical additives on the functional properties of albumen, objective evaluations of the angel cakes were performed. Objective measurements included tests for volume, pH, specific gravity, tenderness, compressibility, and tensile strength.

Specific gravity of foam and batter

After the albumen-sugar mixture had been whipped to the meringue stage, the specific gravity of the 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 distilled water at 25°C.

In the present study, the specific gravity of the foam was done in duplicate. Two half cups of foam were removed from the bowl at two points directly across from each other. A rubber spatula was used to dip out the foam into tared aluminum cups; an ice cream scoop had to be used where there was insufficient foam formation. Each one-half cup of foam was gently leveled with a metal spatula, in order not to destroy the foam structure. The two one-half cups of foam were weighed on the Torsion balance, Model 800, and returned immediately to the bowl. To determine the specific gravity of the foam, the weight of one-half cup foam was divided by the weight of one-half cup of water.

Before the cake batter was weighed into the aluminum loaf pan, two one-half cups of batter were obtained in the same manner as for the foam. The specific gravity of the batter determinations followed the same procedure as used in determining the specific gravity of the foam.

pH of the batter

One of the cups of batter formerly designated for specific gravity of batter determinations was also used to determine the pH. The electrodes were carefully inserted into the center of the cup of batter. The pH determinations were made at room temperature using the Zeromatic Beckman pH meter, equipped with glass and calomel electrodes.

Volume determination

Volume determinations were made by the seed displacement method used by Brown (1964). The technique provides a cake volume measurement in milliliters of seeds. After each cake had cooled 1-1 1/2 hours, Saran was eased over the top of the cake and inner sides of the cake pan. Rape seeds were poured over the cake and heaped above the top of the pan. A metal spatula was used to level the seeds even with the top of the pan; the top was leveled once and the corners, leveled at angles from the center to the side. Then, the pan, cake, and seeds were inverted into another pan. The seeds were poured into a 1000 ml graduate cylinder for measurement. Volume of the cake was calculated as: total of milliliters of seeds held in an empty pan minus the seeds above the cake.

Tenderness

The tenderness of the cake slices were measured with the standard shear-compression cell of the Allo-Kramer shear press, Model SP-12, equipped with an electronic recorder, Model E2EZ. A 100-pound proving ring, a range of 100 pounds, and a pressure of 25 pounds were used. The cut samples, measuring 5.72 centimeters square and 1.63 centimeters thick, were weighed to the nearest hundreth of a gram on the Torsion balance, Model PL 800.

The weighed sample was placed in the lower half of the standard shear compression cell; the upper half was attached to the proving ring. A 30-second downstroke was used to shear the sample. After each sample was sheared, the cell was washed and dried with unheated forced air.

The peak of the graphed curve, drawn by the electronic recorder, was used to compute the maximum force required to shear the sample. The total force was calculated as the peak reading multiplied by the range divided by the sample weight. The total force represented an average of three trials.

The area of the graphed curve also gave an indication of the tenderness of the cakes. The curves were carefully cut and weighed on the Mettler balance, Model H15. A conversion factor, of 174.2, used by Brown (1964) was used to convert the gram weight to area. The area-under-the-tenderness-curve was calculated as curve weight multiplied by the conversion factor. The area of the curve represented an average of three trials.

Compressibility

Circular cake samples, 5.08 centimeters in diameter and 1.63 centimeters thick, were cut for the compressibility tests. The round, flat plunger, 5.73 centimeters in diameter, of the upper assembly of the succulometer cell of the Allo-Kramer shear press was used. The range was set at 5, the pressure at 25 lbs.; and the 100-pound proving ring was attached.

The samples were placed on a wooden platform on the support plates at the base of the main column of the shear press. The plunger, during a 30-second downstroke, depressed the samples. The peak of the curve gave the maximum force needed to depress the samples. Compressibility was calculated as: peaking reading multipled by the range. The final compressibility reading was an average of three trials.

The area of the graphed curve also provided a picture of the compressibility of the cakes and was computed as previously described. The area-under-the-curve was calculated as weight of the curve times the conversion factor. The final area-under-the-curve reading represented an average of three trials.

Tensile strength

The 100-pound proving ring, a range of 1 pound, and a pressure of 25 pounds were employed for these tests. The tensile strength of the cakes were measured using specially designed attachments for the shear press as described by Funk *et al.*, (1965). The Acco clamps, Model 325, were modified by substituting a light weight spring to reduce damage to the cake samples. The clamps were fastened to a U-shaped base plate and an upper plate attached to the proving ring. A set screw in each clamp provided further adjustment. The chart drive cable of the shear press was rewound so that the graph would record on the upstroke.

The samples were cut in an hourglass shape, measuring 2.54 centimeters across the center and 1.63 centimeters thick. The proving ring with the upper tensile strength attachment was allowed to run to almost the end of the stroke. Then the ends of the cake sample were carefully inserted in the upper and lower clamps. When the proving ring and upper attachment began the upstroke, the sample was torn apart at the center.

The peak reading of the graphed curve conveyed the maximum force necessary to tear the sample. The length of the break of the sample was measured with calipers. Tensile strength was calculated as the peak reading multiplied by the range divided by the area of the break (length of the break times width of the sample). Each reading represents an average of three samples.

