A COMPARISON OF FROZEN, FOAM-SPRAY-DRIED, FREEZE-DRIED, AND SPRAY-DRIED EGGS IN BAKED CUSTARDS

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N. Joanne Wolfe

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ABSTRACT

A COMPARISON OF FROZEN, FOAM-SPRAY-DRIED, FREEZE-DRIED, AND SPRAY-DRIED EGGS IN BAKED CUSTARDS

by N. Joanne Wolfe

The primary purpose of this investigation was to determine the effects of foam-spray-, freeze-, and spray-drying of eggs on the color, gel strength, and palatability of baked custards. Of secondary importance was determining the effect of sugar on the coagulating abilities of the processed eggs.

This experiment was divided into two series: (1) standard custards containing sugar which consisted of eight treatments combining each egg process and the two end-point temperature ranges of 81-83°C and 85-87°C; and (2) egg-milk slurries (sugar omitted) which consisted of four types of processed eggs baked to 85-87°C. Both subjective and objective measurements were utilized to evaluate the custards, whereas the baked slurries were evaluated solely by objective means. Data presented are based on the average of six replications.

Sugar affected the baking time and temperature of the custards. Time-temperature relationships revealed similar

heating curves for the custards baked with the four types of processed eggs. Custards prepared with sugar coagulated at a higher temperature and the presence of sugar prolonged the baking time by 3 to 4 minutes.

The sensory evaluation of the custards revealed the following important differences: custards prepared with freeze-dried eggs contained the toughest crusts; the color of frozen egg custards was significantly different from the color of dehydrated egg custards; and frozen and freeze-dried egg custards were considered smoother than foam-spray- and spray-dried egg custards. Custards baked to the high temperature range were firmer and received improved flavor ratings over those custards baked to the low temperature range.

The shear press was utilized to determine the firmness of gels containing and omitting sugar. Force required to shear the gel as well as area-under-the-curve was computed and revealed similar results for all values, as well as an extremely high positive correlation with the sensory evaluation of gel strength. Freeze-dried egg custards (containing sugar) were firmer than frozen egg custards which in turn were firmer than foam-spray- and spray-dried egg custards. The only custards that were affected by the presence of sugar were those prepared with freeze-dried eggs. Freeze-dried eggs containing sugar were firmer than those without sugar.

Percentage drainage was computed for all custards containing sugar. The weak gel structures produced at the low temperature range invalidated the results of this test.

The Hunter color difference meter was utilized to determine the lightness, greenness, and yellowness values of all gels. Analysis of color data indicated that custards baked to the high temperature range were lighter but less yellow than custards baked to the low temperature range. Frozen egg custards were lighter and more yellow than the dehydrated egg custards. Foam-spray- and spray-dried egg custards were lighter than freeze-dried egg custards. Freeze-dried egg custards were more yellow than foam-spray-dried egg custards which in turn were more yellow than spray-dried egg custards. Custards prepared with freeze-dried eggs received greenness values which were lower than the values received by all other types of processed eggs. Lightness and yellowness values correlated positively with the sensory evaluation of color. When sugar was omitted from the formula, the rank order of the slurries was the same as that of the custards, however, there were no significant differences in the lightness and greenness values of the slurries prepared with frozen, spray-dried, and foam-spray-dried eggs. The slurries prepared with these three types of processed eggs were grayer and greener than the gels prepared with freeze-dried eggs. Frozen egg slurries were more yellow than those slurries prepared with dehydrated eggs.

The results indicated that all eggs functioned adequately in the coagulation process, although research is needed in the following areas: (1) an investigation to determine the effect of dextrins on the flavor of protein containing foods; (2) a study to determine whether color differences are due to alterations in the carotenoid pigments; (3) further analyses to determine factors influencing sensory evaluations; and (4) a study to determine the effect of various proportions of sugar on the gel strength of custards prepared with a constant percentage of egg.

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By

N. Joanne Wolfe

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INTRODUCTION

Increased interest in improving the flavor and functional properties of dehydrated eggs has resulted in extensive research to improve processing methods. Presently, spray-drying is the only method of dehydrating eggs being used extensively, however, the newer dehydrating processes of freeze-drying and foam-spray-drying are in the experimental stage. The two potential advantages of the newer processing methods are: (1) the processing methods might be practical for production in communities with limited quantities of eggs; and (2) the improvement of flavor and functional properties would make their consumption feasible in bland products.

Literature pertaining to the coagulating properties of spray-dried eggs is contradictory. Ary and Jordan (1945) and Dawson _et al_. (1945) reported similar gel strengths for custards prepared with fresh and with good quality spray-dried whole egg powders. Miller _et al_. (1959a) found the average gel strength of spray-dried egg custards was significantly lower than blended frozen egg custards. Spray-dried egg custards required a higher internal temperature to obtain a gel strength comparable to custards prepared with frozen eggs.

An objectionable flavor frequently detected in spray-dried eggs has limited their use in bland products. Bennion *et al*. (1942) noted a definite unpleasant flavor in spray-dried eggs which made them unsatisfactory for custards and scrambled eggs. On the contrary, Jordan and Sisson (1943) reported favorable comparisons between baked custards prepared with fresh and good quality spray-dried eggs. Kelly *et al*. (1962) reported a panel preference for custards prepared with spray-dried eggs over those custards prepared with fresh, freeze-dried and frozen eggs. No significant differences were found among the flavors of fresh, frozen, or freeze-dried eggs in custards in their study.

Only a limited amount of research reporting the effects of freeze-drying and foam-spray-drying on the gel strength and color of baked custards appears in the literature. Endres (1965) studied gel strength and color of baked coagulums prepared with spray-dried, freeze-dried, and frozen eggs. Zabik and Figa (1967) made a further comparison of the gel strength and color of the above eggs with foam-spray-dried eggs. Simple egg and milk slurries were used in these studies, and the spray-drying process had more detrimental effects on the gel strength than freezing or freeze-drying, with foam-spray-drying producing the weakest gel structures. Use of the Gardner color-difference meter to compare the color of the gels prepared with the same four types of processed eggs indicated that gels prepared with foam-spray-dried eggs were lighter, greener, but less yellow; frozen eggs were second in lightness and greenness but were the most yellow. Gels prepared with spray-dried eggs were more gray but possessed the lowest amount of greenness and yellowness, whereas the values for freeze-dried egg gels fell between the values for frozen and spray-dried egg gels.

The lack of agreement among the results of different workers indicates that there may be unexplained forces affecting gel formation. Gelation occurring in baked custards is an extremely complex phenomenon. Denatured protein gels are dependent on pH, salt concentration, and on the presence of non-polar solvents (Meyer, 1960). Lowe (1955) and Griswold (1962) conclude that the addition of sucrose decreases the gel strength and raises the coagulation temperature of custards. On the contrary, Longree et al. (1961) found the addition of various levels of sugar in a custard formula had little effect on the baking time and temperature attained.

Since no investigation has been reported on the flavor of foam-spray-dried eggs and the effect of sugar on the coagulable proteins of freeze-dried and foam-spray-dried eggs, a study comparing foam-spray-dried, freeze-dried, and spray-dried eggs in baked custards and slurries was initiated. Custards were selected for the media of study because the majority of the coagulable protein in this system is furnished by the eggs; only about 0.75 percent of milk protein is heat-coagulable (Lowe, 1955). Frozen eggs were chosen for the control inasmuch as Miller _et al_. (1959) and Kelly _et al_. (1962) found no significant differences between frozen and fresh eggs in baked custards.

The primary objective of this investigation was to determine the effect of spray-drying, freeze-drying, and foam-spray-drying on the color, gel strength, and palatability of baked custards. A secondary objective was to determine the effect of sugar on the coagulating properties of the processed eggs. The effect of sugar was determined by comparing baked custards containing sugar with similar slurries omitting sugar.

REVIEW OF LITERATURE

Many constituents affect the coagulation of egg proteins. This review summarizes recent literature on gel formation as well as factors affecting gelation. Recent trends in objective and subjective evaluations pertinent to the evaluation of gels are also included in this survey.

Composition of Eggs

The chemical composition of eggs is extremely complex and merits considerable attention because of their vital role in gel formation. Eggs are composed primarily of water, protein, fat, ash, and carbohydrates. Endres (1965) compiled the approximate percentages of the components present in eggs which are listed in Table 1.

Table 1. Approximate percentage of water, protein, fat, ash, and glucose in egg.

	Components				
	Water (%)	Protein (%)	Fat (%)	Ash (%)	Glucose (%)
Whole egg	74.0	12.8	11.5	1.0	0.32
Yolk	49.4	16.3	31.9	1.7	0.17
Albumen	87.8	10.7	0.0	1.6	0.38

Source: Endres, 1965.

Egg proteins (Meyers, 1960)

Proteins are complex molecules with reactive groups on their surface. The marked sensitivity of proteins to changes in pH and to many different electrolytes is due to their size as well as to the presence of reactive groups on the protein macromolecule. Protein molecules associate with one another or with smaller molecules to form tightly or loosely bound complexes. The size of the molecule is such that adsorption occurs readily, making purification difficult.

Egg white proteins. The difficulty in purifying proteins has resulted in a variety of postulations as to the actual number of proteins present in egg white. Lowe (1955), Meyer (1960), and Griswold (1962) reported that there were five, eight, and nine egg white proteins respectively, whereas Feeney and Hill (1960) found eight identified and eight unidentified proteins in egg white. The appropriate amount and the unique properties of egg white proteins as reported by Feeney and Hill (1960) are presented in Table 2.

Egg yolk proteins. Egg yolk contains simple proteins known as livitins as well as the more complex lipoproteins. The complex composition and physiochemical properties of egg yolk proteins are presently unresolved, however, the constituents and unique properties as reported by Feeney and Hill (1960) are revealed in Table 3.

Table 2. Composition of egg white.

Constituent	Approx. amount (%)	Approx. isoelectric point	Unique properties
Ovalbumin	54.0	4.6	Denatures easily, contains sulfhydryls.
Conalbumin	13.0	6.0	Complexes iron, antimicrobial.
Ovomucoid	11.0	4.3	Inhibits enzyme trypsin.
Lysozyme	3.5	10.7	Polysaccharide enzyme, antimicrobial.
Ovomucin	1.5	?	Viscous, reacts with viruses.
Flavoprotein	0.8	4.1	Binds riboflavin.
Proteinase inhibitor	0.1	5.2	Inhibits enzyme (bacterial proteinase).
Avid	0.05	9.5	Binds biotin, antimicrobial.
Unidentified proteins (8)			Mainly globulins.
Non proteins (8)			Primarily glucose and salts.

Source: Feeney and Hill, 1960.

Table 3. Composition of egg yolk.

Constituent	Approx. amount (%)	Unique properties
<u>Fats</u>		
Natural glycerides	42	Acids vary with diet.
Phospholipids	20	Primarily 3/4 lecithin and 1/4 cephalin
<u>Sterols</u>	2	Primarily cholesterol.
<u>Proteins</u>		
Livitin	7	Contain 10% phosphorous.
Lipoproteins	21	Emulsifiers.
<u>Other</u>	3	Primarily sugar and salt.

Source: Feeney and Hill, 1960.

Egg lipids (Forsythe, 1963)

Lipids, contained entirely in the egg yolk, exist independently and combined with proteins (lipoproteins). The lipoproteins, lipovitellin and lipovitellenin, are complex mixtures which are presently poorly characterized. The lipids of eggs, seventy per cent of which are unsaturated, exist as true fats as well as phospholipids.

Ash components of egg

The ash of egg includes minute quantities of many mineral salts including: potassium, magnesium, sulphur, and copper. Iron, which is perhaps the most important mineral salt, is contained chiefly in the egg yolk.

Carbohydrate present in egg (Kline *et al.*, 1959)

Carbohydrate in the form of glucose is present in eggs. Glucose is a reducing sugar which reacts with the free amino groups of egg proteins resulting in reduced solubility and the occurrence of the Maillard reaction. Glucose also reacts with cephalin yielding an undesirable flavor.

In addition to proteins, fat, ash, glucose, and water, eggs contain generous amounts of the fat-soluble vitamins A, D, and K, and the water soluble vitamin B complex. The chemical constituents of eggs are complex and their exact composition continues to puzzle researchers.

Preservation of Eggs

Egg quality decreases immediately after the egg is laid (Lowe, 1955, Feeney, 1964). Although deterioration of the egg cannot be stopped, the rate of deterioration in shelled eggs may be reduced by storing at low temperatures or in a carbon dioxide atmosphere. The techniques of thermostabilization and dipping in oil are also used to preserve the quality of shell eggs.

Preservation of the coagulating properties of eggs by freezing, spray-drying, freeze-drying, and foam-spray-drying processes was the primary concern of this study. Endres (1965) reviewed the techniques used in the freezing, spray-drying, and freeze-drying processes. The foam-spray-drying process, like the freeze-drying process, is still in the experimental stage. Hanrahan et al. (1966) stated that the foam-spray-drying process required only slight modification in the conventional spray-drying process. Compressed air is injected into the fluid line through a mixing device located between the pressure pump and the spray nozzle. Compressed air has been utilized in the air drying as well as the spray-drying of eggs. Berquist (1964) described the foam-mat process as consisting of whipping the product into a stable foam and spreading it out in a thin layer for air drying. LaBelle (1966) stated that the porous structure of the foam is preserved during the processing, permitting fast drying and improved rehydration of the product.

Color of Eggs

The carotenoid pigments primarily responsible for the color of egg yolks are xanthophylls, luten, and zeaxanthin (Bunnell and Bauerfeind, 1962). In the past few years, there has been an increased demand for egg yolks with higher pigment levels (Forsythe, 1963). In an attempt to meet this demand, research was initiated to determine the effect of altering the hens diet on the color of the eggs laid. Green foods, alfalfa meal, and paprika when added to the hens diet were found to increase the carotenoid content of the yolk (Carlson, 1961 and Deethardt et al., 1965). However, according to the Federal Food and Drug Administration, only naturally occurring pigments can be fed to hens (Forsythe, 1963).

Alterations in the color of dehydrated eggs is of primary concern because: (1) deviations in color might meet with consumer resistance; and (2) if the carotenoid pigment was affected by the drying process, it is conceivable that beta-carotene, the precursor of vitamin A might also be affected. Drying processes have been reported to alter the carotenoid pigment of the egg as evidenced by variation in the color of baked custards. Miller et al. (1959a) found that the color of custards prepared from spray-dried eggs was not only different, but less desirable than custards prepared from fresh and frozen eggs. Zabik and Figa (1967) compared the color of frozen, freeze-dried, spray-dried, and foam-spray-dried eggs in baked coagulums. They found that gels prepared with foam-spray-dried eggs were lighter, greener, but less yellow; frozen egg gels were second in lightness and greenness but were the most yellow. Gels prepared with spray-dried eggs were more gray but possessed the lowest amount of greenness and yellowness, whereas the values for freeze-dried egg gels fell between the values for frozen and spray-dried egg gels. Zabik (1967) compared the color of egg albumen and egg yolk gels prepared with the same four types of processed eggs. Color evaluations showed alterations in all three dehydration processes in a manner similar to that reported for the whole egg gels. On the contrary, Mastic (1959) did not find significant differences between the color of spray-dried and frozen egg custards.

Factors other than egg and milk affect the color of the gels produced. Increased salt concentration as well as the presence of sugar increases the translucency of the gel (Meyer, 1933). Use of sodium chloride in the custard mix produces light yellow colored gels, magnesium chloride produces deep orange-yellow colored systems, whereas calcium chloride results in gels with a green tinge (Meyer, 1933).

Protein Coagulation

Coagulation or denaturation of proteins are concepts familiar to everyone, but not thoroughly understood by anyone. There are many theories on protein denaturation, all of which involve some type of change in the native protein molecule.

Protein structure (Watson, 1965)

Proteins are immensely complex macromolecules that are polymers containing the twenty different amino acids linked by polypeptide bonds. A complete analysis of a given protein involves not only the quantity of each amino acid, but also the sequence in which the amino acid residue appears (primary structure), the interaction of the carbonyl groups with the imino groups which leads to the formation of helices (secondary structure), and the three-dimensional folding of the polypeptide chains (tertiary structure).

The number of chains and the sequence of residues within them constitute the primary structure of proteins. Polypeptides are linear molecules formed by the condensation of the nitrogen containing amino acids which are linked together with peptide bonds in a regular order. Many proteins are composed of more than one polypeptide chain and the manner in which these polypeptide chains are arranged is the quaternary structure.

Polypeptide chains are arranged in helical configurations held together by secondary bonds. These hydrogen bonds between the carbonyl group of one residue and the imino group of the fourth residue down the chain results in the twisting of the polypeptide molecule to form a helix.

The three-dimensional form of a protein is its tertiary structure. If each monomer group is an identical orientation within a polymeric molecule, each monomer forms the same group of the secondary bond as every other monomer. If, however, the monomer group contain irregular side chains, the helical structure need not necessarily be expected. Thus, the three-dimensional structure of many irregular polymers is a compromise between the tendency of the regular backbone to form a regular helix and the tendency of the side groups to twist the backbone into a configuration that maximizes the strength of the secondary bonds formed by the side groups. In proteins the compromise between the side group and the backbone is usually in favor of the side groups.

Thus, the most important reason for irregularity in protein structures arises from the diverse chemical nature of the side groups. Whenever several polypeptide chains are present in the same molecule, they are often held together by secondary forces. In other cases, disulfide bonds (S-S) between cysteine side groups keep them together. When these cysteine residues are in the same polypeptide chain, the helix is necessarily distorted. Hydrolysis of the proteins changes it from a hydrophilic to a hydrophobic molecule. There is a strong tendency for nonpolar groups to arrange themselves so that they are not in contact with the water molecules (hydrophobic bonding), and contact with water requires a considerable input of free energy. Water insoluble side groups are, therefore, found stacked next to each other in the interior of myoglobin, and the external surface contains groups that mix readily with water. Van der Waals bonding arises from a nonspecific attractive force originating when two atoms come close to one another. It is based not only upon the existence of permanent charge separations, but rather upon the induced fluctuating charges caused by the nearness of molecules. Van der Waals forces are effective binding forces at physiological temperatures when several atoms in a given molecule are bound to several atoms in another molecule. Many polar molecules are only seldom affected by the van der Waals interactions, because such molecules can acquire a lower energy state by forming other types of bonds.

Theories of protein denaturation or coagulation

Early researchers reported that the coagulation process occurred in two distinct phases. Chick and Martin (1910) defined coagulation as a reaction between the proteins and water (denaturation) and involved the separation of the altered protein (precipitation). Macleod and Nason (1937) stated that in the first stage of coagulation the protein is modified by the process of hydrolysis which changes the protein from a hydrophylic to a hydrophobic colloid; however, coagulation actually occurs when the denatured protein is precipitated.

Current explanations for protein coagulation and denaturation are concerned with the solubility as well as the actual changes which occur in the protein molecule during the process. Anderson (1953) defined coagulation as a type of irreversible gelation, whereas Lowe (1955) believed coagulation was closely related to denaturation and was the process of rendering proteins insoluble. Scheraga (1961) defined denaturation as the process by which a protein is transformed from an ordered to a disordered state without the rupture of the covalent bonds.

There is presently no precise definition or explanation for the denaturation or coagulation process. A more thorough understanding of the actual protein molecule would aid in clarifying the process.

Theories of gel formation

Theories of egg gelation, like those of coagulation and/or denaturation, have resisted complete elucidation, however, it is known that gelation of eggs plays a vital role in the preparation of custards as well as many other foods. The following postulations speculate about what actually occurs during this process.

Nason (1939) reported two theories of gelation. According to the first theory, molecular aggregates unite to form chains or filaments which interlace and hold liquid in the interfacial spaces. The filaments, usually hydrated, become thickened and the water not adsorbed is held by capillary attraction. The second concept ascertained that instead of having molecular aggregates in the form of filaments, spherical aggregates occurred. Spherical aggregates swell and push against each other, becoming distorted and give the gel its symmetrical honeycomb structure.

Meyer (1960) postulated that there were three theories for gel formation. These were designated as: (1) adsorption of the solvent; (2) the three-dimensional network; and (3) particle orientation.

The theory concerned with the adsorption of the solvent was similar to Nason's (1939) theories of gelation. This theory requires that solute particles form larger particles with increased layers of solute upon cooling. These enlarged particles eventually touch or overlap enclosing more solvent so that the entire system is immobilized and rigidity occurs. Meyer (1960) felt that this theory had pragmatic value only if it was demonstrated that adsorption of the solvent is extensive and increases with decreased temperature.

The three-dimensional network theory postulated that the compound capable of forming a gel was either fibrous in structure or could be polymerized to form a fiber. The bonds which tie the fibers into the three-dimensional network can be primary bonds between the functional groups, secondary bonds, or non-localized secondary attractive forces. This theory would be a possible explanation in systems like baked custards, because of the importance of temperature, pH, and salt concentration in the formation of the gel.

The concept of particle orientation hypothesized a tendency for solute and solvent particles to orient themselves in a definite spatial configuration, because of the influence of long range forces such as those which occur in crystal formation. This theory is dependent on certain crystals having the ability to take on or lose water without distortion of the crystals.

There are many theories explaining the rigid properties of an egg gel. At the present time, Meyer (1960) feels that the most probable explanation seems to be the theory which states that a gel may be produced by non-localized secondary attractive forces within the three-dimensional network.

Factors affecting gelation of custards

The formation of egg gels, best illustrated in baked custards, depends upon two factors; the coagulation of the proteins and the ability of the precipitated protein to hold within its meshes the solution from which it was precipitated (Nason, 1939). Gelations in custards is affected by many factors including; the quality and quantity of egg, salts, pH, sugar, type of milk, baking time and temperature, and processing of eggs.

Quality and quantity of egg. Coagulation of baked custards is primarily due to egg proteins; only about 0.75 per cent of milk proteins are heat coagulable (Lowe, 1955). Undiluted egg white coagulates at a lower temperature than egg yolk;

60°C-65°C and 65°C-70°C respectively (Lowe, 1955 and Griswold, 1960). Increased proportions of high quality eggs produce a firmer, more stable gel at a lower temperature. Dilution of protein elevates the temperature for coagulation and produces a weaker gel, as exemplified by decreasing the amount of egg per cup of milk in baked custards (Lowe, 1955).

Salts. Coagulation is dependent on the kinds of ions present, their valence, and their concentrations. Many salts such as lactates, chlorides, sulfates, and phosphates play a vital role in gelation although they vary greatly in the type of gel they produce. Meyer (1933) found that gels prepared with magnesium chloride, sodium thiocyanate, and milk produced the strongest gels. Sodium chloride, sodium sulfate, and calcium chloride produced gels approximately equal in strength, whereas sodium citrate and monosodium phosphate produced the weakest gels. An increase in the concentration of each salt produced firmer gels until an optimum range was reached. The optimum amount varied for each salt, however, increasing the concentration beyond the optimum point decreased the firmness of all gels. The presence of ions or salts present in milk is essential for the gelation of baked custards; when distilled water is substituted for milk, flocculation rather than gelation occurs (Lowe, 1955).

pH. Proteins are amphoteric compounds having the ability to react with either weak acids or bases. Chick and Martin (1910, 1912-13) reported that acids hastened the second step of the heat-coagulation process whereas alkalies prevented the coagulation process. On the other hand, Endres (1965) reported a reduction in gel strength when the pH of the egg-milk gels was reduced from 7.0 to 6.6. Meyer (1933) noted that a buffering action seemed to exist between the eggs and the salts present in the system. With reduced buffering actions weaker gels were produced.

Sugar. Sugar elevates the temperature of gelation, coagulation and curdling of egg gels, its effect being proportional to the amount added (Nason, 1939, Slosberg *et al.*, 1948, Lowe, 1955). In a custard formula containing 1 cup of milk and 1 egg, increasing the sugar from 1 to 4 tablespoons elevated the coagulation temperature from 80°C to 83°C (Lowe, 1932). The addition of 10 per cent sugar (2 tablespoons per cup of milk and 1 egg) decreased the gel strength of the resulting custard by half, whereas increasing the sugar by 30 per cent practically prevented gelation (Meyer, 1933). Further information was added to this subject by Seideman *et al.* (1962), who reported that the presence of sugar in a custard formula was pH dependent.

When proteins are heated with carbohydrates, particularly the mono- and disaccharides, the proteins and carbohydrates react because the sugar competes with the protein for water (Meyer, 1960). Proteins can complex with carbohydrates either loosely or tightly (Jevons, 1964).

Type of milk. Milk is a complex chemical mixture composed of casein and whey proteins. It is further complicated by its phase structure, stability, and color which are modulated by a series of highly involved interactions among the various protein components, small ions, and small organic molecules present in the sol or suspension (Timasheff, 1964).