RESULTS AND DISCUSSION

The effects of the addition of two anionic type additives (sodium lauryl sulfate and sodium oleate) and one ester type additive (triethyl citrate) on the function of commercial (plain) spray dried albumen and 0.05% yolk-contaminated commercial spray dried albumen have been investigated. The two controls, both egg white systems without the addition of an additive, served as a means for comparison of the physical properties and foaming abilities of treated albumen through an evaluation of angel cakes.

Objective Measurements of Angel Cakes

The replicate averages, albumen type means, and standard deviations for all the objective tests used on the cake variables prepared from commercial spray dried albumen and 0.05% yolk-contaminated albumen, both with and without a chemical additive, are tabled in the Appendix. The data from objective tests made during and after the preparation of the angel cakes were subjected to analyses of variance (Table 2). The very highly significant differences among cake variables for objective

TABLE 2. Analyses of variance for objective tests made during and after the preparation of the cakes

Source of Variance	Degree of Freedom	Mean Squares Sp. Gr. Foam	S. Gr. Batter	Volume
Cake Variables	13	0.1040***	0.0849***	49.9473***
Replications	4	0.0017**	0.0011**	1.4001
Error	52	0.0004	0.0002	24,121.5197
Total	69			

Source of Variance	Degree of Freedom	Mean Squares Compressibility Force Average	Compressibility Area-Under-the-Curve	Tenderness Force Average
Cake Variables	13	4.1250***	73.6348***	0.6302***
Replications	4	0.1200	2.1893	0.0716
Error	52	0.1123	2.2137	0.1470
Total	69			

Source of Variance	Degree of Freedom	Mean Squares Tenderness Area-Under-the-Curve	Tensile Strength Force Average
Cake Variables	13	7586.71***	.00092***
Replications	4	280.89	.00003
Error	52	1360.44	.00004
Total	69		

**Significant at the 1% level.

***Significant at the 0.1% level.

tests were further evaluated using the Studentized multiple range test (Duncan, 1957).

The pH values for the cake batter of all variables were quite similar and are tabled in the Appendix. Photographs of angel cake cellular structure are not included because no obvious differences could be observed.

Specific gravity of the foams

Use of the Studentized range test to evaluate significant differences among the albumen type means (Table 3) showed the following ($p \leq 0.01$). No significant differences occured among the specific gravities of the plain albumen foams with or without an additive with the exception that the use of sodium oleate increased the foam specific gravities in this series. These plain albumen foams also exhibited lower specific gravities than those of foams prepared with 0.05% yolk-contaminated albumen. These results agree with those of Cunningham and Cotterill (1963) who reported that a 0.05% yolk-contamination in frozen albumen reduced the foam specific volume from 10.9 ml/g to 5.5 ml/g.

The effect of chemical additives on the foam specific gravities of the yolk-contaminated albumen has not been explored in the literature. Results of this study presented in Table 3 have shown that the addition of sodium lauryl sulfate and triethyl citrate tends to

TABLE 3. Studentized multiple range test for specific gravity of the foams (Duncan, 1957)

Albumen	Additive	Sample Mean	Rank Order	Specific gravity of the foams differ significantly from rank order: at 1%	at 5%
Plain	.2% Triethyl citrate	.159	1	6[b]	6[b]
Plain	.1% Triethyl citrate	.162	2	6[b]	6[b]
Plain	.2% Sodium lauryl sulfate	.170	3	7[b]	6[b]
Plain	.1% Sodium lauryl sulfate	.175	4	7[b]	6[b]
Plain	Control	.177	5	8[b]	6[b]
Yolk	.1% Sodium lauryl sulfate	.204	6	2[a] & 8[b]	5[a] & 8[b]
Yolk	.2% Sodium lauryl sulfate	.213	7	4[a] & 8[b]	5[a] & 8[b]
Plain	.1% Sodium oleate	.291	8	7[a] & 10[b]	7[a] & 9[b]
Yolk	.2% Triethyl citrate	.326	9	7[a] & 10[b]	8[a] & 10[b]
Yolk	.1% Triethyl citrate	.397	10	9[a] & 12[b]	9[a] & 12[b]
Plain	.2% Sodium oleate	.411	11	9[a] & 12[b]	9[a] & 12[b]
Yolk	Control	.484	12	11[a] & 13[b]	11[a] & 13[b]
Yolk	.1% Sodium oleate	.524	13	12[a]	12[a]
Yolk	.2% Sodium oleate	.546	14	12[a]	12[a]

[a]That rank order and above.

[b]That rank order and below.

lower the specific gravities of the yolk-contaminated foams ($p \leq 0.01$); with sodium lauryl sulfate being more effective in lowering the specific gravity to near that of the plain albumen control. Addition of sodium oleate to both egg white systems increased the specific gravities ($p \leq 0.01$). In accordance with these results, Peter and Bell (1930) stated that the addition of sodium oleate to whey-protein solutions yielded a product of poor foaming properties.

Analysis of the replicate averages (Table 2) showed that there was a significant difference among the replications at the 1% level. This fact decreases the validity of the significant differences among the cake variable means for the foam specific gravities. The wide range of foam specific gravities causing this significance between replications can be traced to those variables with unstable foam structures--the 0.05% yolk-contaminated albumen with and without sodium oleate or triethyl citrate and the plain albumen with sodium oleate. Nevertheless, there was not a wide range of values for those variables with stable foams. The foam specific gravity values and their standard deviations are tabled in the Appendix.