The type of milk used has a pronounced effect on the custard quality. Custards prepared from homogenized milk have weaker gel structures than custards prepared from non-homogenized milk (Jordan et al., 1952, Bittner, 1954, and Topp and McDivitt, 1965). Bittner (1954) reported that custards prepared with pasteurized milk contained the firmest gel structure, whereas gels prepared with homogenized, non-fat dry milk solids, or evaporated milk were equal in firmness. Custards prepared with whole dry milk powder were the weakest in gel structure.

Baking time and temperature. The rate of coagulation increases with increased baking temperatures; at high temperatures it is so rapid that it seems almost instantaneous. As the temperature is elevated, the firmness of the custard increases until an optimum consistency is obtained; heating above this temperature brings about porosity and finally syneresis and curdling (Lowe, 1955). Jordan et al. (1954) stated a preference for an oven temperature of 350°F over 325°F or 400°F for baked custards. This was because the baking period was too long when the custards were baked at 325°F and so short when the custards were baked at 400°F that they were easily overcooked. Griswold (1962) found that the quality of all custards was improved when they were baked in a pan of water for protection against the direct heat.

Processing of eggs. Miller and Winter (1950) and Jordan *et al*. (1952) reported similar gel strengths between custards prepared with fresh and frozen eggs. These results were substantiated by Miller *et al*. (1959a) and Kelly *et al*. (1962) who found no significant difference in gel strength between custards prepared with these two types of eggs.

The effect of the spray-drying process on the coagulating properties of the egg has been the subject of much dispute. Ary and Jordan (1945), Dawson *et al*. (1945) and Schlosser *et al*. (1961) reported similar gel strengths between custards prepared with fresh eggs and good quality spray-dried whole egg powders. Miller *et al*. (1959a) and Endres (1965) found the average gel strength of spray-dried egg custards or slurries (sugar omitted) was not only significantly lower than blended frozen egg custards or slurries, but required a higher internal temperature to obtain a gel strength comparable to custards or slurries prepared with frozen eggs.

Dispersibility of dehydrated eggs is closely related to their functioning ability. Jordan and Sisson (1945) reported that eggs which were reconstituted for eighteen hours prior to use were better dispersed and produced firmer custards than those reconstituted just before using. Miller *et al*.

(1959b) found the dispersibility of spray-dried eggs was improved when the water was added to the egg solids in one or two portions at 45-21^{o}C rather than in three aliquots. Sucrose or aeration of the egg solids before adding the water did not affect the dispersibility of the solids.

A limited amount of research is reported on the effect of foam-spray- and freeze-drying on the gel structure of coagulums. Zabik and Figa (1967) found that foam-spray-dried whole eggs produced gels which were weaker in gel structure than those produced with frozen, freeze-dried, and spray-dried eggs. Gels prepared with foam-spray-dried egg yolks were firmer than those prepared with frozen, freeze-dried or spray-dried egg yolks, although there was also a significant reduction in the rate of heat penetration for the foam-spray-dried egg yolk gels (Zabik, 1967). Wolfe (1966) compared the gel strengths of agglomerated foam-spray- and spray-dried whole eggs in simple egg-milk systems. There was no significant difference between the two processes, however, there was a trend for the foam-spray-dried eggs to produce firmer gels.

Objective Measurements

Objective evaluation of food quality is an extremely useful tool supplementing and controlling, but not replacing subjective measurements (Amerine *et al.*, 1965). Objective evaluations are preferred to sensory evaluations when they furnish a precise measurement of food quality because they can be used repeatedly without the danger of human error and/or fatigue.

Gel strength measurement

The measurement of the gel strength of custards is essentially an exercise of measuring the strength or weakness of the structure formed (Bourne *et al*., 1966). The three most commonly used instruments for measuring gel strength are the penetrometer, curd tension meter, and the Allo-Kramer-shear-press. All these devices have the following common elements: driving mechanism; probe element in contact with the food; force-direction, type, and rate of application; sensing element; and read out system (Szczesniah, 1966).

Penetrometer. The penetrometer measures the distance, in tenth of millimeters, that a specified free falling force will penetrate into a gel structure. The time of penetration is constant, and depending on the consistency of the gel being tested, a cone, disk, or needle attachment is used. The reliability of this instrument for measuring gel strength of custards has been subject to much dispute. MacDougall (1953) and Bittner (1954) reported consistent trends between taste panel scores and penetrometer scores for tenderness of the gel when the crust was contained but not when the crust was removed. On the other hand, Miller *et al*. (1959a) found no consistent trend when the penetrometer was used to determine the firmness of different gels with and without their crust. Szczesniah (1966) felt that this type of test was useful but that caution was needed in the interpretation of the results.

Curd tension meter. Modification of the curd tension meter to measure the firmness of custards was an attempt to devise a more accurate measurement of gel strength. This instrument measures the force, in grams, required for the cutting blades of the instrument to shear through the gel. MacDougall (1953), Bittner (1954), and Miller *et al*. (1959a) indicated that this instrument resulted in more consistent trends between taste panel scores for tenderness of the custard gel than did the penetrometer, however, there was still a need for an instrument which was more precise in measuring gel strength.

Allo-Kramer shear press. The shear press is an instrument which was originally developed to measure the tenderness of lima beans (Kramer *et al*., 1951). Since the time of its development it has been adapted to measure the tenderness of many vegetables, meats, baked products, jellies (Kramer and Hawbecker, 1966), and custards (Endres, 1965).

The shear press is composed of a hydraulic system, which moves a piston with an even application of force at a predetermined rate of speed. The resistance of a food to the force exerted is recorded on an electronic recorder. Proving rings, with ranges from 100 pounds for measuring soft materials to 5000 pounds for hard products, improves the accuracy of the readings by reducing frictional error. The recorder time-force curves may be interpreted as maximum force of each of the peak values or as total work determined by the area-under-the-curve (Endres, 1965).

The shear press has pragmatic value in determining the gel strength of custards. Endres (1965) found significant correlations (1 per cent level of probability) among the shear press with the fixed blade cell, shear press with the succlometer cell, penetrometer, and taste panel evaluation of gel strength of custards. The fixed blade cell seemed to have potential for furnishing further information about the consistency of the gel produced. Kramer and Hawbecker (1966) reported that the shear press was a valuable instrument for measuring the rheological properties of fruit and synthetic jellies. Information provided by curves as well as locations and extent of dips on the graphs gives insight into tenderness, adhesiveness, uniformness, gel strength, and deformation of the gel studied.

Color measurements

Color in foods is primarily affected by the energy coming to the eye from illuminated surfaces, or with transparent foods, through the material. The color perceived by the eye from an illuminated object depends on the spectral composition of the light source, the chemical and physical characteristics of the object, the nature of the background illumination, and the spectral sensitivity of the eye viewing the object. Precise definitions of color phenomena requires specifications of the dominant wavelengths, colorimetric purity, and intensity (Amerine et al., 1965). The human eye has remarkable fine qualitative discrimination for color; it can distinguish between approximately 10 million refracted colors. The eye is not, however, a quantitative instrument (Bedford, 1966).

Precise color measurements require modern instruments. There are presently about thirty available colorimetric instruments on the market and about forty companies producing them. These instruments may be classified as visual colorimeters, spectrophotometers, and photoelectric tristimulus colorimeters (Bedford, 1966).

Visual colorimeters (Mackinney and Little, 1962). Visual colorimeters, both additive and subtractive, are inexpensive methods for determining food grades. In the Macbeth-Munsell disk system, the sample is matched by visual comparison with a spinning disk, having various portions of four adjustable colors exposed. Munsell papers have been measured in terms of the tristimulus values for easy calculation. The Lovibond tintometer is the oldest and most widely used subtractive colorimeter. This instrument allows samples to be viewed with a standard glass, and the match is made by adjusting the glasses for hue, saturation, and the photometric device for luminance. X, Y, and Z coordinates as well as brightness or luminance values are derived from the instrument.

Spectrophotometer. The spectrophotometer is an analytical instrument which measures the amount of light reflected as a function of wave length (Judd and Wyszecki, 1963). This instrument was recognized by the American Standards Association as the basic instrument in the fundamental standardization of color (Mackinney and Chichester, 1954).

The General Electric spectrophotometer was designed over thirty years ago by A. C. Hardy and to date remains the referee instrument in the field (Billmeyer Jr., 1966b). Although this instrument has a wide field and thus eliminates the necessity of taking many readings for the acquisition of the wave lengths, it has the following limitations: (1) a realistic estimate of color can only be obtained after the magnitude of the variable is known (Saltzman and Keay, 1966); (2) extremely time consuming routine calibrations are required (Billmeyer Jr., 1966a); and (3) the performance of the spectrophotometer is more precise in measuring the transmittance than the reflectance of light (Billmeyer Jr., 1966a).

Photoelectric tristimulus colorimeters. The photoelectric tristimulus colorimeters were developed to permit the measurement of the light reflected and from this data specify the color of the sample (Bedford, 1966). This instrument is an attempt to duplicate the human eye by measuring the reflected light in a particular situation (Bedford, 1966). Typical instruments of this type include the Gardner color-difference meter, Hunter color-difference meter, colormaster differential colorimeter, color eye, and the photovolt reflection meter.

Mackinney and Little (1962) stated that the use of the Hunter-designed instruments, whether produced by the Gardner Laboratory or Hunter Associates, is responsible for the tremendous upsurge of color measurements in foods during the past decade. The Hunter color-difference meter, like the Gardner color-difference meter, compares L (lightness values), a_L (redness when plus, gray when zero, and greenness when minus) and b_L values (yellowness when plus, gray when zero, and blueness when minus) with the color of a standard plate. Both instruments possess a light source which strikes the sample at a 45 degree angle, which in turn is diffused from the sample back into the machine. The reflected light passes through each of the three filter photocells which in turn creates a current by which the light's intensity can be measured (Hunter Associates, 1964, and Endres 1965).

The Hunter color-difference meter measures color on the L, a_L, and b_L scales. These three color scales make it possible to represent the colors of specimens by a three-dimensional coordinate system (Hunter Associates, 1964).

The non-homogeneous characteristics of many food samples necessitates taking several readings from a heterogeneous mixture. With the Hunter color-difference meter, arithmetic means of several spot readings must be compared unless it contains a specially adapted attachment which spins or rotates the sample and gives one composite reading. Tinsley *et al*. (1956) reported high correlations between spot and rotation values for raspberry and strawberry samples. Spot and rotation values were further correlated with blended samples, although the blended samples had considerably lower L, a_L, and b_L values.

The Hunter colorimeter was used successfully to measure the color of tomato juice (Robinson *et al*., 1952), citrus juice (Huggart and Wenzel, 1955, 1966), cauliflower and spinach (Boggs and Hanson, 1949). When custards were evaluated with this type of instrument, custards prepared with low egg concentrations received lower interior custard values and higher reflectance values than custards prepared with high egg concentrations (Longree *et al*., 1961). Endres (1965) found that the Gardner colorimeter produced highly significant correlations among the a_L values, b_L values, panel preference scores for color, and panel difference scores for color of baked coagulums.

Subjective Measurements

Consumers expect certain qualities in food, deviations from which are opposed. Perception, motivation, emotions, learning, and thinking play a vital role in food selection patterns (Amerine *et al*., 1965). Food selection and judgment of food quality is a compilation of how the color, size, texture, and shape is perceived. Food color and the environment in which the food is seen has a significant effect on the desire for or against the food. Bright warm colors as red, orange, and yellow tend to stimulate the appetite by inducing digestion through the automic nervous system; whereas soft cool colors tend to retard the appetite (Birren, 1963). Liking or disliking a food is often conditioned by its appearance. Attractive foods are sought as pleasure giving, whereas unattractive foods are avoided as painful. Individuals expect and learn what properties a food should have from past experiences and the majority of the population considers very seriously the foods they eat.

The concensus of opinion among researchers indicates the desirability of employing subjective as well as objective measurements in the evaluation of food quality. Subjective evaluations provide information essential for product improvement, quality maintenance, the development of new products or the analysis of the market (Amerine *et al.*, 1965).

Types of sensory tests

Lowe and Stewart (1946) classified subjective tests into two convenient categories: preference or acceptance tests; and psychometric or difference tests. Preference tests obtain the degree of acceptance of a food, and when conducted with large numbers of the population, permit the determination of consumer acceptance of a product. Psychometric tests are used for determining the quantitative differences, such as rating or scoring food quality characteristics. On the other hand, Amerine et al. (1965) classified sensory tests into eight categories. The classification included difference tests, rank order, scoring tests, descriptive tests, hedonic scaling, acceptance tests, preference tests, and other methods. Aldrich (1967) compiled the advantages and limitations of the available sensory techniques. Table 4 indicates the sensory tests which are presently used for assessing food quality.

Panel selection

Maximum discrimination of products tested necessitates careful selection of judges. Amerine et al. (1965) stated that the following considerations are essential in selecting judges for flavor-difference tests: precision or inherent ability to duplicate a difference judgment; reliability or absence of bias in detecting a flavor difference; and a tolerance level or inherent sensitivity to a particular flavor difference. Many investigators utilize one or more of the screening devices which follow: discrimination differences between solutions or substances of known chemical composition; ability to recognize flavors and odors; performance in comparison with other taste panel members; and the ability to discriminate differences in samples to be used in the actual test (Amerine et al., 1965). Kramer et al. (1961) found that one screening for selecting potential panelists was insufficient. A second screening of the candidates resulted in a

Table 4. Sensory tests for assessing foods.

Type	Variations	Advantages	Limitations
Difference	1. Paired-stimuli 2. Triangle 3. Multi-sample 4. Others	Relatively simple to execute; adequacy depends on purpose of test.	Identification *per se* gives little specific information for follow-up.
Rank Order	1. Intensity of specific characteristic. 2. Relative general acceptability.	Simple to execute	1. Sequence of sampling affects results. 2. Number of samples may affect judgment. 3. Only one criterion can be considered at a time.
Scoring	1. Comparison with control or reference sample. 2. With only each individual judge's point of reference as a standard.	1. Controlled; may be used as basis for interpreting characteristics of judges as well as product. 2. Seems to offer means of gathering variety of data in capsule form.	1. Results may be meaningless if judges change from established standard. 2. Variation attributable to judges' differences may partially mask product differences.
Descriptive	1. Hedonic 2. Semantic differential 3. Flavor profile	Effective for product development, process improvement, training judges.	May not be sufficiently specific for some purposes.
Acceptance	-----	Satisfactory in consumer check.	Primarily a gross screening technique.
Preference	-----	Simple assessment of degree of acceptance of one product over another.	Gross evaluation without specific clues for development.
Other	1. Dilution 2. Threshold	Establishing minimum detectable levels or differences.	Not useful in evaluating complex combinations.

Source: Aldrich, 1967.

more effective group, while further screening would undoubtedly result in further efficiency.

Panel size (Amerine *et al.*, 1965)

The number of panelists evaluating a product varies among experiments. The panel should be large enough to counteract unusual variations which might affect day to day comparisons. Small, highly sensitive panels usually give more reliable results than large, less sensitive groups. Recommendations for panel size for various types of sensory methods range from 3-10, 8-25, and 80+ for trained, semi-trained, or untrained panel members, respectively.

Factors affecting panel sensitivity (Amerine *et al.*, 1965)

Health, age, sex, and smoking habits of taste panel members has been the subject of many investigations. It appears that these are not critical factors in the selection of a panel, however, for improved accuracy among judges it is usually recommended that they do not smoke for one-half hour prior to testing.

Emotional factors such as extreme happiness or upsets seem to affect the ability of panel members to concentrate and thus reduces their accuracy. Important factors in the successful judging of foods include interest, motivation, knowledge and comparison of results, adjustment to the test situation, and memory. It is generally agreed that panel members should be given as much information as possible on the purpose of the investigation, however, information which might influence the subject's responses must be withheld. Discriminatory ability has been illustrated to be significantly greater when the immediate knowledge of noticeable differences was reported.

Lighting, seats, air conditioning, serving procedure, sample size, appearance and utensils, and coding are factors which may affect food evaluations. These factors should be standardized and used throughout the testing period.

Sensory evaluations are extremely complex and are affected by many factors. They are usually desirable, not as an entity in itself for the evaluation of food acceptability, but rather as a basis for correlation with objective measurements (Boggs and Hanson, 1949).

Analysis of sensory tests

Statistical procedures may be used for the interpretation of sensory data. The great variability displayed by the panelists reduces the use of elaborate highly refined techniques, the results of which can be no more valid than the information on which they were based (Amerine *et al.*, 1965). Analysis of variance does provide a method for determining the important interaction between panel members and treatments.

EXPERIMENTAL PROCEDURE

The experimental design for this investigation was divided into two series. The first sequence consisted of the preparation of baked custards; the second sequence involved the preparation of a similar formula omitting sugar.

Design of Experiment

To determine the effects of foam-spray-drying, freeze-drying, and spray-drying on the color, gel strength, and palatability of baked custards and to investigate the effect of sugar on the coagulating ability of the similarly mentioned egg processes, six replications of a standard custard formula were prepared and baked for each egg process. Custards prepared with frozen eggs served as a control. All eggs used in this investigation were processed similarly to those used in the investigations reported by Endres (1965) and Zabik and Figa (1967).

The custard mixture used in this study was baked to two end-point temperature ranges of 81-83°C and 85-87°C. These two end-point temperature ranges were arbitrarily selected to include satisfactory gelation temperatures for all egg processes. A two degree range was used because not all custard samples baked in the same water bath reached the specific temperature simultaneously.

Quality characteristics of the custards were evaluated by both objective and subjective evaluations. All data were subjected to the appropriate statistical analysis.

To determine the effect of sugar on the coagulating properties of the processed eggs, six replications of the basic custard formula were prepared omitting sugar. The procedure varied from that of the baked custards in the following manner: (1) sugar was omitted from the original formula, thus reducing the total solids content; (2) the slurries were baked to one end-point temperature range of 85-87°C; and (3) the baked slurries were evaluated entirely by objective methods.

Procurement of Ingredients

To eliminate any possible variation in ingredients, the whole eggs, milk powder, and sugar were obtained from a common lot. The whole eggs were acquired through a commercial food company[1] whereas the sugar and dried milk were purchased from a local distributor.

Processing of whole eggs (Gorman, 1965)

Shell eggs, varying in age from 1 to 2 weeks and grades from A to C, were machine broken, strained, and churned to produce a homogeneous mixture. Corn sirup solids and salt

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[1]Semour Foods Company, Topeka, Kansas.

were added to the blend of whole eggs on the dry weight basis of 31.5 ± 0.5 per cent carbohydrates and 1.5 ± 0.25 per cent salt. The mixture was pasteurized at 60°C for 3 1/2-4 minutes. Following pasteurization the eggs were frozen in 30-pound metal containers and held at -30°C until further processing and/or shipment. This frozen mixture was used for the frozen, foam-spray-dried, freeze-dried, and spray-dried whole eggs used in this investigation.

Foam-spray-drying (Dawson, 1965). The portion of eggs to be used for the foam-spray-drying was packed in dry ice, shipped to the appropriate processor,[2] and held at -23.3°C for 2 months before processing. Prior to processing the eggs were partially thawed at 15.6°C, held at 1°C until they were heated with constant stirring to 54°C, and placed in a 60°C water bath. Foam-spray-drying was carried out using a modification of the foam-spray-drying procedure described by Blakely and Stine (1964). The eggs were foam-spray-dried using a co-current horizontal inverted teardrop dryer equipped with two number 62 nozzles with number 20 spinners. Automation pressure was 850 pounds per square inch and nitrogen gas pressure was between 900-1000 pounds. Inlet temperature ranged from 124-127°C and exit air ranged from 79-82°C.

Freeze-drying (Amato, 1965). The frozen eggs for the freeze-drying process were shipped to the appropriate processor[3] and

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[2]Food Science Department, Michigan State University, East Lansing, Michigan.
[3]Armour Grocery Products Company, Bellwood, Illinois.

held at -40°C until the final processing. Prior to freeze-drying, the eggs were tempered for 48 hours at 14.4°C. The thawed product was then mixed and 10 pounds of the mixture were placed into each dryer pan of a Vacudyne sublimator. The eggs were frozen under a pressure of 100 microns to -29.9°C. This process was followed by drying, during which the temperature of the product did not exceed 50°C. Upon completion of the 15 1/2 hour drying cycle, the chamber vacuum was broken with air. The egg was removed, allowed to reach 25°C., and then sealed into five gallon tins until final packaging.

<u>Spray-drying</u> (Gorman, 1965). The portion of whole eggs used to prepare the spray-dried product was thawed, blended, and spray-dried,[4] using a pilot plant spray-dryer under an atomizing pressure of approximately 2000 pounds. Intake temperature ranged from 149-163°C and exhaust temperature ranged from 66-71°C. Upon completion of drying, the whole egg mixture was screened through 16 mesh USBS screens and cooled to 29°C. The dried eggs were packed in polyethylene lined fiber drums and held at 20.6°C until packaged.

<u>Packaging, shipment, and storage</u>. The frozen eggs were shipped to Michigan State University in 30-pound containers which were packed in dry ice. Upon arrival, the mixture was held at

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[4]Semour Foods Company, <u>op</u>. <u>cit</u>.

$-23^{\circ}C$ until the investigation was initiated. At this time the frozen eggs were thawed for 24 hours under running water, subdivided into appropriate amounts and placed in plastic pouches which were contained inside round plastic-lined, quart size cardboard containers. The eggs were then frozen at $-23^{\circ}C$ for the 1-9 week period prior to use.

The freeze-dried and spray-dried eggs were similarly packaged in one-pound laminated-foil pouches, whereas the foam-spray-dried eggs were similarly packaged in 6-ounce pouches.[5] The pouches consisted of the following materials: polyethylene terephthalate (.005 in. thickness), foil aluminum (.001 in. thickness), and polyethylene(.002 in. thickness). The packaging process involved drawing 27 inches of vacuum, plunging the eggs with nitrogen twice, and sealing on the third vacuum. The eggs were held at $20.6^{\circ}C$ after the packaging process. Following shipment to Michigan State University the dried egg packages were frozen and held at $-23^{\circ}C$ for the 8-month period prior to use. At the beginning of this investigation, the dried eggs were opened and dry blended in the 12-quart bowl of the Hobart Mixer, Model A-200, for 5 minutes. The eggs were then portioned into appropriate amounts, heat sealed in heat sealable polyester pouches and held at $-23^{\circ}C$ until used.

Bacterial analysis (Mallmann, 1966). Bacterial analyses were run on the foam-spray-dried, freeze-dried, and frozen eggs. The

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[5]Jianas Brothers, Kansas City 8, Missouri.

method for the bacterial analyses are included in the appendix.

Milk source

Dried whole milk in nitrogen packed number 10 cans was used in this investigation.[6] The milk powder was combined in the 12 quart bowl of the Hobart Mixer, Model A-200 and dry-blended for 5 minutes. Appropriate weights of milk powder for each replication were weighed to the nearest 0.1 gram on the Triple beam balance (1.6 kg. capacity), heat sealed into heat sealable pouches, and held at 4.5°C until used.

Sugar source

A commercial brand of pure cane granulated sugar was used in this investigation.[7] All the sugar was placed in the 12-quart bowl of the Hobart Mixer, Model A-200, and dry blended for 5 minutes. Appropriate weights of sugar for each replication were weighed to the nearest 0.1 gram on the Triple beam balance (1.6 kg. capacity), and were stored in closed polyethylene pouches at room temperature.

Basic Formula

The formula selected for this study based on Lowe's (1955) recommendation of the use of 244 grams milk, 48 grams

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[6]Snow Flake, Webster Van Winkle Corporation, Summit, New Jersey.
[7]Domino Pure Cane Sugar, American Sugar Company, New York.

egg, and 25 grams sugar for a standard custard formula. Vanilla and salt were omitted to avoid any effect that they might have on flavor and color. Custards were prepared according to the formula listed in Table 5.

Table 5. Formula used in the preparation of baked custards.

Ingredients	Frozen Egg Custard Mix	Dried Egg Custard Mix		
		Foam-spray-dried Egg	Freeze-dried Egg	Spray-dried Egg
	g	g	g	g
Frozen eggs	396.0	-	-	-
Foam-spray-dried eggs	-	140.4	-	-
Freeze-dried eggs	-	-	138.8	-
Spray-dried eggs	-	-	-	140.0
Sugar	187.0	187.0	187.0	187.0
Dried Milk Powder	195.6	195.6	195.6	195.6
Distilled water for:				
Dried Milk reconstitution	1635.0	1635.0	1635.0	1635.0
Dried egg reconstitution	-	255.6	257.2	256.0

The formula for the baked slurries contained the same percentage of egg (16.41%) as the baked custards. Sugar was omitted in the baked slurry formula reducing the total solid content by 7 per cent. A smaller quantity of the formula was prepared because the sensory evaluations were omitted in this series. The formula for the baked whole egg and milk slurries is included in Table 6.