Specific gravity of the batter

Analysis of variance for specific gravity of the cake batters indicated that there were highly significant differences among batters prepared from plain albumen and albumen with yolk added, both series with and without a chemical additive. Significant differences among variables for the specific gravity of the batter (Table 4) follow the trend for those of the foam specific gravities with two differences: (1) the addition of 0.1% sodium oleate to the albumen with yolk added also produced batters whose specific gravities were significantly higher at the 1% level than those of the control with yolk added (2) at all levels of significance, the batters prepared with sodium lauryl sulfate and 0.05% yolk-contaminated albumen were not significantly different from those prepared with the plain albumen.

Analysis of the replicate averages (Table 2) revealed that there was a significant difference between the replications at the 1% level. In concurrence with the foam specific gravities, the wide range of values can be attributed to those variables with the unstable foam structures.

Volume

The use of the Studentized range test (Table 5) revealed no significant differences among the cake volumes of the commercial albumen series with and without an additive except that the use of 0.2% sodium oleate reduced the volume in this series ($p \leq 0.01$).

TABLE 5. Studentized multiple range test for volume of cakes (Duncan, 1957)

Albumen	Additive	Sample Mean	Rank Order	Volume differs significantly from rank order: at 1%	at 5%
Plain	Control	3369	1	9[b]	8[b]
Yolk	.1% Sodium lauryl sulfate	3346	2	9[b]	8[b]
Plain	.1% Sodium lauryl sulfate	3321	3	9[b]	8[b]
Plain	.2% Triethyl citrate	3309	4	9[b]	8[b]
Plain	.2% Sodium lauryl sulfate	3304	5	9[b]	8[b]
Plain	.1% Triethyl citrate	3292	6	9[b]	8[b]
Yolk	.2% Sodium lauryl sulfate	3292	7	9[b]	8[b]
Plain	.1% Sodium oleate	3111	8	10[b]	7[a] & 9[b]
Yolk	.2% Triethyl citrate	2874	9	7[a] & 12[b]	8[a] & 12[b]
Plain	.2% Sodium oleate	2725	10	8[a] & 12[b]	8[a] & 12[b]
Yolk	.1% Triethyl citrate	2683	11	8[a] & 12[b]	8[a] & 12[b]
Yolk	Control	2311	12	11[a]	11[a] & 14
Yolk	.1% Sodium oleate	2184	13	11[a]	11[a] & 14
Yolk	.2% Sodium oleate	1935	14	12[a]	13[a]

[a]That rank order and above.

[b]That rank order and below.

A 0.05% yolk-contamination significantly reduced the cake volumes and this was further reduced by sodium oleate additions. However, when sodium lauryl sulfate (in the 0.1% and 0.2% concentration) was added to the 0.05% yolk-contaminated albumen, the resulting cakes had volumes approximately equal to those made with the plain albumen control. The addition of triethyl citrate also improved the volumes of cakes made from the 0.05% yolk-contaminated albumen; however, these volumes never equalled those of the plain albumen control cakes.

These results are in accordance with Cotterill et al., (1963) who found that triethyl citrate in concentrations up to 0.03% (on a liquid basis) improved the volumes of cakes made from frozen albumen contaminated with 0.1% yolk. Moreover, these researchers were in agreement with the results of this study indicating that an anionic type additive similar to sodium lauryl sulfate was more effective than the ester additive in producing cakes from yolk-contaminated albumen with volumes equivalent to those made from the plain albumen.

The addition of sodium oleate in 0.2% concentrations to both the plain and yolk series further impaired the foaming ability of the albumen as evidenced by decreased angel cake volumes. Gardner (1960) offered a possible explanation for this fact; he found that sodium oleate, unlike most whipping aids, increased the whipping time of the albumen. In the present study the whipping time of all the albumen variables was the same; therefore, those with sodium oleate could have been underbeaten. The results of this study are also in accordance with Peter and Bell (1930) who reported that the addition of sodium oleate created a whey product of poor foaming properties.

Shear press tests

Shear press tests included measurements of the compressibility, tenderness, and tensile strength of the cake slices. Both the maximum force and area-under-the-curve values were analyzed for compressibility and tenderness; however, Funk et al., (1964) recommended using only the maximum force values for an accurate measurement of the tensile strength of angel cakes.

Compressibility.--The results for both compressibility force average and area revealed the same pattern of significant differences at the 1% level (Tables 6 and 7). There were no significant differences in the compressibility of cakes prepared using the commercial albumen with and without a chemical additive except that the addition of 0.2% sodium oleate reduced the compressibility in this series. In addition, the angel cakes prepared with the plain albumen were significantly more compressible than those of the albumen with yolk with or without sodium

TABLE 6. Studentized multiple range test for compressibility (force averages) of cakes (Duncan, 1957)

Albumen	Additive	Sample Mean	Rank Order	Compressibility differs significantly from rank order: at 1%	at 5%
Plain	Control	0.82	1	10[b]	10[b]
Yolk	.1% Sodium lauryl sulfate	0.89	2	10[b]	10[b]
Plain	.1% Triethyl citrate	0.90	3	10[b]	10[b]
Yolk	.2% Sodium lauryl sulfate	0.91	4	10[b]	10[b]
Plain	.2% Triethyl citrate	0.97	5	10[b]	10[b]
Plain	.2% Sodium lauryl sulfate	0.98	6	10[b]	10[b]
Plain	.1% Sodium oleate	1.03	7	10[b]	10[b]
Plain	.1% Sodium lauryl sulfate	1.05	8	10[b]	10[b]
Yolk	.2% Triethyl citrate	1.25	9	11[b]	10[b]
Yolk	.1% Triethyl citrate	1.75	10	8[a] & 11[b]	9[a] & 11[b]
Yolk	Control	2.66	11	10[a]	10[a] & 13[b]
Plain	.2% Sodium oleate	2.79	12	10[a]	10[a]
Yolk	.1% Sodium oleate	2.96	13	10[a]	11[a]
Yolk	.2% Sodium oleate	3.24	14	10[a]	11[a]

[a]That rank order and above.