Table 6. Formula used in the preparation of baked slurries.

Ingredients	Frozen Egg Slurry Mix	Dried Egg Slurry Mix: Foam-spray-dried Egg	Dried Egg Slurry Mix: Freeze-dried Egg	Dried Egg Slurry Mix: Spray-dried Egg
	g	g	g	g
Frozen eggs	179.7	-	-	-
Foam-spray-dried eggs	-	63.2	-	-
Freeze-dried eggs	-	-	63.0	-
Spray-dried eggs	-	-	-	63.0
Dried milk powder	97.8	97.8	97.8	97.8
Distilled water for:				
Dried milk reconstitution	817.5	817.5	817.5	817.5
Dried egg reconstitution	-	116.4	116.6	116.6

The proportion of egg contained in each formula was based on dextrin and moisture content of the various types of processed eggs. The amount of egg used in the formula was increased by ten per cent because of the fact that the liquid eggs contained ten per cent dextrins in the form of corn sirup solids. The exact amount of whole egg solid and the quantity of water equal to that of frozen eggs (69.5 per cent) was determined for each type of egg process from moisture data obtained by using the AOAC vacuum oven method (1955). The actual weight of all dehydrated eggs were corrected for variance in moisture content of the egg powder. The amount of egg powder in the formula increased and the water decreased as the percentage moisture of the egg powders increased.

Preparation of Mix

Preparation for this investigation was divided into two series. The first series consisted of preparing custard mix; the second series was composed of preparing whole egg-milk slurries.

Custard mix

Forty-eight batches of custards were prepared in a randomized order, 3 batches on each of 16 days. The method of preparation for the custards prepared with frozen, foam-spray-dried, freeze-dried, and spray-dried eggs was carried out under similarly controlled conditions.

All eggs for the investigation were utilized at room temperature. Frozen eggs were thawed at 4-5°C for 20-24 hours and were allowed to remain at room temperature for 30-45 minutes so that they were 24-25°C when used in the custards. The dried eggs were removed from the freezer 15-20 minutes before preparation to allow the eggs to reach 24-25°C. The exact amount of egg used in the formula was weighed to the nearest 0.1 g on the Triple beam balance (1.6 kg. capacity) on the day of preparation.

The custards were prepared by a method similar to that described by Endres (1965). The egg powder, milk powder, and sugar were placed in a 12-quart bowl of the Hobart Mixer, Model A-200, and dry blended for 60 seconds at speed 2 (86 rpm) using the whip attachment. The bowl was scraped thoroughly after each beating period. The distilled water used for the reconstitution of the dried mixture was warmed to 40-50°C upon recommendation by the milk manufacturer, and was added in three allotments. To make a smooth paste for improved dispersibility, 300 ml of distilled water was blended with the dry mixture for 10 seconds at speed 1 (48 rpm) and 50 seconds at speed 3 (140 rpm) using the paddle attachment. The remaining water was added in two equal portions; the first of which was followed by mixing for 30 seconds at speed 2 (86 rpm), whereas the final water portion was mixed an additional 60 seconds at speed 1 (48 rpm). The mixture was removed from the mixer and strained through a fine wire household strainer (25 wires per in.) into three 1-quart pitchers. The control custards made with frozen eggs were combined similarly; however, the frozen eggs were not added until the first water addition. The pH of a 100 ml sample of custard mix was recorded using a Beckman Zeromatic pH meter.

Slurry mix

Twenty-four batches of slurry mix were prepared, six batches on each of four days. The four types of processed eggs utilized and the order of preparation were randomized.

The preparation described for the baked custards was modified to prepare the baked slurries. The sugar was not added with the egg and milk powder; and the first water addition was reduced to 150 ml.

Baking Procedure

The custards and slurries were baked in sequence. The custards were baked to the two end-point temperature ranges of 81-83^{o}C and 85-87^{o}C; while the slurries were baked to the end-point temperature range of 85-87^{o}C.

Baked custards

The custard mix for objective and subjective evaluations was baked in appropriate containers. Custards for gel strength determination on the Allo-Kramer shear press were baked in 5 in. x 3 1/2 in. x 2 1/2 in. aluminum loaf pans. Each pan contained 350 ml of mix, which filled the pan to a depth of 4.1 cm. Duplicate samples of the custard mix for each variable were baked simultaneously. A perforated stainless steel frame was used to support the individual loaf pans in a large aluminum baking pan (18 5/8 in. x 3 3/4 in. x 3 1/2 in). Custard mix for color, percentage drainage, and sensory evaluations were baked in conventional Pyrex 5-ounce baking cups. Each cup contained 110 ml of mix which filled the cup to a depth of 3.8 cm. Fourteen cups were baked at one time in two (15 1/2 in. x 8 1/2 in. x 2 1/2 in.) pans.

Baking positions of the pans and cups were rotated so that each variable had comparable oven positions for the subjective and objective tests. Oven positions for the custards evaluated by the taste panel were rotated; however, samples for any one taste panel member for any one day were baked in the same oven position.

Prior to placing the custard mix in the oven, thermocouples were secured in place and tap water at 20-23°C was placed in the aluminum pans to a level equal to that of the mix. Thermocouple supports were clamped to each individual pan to insure that the thermocouple remained securely positioned in the center of the mix at a depth of 2.1 cm. The perforated stainless steel frames holding the cups were used to support the thermocouples in the center of the gel at a depth of 1.9 cm. To eliminate any possible destruction of the gel, thermocouples were not placed in those custards to be used for sensory evaluation. The apparatus used for baking the custard mix were illustrated and described by Endres (1965).

The custard mix was baked in two General Electric 30-inch compact ovens, Model CN 16, with the damper half-way closed and the grids set on high. Oven temperature was preheated and maintained at 177 ± 10°C with Minneapolis Honeywell

Versatronik Controllers. Removal of the center racks of the ovens allowed sufficient room for the baking apparatus.

The same end-point temperature range was used for all variables prepared the same day. Oven and internal gel temperature were recorded every 3 minutes with a Brown Electronic Potentiometer equipped with a 12-point high speed multiple point recorder. When the custards reached the appropriate end-point temperature range of 81-83°C or 85-87°C, the rack supporting the custards was removed and the gels were allowed to cool at room temperature for 1 hour. Custards used for taste panel evaluations were stored uncovered and the remainder of the custards were covered with Saran. All custards were held at refrigerator temperature (4-5°C) for 18-24 hours before they were evaluated.

Baked slurries

The baking procedure explained for custards was altered slightly for the baking of the slurries. Three variables were baked simultaneously with duplicate samples for each objective evaluation. As only six cups were baked at one time, only one baking pan was utilized. The oven was preheated and the temperature was maintained at 177 ± 7°C.

Evaluation of Custards and Slurries

The baked custards were evaluated with both objective and subjective methods. The baked whole egg and milk slurries were evaluated solely by objective methods.

Objective evaluations

Objective evaluations were performed to determine the pH percentage drainage, gel strength, and color of the custards prepared with the four types of processed eggs baked to the two end-point temperature ranges of 81-83^{o}C and 85-87^{o}C. Objective evaluations were utilized to determine pH, gel strength, and color of the baked slurries. All samples were tested at 4-9^{o}C on the day following preparation.

pH of the baked custards. The pH determinations were made with a Beckman Zeromatic pH meter equipped with calomel and glass electrodes which was standardized with a 7.0 buffer. A 10-gram sample of the custard was blended for 1 minute with 20 ml of water, placed in a 50 ml beaker and pH recorded. The pH values recorded are the averages of two samples.

Percentage drainage. Percentage drainage of the baked custards was determined by the method described by Miller et al. (1959a). The gel was carefully removed from the custard cup and inverted, crust down, on a weighed wire screen (18 wires per inch) which was located over a weighed petri dish. The dish, screen, and inverted sample were weighed to the nearest 0.1 g on the Triple beam balance (1.6 kg. capacity), covered with a large glass bowl to prevent evaporation, and allowed to stand for 1 hour. At the end of this period, the gel was removed from the wire screen and the weight of the drainage was calculated to the nearest 0.1 g from the difference in weights of the petri dish and screen before and after the drainage period. Percentage drainage was derived by dividing the weight of drainage by the weight of the custard before drainage and multiplying by 100. Averages of two values were reported for each replication.

Gel strength determination. The upper assembly of the fixed blade cell of the Allo-Kramer shear press, Model SP 12, was used to determine the gel strength of the custards. The method used was described and illustrated by Endres (1965). A 100 pound proving ring, 10 pound range, 25 pound pressure, and 30 second downstroke was used in this operation.

Each custard sample was removed from the refrigerator and positioned directly on the cell block under the upper assembly. The fixed blade cell was lowered into the custard to a depth of 3.8 cm while readings were recorded on the Electronic Recorder, Model E-2EZ. The cell blade was rinsed with warm water before each evaluation was performed.

Gel strength of the baked custards was determined by computing the force required to shear through the gel following the method described by Endres (1965). Three peaks were determined from the graphs drawn by the electronic recorder. The force was computed for each of the three peaks by multiplying the peak value by the range/ring proportion. The values are referred to as Peak I, Peak II, and Peak III respectively.

Gel strength derived by computing the area-under-the-curve was determined by utilizing the method described by Brown (1964). Each graph drawn by the electronic recorder was carefully cut out and weighed on a Mettler Balance, Model H15. The weight was computed to area by multiplying the weight of the graph by 174.2. The conversion factor of 174.2 was determined by weighing multiple squares of varying known area from random locations on chart paper. Averages of two samples were recorded for each replication.

Color measurement. Color of the baked custards was measured by a Hunter color-difference meter, model D-25. The instrument was standardized with a yellow tile covered with an optical lens (L, 82.8; a_L -3.5; b_L +26.2) in preparation for determination of L (lightness), a_L- (greenness), and b_L+ (yellowness) values of the custard samples.

The following procedure was used for the color analysis of all variables. The gel was removed from the custard cup and inverted, crust down, on a clear flat piece of high quality plate glass (5 in. x 5 in. x 1/8 in.). Approximately 1/2 inch was removed from the original bottom of the custards with a 2 1/2 in. x 4 in. metal spatula. The freshly cut flat surface was covered with a special optical lens (3 in. x 4 in. x 1/8 in.). The glass, custard, and optical lens were placed under the viewing area of the Hunter color-difference meter, and two sets of values were derived from different gel positions by moving the glass supporting the gel one quarter turn.

Each value reported represents an average of four readings, two readings for each of two custards.

Subjective evaluation

Subjective evaluation was utilized to determine the acceptability of the crust tenderness, inside color, firmness, syneresis, smoothness, and flavor of baked custards prepared with the various types of processed eggs. An eight membered taste panel evaluated the previously mentioned custard qualities using a 7-point rating scale.

Baked custards for sensory evaluation were prepared as follows: (1) the custard was carefully loosened from the sides of the custard cup; (2) the cup, with the custard still intact, was placed on a white plate coded with pre-determined random numbers; and (3) the plate containing the custard was placed on a tray containing the judge's name and was stored in the refrigerator. The panel members were directed to remove their samples from the refrigerator and to proceed to their assigned seat in the taste panel room.

The taste panel room was equipped with necessary silver, lukewarm water, and crackers. All evaluations were carried out under 15-watt cool fluorescent lighting.

The procedure for evaluating the custards was demonstrated for the judges. First, the crust was carefully removed and evaluated for tenderness. Second, the custard was inverted and carefully removed from the cup. Third, the custard was evaluated for color, gel strength, syneresis, smoothness and flavor; in that order. Judges were requested to partake of the crackers and water provided to eliminate any possible carry-over of flavor among samples. Taste panel directions and a sample score sheet used for the sensory evaluations are included in the Appendix.

Analysis of Data

The data obtained from both the objective and subjective evaluations were summarized and analyzed by the use of three computer programs on the CDC-3600 Computer at Michigan State University. The Rand Routine (Option 3) was used to calculate the analyses of variance, the BaStat Routine was employed to ascertain simple correlations, and the MdStat Routine was utilized to determine standard deviations of the means. Significant differences among types of egg, individual treatment combinations, mean sensory evaluation scores, and judges were evaluated through the use of the Studentized range test (Duncan, 1957).

RESULTS AND DISCUSSION

The primary purpose of this investigation was to determine the effects of foam-spray-, freeze-, and spray-drying of eggs on the color, gel strength, and palatability of baked custards. Determining the effect of sugar on the protein coagulation of the processed eggs was of secondary importance in this inquiry. Gels prepared with frozen eggs served as the control.

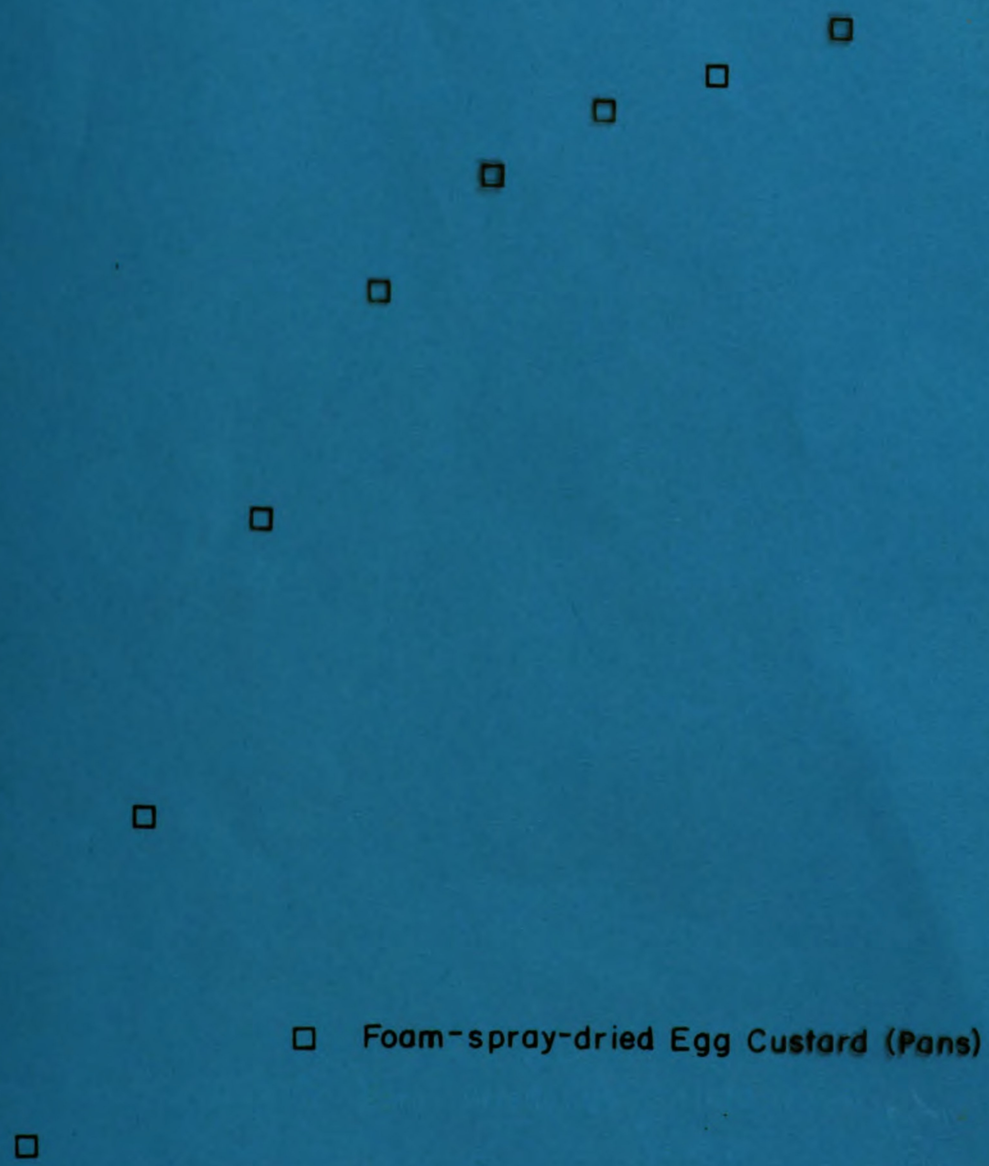
This investigation was divided into two series: (1) standard custards containing sugar which consisted of eight treatments combining each egg process and two end-point temperature ranges, and (2) egg-milk slurries omitting sugar which consisted of four types of processed eggs baked to one end-point temperature range. Standard procedures were utilized in the preparation and evaluation of the gels. Additional information on time-temperature relationships during baking, length of baking time, and pH before and after baking were collected.

Time-temperature Relationships of Gels

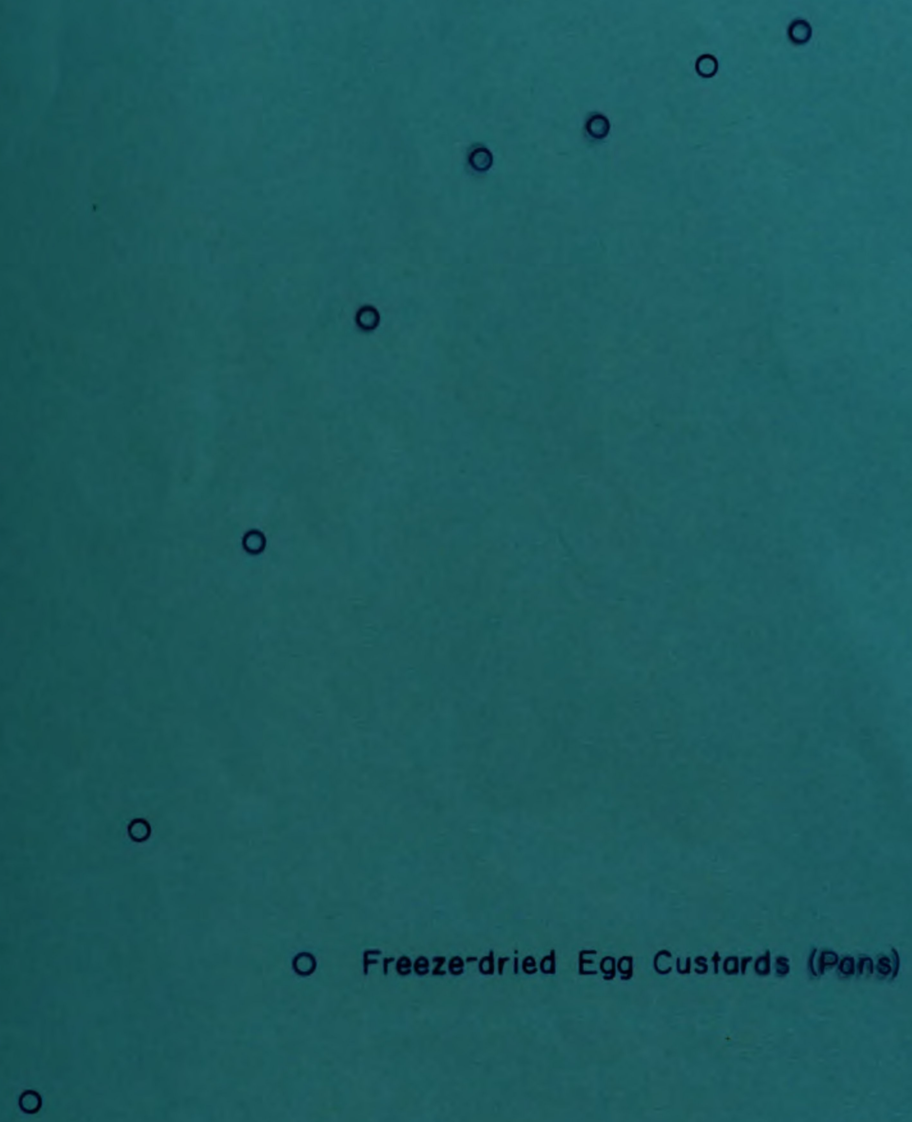
The time-temperature relationships for custards prepared with frozen, freeze-dried, foam-spray-dried, and spray-dried eggs are illustrated in Figure 1. A rapid increase in temperature during the early part of the baking period which was

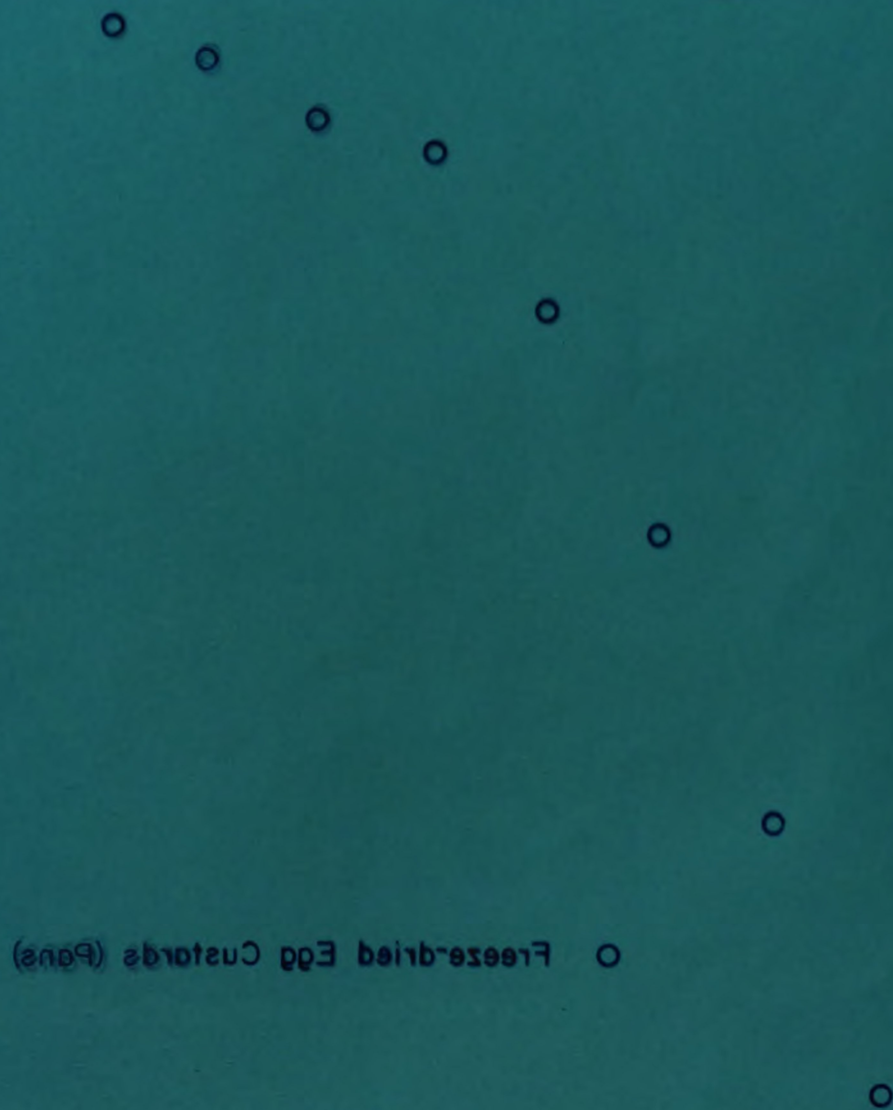

Spray-dried Egg Custard (Pans)

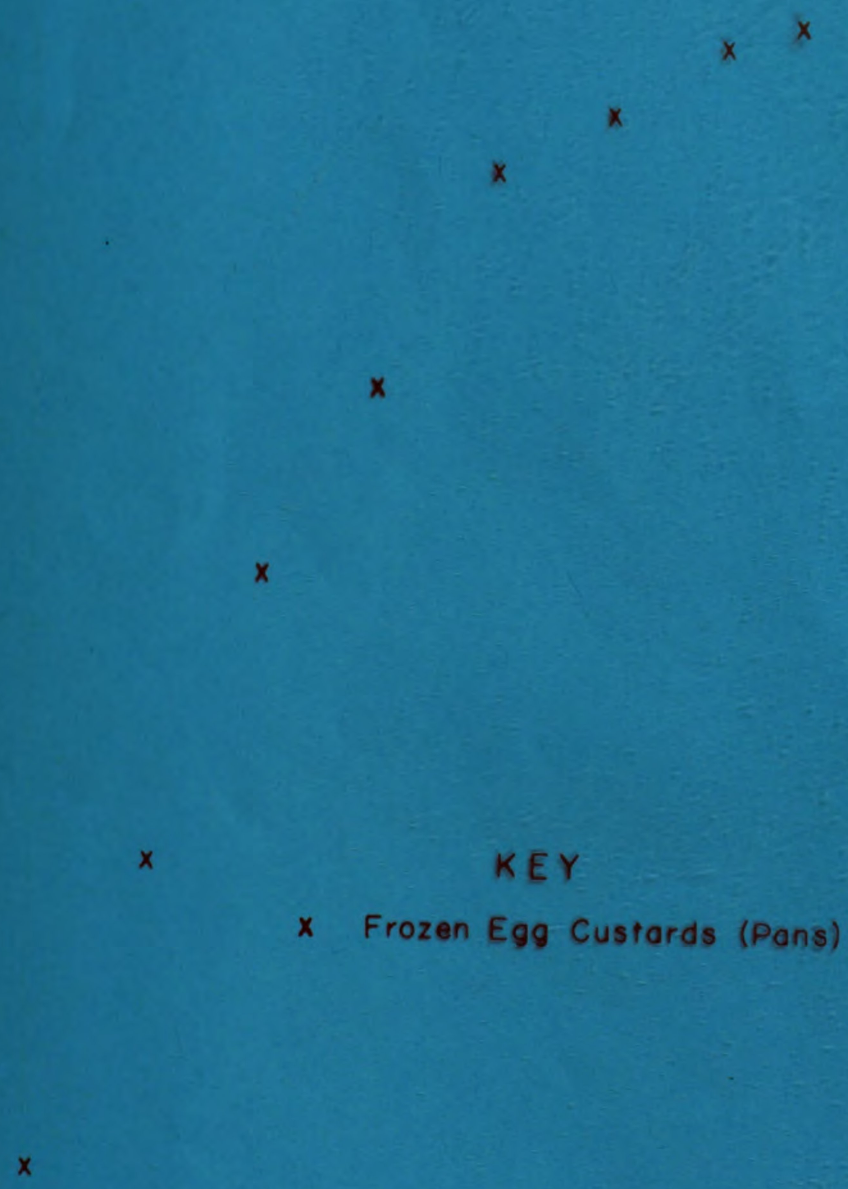

Spray-dried Egg Custard (Pans)