[b]That rank order and below.

TABLE 7. Studentized multiple range test for compressibility (areas) of cakes (Duncan, 1957)

Albumen	Additive	Sample Mean	Rank Order	Compressibility differs significantly from rank order: at 1%	at 5%
Plain	Control	3.41	1	10^b	9^b
Plain	.1% Triethyl citrate	3.72	2	10^b	9^b
Plain	.2% Triethyl citrate	3.93	3	10^b	9^b
Yolk	.1% Sodium lauryl sulfate	4.05	4	10^b	9^b
Yolk	.2% Sodium lauryl sulfate	4.08	5	10^b	9^b
Plain	.2% Sodium lauryl sulfate	4.24	6	10^b	9^b
Plain	.1% Sodium oleate	4.32	7	10^b	9^b
Plain	.1% Sodium lauryl sulfate	4.53	8	10^b	9^b
Yolk	.2% Triethyl citrate	5.37	9	11^b	8^a & 10^b
Yolk	.1% Triethyl citrate	7.51	10	8^a & 11^b	9^a & 13^b
Plain	.2% Sodium oleate	11.33	11	10^a	9^a & 13^b
Yolk	Control	11.41	12	10^a	9^a & 13^b
Yolk	.1% Sodium oleate	12.77	13	10^a	12^a
Yolk	.2% Sodium oleate	13.84	14	10^a	12^a

[a]That rank order and above.

[b]That rank order and below.

oleate. The addition of both levels of sodium lauryl sulfate and 0.2% triethyl citrate to the 0.05% yolk-contaminated albumen improved the compressibility of the cakes so that they were similar in compressibility to that of the plain albumen cakes.

Tenderness.--Significant differences in the tenderness (based on both maximum force and area-under-the-tenderness-curve values) of the cake variables (Tables 8 and 9) were found to be attributable to the presence of sodium oleate and/or 0.05% yolk. For both values, there were no significant differences in the tenderness of the cakes made from the plain albumen with or without a chemical additive ($p \leq 0.01$).

The following was true for tenderness based on the maximum force values only. At the 1% level, the addition of 0.05% yolk to the albumen produced cakes that were as tender as all the other cakes with two exceptions: (1) those of the plain albumen with 0.2% sodium oleate were more tender (2) those of the 0.05% yolk-contaminated albumen with sodium oleate were less tender. However, at the 5% level, the 0.05% yolk control cakes were significantly less tender than the plain albumen cakes with 0.2% sodium oleate, 0.1% triethyl citrate, 0.1% and 0.2% sodium lauryl sulfate, and the 0.05% yolk-contaminated cakes with 0.2% sodium lauryl sulfate. Also at the 5% level, the

TABLE 9. Studentized multiple range test for tenderness (areas) of the cakes (Duncan, 1957)

Albumen	Additive	Sample Mean	Rank Order	Tenderness differs significantly from rank order: at 1%	at 5%
Yolk	.2% Sodium lauryl sulfate	147.9	1	12[b]	12[b]
Yolk	.1% Sodium lauryl sulfate	157.7	2	12[b]	12[b]
Plain	.1% Sodium oleate	158.1	3	12[b]	12[b]
Plain	Control	159.9	4	12[b]	12[b]
Plain	.1% Sodium lauryl sulfate	163.1	5	13[b]	12[b]
Plain	.2% Sodium lauryl sulfate	164.3	6	13[b]	12[b]
Plain	.1% Triethyl citrate	170.9	7	13[b]	12[b]
Yolk	.1% Triethyl citrate	171.3	8	13[b]	12[b]
Plain	.2% Sodium oleate	172.3	9	13[b]	12[b]
Yolk	.2% Triethyl citrate	178.8	10	13[b]	12[b]
Plain	.2% Triethyl citrate	184.6	11	13[b]	12[b]
Yolk	Control	232.1	12	4[a]	11[a]
Yolk	.1% Sodium oleate	254.1	13	11[a]	11[a]
Yolk	.2% Sodium oleate	273.1	14	11[a]	11[a]

[a]That rank order and above.

[b]That rank order and below.

addition of 0.2% sodium oleate to the albumen with yolk added produced cakes that were significantly less tender than all but those of the 0.05% yolk-contaminated albumen with or without 0.1% sodium oleate.

The area-under-the-tenderness curve values disclosed few significant differences in the tenderness of the cakes. At the 5% level, cakes prepared using albumen with 0.05% yolk added with and without sodium oleate were significantly tougher than all the other cake variables.

The high degree of tenderness of the cakes prepared with plain albumen and 0.2% sodium oleate according to the tenderness maximum force values did not hold true for the tenderness area-under-the-curve values. The high rank order of this variable in the maximum force test can be traced to its higher sample weights. Because of their poor foam structures, these cakes had lower volumes and heavy, compact textures; thus, the samples weighed more per square inch. Sample weight was an integral part of the formula for calculating maximum force, whereas it was not used in calculating the area-under-the-tenderness-curve values.