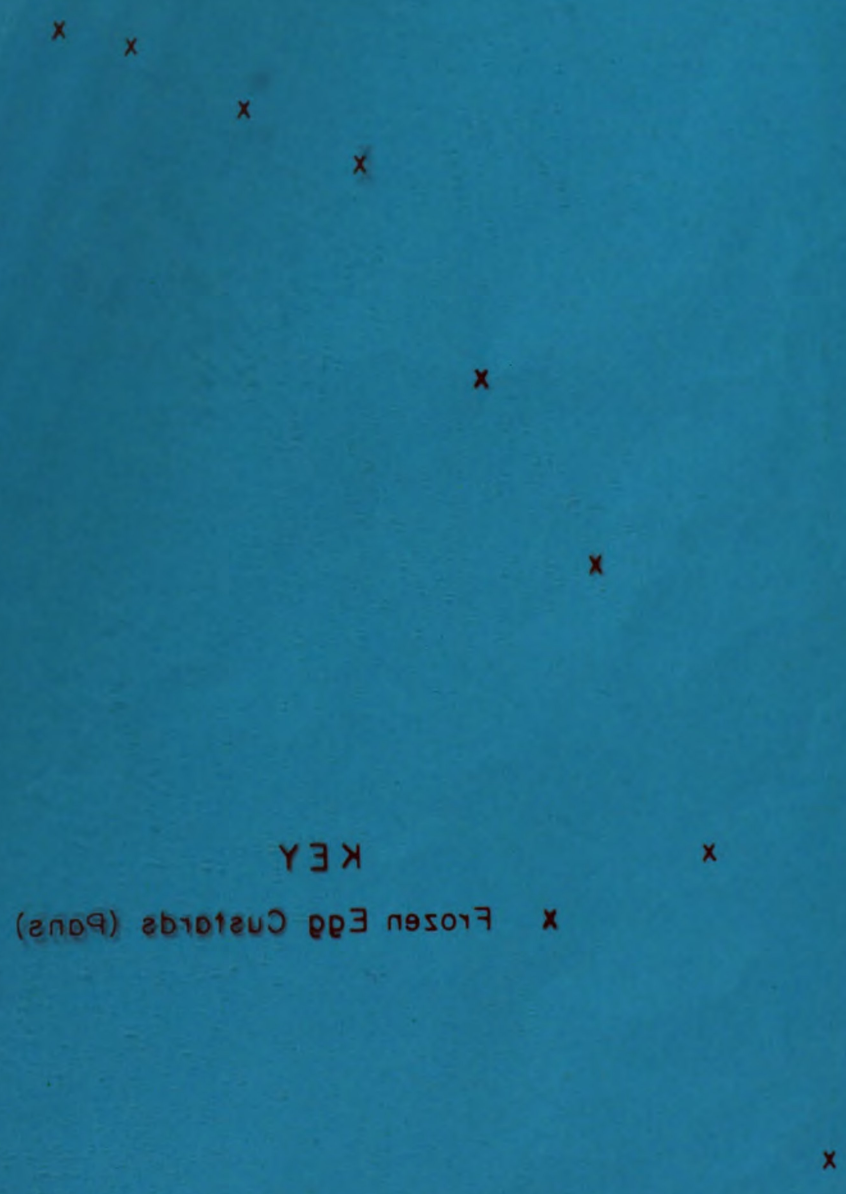

Foam-spray-dried Egg Custard (Pans)


Foam-spray-dried Egg Custard (Pans)


Freeze-dried Egg Custards (Pans)


○ Freeze-dried Egg Custards (Pans)


KEY
x Frozen Egg Custards (Pans)


KEY
x Frozen Egg Custards (Pans)

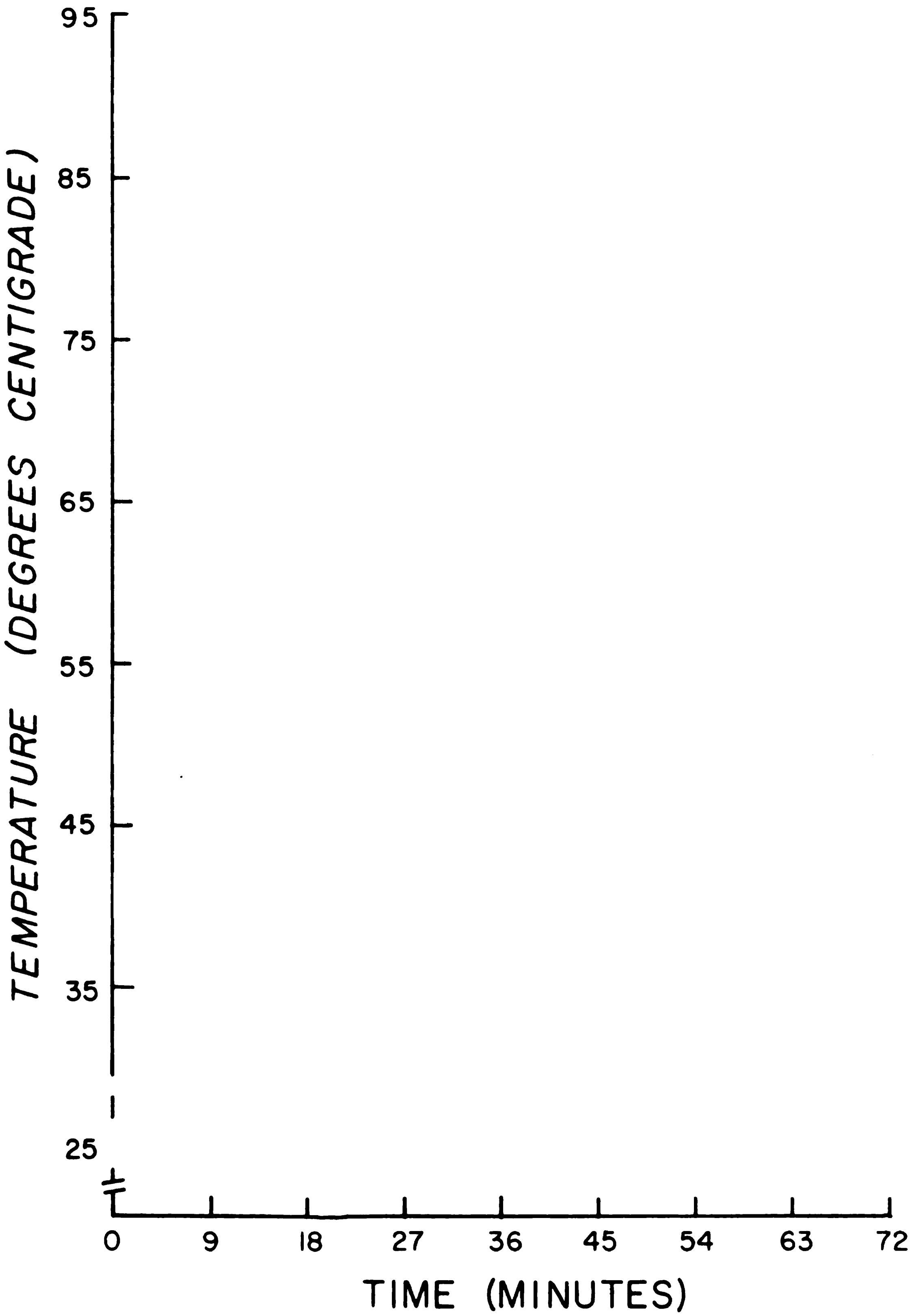


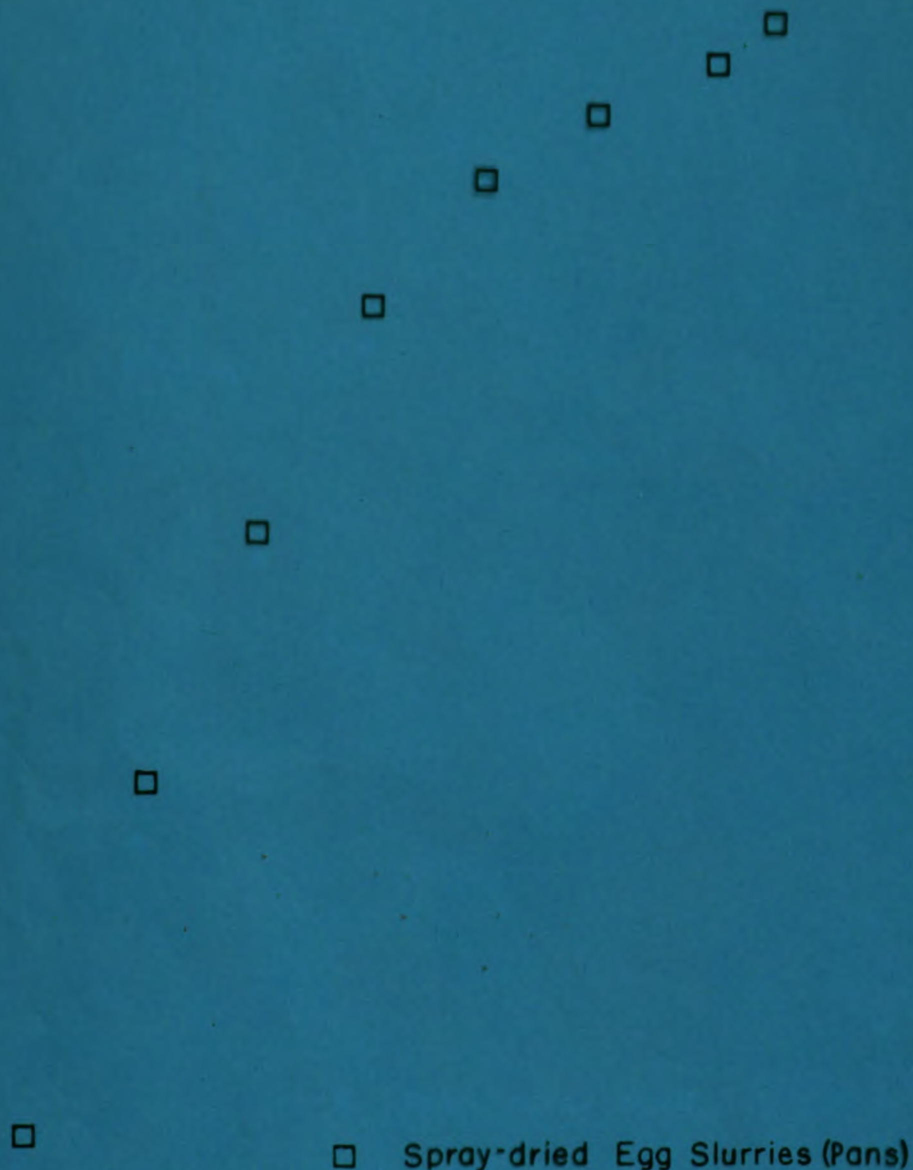
Figure 1. Mean time temperature relationships during baking of custards prepared with four types of processed eggs.

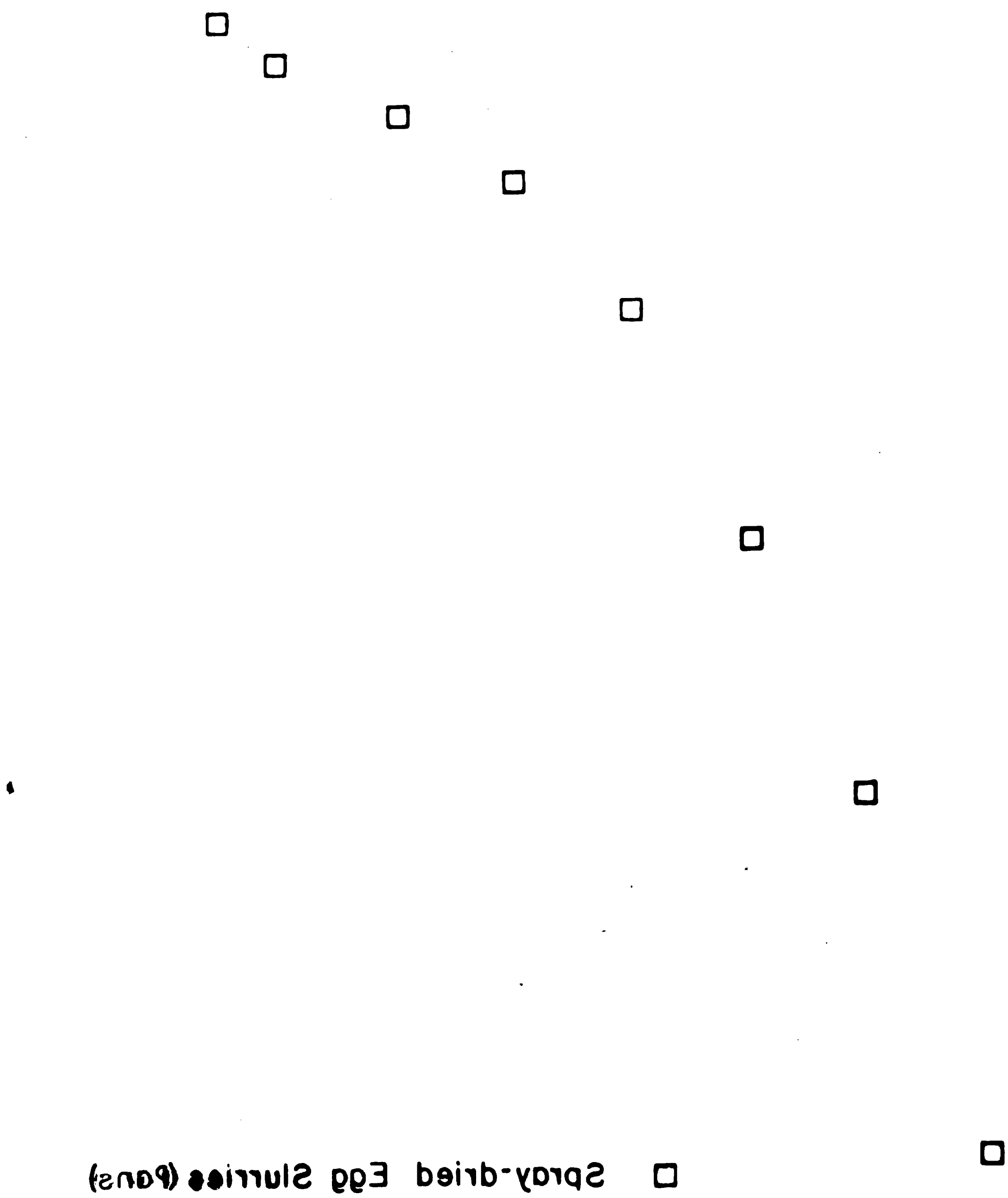
followed by the formation of a plateau was evident for gels prepared with all types of processed eggs. The similarity among the time-temperature relationships for gels prepared with frozen, freeze-dried, and spray-dried eggs is in agreement with the results of Endres (1965).

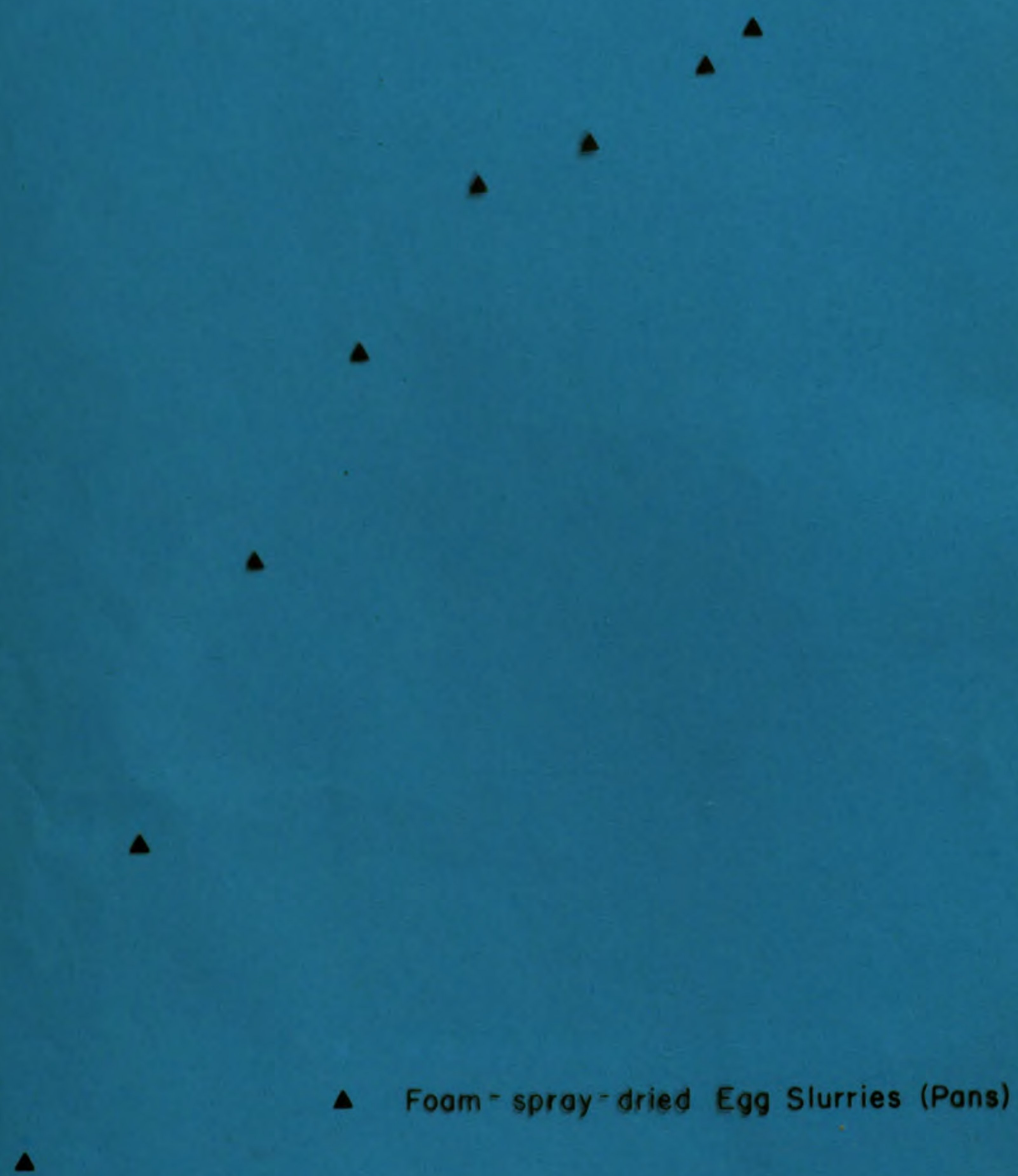
The time-temperature relationships for the slurries prepared without sugar are depicted in Figure 2. Sugar increaed the rate of heat penetration for systems prepared with all types of processed eggs. Gels prepared without sugar leveled off at a lower temperature than did gels containing sugar, however, after leveling off the internal temperature again increased. According to Longree _et al_. (1961) this would indicate that the gels containing sugar were coagulating at a higher temperature than those gels without sugar. This finding is verified by Solsberg _et al_. (1948), Lowe (1955), and Seideman _et al_. (1963).

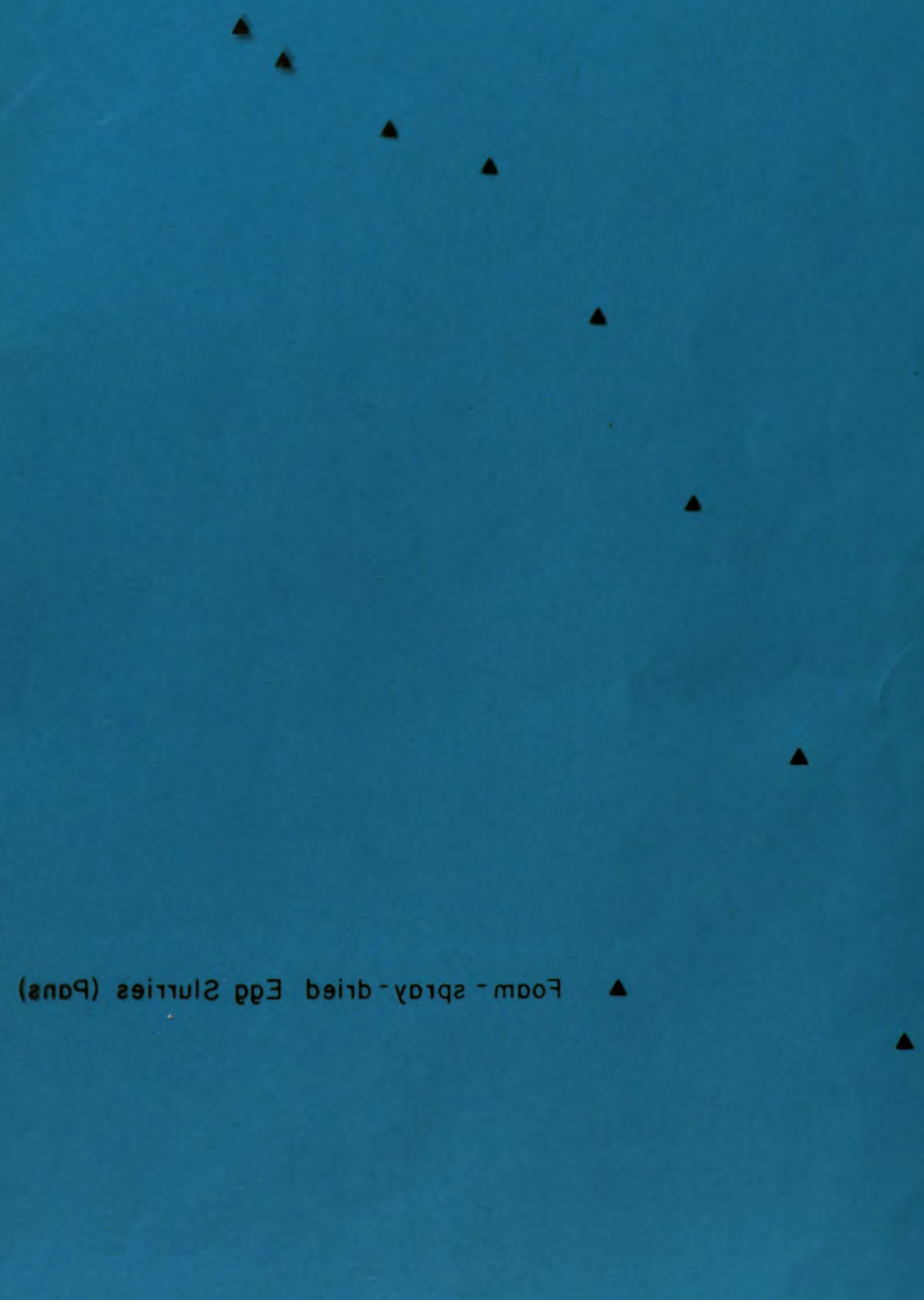
Baking Times of Gels

The average baking time for custards baked to 81-83°C and 85-87°C was 51 and 63 minutes respectively. Analyses of variance for length of baking time (Table 7) showed the difference in length of baking time to be highly significant as expected; however, there was not a significant difference in the baking time among gels prepared with various types of processed eggs.