Tensile strength.--Tensile strength, based on the maximum force readings, provided another fairly accurate measurement of tenderness (with the lower readings being more tender) of the cake variables (Table 10). As

TABLE 10. Studentized multiple range test for tensile strength (maxiumum force values) of cakes (Duncan, 1957)

Albumen	Additive	Sample Mean	Rank Order	Tensile strength differs significantly from rank order: at 1%	at 5%
Plain	.2% Triethyl citrate	0.025	1	9[b]	8[b]
Plain	.1% Triethyl citrate	0.026	2	9[b]	9[b]
Plain	.1% Sodium lauryl sulfate	0.026	3	9[b]	9[b]
Plain	.2% Sodium lauryl sulfate	0.027	4	9[b]	9[b]
Yolk	.1% Sodium lauryl sulfate	0.028	5	10[b]	9[b]
Plain	Control	0.029	6	10[b]	9[b]
Yolk	.2% Sodium lauryl sulfate	0.030	7	10[b]	9[b]
Plain	.1% Sodium oleate	0.035	8	11[b]	1[a] & 10[b]
Yolk	.2% Triethyl citrate	0.040	9	4[a] & 12[b]	7[a] & 11[b]
Plain	.2% Sodium oleate	0.044	10	7[a] & 13[b]	8[a] & 12[b]
Yolk	.1% Triethyl citrate	0.049	11	8[a] & 14	9[a] & 14[b]
Yolk	Control	0.055	12	9[a]	10[a] & 14[b]
Yolk	.1% Sodium oleate	0.057	13	10[a]	10[a] & 14[b]
Yolk	.2% Sodium oleate	0.066	14	11[a]	13[a]

[a]That rank order and above.

[b]That rank order and below.

indicated by the tensile strength readings, there was no significant differences among the plain albumen cakes with exception that the cakes with 0.2% sodium oleate were significantly less tender ($p \leq 0.01$).

The tensile strength readings showed that the addition of yolk produced cakes that were significantly less tender than those prepared from the plain albumen with exception of the plain albumen with 0.2% sodium oleate ($p \leq 0.01$). When both levels of sodium lauryl sulfate or 0.2% triethyl citrate was added to the 0.05% yolk-contaminated albumen, the resultant cakes were more tender than those of the control with yolk ($p \leq 0.01$); sodium lauryl sulfate produced cakes that were significantly equivalent to the plain albumen cakes ($p \leq 0.01$). The addition of 0.2% sodium oleate decreased the tenderness of the 0.05% yolk-contaminated cakes ($p \leq 0.05$), producing the toughest cakes of all the variables.

Correlations for Objective Tests

Simple correlations were calculated for the replicate averages of all the objective tests made during and after the preparation of each angel cake. Highly significant correlations were found among all the objective tests with exception of the pH of the batters for which there were no significant correlations. The correlation coefficients which were significant are presented in Table 11.

Specific gravities of the foam and batter

A highly significant positive correlation was found between the specific gravity of the foams and the batters, indicating that as the specific gravity of the foam decreased so did the specific gravity of the batter. Highly significant negative correlations were disclosed between the specific gravities of foam and batter and the volumes of the angel cakes. As the specific gravities decreased, the volumes of the cakes increased; suggesting that up to a certain point, the more air incorporated into the cake, the higher the cake volume.

Also, highly significant correlations were found among the specific gravities of foam and batter and the shear press tests. Cakes with lower specific gravities were more compressible and tender (according to both tenderness and tensile strength tests).

Cake volumes

As previously mentioned, highly significant negative correlations were found between volumes of cakes and specific gravities of foam and batter. Highly significant negative correlations were also apparent among volumes of cakes and shear press tests for compressibility, tenderness,

TABLE 11. Significant correlation coefficients of functional properties of commercial (plain) and 0.05% yolk-contaminated spray dried albumen[a]

Objective Measurement	Specific Gravity of Foam	Specific Gravity of Batter	Cake Volume	Tenderness Maximum Force	Tenderness Area-Under-Curve	Compressibility Maximum Force	Compressibility Area-Under-Curve
Specific Gravity of Foam							
Specific Gravity of Batter	.995***						
Cake Volume	-.943***	-.947***					
Tenderness Maximum Force	.509***	.538***	-.519***				
Tenderness Area-Under-Curve	.630***	.650***	-.659***	.884***			
Compressibility Maximum Force	.901***	.898***	-.898***	.410***	.605***		
Compressibility Area-Under-Curve	.903***	.900***	-.897***	.428***	.615***	.997***	
Tensile Strength Maximum Force	.916***	.916***	-.894***	.595***	.661***	.868***	.876***

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

***Significant at 0.1 per cent level of probability.

and tensile strength. Cakes with higher volumes were more easily torn apart, compressible, and tender. A possible explanation for this fact is that the cakes with the lowest volumes were generally those with 0.05% yolk added or those with poor foam structures; such cakes had a compact, rubbery-like texture.

<u>Compressibility, tenderness, and tensile strength</u>

A highly significant positive correlation was found between compressibility maximum force and area-under-the-curve values, indicating that as one measurement increased, the other increased also. The same was true for the tenderness maximum force and area-under-the-curve values; thus, suggesting the reliability of these tests. Highly significant correlations existed among all the shear press tests, indicating that as one increased, the other two increased also. Although highly significant correlations existed for tenderness maximum force values, these correlations (ranging between 0.4-0.6) were lower than those for the other shear press measurements. Again, the increased sample weight of the cakes with poor foam structures could have contributed to the lower correlations.