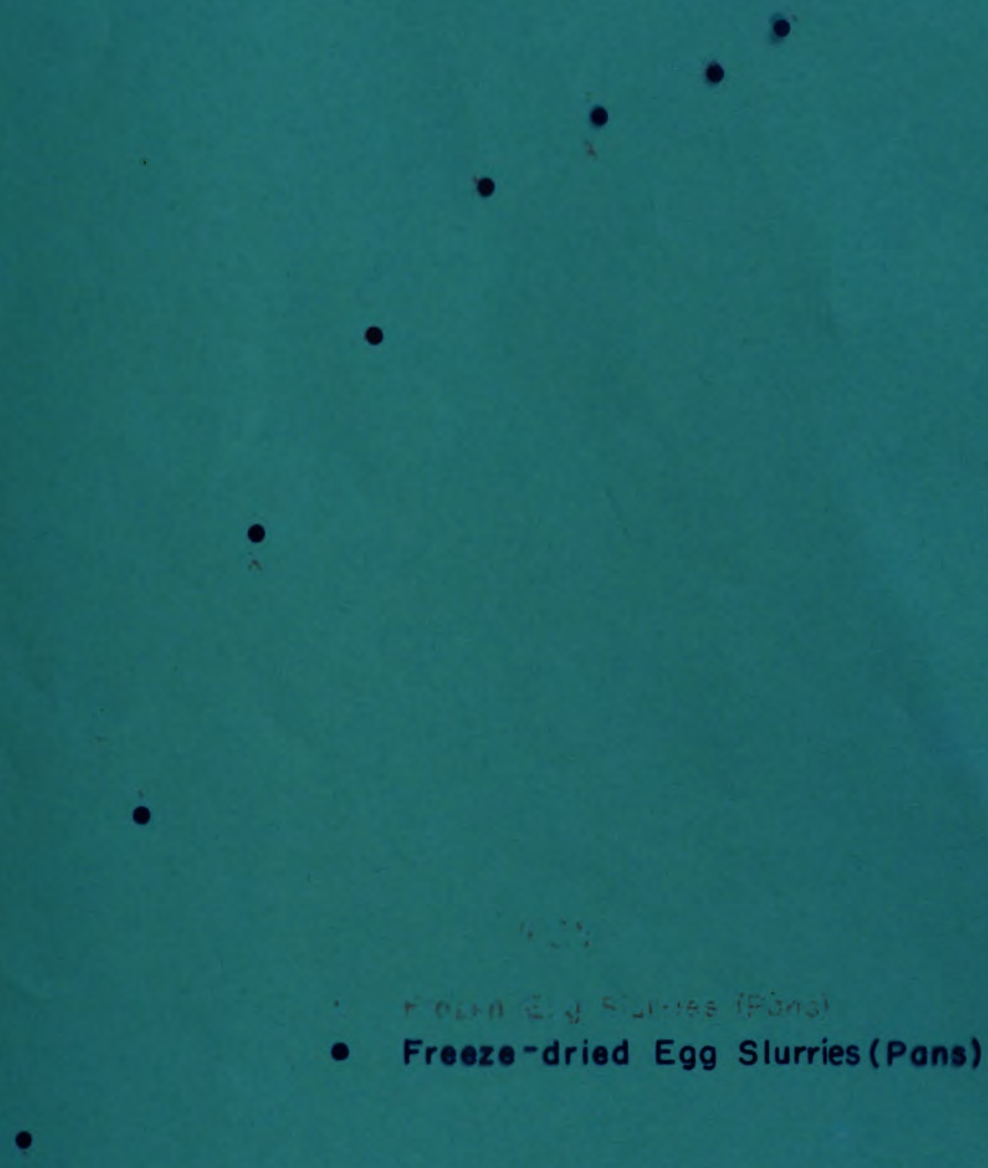

Spray-dried Egg Slurries (Pans)

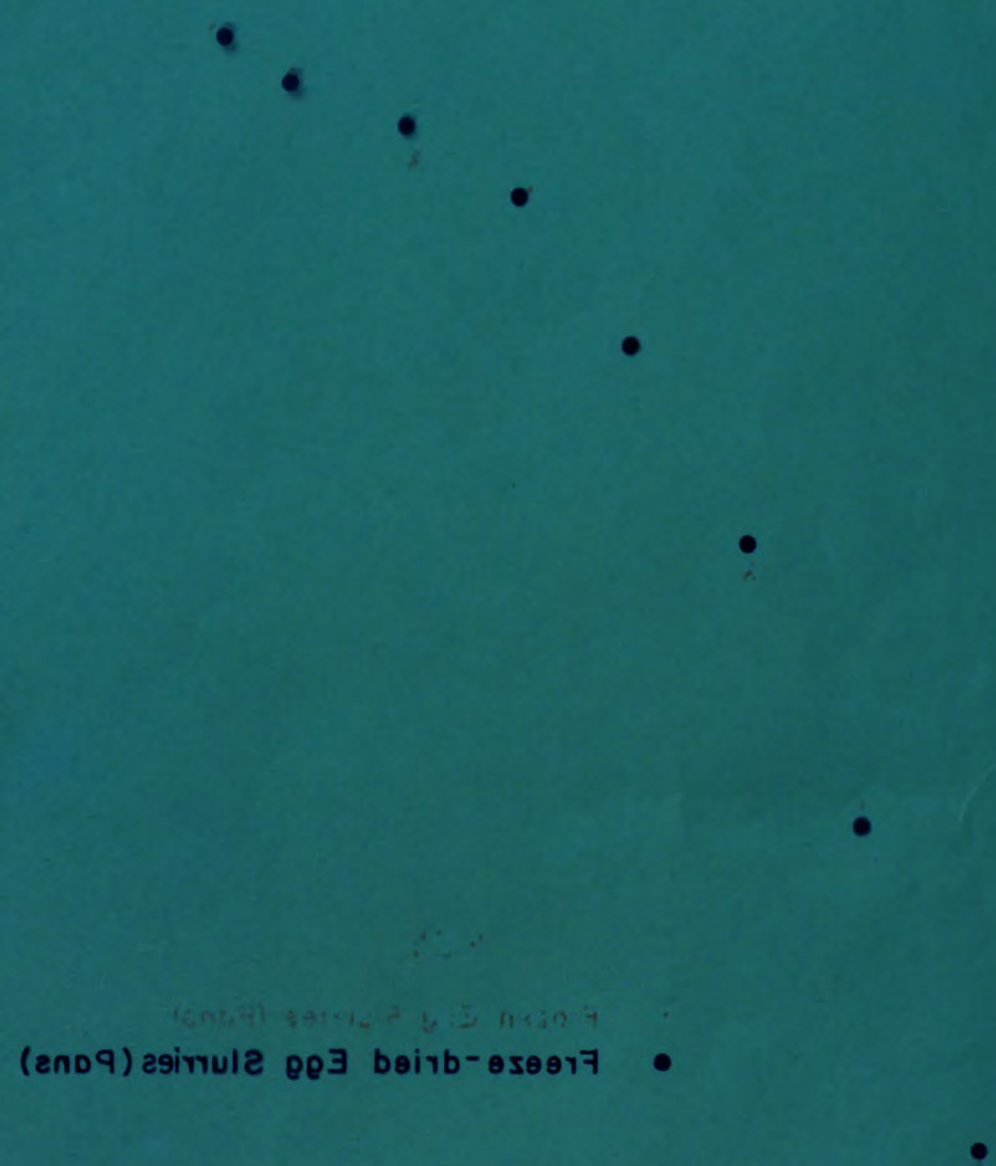

Spray-dried Egg Slurries (Pans)


▲ Foam-spray-dried Egg Slurries (Pans)

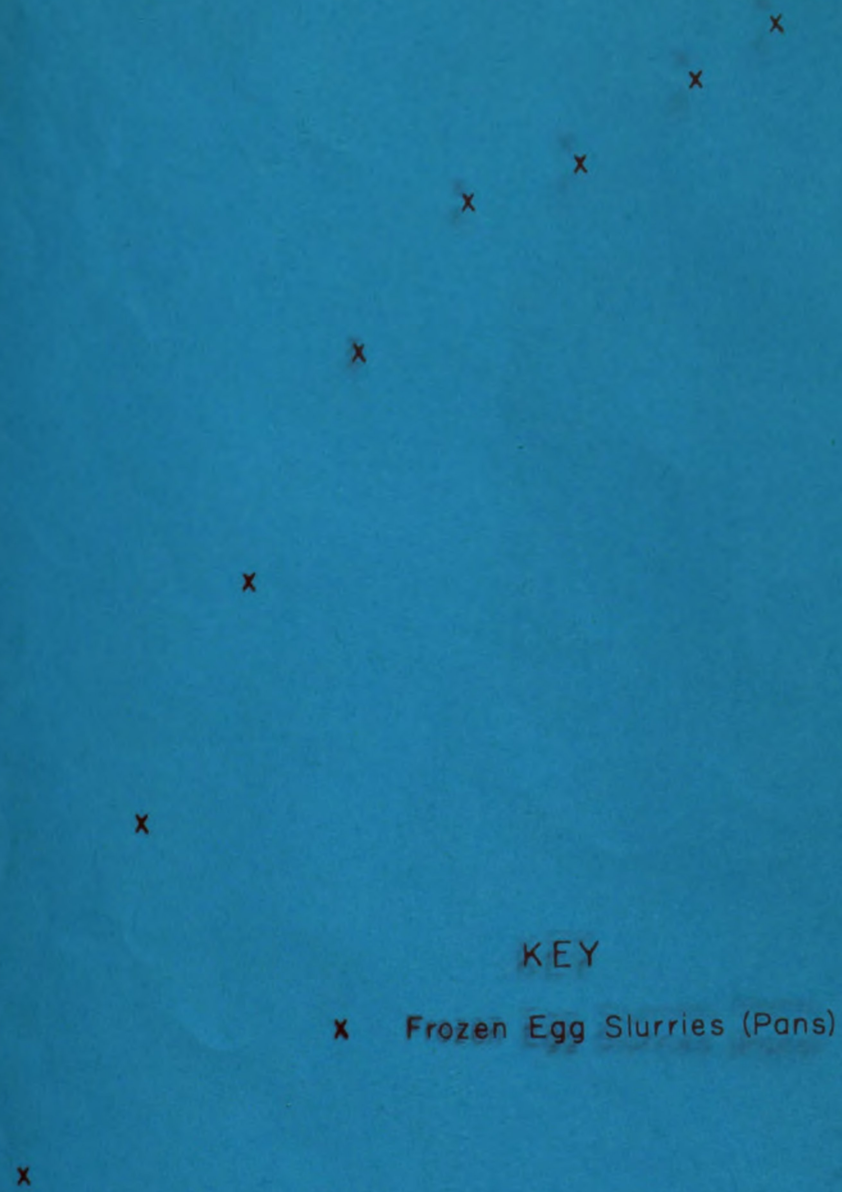


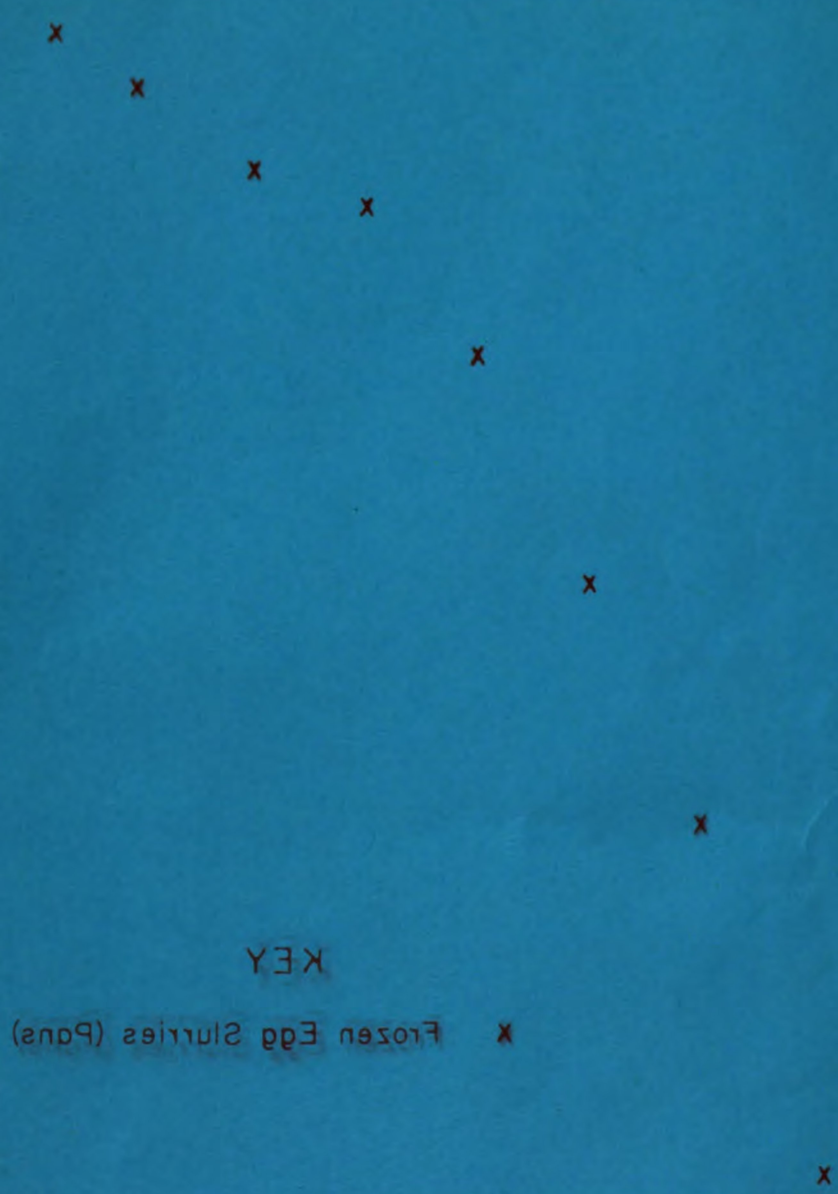
▲ Foam - spray - dried Egg Slurries (Pans)


Freeze-dried Egg Slurries (Pans)



Freeze-dried Egg Slurries(Pans)


KEY
x Frozen Egg Slurries (Pans)


KEY
x Frozen Egg Slurries (Pans)

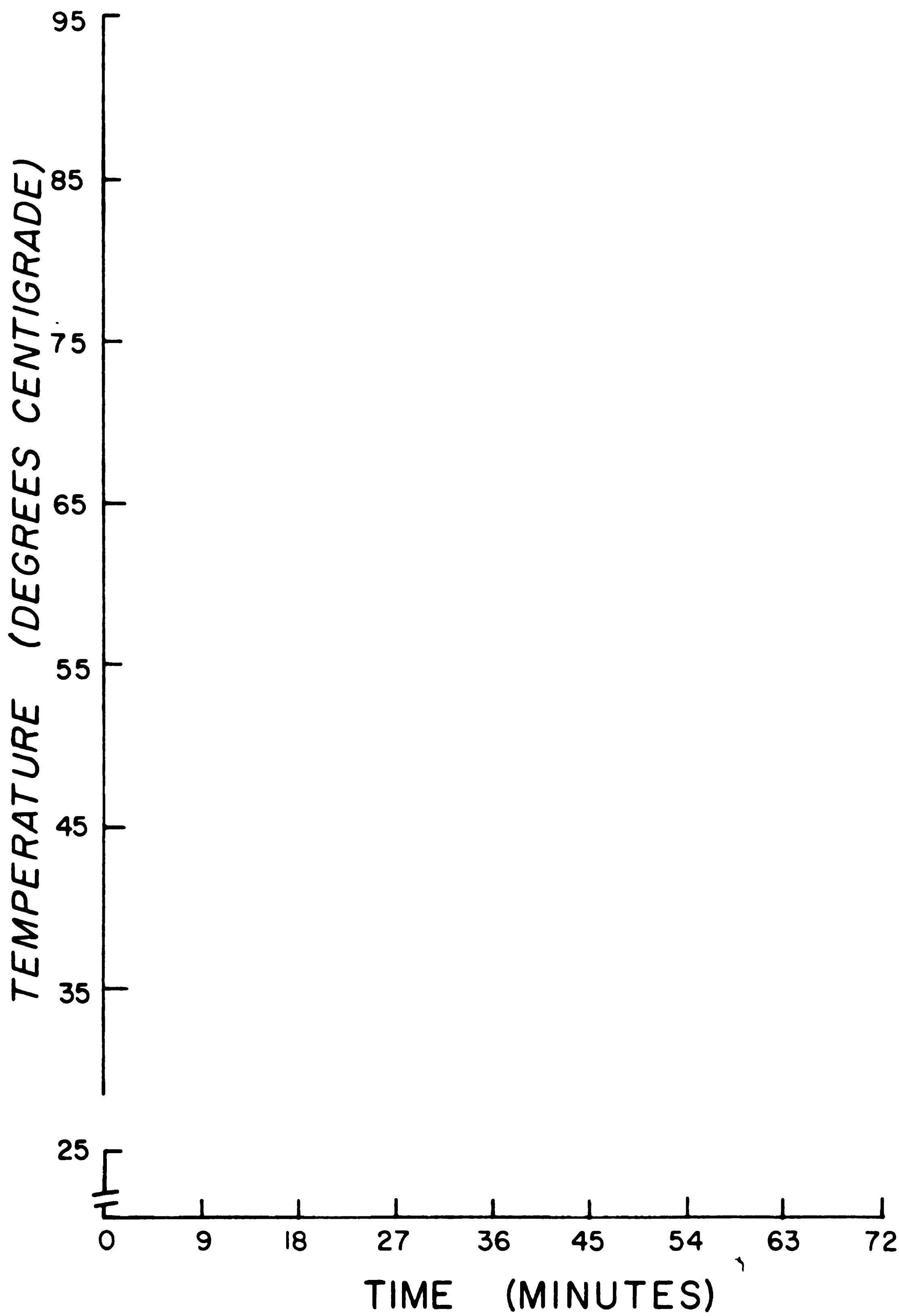


Figure 2. Mean time temperature relationships during baking of slurries (sugar omitted) prepared with four types of processed eggs.

Table 7. Analyses of variance for determining the effect of egg process and end temperature range on baking time of custards used for objective evaluation.

Source of Variance	Degrees of Freedom	Mean Squares for Custard Used for: Gel strength Tests	Color Tests	Percentage Drainage Tests
Total	47			
Replication	5	27.67	49.76	63.33**
Egg Process	3	52.02	20.69	12.45
End Temperature	1	1507.52***	1419.19***	1338.80***
EP X ET	3	18.08	41.24	30.24
Error	35	21.57	13.86	14.36

**Significant at the 1 per cent level of probability.
***Significant at the 0.1 per cent level of probability.

Table 8. Analyses of variance for determining the effect of sugar on the baking time of gels.

Source of Variance	Degrees of Freedom	Mean Squares for Gels Baked in: Pans	Cups
Total	47		
Replication	5	33.97*	10.55
Egg Process	3	14.19	35.17
Sugar	1	221.02***	75.00
EP X Sugar	3	21.18	33.17
Error	35	11.28	18.75

*Significant at the 5 per cent level of probability.
***Significant at the 0.1 per cent level of probability.

In the second series of gels studied, the end-point temperature range of 85-87^{o}C was selected and the percentage of egg was held constant. The four types of processed egg gels were prepared without sugar to determine the effect of sugar on the resulting gels. Sugar was found to increase the baking times of the gels prepared with all types of processed eggs. The mean increase in baking time was 3 and 4 minutes for the cups and pans respectively. The analyses of variance (Table 8) showed that sugar was responsible for a significant increase in the baking time of the pans only. The lengthened baking time resulting with the addition of sugar was in agreement with Solsberg et al. (1948), Lowe (1955), and Seideman et al. (1963). Since there was no significant difference in baking times for custards contained in cups, this study did not dispute the work of Longree et al. (1961) who reported that sugar had no significant effect on the baking time of gels baked in custard cups. This study indicated that a significant increase in baking time was dependent not only on the presence of sugar, but type of container and/or amount of mix in the container.

End-point Temperature

The analysis of variance for the end temperatures of the baked custards are included in Table 9. There were no significant differences attributed to egg process. However, all gels did not reach the same range simultaneously. The custards

Table 9. Analyses of variance for determining differences among end-point temperatures of custards used for objective evaluation.

Source of Variance	Degrees of Freedom	Mean Squares for Gels Used for Gel Strength Tests	Color Tests	Percentage Drainage Tests
Total	47			
Replications	5	0.51	0.85	0.93
Egg Process	3	0.07	0.23	0.14
End Temperature	1	227.51***	240.76***	194.01***
EP X ET	3	0.38	0.10	0.34
Error	35	0.27	0.53	0.45

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

were therefore removed from the oven when the majority of the gels fell within the designated range. Difficulty in achieving the desired range may have been the result of variation in oven cycling and/or oven drafts caused by the large number of thermocouple leads which were extended from the oven.

pH of Gels Before and After Baking

The pH values for the custards baked to both end-point temperature ranges and the slurries (sugar omitted) appear in the Appendix. Analyses of variance showed no significant differences among the pH of the gels which could be attributed to egg process. The results indicated that the pH of the mix ranged from 6.7-7.1 regardless of type of egg, end temperature, or sugar. The pH of the mix did not always increase during baking. This finding is in agreement with Longree *et al*. (1961) but differs from those findings reported by Lowe (1955), Miller *et al*. (1959a) and Endres (1965).

Subjective Evaluation of Baked Custards

The crust tenderness, inside color, gel strength, syneresis, smoothness, and flavor of baked custards were evaluated by an eight membered taste panel using a 7-point rating scale. Data were analyzed for variance, significant differences were determined, and simple correlation coefficients were derived.

Analysis of custard attributes

Replicate averages for egg processes, egg process means for a particular end-point temperature range, egg process conglomerate averages, as well as standard deviations for the subjective evaluation of custard attributes are included in the Appendix. The mean scores were subjected to a three-way analysis of variance. Significant data were persued further using the Studentized Multiple Range Test (Duncan, 1957) to determine significant differences which could be attributed to egg process or a combination of egg process and end temperature.

Crust tenderness. Analysis of variance for the sensory evaluation of crust tenderness (Table 10) indicated a highly significant difference among custards prepared with frozen, freeze-, spray-, and foam-spray-dried eggs. Comparisons of

Table 10. Analysis of variance for determining the effect of egg process and end-point temperature range on the subjective evaluation of custard attributes.

Source of Variance	Degrees of Freedom	Mean Squares					
		Crust	Color	Firmness	Syneresis	Smoothness	Flavor
Total	47						
Replication	5	0.50	0.14	1.20	0.19**	0.20	0.08
Egg Process	3	2.93***	0.56**	1.08	0.16*	2.06***	0.37
End Temperature	1	0.40	0.00	115.01***	0.46***	0.24	1.58*
EP X ET	3	0.13	0.02	0.31	0.01	0.35	0.29
Error	35	0.38	0.11	0.89	0.05	0.19	0.29

*Significant at the 5 per cent level of probability.
**Significant at the 1 per cent level of probability.
***Significant at the 0.1 per cent level of probability.

the egg processes (Table 11) revealed that at the 0.1 per cent level of probability the crusts of custards prepared with foam-spray-dried eggs were preferred over the crusts of custards prepared with freeze-dried eggs. At the 1 per cent level of probability the foam-spray-dried, spray-dried, and frozen egg custard crusts were not significantly different, however, they were all considered more tender than the crusts of the custards prepared with freeze-dried eggs. When egg processes and end temperature were considered independently (Table 12), the crusts of the foam-spray-dried egg custards baked to the low temperature range were more tender (at the 5 per cent level of probability) than gels prepared with freeze-dried eggs baked to the low temperature range. The crusts of the custards prepared with foam-spray-dried, frozen, and spray-dried eggs baked to the high temperature range were more tender than gels prepared with freeze-dried eggs baked to the same temperature range (0.1 per cent level of probability). Additional differences among the crusts of the custards at the lower levels of probability are illustrated in Table 12. End point temperature did not have a significant effect on any of the values.

<u>Inside color</u>. Analysis of color data (Table 10) showed highly significant differences which could be attributed directly to the type of egg used. Analysis of the conglomerate egg processes and end temperature means (Table 11), indicated that the color of frozen egg custards was preferred over the color

Table 11. Significant differences for factors relating to sensory evaluation of custard attributes for conglomerate averages of egg process and temperature range.

Subjective Evaluation of Custards for:	Source of Variance	Significant Difference[a] 0.1% level	1% level	5% level
Crust Tenderness	Egg Process	FSD[b] SD Froz FD	FSD SD Froz FD	FSD SD Froz FD
	Temperature	None	None	None
Inside Color	Egg Process	Froz SD FD FSD	Froz SD FD FSD	Froz SD FD FSD
	Temperature	None	None	None
Gel Strength	Egg Process	None	None	None
	Temperature	85-87°C>81-83°C	85-87°C>81-83°C	85-87°C>81-83°C
Syneresis	Egg Process	None	None	FD FR SD FSD
	Temperature	85-87°C>81-83°C	85-87°C>81-83°C	85-87°C>81-83°C
Smoothness	Egg Process	Froz FD SD FSD	Froz FD SD FSD	Froz FD SD FSD
	Temperature	None	None	None
Flavor	Egg Process	None	None	None
	Temperature	None	None	85-87°C>81-83°C

[a]Significantly greater than those that follow. Underlining denotes no significant difference (Duncan, 1957).

[b]Froz denotes frozen egg custards.
FD denotes freeze-dried egg custards.
SD denotes spray-dried egg custards.
FSD denotes foam-spray-dried egg custards.

Table 12. Treatment means and significant differences for factors relating to sensory evaluations of custard attributes for combinations of process versus end temperature.

Factor	End Temp. (°C)	Treatment means				Significant differences[a]		
		Froz[b]	FD	FSD	SD	At 0.1% level	Additional at 1% level	Additional at 5% level
Crust Tenderness	81-83	4.8	4.2	5.0	4.7	None	None	FSD Froz SD FD
	85-87	4.6	3.8	5.0	5.0	FSD SD Froz FD	None	SD>Froz
Inside Color	81-83	6.5	6.4	6.4	6.3	None	None	None
	85-87	6.8	6.3	6.3	6.4	None	None	Froz>SD FD FSD
Smoothness	81-83	5.8	4.6	5.3	5.0	Froz FSD SD FD	Froz>SD	SD>FD
	85-87	5.7	5.7	5.1	5.0	None	None	Froz FD FSD SD

[a]Significantly greater than those that follow. Processes joined by one line did not differ significantly (Duncan, 1957).

[b]Froz denotes frozen egg custards.
FD denotes freeze-dried egg custards.
FSD denotes foam-spray-dried egg custards.
SD denotes spray-dried egg custards.

of custards prepared with spray-dried, freeze-dried, and foam-spray-dried eggs (0.1 per cent level of probability). There were no significant differences among the color of custards prepared with dehydrated eggs. Analysis of the color of the gels prepared with the processed eggs baked to the two temperature ranges (Table 12) indicated that the only significant difference detected by the panel members was between the frozen and dehydrated egg custards baked to the high temperature range (5 per cent level of probability). This finding seems to be in agreement with Kline et al. (1959) who reported that the color of spray-dried eggs was altered because of glucose-protein interactions and oxidative destruction of the carotenoid pigment. The results of the sensory evaluations for inside color of the custards is also in agreement with Miller et al. (1959a) who reported that spray-dried egg custards were significantly different from frozen egg custards: however, the color of the spray-dried egg custards used in this investigation were not objectionable as were those reported by Miller et al. (1959a). All custards received mean color scores of 6.3 or over. The findings are also in disagreement with Mastic (1959) who reported no significant difference between the color of spray-dried and frozen egg custards.

Gel strength. Analysis of variance for gel strength (Table 10) revealed a significant difference in gel strength which could be attributed to end-point temperature range. Gels baked to the internal temperature of 85-87°C were significantly firmer (at the 0.1 per cent level of probability) than custards baked to the temperature of 81-83°C. Egg process was not found to produce a significant difference in the gel strength of the custards. This finding is in agreement with Ary and Jordan (1945), Dawson et al. (1945), and Schlosser et al. (1961). It is in disagreement with the work of Miller et al. (1959a) who found that spray-dried egg custards baked to 86-88°C were objectionably softer than those custards prepared with frozen eggs.

Syneresis. Analysis of variance for syneresis (Table 10) indicated that there were significant differences which could be attributed to replications, egg processes, and end temperature ranges (1, 5, and 0.1 per cent level of probability respectively). When conglomerate averages for egg process and end temperature were considered (Table 11), foam-spray-dried eggs produced a less stable gel structure (5 per cent level of probability) than gels prepared with the other types of processed eggs. There were no significant differences among egg processes when the custards were examined at each temperature range. Gels baked to the end temperature range of 81-83°C produced significantly greater amounts of syneresis than gels baked to the temperature range of 85-87°C. This finding is contrary to the accepted phenomenon regarding the effect of end temperature on syneresis. It was evident from the evaluations that some judges were referring to syneresis when there was in fact only a partial gel formed.

Smoothness. Analysis of variance for smoothness (Table 10) of custards indicated that egg process was responsible for a highly significant difference. The analysis of conglomerate averages for egg process and end temperature (Table 11) revealed that frozen and freeze-dried egg custards were considered smoother than spray-dried egg custards (0.1 and 5 per cent level of probability respectively). When smoothness of custards was considered for combinations of the egg processes at the low temperature range (Table 12), the consistency of frozen egg custards was preferred over the consistency of freeze- and spray-dried egg custards (0.1 per cent level of probability). Frozen egg custards were smoother than spray-dried egg custards and spray-dried egg custards were smoother than freeze-dried egg custards (1 and 5 per cent level of probability respectively). At the high temperature range frozen and freeze-dried egg custards were not considered significantly different in smoothness (Table 12), however, they were considered smoother than custards prepared with foam-spray- and spray-dried eggs (5 per cent level of probability).

Flavor. No significant difference in flavor was attributed to egg process (Table 10). However, at the 5 per cent level of probability, custards baked to the high temperature range were judged superior to the flavor of those custards baked to the low range. Custards baked to the low temperature range were often reported as being sweeter than those custards baked to the high temperature range. Carr and Trout (1942) reported similar comments and postulated that the custards tasted sweeter because the sugar was concentrated in the liquid phase. Custards were often described as having a foreign unpleasant flavor which left somewhat of an aftertaste in the mouth. Increased flavor scores with increased internal temperature would indicate that a browning reaction was not responsible for this flavor. All eggs contained added dextrins in the form of corn sirup solids and it may have been this substance that was responsible for the objectionable flavor. Flavorings were omitted in the formula and may have been in part responsible for the objectionable flavor. The equality among the flavors of spray-dried and frozen egg custards is in agreement with Jordan and Sisson (1943) and Dawson _et al_. (1945). The flavor scores are in disagreement with Bennion _et al_. (1942) and Miller _et al_. (1959a) who reported the flavor of spray-dried egg custards to be more objectionable than the flavor of frozen egg custards; and Kelly _et al_. (1962) who found that the flavor of spray-dried egg custards was superior to the flavor of frozen egg custards.

Correlations between custard attributes

Significant correlation coefficients between custard attributes are included in Table 13. A highly significant positive correlation existed between syneresis and gel strength evaluations (1 per cent level of probability). This indicated that syneresis scores increased as the sensory evaluation of

Table 13. Significant correlation coefficients for custard attributes evaluated by subjective evaluation.

Custard Attributes	Crust Tenderness	Inside Color	Gel Strength	Syneresis	Smoothness	Flavor
Crust Tenderness				-0.29*	-0.36**	
Inside Color					0.36**	
Gel Strength				0.37**		0.54***
Syneresis	-0.29*		0.37**			
Smoothness	-0.36**	0.36**				
Flavor			0.54***			

*Significant at the 5 per cent level of probability.

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

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

gel strength increased. Although this is contrary to literature, it seems to substantiate the fact that the judges were not all defining syneresis correctly. A positive correlation existed between gel strength and flavor and between color and smoothness, whereas a negative correlation existed between crust tenderness and smoothness (0.1, 1, and 1 per cent level of probability respectively). Flavor scores increased as gel strength values increased. Similarly color scores increased as smoothness scores increased. It is hard to determine whether these correlations resulted because of actual differences or whether they more accurately illustrate a "halo effect." The correlation between crust tenderness and smoothness is logical since smoothness scores increased with increased temperatures whereas the crust tenderness would very likely become tougher with increased baking time.

Analysis of taste panel member data

To determine variations among the scoring of judges, sensory data for custard attributes were subjected to four-way analyses of variance (Table 14). These analyses indicated highly significant differences which could be attributed to egg process, temperature, and judges, as well as an interaction between these factors. The same general trends held true for egg process and end temperature as those described for the three-way analyses of variance. The conglomerate averages for the custard attributes as evaluated by the

Table 14. Analyses of variance for determining significant differences among judges.

Source of Variance	Degrees of Freedom	Mean Squares					
		Crust	Color	Firmness	Syneresis	Smoothness	Flavor
Total	383						
Replication	5	4.11	1.12	4.54*	2.75*	0.95	2.07
Egg Process	3	23.05***	4.09**	18.68***	58.13***	15.22***	2.97
End Temperature	1	3.57	0.02	658.88***	92.04***	12.04**	6.00
EP X ET	1	1.25	0.18	19.95***	57.10	6.30	4.56
Judge	7	3.99*	11.23***	8.75	7.55***	18.07***	47.50***
EP X Judge	21	1.64	0.92	2.20	1.15	0.90	4.40
ET X Judge	7	3.20	1.14	10.11**	3.51	4.58	5.29
EP X ET X Judge	21	0.76	0.55	1.50	0.81	1.54	2.50
Error	315	1.99	0.52	1.62	0.82	1.09	1.20

*Significant at the 5 per cent level of probability.

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

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

various judges are included in Table 15. The results of this table indicated that there was not any one judge evaluating at the extreme ranges for all characteristics, however, variations among judges existed for all factors. A significant interaction between judges and end temperature as well as a significant difference among replications seemed to indicate that some judges preferred firmer gel structures than others, however, not consistently. These results would invalidate the significant differences among the gel strengths of the custards which were attributed to egg process in the four-way analysis of variance. Significant differences among replications as well as for judges in the four-way analysis of variance seemed to further substantiate that the syneresis scores were unreliable. The lack of significant differences among replications and interactions for crust tenderness, inside color, smoothness, and flavor attributes seemed to justify the results of the three-way analyses of variance for these factors. Even though a judge might lower a mean score, for example, taste panel member 1 who rated the flavor of the custards significantly more objectionable than all other members (0.1 per cent level of probability), significant differences among processes would not be affected. The analyses of variance incorporating replicate averages for each taste panel member has not been reported in literature, however, it seems to have potential for giving insight into the reliability of the judges, and thus the validity of the sensory data obtained.

Table 15. Conglomerate means and significant differences[a] among judges evaluating custard attributes.

Subjective evaluation of crust tenderness at the 5 per cent level of probability.

Judge Identity[b]	F	G	B	H	C	E	D	A
Mean[c]	5.0	4.9	4.8	4.7	4.6	4.5	4.4	4.1

Subjective evaluation of color at the 0.1 per cent level of probability.

Judge Identity	D	E	A	G	C	B	F	H
Mean	7.0	7.0	6.8	6.5	6.3	6.2	5.8	5.8

Subjective evaluation of gel strength at the 1 per cent level of probability.

Judge Identity	F	E	C	H	B	A	G	D
Mean	5.4	5.4	5.1	4.8	4.7	4.5	4.5	4.3

Subjective evaluation of syneresis at the 0.1 per cent level of probability.

Judge Identity	B	E	F	C	D	A	G	H
Mean	6.3	6.3	5.8	5.7	5.6	5.5	5.3	5.3

Subjective evaluation of smoothness at the 0.1 per cent level of probability.

Judge Identity	E	B	A	F	C	G	H	D
Mean	6.5	6.3	5.5	5.4	5.2	5.1	4.9	4.8

Subjective evaluation of flavor at the 0.1 per cent level of probability.

Judge Identity	E	B	C	G	F	H	D	A
Mean	5.8	5.4	5.1	5.1	5.0	4.9	4.3	2.5

[a] Significantly greater than those that follow. Means joined by one line did not differ significantly (Duncan, 1957).
[b] Judges are identified by letters, a particular letter always referring to the same judge.
[c] Conglomerate means for the four types of processed egg custards baked to the two end-point temperature ranges.

Objective Evaluation of Gel Strength

Objective evaluation of the gel strength of custards was determined by the Allo-Kramer shear press and by computing the percentage drainage. The gel strength of baked slurries (sugar omitted) was ascertained solely by the shear press. Data were analyzed for variance, significant differences were derived, and correlation coefficients were calculated.

Objective evaluation of gel strength for baked custards

Replicate averages for egg processes, egg process means for a particular end-point temperature range, egg process conglomerate averages, as well as standard deviations for the objective evaluation of gel strength are included in the Appendix. The mean scores were subjected to a three-way analysis of variance and significant differences which could be attributed to egg process were determined by the Studentized Multiple Range Test (Duncan, 1957).

<u>Shear press measurements of gel strength for baked custards</u>. The shear press was used to determine both the number of pounds required to shear through the gel and area-under-the-curve (cm^2). A typical shear press graph illustrated in Figure 3 depicts the three defined peaks which are referred to as Peak I, II, and III respectively. Endres (1965) postulated that peak I was the force needed to shear through the crust; peak II represented the force required to shear through

the gel structure; peak III represented the force created by the increase in surface area exposed as the fixed blades penetrated the gel; whereas area-under-the-curve was a composite representation of gel strength.

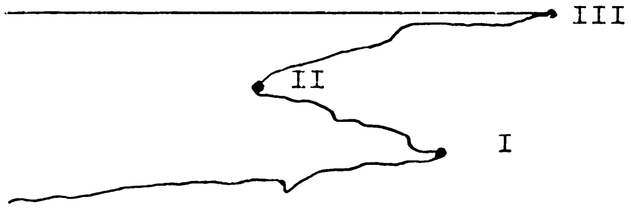


Figure 3. Typical shear press graph illustrating the three defined peaks.

Analyses of variance for gel strength measured by maximum force (peak I, II, III) and area-under-the-curve are included in Table 16. Highly significant differences were determined for both egg process and end-point temperature range. Comparison of the egg process means for gel strength (Table 17) revealed complete agreement among all measurements. Freeze-dried egg gels were significantly firmer than frozen egg gels (0.1 per cent level of probability) which in turn were firmer than foam-spray-dried egg gels (1 per cent level of probability). Foam-spray- and spray-dried egg custards were not significantly different in gel strength. In addition significantly firmer gels were produced at the high temperature range over those formed at the low temperature range. The gels prepared with the four types of processed eggs were

Table 16. Analyses of variance for determining the effect of egg process and end-point temperature range on the shear press evaluation of gel strength.

Source of Variance	Degrees of Freedom	Mean Squares			
		Peak I	Peak II	Peak III	Area
Total	47				
Replication	5	0.18	0.05	0.28	1.24
Egg Process	3	3.92***	1.29***	5.79***	22.87***
Temperature	1	21.61***	7.18***	25.38***	115.65***
EP X ET	3	0.13	0.05	0.46	0.56
Error	35	0.11	0.04	0.31	0.80

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

divided into the independent end-point temperature ranges and were again analyzed for significant differences (Table 18). Endres (1965) postulated that it was the peak II value that was the measure of gel strength per se and area-under-the-curve which was a composite representation of gel strength. Therefore, further discussion of gel strength will be limited to these two factors, although differences in the Peak I and Peak III values may be obtained from Table 18.

The shear press peak II values indicated the following significant differences among custards prepared with the four types of processed eggs baked to the two end-point temperature ranges of 81-83°C and 85-87°C. Freeze-dried egg custards baked to the high temperature range were significantly

Table 17. Significant differences for factors relating to the shear press evaluation of gel strength for conglomerate averages of egg process and temperature range for baked custards.

Objective Measurement	Source of Variance	Significant Difference[a] 0.1 per cent level	1 per cent level	5 per cent level
Shear Press	Egg Process	FD[b]>Froz=FSD=SD	FD>Froz>FSD=SD	FD>Froz>FSD=SD
Peak I Force	Temperature	85-87>81-83	85-87>81-83	85-87>81-83
Shear Press	Egg Process	FD>Froz=FSD=SD	FD>Froz>FSD=SD	FD>Froz>FSD=SD
Peak II Force	Temperature	85-87>81-83	85-87>81-83	85-87>81-83
Shear Press	Egg Process	FD>Froz=FSD=SD	FD>Froz>FSD=SD	FD>Froz>FSD=SD
Peak III Force	Temperature	85-87>81-83	85-87>81-83	85-87>81-83
Shear Press	Egg Process	FD>Froz>FSD=SD	FD>Froz>FSD=SD	FD>Froz>FSD=SD
Area-under-the-curve	Temperature	85-87>81-83	85-87>81-83	85-87>81-83

[a]Significantly greater than those that follow (Duncan, 1957).

[b]FD denotes freeze-dried egg custards.
Froz denotes frozen egg custards.
FSD denotes foam-spray-dried egg custards.
SD denotes spray-dried egg custards.

Table 18. Treatment means and significant differences[a] for factors relating to shear press measurements of gel strength which could be attributed to egg process and end temperature.

85-87°C				81-83°C			
FD[b]	Froz	FSD	SD	FD	Froz	FSD	SD
Shear Press Peak I evaluation of gel strength at the 0.1 per cent level of probability.							
3.9	3.2	2.6	2.5	2.3	1.8	1.4	1.2
Shear Press Peak I evaluation of gel strength at the 1 per cent level of probability.							
3.9	3.2	2.6	2.5	2.3	1.8	1.4	1.2
Shear Press Peak I evaluation of gel strength at the 5 per cent level of probability.							
3.9	3.2	2.6	2.5	2.3	1.8	1.4	1.2
Shear Press Peak II evaluation of gel strength at the 0.1 per cent level of probability.							
2.7	2.3	2.2	2.0	2.0	1.8	1.3	1.2
Shear Press Peak II evaluation of gel strength at the 1 per cent level of probability.							
2.7	2.3	2.2	2.0	2.0	1.8	1.3	1.2
Shear Press Peak II evaluation of gel strength at the 5 per cent level of probability.							
2.7	2.3	2.2	2.0	2.0	1.8	1.3	1.2

Shear Press Peak III evaluation of gel strength at the 0.1 per cent level of probability.

5.1	4.2	3.4	3.2	3.2	2.7	2.2	2.0

Shear Press Peak III evaluation of gel strength at the 1 per cent level of probability.

5.1	4.2	3.4	3.2	3.2	2.7	2.2	2.0

Shear Press Peak III evaluation of gel strength at the 5 per cent level of probability.

5.1	4.2	3.4	3.2	3.2	2.7	2.2	2.0

Shear Press Area-under-the-curve measurement of gel strength at the 0.1 per cent level of probability.

10.4	8.8	7.2	7.0	6.7	5.7	4.5	4.0

Shear Press Area-under-the curve measurement of gel strength at the 1 per cent level of probability.

10.4	8.8	7.2	7.0	6.7	5.7	4.5	4.0

Shear Press Area-under-the-curve measurement of gel strength at the 5 per cent level of probability.

10.4	8.8	7.2	7.0	6.7	5.7	4.5	4.0

[a]Means underscored by the same line are not significantly different (Duncan, 1957).

[b]FD denoted freeze-dried egg custards.
Froz denotes frozen egg custards.
FSD denotes foam-spray dried egg custards.
SD denotes spray-dried egg custards.

firmer than all other custards (1 per cent level of probability). Frozen, foam-spray-dried, and spray-dried egg custards baked to the high temperature range were considered equal in firmness, whereas spray-dried egg custards baked to the high temperature range and freeze-dried and frozen egg custards baked to the low temperature range were significantly firmer than foam-spray- and spray-dried egg custards baked to the low temperature range (0.1 per cent level of probability).

Significant differences determined by the area-under-the-curve were similar to those found by the force required to shear through the gel. Freeze-dried egg custards baked to the high temperature range were significantly firmer than frozen egg custards baked to the same temperature range (1 per cent level of probability). Freeze-dried egg custards at the high temperature range and frozen egg custards at the same range were significantly firmer than all other custards (0.1 and 1 per cent level of probability respectively). Foam-spray- and spray-dried egg custards baked to the high temperature range were considered equal in firmness to freeze-dried and frozen egg custards baked to the low temperature range. Freeze-dried and frozen egg custards at the low temperature range were not significantly different, however, they were significantly firmer than custards prepared with foam-spray- and spray-dried eggs (0.1 and 5 per cent level of probability respectively).

The weaker gel structures produced by spray-dried eggs as well as the equality in gel structures between spray-dried egg custards baked to the high temperature range and frozen egg custards, baked to the low temperature range substantiates the work of Miller *et al*. (1959a). However, the results are in sharp disagreement with the work of Ary and Jordan (1945), Dawson *et al*. (1945), and Schlossler *et al*. (1961). Zabik and Figa (1967) found that frozen egg slurries (sugar omitted) were firmest with the rest of the processes in decreasing order as follows: freeze-dried, spray-dried, and foam-spray-dried. Therefore, to determine the effect of sugar on the coagulating properties of the processed eggs, six replications of a custard formula was prepared omitting sugar.

Percentage drainage of baked custards. Analysis of variance for percentage drainage (Table 19) revealed a highly significant difference (0.1 per cent level of probability) which could be attributed to end-point temperature range. Custards baked to 81-83°C had a higher percentage drainage than custards baked to 85-87°C. The reason for this finding which is contradictory to that reported in the literature is that when no gel or only a partial gel was formed, the liquid passed through the wire screen. Thus at the low temperature range syneresis determination was actually a measure of gel formation rather than the separation of the two phases of a previously formed gel. Miller *et al*. (1959a), Garlick (1964),

Table 19. Analysis of variance for determining the effect of egg process and end temperature on percentage drainage.

Source of Variance	Degrees of Freedom	Mean Squares
Total	47	
Replication	5	276.51
Egg Process	3	123.48
End Temperature	1	4687.07***
EP X ET	3	80.03
Error	35	237.86

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

and Endres (1965) experienced similar difficulties with this method, thus concluding that it was not a true measure of syneresis.

<u>Correlations between objective and subjective evaluations for gel strength of baked custards</u>

Significant correlation coefficients among the shear press values and sensory evaluation of gel strength are included in Table 20. Highly significant positive correlations existed among all shear press measurements as well as with the sensory evaluation of gel strength (0.1 per cent level of probability). These results indicate that all shear press values are excellent determinants of the gel strength of baked custards. Endres (1965) reported similarly high correlations

Table 20. Significant correlation coefficients among shear press measurements and sensory evaluations of gel strength.

Measurements	Shear Press Peak I	Shear Press Peak II	Shear Press Peak III	Shear Press Area	Sensory Test-crust	Sensory Test-firmness	Sensory Test syneresis
Shear Press Peak I		.958***	.925***	.987***	-.441***	.711***	-.379***
Shear Press Peak II	.958***		.889***	.956***	-.374***	.692***	-.364**
Shear Press Peak III	.925***	.889***		.940***	-.453***	.636***	-.332*
Shear Press Area	.987***	.956***	.940***		-.457***	.685***	-.348**
Sensory test-crust	-.441***	-.374***	-.453***	-.457***			.290*
Sensory test-firmness	.711***	.692***	.636***	.685***			-.370**
Sensory test-syneresis	-.379***	-.364**	-.332*	-.348**	-.290*	-.370**	

*Significant at the 5 per cent level of probability.
**Significant at the 1 per cent level of probability.
***Significant at the 0.1 per cent level of probability.

among all shear press measurements for the evaluation of egg-milk slurries. The negative correlations among the shear press values and the sensory evaluation of syneresis further substantiates the fact that the judges were not defining syneresis correctly. There were high negative correlations (0.1 per cent level of probability) among all shear press values and crust tenderness. This indicated that crust tenderness scores decreased as the shear press values increased. Endres (1965) postulated that Peak I was the force required to shear the crust. This investigation revealed that the character of the crust also affected the peak III values. The increased force required to penetrate through the tougher crusts seemed to push the gel out of the pan with very little of the gel going between the blades, whereas with the more tender crusts the blades more easily penetrated the crust and the blades penetrated the gel.

Shear press evaluation of gels containing and omitting sugar

Replicate averages for egg processes, egg process means for gels baked to 85-87°C containing and omitting sugar, egg process conglomerate averages, as well as standard deviations for the objective evaluation of gel strength are included in the Appendix. The mean scores were subjected to three-way analyses of variance and significant differences which could be attributed to egg process or an interaction between egg process and sugar were determined by the Studentized Multiple Range Test (Duncan, 1957).

Analyses of variance for gel strength measured by maximum force (peak I, II, III) and area-under-the-curve are included in Table 21. All measurements revealed highly significant differences among egg processes as well as an interaction between egg processes and sugar. Sugar was found to have a significant (0.1 per cent level of probability) effect on peak II and peak III values only. The gels prepared with the four types of processed eggs were analyzed for significant differences for conglomerate averages of egg processes with and without sugar (Table 22).

Table 21. Analysis of variance to determine the effect of sugar on the shear press evaluation of gel strength.