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine the effect of two different types of chemical additives on the functionality of commercial (plain) spray dried albumen and commercial spray dried albumen with a 0.05% yolk-contamination. One ester type additive (triethyl citrate) and two anionic type additives (sodium oleate and sodium lauryl sulfate) were added to the reconstituted albumen in 0.1% and 0.2% concentrations (based on the egg white solids' weight). The two egg white systems without an additive served as the two controls. The fourteen variables were replicated five times.

Objective measurements to evaluate the foaming ability of the albumen variables were made during and after the preparation of angel cakes. Specific gravities of foam and cake batter and the pH of the batter were measured while the cakes were being prepared. After the cakes were baked, the volume, compressibility, tenderness, and tensile strength were measured.

Highly significant correlations were found among the specific gravities of foam and batter, cake volumes, and shear press tests for compressibility, tenderness, and tensile strength. No significant differences or correlations were found for the pH of the batter determinations.

The results of all seven objective tests indicated that with exception of sodium oleate, the addition of a chemical additive did not significantly change or improve the functional properties of the commercial (plain) spray dried albumen. The addition of 0.1% sodium oleate significantly increased the specific gravities and decreased the cake volumes of this egg white system; while the 0.2% addition proved significantly detrimental to the albumen according to all the objective measurements except those for tenderness and pH of the batter.

A yolk-contamination of 0.05% significantly decreased the foaming ability of the spray dried albumen as evidenced by tests for specific gravity of foam and batter and cake compressibility, tensile strength, and volume. The addition of chemical additives to this egg white system produced more pronounced effects than in the plain albumen system. The addition of sodium lauryl sulfate and triethyl citrate significantly improved the functional properties of the 0.05% yolk-contaminated albumen in angel cake production. Sodium lauryl sulfate, the more beneficial of the two additives, yielded a 0.05% yolk-contaminated albumen that functioned the same as the plain albumen control in angel cake production ($p \leq 0.01$).

Improvements to the 0.05% yolk-contaminated albumen by both concentrations of triethyl citrate were evident in decreased specific gravities and increased cake volumes, compressibility, and tenderness (area). A 0.2% concentration of triethyl citrate also produced cakes with significantly lower tensile strength readings.

The addition of sodium oleate likewise further impaired the quality of the 0.05% yolk-contaminated egg white system. In comparison to the 0.05% yolk control, both concentrations of this additive significantly increased specific gravities and decreased the compressibility of the angel cakes. A 0.2% concentration of sodium oleate also significantly decreased the tenderness of the cakes based on the tensile strength readings.

In summation, sodium lauryl sulfate and triethyl citrate did not effect the function of the plain albumen, but their addition significantly improved the performance of the 0.05% yolk-contaminated albumen in angel cake production. Sodium lauryl sulfate was more effective than triethyl citrate in producing angel cakes from the 0.05% yolk-contaminated albumen which were approximately equal to those of the plain albumen control.

Previously, it has been reported that the effect of the same yolk-contamination in frozen and spray dried albumen cannot be accurately compared, since a 0.02% yolk-contamination is equivalent to a 0.2% yolk-contamination in the same albumen after spray drying. This fact could lead to further investigation: comparison of the effect of chemical additives in frozen and spray dried albumen with identical yolk-contaminations and then spray dried albumen with one-tenth the contamination.

Further evaluation of the results of this study advocates the need for future investigation in these related areas: (1) variation of albumen whipping times to determine if the failure of sodium oleate was due to an underbeaten foam (2) the effect of adding lower concentrations of sodium lauryl sulfate to plain and yolk-contaminated albumen (3) a study to determine the highest level of yolk-contamination in which chemical additives are still effective (4) a study of the effect of chemical additives on the surface tension in relation to effects on other properties and (5) the effect of cationic and nonionic type additives on both egg white systems.

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APPENDIX

TABLE 12. Replicate averages, albumen type means, and standard deviations for specific gravity of foams

	Plain Albumen Series						0.05% Yolk-Contaminated Albumen Series					
	Replication						Replication					
	1	2	3	4	5	Mean/S.D.	1	2	3	4	5	Mean/S.D.
Control	.180	.178	.172	.176	.180	.177/.003	.442	.469	.463	.531	.513	.484/.037
.1% Sodium lauryl sulfate	.172	.173	.177	.175	.180	.175/.003	.199	.207	.210	.204	.200	.204/.005
.2% Sodium lauryl sulfate	.168	.173	.163	.171	.174	.170/.004	.200	.205	.217	.219	.222	.213/.010
.1% Triethyl citrate	.151	.164	.162	.171	.164	.162/.007	.308	.412	.397	.424	.445	.397/.053
.2% Triethyl citrate	.156	.156	.161	.159	.162	.159/.003	.327	.312	.357	.317	.317	.326/.018
.1% Sodium oleate	.298	.285	.269	.303	.304	.292/.015	.513	.519	.531	.518	.541	.524/.011
.2% Sodium oleate	.388	.392	.410	.428	.439	.411/.022	.549	.530	.491	.570	.591	.546/.038

TABLE 13. Replicate averages, albumen type means, and standard deviations for specific gravity of batters