Source of Variance	Degrees of Freedom	Mean Squares			
		Peak I	Peak II	Peak III	Area
Total	47				
Replications	5	0.12	0.02	0.26	1.03
Egg Process	3	3.44***	0.74***	4.24***	16.68***
Sugar	1	0.13	0.24***	3.64***	0.12
EP X Sugar	3	0.35**	0.13***	1.11**	2.37**
Error	35	0.08	0.02	0.23	0.43

**Significant at the 1 per cent level of probability.
***Significant at the 0.1 per cent level of probability.

The shear press peak II values for the processed egg gels containing and omitting sugar are included in Table 23.

Table 22. Significant differences for factors relating to the shear press evaluation of gel strength for conglomerate averages of egg process with and without sugar.

Objective Measurement	Source of Variance	Significant Difference[a] 0.1 per cent level	1 per cent level	5 per cent level
Shear Press	Egg Process	FD[b]=Froz>FSD=SD	FD=Froz>FSD=SD	FD=Froz>FSD=SD
Peak I Force	Sugar	None	None	None
Shear Press	Egg Process	FD=Froz>FSD=SD	FD=Froz>FSD=SD	FD>Froz>FSD>SD
Peak II Force	Sugar	Sugar>No Sugar	Sugar>No Sugar	Sugar>No Sugar
Shear Press	Egg Process	FD Froz FSD SD	FD Froz FSD SD	FD Froz FSD SD
Peak III Force	Sugar	Sugar>No Sugar	Sugar>No Sugar	Sugar>No Sugar
Shear Press	Egg Process	FD>Froz>FSD=SD	FD>Froz>FSD=SD	FD>Froz>FSD>SD
Area-under-the-curve	Sugar	None	None	None

[a]Significantly greater than those that follow. Underlining denotes no significant difference (Duncan, 1957).

[b]FD denotes freeze-dried egg custards.
Froz denotes frozen egg custards.
FSD denotes foam-spray dried egg custards.
SD denotes spray-dried egg custards.

Table 23. Treatment means and significant differences[a] for shear press peak II measurement of gel strength which could be attributed to egg process or sugar.

FD[b] Sugar	Froz No Sugar	FD No Sugar	Froz Sugar	FSD Sugar	FSD No Sugar	SD Sugar	SD No Sugar
Shear press peak II evaluation of gel strength at the 0.1 per cent level of probability.							
2.7	2.4	2.3	2.3	2.2	2.1	2.1	1.9
Shear press peak II evaluation of gel strength at the 1 per cent level of probability.							
2.7	2.4	2.3	2.3	2.2	2.1	2.1	1.9
Shear press peak II evaluation of gel strength at the 5 per cent level of probability.							
2.7	2.4	2.3	2.3	2.2	2.1	2.1	1.9

[a]Means underscored by the same line are not significantly different (Duncan, 1957).

[b]FD denotes freeze-dried egg custards.
Froz denotes frozen egg custards.
FSD denotes foam-spray dried egg custards.
SD denotes spray-dried egg custards.

Freeze-dried egg custards containing sugar were found to be significantly firmer than those slurries omitting sugar (5 per cent level of probability). The gels prepared with all other types of processed eggs were not significantly affected by the percentage of sugar used in this formula. This finding is in extreme opposition with the reports that sugar decreases the gel strength of custards (Meyer, 1937, Lowe, 1955, and Griswold, 1962). Meyer (1937) was the first investigator reporting the objective evaluation of the gel strength of egg-milk systems. Meyer (1937) found that when 10 per cent sugar was added to a custard formula (2 table-spoon per cup of milk and 1 egg) the gel strength was reduced by half. Lowe (1955) demonstrated similar findings by holding the egg and milk constant and varying the proportion of sugar. It is conceivable from these investigations that the reduced gel structure could have existed from a protein dilution effect. Perhaps sugar acts as a dehydrating agent in egg gels in a manner similar to the way it behaves in starch pastes. Further work in this area is definitely needed to substantiate or disprove the current concepts on the effect of sugar on egg-milk gels.

Objective Evaluation of Color

Differences in the color of all custards prepared with and without sugar were determined through the use of the Hunter color difference meter. L (lightness), a_L (greenness), and b_L (yellowness) values were determined and analyzed for variance among processes and end temperature as well as among the egg processes containing and omitting sugar. Replicate averages for egg processes, egg process means for a particular end-point temperature range, egg process conglomerate averages, as well as standard deviations for all objective evaluation of inside color are included in the Appendix.

Color differences among baked custards

Analyses of variance for inside color differences measured by the L, a_L, and b_L values (Table 24) revealed highly significant differences which could be attributed to the processing of eggs as well as to the end temperature.

Table 24. Analyses of variance for determining the effect of egg process and end-temperature on the Hunter color difference meter measurements of baked custards.

Source of Variance	Degrees of Freedom	Mean Squares		
		L Values	a_L Values	b_L Values
Total	47			
Replication	5	0.10	0.09	0.13
Egg process	3	5.18***	0.92***	4.69***
End temperature	1	2.09***	0.16	1.01**
EP X ET	3	0.36	0.22	0.90
Error	35	0.14	0.10	0.15

**Significant at the 1 per cent level of probability.
***Significant at the 0.1 per cent level of probability.

Comparison of the conglomerate egg process means (Table 25) indicated that frozen egg custards were lighter than foam-spray- and spray-dried egg custards, which in turn were lighter than freeze-dried egg custards (0.1 per cent level of probability). Analysis of the a_L values indicated that custards prepared with freeze-dried eggs were less green than custards prepared with all other types of eggs (0.1 per cent level of probability). Analysis of the b_L values indicated that frozen egg custards were the most yellow with the remainder of the processes in decreasing order as follows: freeze-dried, foam-spray-dried, and spray-dried (0.1, 5, 5, and 5 per cent levels of probability respectively). Custards baked to the high temperature range were lighter than custards baked to the low temperature range, whereas custards baked to the low temperature were more yellow than custards baked to the high temperature range. When the color differences were determined among the egg processes for the particular temperature ranges (Table 26), the L values indicated that frozen egg custards baked to the low temperature range were lighter than custards prepared with all other types of processed eggs and baked to the low temperature range (0.1 per cent level of probability). Custards prepared with foam-spray-dried eggs were lighter than custards prepared with freeze-dried eggs (0.1 per cent level of probability). At the high temperature range freeze-dried egg custards were grayer than custards prepared with all other types of

Table 25. Significant differences for factors relating to Hunter colorimeter measurements of color among conglomerate averages for egg process and end temperature for baked custards.

Objective Measurement	Source of Variance	Significant Difference[a]		
		0.1 per cent level	1 per cent level	5 per cent level
Hunter Colorimeter L Values	Egg Process	Froz[b]>FSD=SD>FD	Froz>FSD=SD>FD	Froz>FSD=SD>FD
	Temperature	85-87>81-83	85-87>81-83	85-87>81-83
Hunter Colorimeter a_L Values	Egg Process	FSD=SD=Froz>FD	FSD=SD=Froz>FD	FSD=SD=Froz>FD
	Temperature	None	None	None
Hunter Colorimeter b_L Values	Egg Process	Froz>FD=FSD=SD	Froz>FD=FSD=SD	Froz>FD>FSD>SD
	Temperature	None	81-83>85-87	81-83>85-87

[a]Significantly greater than those that follow (Duncan, 1957).

[b]Froz denotes frozen egg custards.
FSD denotes foam-spray-dried egg custards.
SD denotes spray-dried egg custards.
FD denotes freeze-dried egg custards.

Table 26. Treatment means and significant differences for factors relating to the Hunter colorimeter measurements of color difference for combinations of process versus end temperature in baked custards.

Factor	End Temperature (°C)	Treatment means				Significant differences[a]		
		Froz[b]	FD	FSD	SD	At 0.1%	Additional At 1%	Additional At 5%
Hunter	81-83	90.3	88.7	89.5	89.1	Froz FSD SD FD	None	None
L values	85-87	90.5	88.9	89.9	90.0	Froz SD FSD>FD	None	None
Hunter	81-83	-3.9	-3.3	-4.2	-4.1	FSD SD Froz FD	Froz>FD	None
a_L values	85-87	-3.9	-3.5	-3.8	-3.8	None	None	None
Hunter	81-83	24.0	23.3	23.0	22.4	Froz FD FSD SD	Froz>FD	FSD>SD
b_L values	85-87	23.7	23.0	22.6	22.5	Froz FD FSD SD	None	Froz>FD

[a]Significantly greater than those that follow. Processes joined by same line are not significantly different (Duncan, 1957).

[b]Froz denotes frozen egg custards.
FD denotes freeze-dried egg custards.
FSD denotes foam-spray dried egg custards.
SD denotes spray-dried egg custards.

processed eggs (0.1 per cent level of probability). At the low temperature range foam-spray-dried, spray-dried, and frozen egg custards were greener than freeze-dried egg custards (0.1, 1, and 1 per cent level of probability respectively). There were no significant differences in the a_L values for the custards baked to the high temperature range. Analysis of the b_L values at the low temperature range indicated that frozen egg custards were more yellow than custards prepared with all other types of eggs (1 per cent level of probability). Freeze-dried and foam-spray-dried egg custards were equally yellow, however, they were more yellow than spray-dried egg custards (0.1 and 5 per cent level of probability respectively). At the high temperature range frozen egg custards were more yellow than freeze-, foam-spray-, and spray-dried egg custards (5, 0.1, and 0.1 per cent level of probability respectively).

Correlations among the objective and subjective measurements of color

Significant correlation coefficients among the Hunter color difference meter and the sensory evaluation of color appear in Table 27. Significant positive correlations existed between the Hunter L values (lightness), a_L values (greenness), and b_L values (yellowness). This suggests that the greenness and yellowness values increase as the lightness values increase. Endres (1965) reported similar correlations among the Gardner L, a_L, and b_L values for egg-milk slurries. The sensory

Table 27. Significant correlation coefficients among Hunter colorimeter measurements of color and sensory evaluation of color.

Measurement	Hunter L values	Hunter a_L values	Hunter b_L values	Sensory test-color
Hunter L values		.290*	.281*	.288*
Hunter a_L values	.290*			
Hunter b_L values	.281*			.503***
Sensory test-color	.288*		.503***	

*Significant at the 5 per cent level of probability.
***Significant at the 0.1 per cent level of probability.

evaluation of color correlated with the Hunter L (lightness) and b_L (yellowness) values (5 and 0.1 per cent level of probability respectively). This implies that differences in the sensory evaluation of color was determined primarily by yellowness with a lesser consideration for lightness. This further supports the possibility that the carotenoid pigment of egg yolk is altered during the drying processes.

Effect of sugar on the color of egg gels

Analyses of variance among the Hunter L (lightness), a_L (greenness), and b_L (yellowness) values (Table 28) revealed highly significant differences which could be attributed to

Table 28. Analyses of variance for determining the effect of sugar on the Hunter colorimeter evaluation of color.

Source of Variance	Degrees of Freedom	Mean Squares L Values	a_L Values	b_L Values
Total	47			
Replication	5	0.06	0.10	0.12
Egg process	3	5.44***	1.01***	4.03***
Sugar	1	53.18***	2.72***	3.53***
EP X ET	3	0.00	0.15	0.22*
Error	35	0.32	0.11	0.07

*Significant at the 5 per cent level of probability.
***Significant at the 0.1 per cent level of probability.

both egg process and sugar for all values. Comparison of the conglomerate averages for egg process means (Table 29) showed highly significant differences among the L and b_L values for the custards. Frozen egg gels were lighter and yellower than gels prepared with all dehydrated eggs (0.1 per cent level of probability). Further differences among the egg processes for the conglomerate averages of the color of the gels at different levels of probability can be derived from Table 28. Gels containing sugar were found to be grayer, greener, and more yellow than gels prepared without sugar. When color differences were determined for the gels prepared with the various types of processed eggs with and without sugar (Table 30), frozen egg custards containing sugar were the most yellow

Table 29. Significant differences for factors relating to Hunter colorimeter measurements of color among conglomerate averages of egg process and sugar for baked coagulums.

Objective Measurement	Source of Variance	Significant Difference[a] 0.1% level	1% level	5% level
Hunter Colorimeter	Egg Process	Froz[b] SD FSD FD	Froz SD FSD FD	Froz SD FSD FD
L Values	Sugar	Sugar<No Sugar	Sugar<No Sugar	Sugar<No Sugar
Hunter Colorimeter	Egg Process	Froz SD FSD FD	Froz SD FSD FD	Froz SD FSD FD
a_L Values	Sugar	Sugar>No Sugar	Sugar>No Sugar	Sugar>No Sugar
Hunter Colorimeter	Egg Process	Froz SD FSD FD	Forz SD FSD FD	Froz SD FSD FD
b_L Values	Sugar	Sugar>No Sugar	Sugar>No Sugar	Sugar>No Sugar

[a]Significantly greater than those that follow (Duncan, 1957).

[b]Froz denotes frozen egg custards.
SD denotes spray-dried egg custards.
FSD denotes foam-spray-dried egg custards.
FD denoted freeze-dried egg custards.

Table 30. Treatment means, and significant differences for factors relating to the Hunter colorimeter measurements of color difference for combinations of process versus the effect of the presence of sugar.

Factor	Sugar	Treatment means				Significant differences[a]		
		Froz[b]	FD	FSD	SD	At 0.1%	Additional at 1%	Additional at 5%
Hunter	Sugar	90.5	88.9	89.9	90.0	Froz>SD>FSD>FD	None	None
L values	No Sugar	92.5	91.0	92.1	92.1	Froz SD FSD>FD	None	None
Hunter	Sugar	-3.9	-3.5	-3.8	-3.8	None	Froz>FD	FSD SD>FD
a_L values	No Sugar	-3.5	-2.7	-3.5	-3.4	Froz FSD SD>FD	None	None
Hunter	Sugar	23.7	23.0	22.6	22.4	Froz>FD FSD SD	None	FD>FSD
b_L values	No Sugar	23.3	22.0	22.2	22.0	Froz>FSD SD FD	None	None

[a]Significantly greater than those that follow. Processes joined by the same line are not significantly different (Duncan, 1957).

[b]Froz denotes frozen egg custards.
FD denotes freeze-dried egg custards.
FSD denotes foam-spray-dried egg custards.
SD denotes spray-dried egg custards.

with the rest of the processes in decreasing order as follows: spray-, foam-spray, and freeze-dried egg custards (0.1 per cent level of probability). When sugar was omitted from the formula the rank order of the custards prepared with the various types of eggs was the same, however, there was no significant difference in lightness values among custards prepared with frozen, spray-, and foam-spray dried eggs. They were all grayer than custards prepared with freeze-dried eggs (0.1 per cent level of probability). The b_L values indicated that frozen egg custards containing sugar were more yellow than freeze-dried egg custards which in turn were more yellow than foam-spray-dried egg custards (0.1 and 5 per cent level of probability respectively). When sugar was omitted from the formula, frozen egg custards were considered more yellow than the dehydrated egg custards (0.1 per cent level of probability). The results of color differences among custards prepared with various types of processed eggs is in disagreement with Mastic (1959) who reported no significant difference between the color of spray-dried and frozen egg custards. The effect of sugar on the color of egg-milk gels substantiated the work of Meyer (1937), who reported that sugar increased the translucency of custards.

SUMMARY AND CONCLUSIONS

The primary purpose of this investigation was to determine the effect of foam-spray-, freeze-, and spray-drying of eggs on the color, gel strength, and palatability of baked custards. Of secondary importance was determining the effect of sugar on the coagulating properties of the processed eggs.

The experiment was divided into two series: (1) standard custards containing sugar which consisted of eight treatments combining each egg process and the two end-point temperature ranges of 81-83°C and 85-87°C; and (2) egg-milk slurries (sugar omitted) which consisted of four types of processed eggs baked to the end-point temperature range of 85-87°C. All eggs used in this investigation came from a common lot; standardized procedures were utilized in the preparation, baking, and testing of all gels; and all data reported are the average of six replications.

Sugar affected the baking time and temperature of the custards. Time-temperature relationships revealed similar heating curves for custards baked with the four types of processed eggs. Custards prepared with sugar coagulated at a higher temperature and the presence of sugar prolonged the baking time by 3 to 4 minutes.

Sensory evaluation of the custard attributes were evaluated by an eight membered taste panel using a 7-point rating scale. The results of the sensory tests indicated that the crusts of freeze-dried egg custards baked to the low temperature range were tougher than the crusts of custards prepared with foam-spray-dried eggs baked to the same temperature range. When the custards were baked to the high temperature range, the crusts of freeze-dried egg custards were tougher than the crusts of custards prepared with all other types of eggs (0.1 per cent level of probability). Sensory evaluation of color revealed that the only significant difference occurred between frozen and the dehydrated egg custards baked to the high end-point temperature range (5 per cent level of probability). There was no significant difference in the subjective evaluation of gel strength which could be attributed to egg process, however, gels baked to the internal temperature of 85-87°C were significantly firmer than those baked to 81-83°C (0.1 per cent level of probability). Subjective evaluation of syneresis revealed significant differences which could be attributed to replication, egg process, and temperature differences (1, 5, and 0.1 per cent level of probability respectively). Because of the difference among replications and the fact that the custards baked to the high end-point temperature range revealed higher syneresis scores than those baked to the lower temperature range, the results were considered invalid. Smoothness values at the low temperature range indicated that frozen egg custards were smoother than freeze- and spray-dried egg custards (0.1 per cent level of probability). Frozen egg custards were smoother than spray-dried egg custards and spray-dried egg custards were smoother than freeze-dried egg custards (1 and 5 per cent level of probability respectively). At the high temperature range frozen and freeze-dried egg custards were not considered different, however, they were smoother than foam-spray- and spray-dried egg custards (5 per cent level of probability). Analysis of the flavor scores indicated no significant differences in the flavor of the custards which could be attributed to egg process, however, custards baked to 85-87°C were preferred over those custards baked to 81-83°C. Custards were often described as having an objectionable foreign flavor which left somewhat of an aftertaste in the mouth. The most probable explanation for this flavor was the dextrins which were present in all of the eggs. A four-way analysis of variance was used to determine significant differences among the judges evaluating the custards. The results previously reported were substantiated by this analysis.

The shear press was utilized to determine both the maximum force required to shear the gel structures as well as the composite representation of gel strength. These tests revealed similar results for all values as well as extremely high positive correlations between sensory evaluation of gel strength. Freeze-dried egg custards containing sugar were firmer than frozen egg custards which in turn were firmer than foam-spray- and spray-dried egg custards (0.1 per cent level of probability). To determine the effect of sugar on the coagulating properties of the processed eggs, gels containing sugar were compared with similar gels omitting sugar. The increase in gel strength of the freeze-dried egg custards containing sugar over the slurries omitting sugar was attributed to the presence of sugar. Freeze-dried egg custards were significantly firmer when sugar was contained in the formula (5 per cent level of probability). Sugar did not have a significant effect on the gel strength of the custards prepared with the other types of processed eggs.

Percentage drainage was computed for all custards containing and omitting sugar. The weak gel structures produced at the low temperature range resulted in the mixture passing through the wire screen, invalidating the results.

The Hunter color difference meter was utilized to determine differences in the color of gels. Analyses of the color data indicated that custards baked to the high temperature range were lighter and less yellow than custards baked to the low range. Frozen egg custards baked to the low temperature range were lighter than custards prepared with all other types of processed eggs (0.1 per cent level of probability). Foam-spray-dried egg custards were also lighter than freeze-dried egg custards (0.1 per cent level of probability). At the high temperature range frozen, foam-spray-dried and spray-dried egg custards baked to the low temperature range were greener than custards made with freeze-dried eggs. At the high temperature range there was no significant differences among the greenness values of the custards. Analysis of the yellowness values of custards revealed that frozen egg custards baked to the low temperature range were more yellow than freeze-dried egg custards baked to the same temperature range (1 per cent level of probability). At the high temperature range frozen egg custards were more yellow than freeze-, foam-, and spray-dried egg custards (5, 0.1, and 0.1 per cent level of probability respectively). Correlation coefficients were determined between sensory evaluation of color and the Hunter values. Positive correlations were found between the sensory data and Hunter L and b_L values (5 and 0.1 per cent level of probability respectively).

The effect of sugar on the color of the custards prepared with the various types of processed eggs was determined by the Hunter colorimeter. When sugar was omitted from the formula the rank order of the slurries prepared with the processed eggs was the same, however, there were no significant differences in lightness and greenness values among the slurries prepared with frozen, spray-, and foam-spray-dried eggs. Slurries prepared with these three types of processed eggs were all grayer and greener than custards prepared with freeze-dried eggs (0.1 per cent level of probability). Frozen egg slurries were more yellow than slurries prepared with the dehydrated eggs (0.1 per cent level of probability).

The results of this investigation indicated that all eggs functioned adequately in the coagulation process, although research is needed in the following areas: (1) an investigation to determine the effect of dextrins on the flavor of protein containing foods; (2) an analysis to determine if the alterations in the carotenoid pigment is reducing the vitamin content of the eggs; (3) a study to determine if the color differences were due to the alteration of the carotenoid pigment; (4) a more accurate method for determining percentage drainage; (5) further statistical analyses to determine the effect of variation among judges on the evaluation of food products; (6) an investigation of psychological factors affecting the accuracy of judges evaluations; (7) a study to determine the effect of various proportions of sugar on the gel strength of custards prepared with a constant percentage of eggs; and (8) an investigation to determine the effect of percentage solids on the resulting egg-milk gels.

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APPENDIX

Method of Bacterial Analysis for Egg Samples (Mallmann, 1966)

Procedure and materials

Five replications of lauryl tryptose broth dilutions were utilized for the determination of the coliform index. After four hours at 35°C the total counts were made in a Tryptose glucose agar.

Salmonella detection

Five grams of egg was added to 50 milliliters of sterile buffered water, 1-10 dilutions. One milliliter of this mixture was added to 10 milliliters of selenite brilliant green broth (SBG). This mixture was prepared in triplicate and was incubated for twenty-four hours at 35°C. One milliliter of this solution was added to 10 milliliters of tetrathiolate broth (TT). This mixture was similarly allowed to incubate for twenty-four hours at 35°C. The remainder of the above 1-10 dilution incubated for three hours at 35°C and inoculations were made as above into the SBG and TT broths.

Incubation smears of all tubes were made into brilliant green agar after forty-eight hours. These cultures were incubated for twenty-four hours at 35°C. Suspect salmonella colonies from the above plates were then transferred to lactose broth. If no gas was produced in the lactose broth, inoculations were made into Kleigler's medium. Organisms containing salmonellae were inoculated into urea broth and the salmonella was serotyped for grouping.

You will be provided with a schedule of times and dates of taste panels. Your samples will be on trays bearing your name and will be kept in the refrigerator in Room 110. You will be assigned a desk to evaluate the samples and are asked to always use the same place. Please refrain from smoking, eating, or drinking for 1/2 hour prior to evaluation. Please do not give any facial or verbal expressions as you evaluate your products.

The samples are coded with random numbers and are presented in a randomized fashion. Each sample is to be evaluated on a separate score sheet using a 7-point scale. A score of 7 being the highest to be given. Seven attributes are to be judged. Descriptive terms for the scores of 7, 4, and 1 are given to aid in your evaluation. Descriptive terms are also listed for each quality characteristic. Please check the reason if you give a sample a score of 4 or lower. Place a large X through the box with the score that best describes your evaluation. Please rinse your mouth between samples.

Procedure for Rating Custards

1. Remove tray of samples from the refrigerator in Room 110 and go to assigned seat in taste panel room.

2. Evaluate custard in lower left corner of tray first, lower right second, and proceed to the upper row. Crackers and water are provided for eating between samples.

3. Check to make sure the random number on the score card is the same as for the sample.

4. For each sample:

   a. Evaluate crust first, being careful not to damage the gel structure below. Mark an X through the box for the appropriate score.
   b. Carefully invert the custard on a plate and evaluate the remaining characteristics in the order given on the score card. Make sure you make the score for <u>all 6 inside characteristics</u>.
   c. Check descriptive term appropriate whenever a score of 4 or lower is given.

PLEASE BE SURE YOU HAVE <u>6 X's ON EACH SCORE CARD</u> BEFORE LEAVING TASTE PANEL ROOM.

Figure 4. General directions for taste panel members.

Judge____________________

Date____________________

BAKED CUSTARD
Score Sheet

Egg Project 719

Sample Code______

Quality Characteristic	7	6	5	4	3	2	1	Check Reason for Scores of 4 or lower
Crust	Very Tender			Slightly Tough			Unacceptable	Tough____ Rubbery____
Color Inside	Light Yellow Color			Slightly Off Color			Unacceptable	Greenish Yellow____ Yellowish Orange____ Gray____
Firmness	Holds Shape When Cut			Too Rigid or Too Weak			Unacceptable	Rigid____ Too Soft____ No Gel____
Syneresis	No Separation			Moderate Separation			Unacceptable	Separation Before Cutting____ Separation After Cutting____
Smoothness	Homogeneous			Small Bubbles Throughout			Unacceptable	Small Bubbles Throughout____ Pebbley____ Granular____
Flavor	Bland			Slight Off Flavor			Unacceptable	Sulphury____ Rancid____ Bitter____ Stale____ Aftertaste____

General
Comments ____

Figure 5. Score sheet for sensory evaluation of baked custards.