	Plain Albumen Series						0.05% Yolk-Contaminated Albumen Series					
	----------Replication----------						----------Replication----------					
	1	2	3	4	5	Mean/S.D.	1	2	3	4	5	Mean/S.D.
Control	.338	.349	.345	.349	.338	.344/.006	.572	.593	.588	.635	.625	.603/.026
.1% Sodium lauryl sulfate	.334	.325	.320	.324	.343	.329/.009	.333	.341	.363	.370	.369	.355/.017
.2% Sodium lauryl sulfate	.315	.339	.322	.310	.321	.321/.011	.359	.367	.357	.355	.362	.360/.005
.1% Triethyl citrate	.320	.336	.330	.330	.316	.326/.008	.453	.551	.527	.541	.560	.526/.043
.2% Triethyl citrate	.325	.330	.325	.335	.325	.328/.005	.462	.467	.502	.476	.468	.475/.016
.1% Sodium oleate	.439	.437	.434	.458	.448	.443/.010	.629	.629	.664	.664	.642	.646/.018
.2% Sodium oleate	.517	.535	.541	.547	.546	.537/.012	.681	.671	.670	.704	.702	.686/.017

TABLE 14. Replicate averages, albumen type means, and standard deviations for volumes of cakes

	Plain Albumen Series						0.05% Yolk-Contaminated Albumen Series					
	Replication						Replication					
	1	2	3	4	5	Mean/ S.D.	1	2	3	4	5	Mean/ S.D.
Control	3337	3415	3390	3360	3347	3370/ 32.2	2380	2387	2456	2120	2216	2312/138.8
.1% Sodium lauryl sulfate	3371	3217	3250	3310	3460	3322/ 97.2	3397	3330	3334	3270	3400	3346/ 54.1
.2% Sodium lauryl sulfate	3340	3300	3330	3140	3410	3304/100.1	3290	3290	3127	3447	3310	3293/113.6
.1% Triethyl citrate	3170	3270	3370	3220	3430	3292/106.9	3086	2660	2660	2500	2510	2683/238.2
.2% Triethyl citrate	3521	3110	3077	3440	3400	3310/202.4	3020	2870	2780	2870	2830	2874/ 89.6
.1% Sodium oleate	3132	3070	3250	3080	3027	3112/ 85.8	2190	2200	2036	2410	2087	2185/143.8
.2% Sodium oleate	2890	2877	2250	2990	2620	2725/298.8	1790	1820	1810	2357	1900	1935/239.4

TABLE 15. Replicate averages, albumen type means, and standard deviations for pH of the batters

	Plain Albumen Series						0.05% Yolk-Contaminated Albumen Series					
	Replication						Replication					
	1	2	3	4	5	Mean/S.D.	1	2	3	4	5	Mean/S.D.
Control	5.8	5.7	5.7	5.8	5.8	5.76/.055	5.9	5.7	5.9	5.8	5.7	5.80/0.10
.1% Sodium lauryl sulfate	5.8	5.6	5.8	5.7	5.8	5.74/.089	5.8	5.7	5.7	5.8	5.8	5.76/.055
.2% Sodium lauryl sulfate	5.7	5.7	5.8	5.8	5.8	5.76/.055	5.8	5.7	5.8	5.8	5.9	5.80/.071
.1% Triethyl citrate	5.8	5.8	5.8	5.8	5.9	5.82/.045	5.8	5.8	5.8	5.8	5.9	5.82/.045
.2% Triethyl citrate	5.8	5.7	5.8	5.8	5.8	5.78/.045	5.8	5.8	5.8	5.8	5.8	5.80/.000
.1% Sodium oleate	5.6	5.8	5.7	5.8	5.8	5.74/.089	5.8	5.8	5.8	5.7	5.7	5.76/.055
.2% Sodium oleate	5.7	5.8	5.7	5.8	5.8	5.76/.055	5.7	5.8	5.8	5.8	5.9	5.80/.071

TABLE 16. Replicate averages, albumen type means, and standard deviations for shear press maximum force values for compressibility of cakes

	Plain Albumen Series						0.05% Yolk-Contaminated Albumen Series					
	Replication						Replication					
	1	2	3	4	5	Mean/S.D.	1	2	3	4	5	Mean/S.D.
Control	0.88	0.77	0.77	0.73	0.95	0.82/.092	2.25	2.60	2.60	3.10	2.77	2.66/.309
.1% Sodium lauryl sulfate	0.87	1.33	1.12	0.97	0.98	1.05/.178	0.83	0.97	0.92	0.92	0.82	0.89/.065
.2% Sodium lauryl sulfate	0.85	0.87	0.92	1.33	0.92	0.98/.199	0.90	0.90	1.02	0.78	0.93	0.91/.086
.1% Triethyl citrate	0.93	0.93	0.75	1.00	0.90	0.90/.093	1.22	1.95	1.62	1.63	2.35	1.75/.422
.2% Triethyl citrate	0.92	1.13	1.15	0.77	0.87	0.97/.166	1.00	1.25	1.43	1.22	1.35	1.25/.163
.1% Sodium oleate	1.03	1.12	0.88	1.03	1.07	1.03/.089	2.98	3.00	3.10	2.77	2.95	2.96/.120
.2% Sodium oleate	1.55	3.12	3.88	3.27	2.13	2.79/.936	3.88	3.08	2.78	3.65	2.80	3.24/.502

TABLE 17. Replicate averages, albumen type means, and standard deviations for area-under-the-curve values for compressibility of cakes

	Plain Albumen Series						0.05% Yolk-Contaminated Albumen Series					
	Replication						Replication					
	1	2	3	4	5	Mean/S.D.	1	2	3	4	5	Mean/S.D.
Control	3.37	3.63	2.70	3.43	3.95	3.41/0.46	9.99	10.54	10.74	13.30	12.48	11.41/1.41
.1% Sodium lauryl sulfate	3.77	5.72	4.73	4.12	4.30	4.53/0.75	3.69	4.27	4.27	4.27	3.77	4.05/0.94
.2% Sodium lauryl sulfate	3.57	3.77	4.21	5.69	3.98	4.24/0.84	3.60	4.27	4.56	3.75	4.24	4.08/0.40
.1% Triethyl citrate	3.66	3.95	3.16	4.04	3.80	3.72/0.35	5.43	8.74	6.76	6.56	10.07	7.51/1.84
.2% Triethyl citrate	3.89	4.65	4.67	2.76	3.69	3.93/0.79	4.30	5.31	6.27	4.96	6.01	5.37/0.80
.1% Sodium oleate	4.15	4.56	3.75	4.44	4.70	4.32/0.38	13.21	12.83	13.53	11.64	12.63	12.77/0.23
.2% Sodium oleate	6.34	12.77	15.97	13.85	7.72	11.33/4.12	16.37	12.80	11.93	16.03	12.08	13.84/2.18

TABLE 18. Replicate averages, albumen type means, and standard deviations for shear press maximum force values for tenderness of cakes

	Plain Albumen Series						0.05% Yolk-Contaminated Albumen Series					
	Replication						Replication					
	1	2	3	4	5	Mean/S.D.	1	2	3	4	5	Mean/S.D.
Control	2.46	2.71	2.58	2.36	1.89	2.40/.314	1.95	2.51	3.65	2.89	3.03	2.81/.630
.1% Sodium lauryl sulfate	2.28	2.01	1.83	2.26	2.25	2.13/.199	2.44	2.29	2.50	1.91	2.58	2.34/.265
.2% Sodium lauryl sulfate	2.58	2.33	2.16	1.87	1.78	2.15/.329	1.96	2.11	2.01	2.19	2.43	2.14/.185
.1% Triethyl citrate	2.73	2.07	1.94	1.78	2.21	2.15/.363	1.87	2.63	2.24	2.49	2.03	2.25/.314
.2% Triethyl citrate	2.71	2.42	2.39	2.06	2.21	2.36/.245	1.88	2.72	2.18	2.45	2.71	2.39/.360
.1% Sodium oleate	2.43	1.86	2.32	2.36	2.56	2.31/.266	2.44	2.16	3.82	2.96	3.17	2.91/.648
.2% Sodium oleate	2.08	1.92	1.65	2.06	1.93	1.93/.172	2.31	3.32	3.26	3.66	3.59	3.23/.541

TABLE 19. Replicate averages, albumen type means, and standard deviations for shear press area-under-the-curve values for tenderness of cakes

	Plain Albumen Series						0.05% Yolk-Contaminated Albumen Series					
	Replication						Replication					
	1	2	3	4	5	Mean/S.D.	1	2	3	4	5	Mean/S.D.
Control	123.3	180.7	191.2	181.2	123.1	159.9/3.38	167.5	218.5	297.1	236.1	241.5	232.1/4.66
.1% Sodium lauryl sulfate	186.5	154.2	145.6	162.6	166.8	163.1/1.54	165.6	155.6	162.7	134.9	169.7	157.7/1.37
.2% Sodium lauryl sulfate	171.8	169.2	213.9	141.7	124.9	164.3/3.39	148.5	134.0	141.0	138.3	177.6	147.9/1.74
.1% Triethyl citrate	247.6	157.9	130.1	149.1	169.6	170.9/4.53	131.0	179.1	185.9	185.3	175.0	171.3/2.30
.2% Triethyl citrate	246.2	193.3	180.5	144.5	158.6	184.6/3.93	134.2	208.6	162.9	183.6	205.0	178.8/3.10
.1% Sodium oleate	200.0	135.6	97.3	179.8	177.7	158.1/4.13	223.4	192.5	341.0	235.7	277.8	254.1/5.74
.2% Sodium oleate	197.5	159.2	157.9	188.7	158.4	172.3/1.92	194.3	285.1	271.9	325.3	288.8	273.1/4.83

TABLE 20. Replicate averages, albumen type means, and standard deviations for shear press maximum force values for tensile strength of cakes

	Plain Albumen Series						0.05% Yolk-Contaminated Albumen Series					
	Replication						Replication					
	1	2	3	4	5	Mean/S.D.	1	2	3	4	5	Mean/S.D.
Control	.036	.028	.026	.028	.027	.029/.004	.038	.059	.052	.070	.058	.055/.014
.1% Sodium lauryl sulfate	.027	.025	.022	.024	.034	.026/.005	.024	.027	.029	.032	.029	.028/.003
.2% Sodium lauryl sulfate	.034	.030	.028	.026	.018	.027/.006	.021	.024	.034	.030	.040	.029/.008
.1% Triethyl citrate	.033	.028	.021	.021	.028	.026/.005	.042	.057	.049	.056	.041	.049/.008
.2% Triethyl citrate	.027	.026	.027	.019	.025	.025/.003	.035	.041	.046	.038	.038	.040/.004
.1% Sodium oleate	.029	.031	.035	.043	.035	.035/.005	.055	.053	.064	.053	.058	.057/.005
.2% Sodium oleate	.033	.048	.051	.054	.033	.044/.010	.073	.063	.057	.066	.068	.066/.006