Table 31. Replicate averages for pH values before and after baking of egg milk systems containing and omitting sugar.

End Baking Temperature		81-83°C		85-87°C			
		Sugar		Sugar		Sugar Omitted	
pH		Before Baking	After Baking	Before Baking	After Baking	Before Baking	After Baking
Egg Process	Rep.						
Frozen	1	7.0	7.0	7.0	7.0	7.0	7.1
	2	6.9	7.0	6.0	7.0	6.8	7.0
	3	6.9	6.9	6.9	7.0	6.7	7.0
	4	6.9	7.0	7.0	7.0	7.0	6.9
	5	6.9	6.9	6.9	6.9	7.0	7.0
	6	7.0	7.0	6.9	6.9	7.0	7.0
Freeze-dried	1	7.0	7.0	7.0	7.1	7.0	6.8
	2	7.0	7.0	6.9	7.0	7.0	6.9
	3	7.0	7.0	6.9	7.0	6.8	7.0
	4	7.0	7.0	6.9	7.0	7.0	7.0
	5	6.9	7.0	6.9	6.9	6.9	7.0
	6	6.9	7.0	7.0	7.0	6.9	7.0
Foam-spray-dried	1	6.9	7.0	7.0	7.0	7.0	6.9
	2	6.9	7.0	7.0	7.0	6.8	7.0
	3	7.0	7.1	7.0	7.0	6.9	6.9
	4	6.9	7.0	6.9	6.9	6.9	7.0
	5	6.9	6.9	6.9	7.0	7.0	7.0
	6	7.0	7.0	7.0	7.1	7.0	7.0
Spray-dried	1	6.9	7.0	7.0	7.1	7.1	6.9
	2	6.9	7.0	6.9	7.0	6.8	7.0
	3	7.0	7.1	7.0	7.0	6.9	7.0
	4	6.9	7.0	6.9	7.0	6.9	7.0
	5	7.0	7.0	6.9	7.0	6.9	7.0
	6	6.8	7.0	7.0	6.9	7.0	7.0

Table 32. Replicate averages for egg processes, egg process means for custards baked to 81-83°C, and standard deviations for sensory evaluation of custard attributes (7-point scale).

Custard Attribute	Rep.	Processed Eggs Utilized in Custard Preparation				Mean/Standard Deviation (81-83°C)
		Frozen	Freeze-dried	Foam-Spray-dried	Spray-dried	
Crust Tenderness	1	4.5	3.9	5.8	4.5	
	2	5.0	3.4	4.4	5.5	
	3	4.5	3.8	4.6	5.0	
	4	4.4	4.1	5.3	5.0	4.7±0.60
	5	5.0	4.3	4.6	5.0	
	6	5.1	5.4	5.7	4.7	
Mean/Standard Deviation for egg processes		4.8±0.31	4.2±0.68	5.1±0.61	5.0±0.34	
Inside Color	1	6.5	5.9	6.4	6.4	
	2	6.8	6.5	6.0	6.0	
	3	6.5	5.9	6.6	6.3	
	4	6.9	6.9	6.4	6.9	6.4±0.36
	5	6.9	6.7	6.4	6.6	
	6	6.9	6.3	6.4	5.6	
Mean/Standard Deviation for egg processes		6.8±0.20	6.4±0.39	6.4±0.20	6.3±0.34	
Firmness	1	4.1	5.1	5.4	4.3	
	1	1.8	4.4	1.9	3.5	
	3	2.1	5.1	1.9	1.9	
	4	2.6	3.8	2.0	4.4	3.1±1.35
	5	3.4	1.1	3.1	1.0	
	6	3.0	2.9	2.4	2.0	
Mean/Standard Deviation for egg processes		2.9±0.85	3.7±0.65	2.8±1.34	2.9±1.41	

Syneresis	1	6.0	6.4	6.1	6.1	
	2	5.4	6.1	6.1	6 0	
	3	6.0	6.4	5.3	6.1	
	4	6.1	5.8	5.6	5.8	6.1±0.56
	5	6.1	6.9	6.1	6.3	
	6	6.1	6.0	6.0	6.1	
Mean/Standard Deviation for egg processes		6.0±0.27	6.2±0.26	5.9±0.34	6.1±0.21	
Smoothness	1	5.6	5.9	5.3	5.8	
	2	5.5	5.4	5.8	4.8	
	3	5.8	5.4	5.0	5.1	
	4	6.1	5.1	5.3	4.9	5.3±0.40
	5	6.0	5.4	5.9	5.0	
	6	6.0	5.4	5.9	5.0	
Mean/Standard Deviation for egg processes		5.8±0.24	5.4±0.26	5.6±0.49	5.1±0.64	
Flavor	1	4.8	4.6	5.0	4.4	
	2	4.5	5.3	4.0	5.4	
	3	4.5	4.8	4.5	4.8	
	4	3.8	4.5	4.0	5.6	4.5±0.51
	5	4.4	3.9	4.9	3.4	
	6	4.5	4.6	4.9	4.0	
Mean/Standard Deviation for egg processes		4.4±0.33	4.6±0.45	4.5±0.43	4.6±0.84	

Table 33. Replicate averages for egg processes, egg process means for custards baked to 85-87°C, and standard deviations for sensory evaluation of custard attributes (7-point scale).

Custard	Rep.	Processed Eggs Utilized in Custard Preparation: Frozen	Freeze-dried	Foam-Spray-dried	Spray-dried	Mean/Standard Deviation (85-87°C)
Crust Tenderness	1	4.8	4.9	4.6	3.6	
	2	4.3	4.9	5.9	4.1	
	3	4.6	2.1	4.6	5.1	
	4	4.4	2.9	5.1	4.9	4.5±0.85
	5	4.9	3.8	4.9	5.3	
	6	4.6	3.9	5.9	5.0	
Mean/Standard Deviation for egg processes		4.6±0.23	3.8±1.11	5.1±0.35	4.7±0.52	
Inside Color	1	6.9	6.0	6.3	6.5	
	2	6.3	6.0	6.4	6.6	
	3	6.7	6.6	6.5	6.0	
	4	6.9	5.6	6.3	6.9	6.4±0.38
	5	6.9	6.8	6.1	6.4	
	6	6.9	6.7	6.0	5.8	
Mean/Standard Deviation for egg processes		6.8±0.21	6.3±0.40	6.3±0.19	6.3±0.41	
Firmness	1	6.0	5.9	5.9	5.9	
	2	5.5	6.3	5.4	6.1	
	3	6.1	6.6	6.4	5.9	
	4	6.5	6.4	5.7	5.9	6.1±0.35
	5	6.6	6.3	6.1	6.1	
	6	6.8	6.6	6.3	6.3	
Mean/Standard Deviation for egg processes		6.2±0.48	6.4±0.26	5.9±0.38	6.0±0.16	

Syneresis	1	6.5	5.5	5.3	6.4	
	2	6.4	6.3	6.1	6.6	
	3	6.3	6.3	5.9	6.0	
	4	5.7	6.4	5.9	6.1	6.2±0.25
	5	6.4	6.3	6.3	6.4	
	6	6.1	6.0	6.0	5.8	
Mean/Standard Deviation for egg processes		6.2±0.29	6.3±0.19	6.1±0.18	6.2±0.30	
Smoothness	1	5.4	5.9	3.9	6.0	
	2	4.8	5.5	4.5	4.8	
	3	5.6	5.5	5.8	4.7	
	4	6.1	5.3	4.6	4.5	5.2±0.68
	5	6.1	5.9	4.3	5.1	
	6	6.1	6.0	4.4	5.0	
Mean/Standard Deviation for egg processes		5.7±0.53	5.7±0.29	4.6±0.64	5.0±0.53	
Flavor	1	5.3	5.0	4.4	5.4	
	2	4.6	5.3	4.5	4.6	
	3	5.4	4.6	5.1	4.0	
	4	4.0	5.6	6.6	4.8	4.9±0.52
	5	5.1	5.8	4.6	4.9	
	6	5.6	5.4	4.8	4.1	
Mean/Standard Deviation for egg processes		5.0±0.33	5.3±0.45	4.6±0.43	4.6±0.84	

Table 34. Replicate averages for egg processes, egg process means for custards baked to 81-83°C, and standard deviations for shear press measurements of gel strength.

Factor	Rep.	Processed Eggs Utilized in Custard Preparation: Frozen	Freeze-dried	Foam-Spray-dried	Spray-dried	Mean/Standard Deviation (81-83°C)
Shear press peak I (lbs)	1	1.9	1.4	1.4	1.3	
	2	2.1	1.9	1.3	1.4	
	3	1.8	3.0	1.4	1.3	
	4	1.2	2.3	1.4	1.3	1.7±0.55
	5	1.8	2.4	1.9	1.1	
	6	2.2	2.9	1.3	1.0	
Mean/Standard Deviation for egg processes		1.8±0.34	2.3±0.61	1.4±0.24	1.2±0.14	
Shear press peak II (lbs)	1	1.8	1.3	1.3	1.2	
	2	1.7	1.7	1.1	1.3	
	3	1.8	2.4	1.3	1.3	
	4	1.3	1.9	1.3	1.2	1.5±0.39
	5	1.7	2.3	1.7	1.2	
	6	1.9	2.3	1.2	1.0	
Mean/Standard Deviation for egg processes		1.7±0.20	2.0±0.41	1.3±0.21	1.19±0.15	

Shear press peak III (lbs)	1	3.1	2.0	2.0	2.5	
	2	3.2	2.6	1.9	2.3	
	3	2.4	4.6	2.1	2.2	
	4	2.4	3.2	2.8	1.9	2.5±0.69
	5	2.4	3.5	2.6	1.8	
	6	3.0	3.2	1.8	1.6	
Mean/Standard Deviation for egg processes		2.7±0.39	3.2±0.37	2.2±0.42	2.0±0.33	
Shear press area-under-the curve (cm^2)	1	6.1144	3.7801	4.4595	4.3898	
	2	5.9925	5.6267	3.7453	4.3898	
	3	5.5744	8.2745	4.4595	4.0937	5.2245±1.44
	4	4.3396	6.9506	4.4421	3.8150	
	5	5.4350	7.0551	6.0099	3.3621	
	6	6.7590	8.3268	3.8150	4.1808	
Mean/Standard Deviation for egg processes		5.7021±0.82	6.6689±1.73	4.4886±0.82	4.0386±0.39	

Table 35. Replicate averages for egg processes, egg process means for custards baked to 85-87°C, and standard deviations for shear press measurement of gel strength.

Factor	Rep.	Processed Eggs Utilized in Custard Preparation				Mean/Standard Deviation (85-87°C)
		Frozen	Freeze-dried	Foam-Spray-dried	Spray-dried	
Shear press peak I (lbs)	1	3.2	3.6	2.5	2.2	
	2	3.2	3.2	2.2	2.6	
	3	3.3	4.4	2.8	2.5	
	4	3.2	4.4	2.6	2.5	3.0±0.67
	5	3.0	4.5	2.8	2.5	
	6	3.3	3.5	2.6	2.6	
Mean/Standard Deviation for egg processes		3.2±0.12	3.93±0.58	2.57±0.21	2.47±0.16	
Shear press peak II (lbs)	1	2.4	2.7	2.2	1.9	
	2	2.4	2.7	2.0	2.0	
	3	2.3	2.7	2.3	2.1	
	4	2.4	2.8	2.3	1.9	2.3±0.30
	5	1.9	2.7	2.3	2.1	
	6	2.4	2.7	2.2	2.1	
Mean/Standard Deviation for egg processes		2.3±0.18	2.7±0.10	2.2±0.13	2.0±0.12	

Shear press peak III (lbs)	1	3.6	4.8	2.9	2.9	
	2	5.8	4.5	2.7	3.5	
	3	3.8	5.6	3.7	3.8	
	4	4.1	4.9	3.3	3.9	4.0±0.94
	5	4.2	6.1	3.6	2.9	
	6	3.8	5.1	3.3	3.4	
Mean/Standard Deviation for egg processes		4.2±0.79	5.1±0.57	3.2±0.38	3.4±0.43	
Shear press area-under-the-curve (cm^2)	1	8.3442	9.1281	6.6196	6.5848	
	2	9.4765	8.7971	6.8635	7.3687	
	3	8.9190	11.7933	8.1003	7.3512	
	4	8.8319	11.2359	7.1596	7.0899	8.3±1.44
	5	8.1351	11.6191	7.4906	6.6544	
	6	8.9016	9.6507	6.7590	7.0203	
Mean/Standard Deviation for egg processes		8.7680±0.47	10.3707±1.33	7.1654±0.55	7.0116±0.33	

Table 36. Replicate averages for egg processes, egg process means for slurries (sugar omitted) baked to 85-87°C, and standard deviations for shear press measurements of gel strength.

Factor	Rep.	Processed Eggs Utilized in Custard Preparation: Frozen	Freeze-dried	Foam-Spray-dried	Spray-dried	Mean/Standard Deviation (85-87°C)
Shear press peak I (lbs)	1	27.0	32.1	28.0	22.0	
	2	33.5	33.0	30.0	23.0	
	3	30.5	32.3	33.0	25.0	2.9±0.45
	4	34.0	34.8	24.5	25.8	
	5	34.8	35.0	23.8	21.0	
	6	31.0	33.8	28.5	26.3	
Mean/Standard Deviation for egg processes		3.2±0.29	3.3±0.12	2.8±0.35	2.4±0.24	
Shear press peak II (lbs)	1	21.0	21.5	20.0	17.5	
	2	24.5	23.5	22.5	17.5	
	3	24.5	20.8	22.5	19.0	2.2±0.24
	4	24.0	24.0	20.5	19.8	
	5	24.3	25.3	18.5	18.5	
	6	23.0	24.0	22.5	19.8	
Mean/Standard Deviation for egg processes		2.4±0.14	2.3±0.17	2.1±0.17	1.9±0.10	

Shear press peak III (lbs)	1	38.0	51.5	45.0	39.0	
	2	51.5	53.0	43.5	44.5	
	3	45.8	44.0	47.0	41.0	4.5±0.48
	4	46.3	48.8	42.3	39.0	
	5	51.0	45.0	48.8	36.5	
	6	46.8	53.8	42.8	45.3	
Mean/Standard Deviation for egg processes		4.7±0.49	4.9±0.41	4.5±0.26	4.1±0.34	
Shear press area-under-the-curve (cm^2)	1	7.6658	8.8145	7.8390	6.6196	
	2	9.6681	9.4939	8.6403	7.5254	
	3	8.7623	8.3616	9.1629	7.6474	8.4±0.95
	4	8.9713	9.7204	7.7519	7.4035	
	5	9.1455	9.5462	7.6648	6.5499	
	6	9.1280	9.6333	8.0306	8.5184	
Mean/Standard Deviation for egg processes		8.9±0.67	9.3±0.54	8.2±0.59	7.4±0.73	

Table 37. Replicate averages for egg processes, egg process means for custards baked to 81-83°C, and standard deviations for percentage drainage values.

Factor	Rep.	Processed Eggs Utilized in Custard Preparation				Mean/Standard Deviation (81-83°C)
		Frozen	Freeze-dried	Foam-spray-dried	Spray-dried	
Percentage drainage	1	5.2	4.8	6.5	8.0	
	2	3.6	8.7	22.8	29.0	
	3	2.0	2.4	14.5	26.1	21.45±21.45
	4	82.6	7.8	8.5	21.3	
	5	7.7	63.4	24.5	38.9	
	6	7.3	31.0	31.4	56.7	
Mean/Standard Deviation for egg processes		18.0±31.7	19.7±23.7	18.0±9.8	30.6±16.6	

Table 38. Replicate averages for egg processes, egg process means for custards baked to 85-87°C, and standard deviations for percentage drainage values.

Factor	Rep.	Processed Eggs Utilized in Custard Preparation				Mean/Standard Deviation (85-87°C)
		Frozen	Freeze-dried	Foam-spray-dried	Spray-dried	
Percentage drainage	1	0.9	1.2	1.3	4.5	
	2	1.5	1.7	1.2	1.5	
	3	1.9	1.5	1.4	1.0	1.69±1.09
	4	2.0	0.8	2.0	5.3	
	5	1.0	1.5	1.0	1.0	
	6	1.2	1.1	1.9	2.7	
Mean/Standard Deviation for egg processes		1.4±0.47	1.3±0.36	1.5±0.38	2.7±0.87	

Table 39. Replicate averages for egg processes, egg process means for custards baked to 81-83°C, and standard deviations for Hunter colorimeter measurement of color.

Factor	Rep.	Processed Eggs Utilized in Custard Preparation				Mean/Standard Deviation (81-83°C)
		Frozen	Freeze-dried	Foam-spray-dried	Spray-dried	
Hunter L values	1	90.2	89.0	90.1	89.6	
	2	91.0	88.8	88.7	89.2	
	3	90.7	88.9	89.6	88.9	89.4±0.75
	4	90.2	88.6	89.8	88.2	
	5	89.4	88.4	89.1	89.8	
	6	90.2	88.5	89.8	89.1	
Mean/Standard Deviation for egg processes		90.3±0.58	88.7±0.09	89.5±0.51	89.1±0.57	
Hunter a_L values	1	-4.5	-3.7	-4.0	-4.3	
	2	-3.9	-3.2	-4.2	-4.2	
	3	-3.7	-3.3	-4.3	-3.9	-3.9±0.46
	4	-4.4	-2.9	-4.2	-4.3	
	5	-3.6	-3.6	-4.6	-3.6	
	6	-3.4	-3.1	-3.8	-4.2	
Mean/Standard Deviation for egg processes		-3.9±0.43	-3.3±0.31	-4.2±0.29	-4.1±0.26	
Hunter b_L values	1	24.1	23.1	23.7	22.8	
	2	23.5	23.1	22.5	22.9	
	3	23.7	23.6	23.2	22.9	23.2±0.73
	4	24.3	23.4	23.0	22.0	
	5	24.2	23.3	22.7	23.0	
	6	24.4	23.4	23.0	21.2	
Mean/Standard Deviation for egg processes		24.0±0.34	23.3±0.18	23.0±0.42	22.4±0.73	

Table 40. Replicate averages for egg processes, egg process means for custards baked to 85-87°C, and standard deviations for Hunter colorimeter measurements for color.

Factor	Rep.	Processed Eggs Utilized in Custard Preparation: Frozen	Freeze-dried	Foam-spray-dried	Spray-dried	Mean/Standard Deviation (85-87°C)
Hunter L values	1	90.2	88.8	89.9	90.0	
	2	90.3	88.9	89.6	89.9	
	3	90.8	88.7	90.2	90.2	89.8±0.62
	4	90.3	88.8	90.0	90.0	
	5	91.0	89.0	89.9	90.1	
	6	90.7	88.9	90.0	90.0	
Mean/Standard Deviation for egg processes		90.5±0.23	88.9±0.09	88.9±0.21	90.0±0.09	
Hunter a_L values	1	-3.8	-3.7	-3.8	-3.9	
	2	-3.8	-3.7	-3.1	-3.9	
	3	-3.9	-3.3	-3.9	-3.5	-3.7±0.32
	4	-4.3	-3.6	-4.1	-3.5	
	5	-3.7	-2.9	-3.9	-4.1	
	6	-4.1	-3.7	-3.8	-4.1	
Mean/Standard Deviation for egg processes		-3.9±0.23	-3.5±0.33	-3.8±0.34	-3.8±0.28	
Hunter b_L values	1	24.2	23.0	22.2	22.7	
	2	23.9	23.0	23.2	22.4	
	3	23.8	23.3	22.6	22.6	22.9±0.59
	4	23.2	22.6	22.7	22.3	
	5	23.6	22.8	22.3	22.1	
	6	23.7	23.2	22.4	22.3	
Mean/Standard Deviation for egg processes		23.7±0.31	23.0±0.25	22.6±0.35	22.5±0.22	

Table 41. Replicate averages for egg processes, egg process means for slurries baked to 85-87°C (sugar omitted), and standard deviations for Hunter colorimeter measurements for color.

Factor	Rep.	Processed Eggs Utilized in Custard Preparation				Mean/Standard Deviation (85-87°C)
		Frozen	Freeze-dried	Foam-spray-dried	Spray-dried	
Hunter L values	1	92.6	90.8	92.2	91.9	
	2	92.7	91.0	91.7	92.2	
	3	92.8	91.1	91.9	92.4	91.9±0.62
	4	92.4	90.6	92.2	92.2	
	5	92.2	91.4	92.2	92.1	
	6	92.5	91.1	92.1	92.2	
Mean/Standard Deviations for egg processes		92.5±0.20	91.0±0.26	92.1±0.21	92.1±0.15	
Hunter a_L values	1	-3.2	-3.1	-3.0	-3.8	
	2	-3.1	-3.0	-3.5	-3.9	
	3	-3.2	-2.3	-3.8	-2.8	-3.27±0.48
	4	-3.8	-2.7	-3.7	-3.3	
	5	-4.0	-2.5	-3.5	-3.4	
	6	-3.8	-2.6	-3.5	-3.5	
Mean/Standard Deviations for egg processes		-3.5±0.41	-2.7±0.29	-3.5±0.27	-3.4±0.39	
Hunter b_L values	1	23.2	21.5	21.9	21.5	
	2	23.5	21.9	22.5	21.8	
	3	23.4	22.1	22.3	22.4	22.4±0.58
	4	23.3	22.5	22.2	22.0	
	5	23.0	22.2	22.3	21.9	
	6	23.3	22.1	22.2	22.3	
Mean/Standard Deviations for egg processes		23.3±0.16	22.0±0.32	22.2±0.18	22.0±0.33	

Table 42. Conglomerate averages and standard deviations for shear press and Hunter colorimeter measurements for slurries (sugar omitted) baked to 85-87°C.

Factor	Conglomerate Mean/Standard Deviation for custards prepared with:			
	Frozen eggs	Freeze-dried eggs	Foam-spray-dried eggs	Spray-dried eggs
Shear press peak I values (lbs)	3.2±0.21	3.6±0.50	2.7±0.30	2.3±0.19
Shear press peak II values (lbs)	2.3±0.16	2.5±0.25	1.9±0.15	1.9±0.13
Shear press peak III values (lbs)	4.4±0.67	5.0±0.48	3.9±0.73	3.7±0.51
Shear press area-under-the curve (cm^2)	8.8±0.56	9.8±1.13	7.7±0.76	7.2±0.57
Hunter L values	91.5±1.10	89.9±1.12	91.0±1.12	91.1±1.11
Hunter a_L values	-3.7±0.38	-3.1±0.51	-3.6±0.33	-3.6±0.39
Hunter b_L values	23.5±0.34	22.5±0.56	22.4±0.31	22.2±0.35

Table 43. Conglomerate averages and standard deviations for sensory evaluation, shear press measurements, percentage drainage values, and Hunter colorimeter measurements for custards baked to 81-83°C and 85-87°C.

Factor	Conglomerate Mean/Standard Deviation for custards prepared with:			
	Frozen eggs	Freeze-dried eggs	Foam-spray-dried eggs	Spray-dried eggs
Sensory evaluation of crust tenderness	4.7±0.27	4.0±0.90	5.1±0.58	4.8±0.52
Sensory evaluation of inside color	6.8±0.21	6.3±0.40	6.3±0.19	6.3±0.41
Sensory evaluation of gel strength	4.5±1.88	5.0±1.73	4.4±1.19	5.3±0.94
Sensory evaluation of syneresis	6.1±0.31	6.3±0.28	6.0±0.28	4.5±0.20
Sensory evaluation of smoothness	5.8±0.40	5.6±0.29	4.9±0.62	5.5±0.66
Sensory evaluation of flavor	4.7±0.55	5.0±0.55	4.6±0.35	4.9±0.49
Shear press peak I values	2.5±0.73	3.1±1.02	2.0±0.64	1.8±0.61
Shear press peak II values	2.0±0.37	2.4±0.49	1.7±0.49	1.6±0.45
Shear press peak III values	3.5±0.97	4.2±1.24	2.7±0.65	2.7±0.81
Shear press area-under-the-curve	7.2±1.72	8.5±2.4	5.8±1.54	5.5±1.59
Percentage drainage values	84.0±2.07	83.9±2.20	84.2±2.08	84.0±2.47
Hunter L values	90.4±0.42	88.8±0.21	89.7±0.43	89.6±0.61
Hunter a_L values	-3.9±0.33	-3.4±0.32	-4.0±0.37	-3.9±0.29
Hunter b_L values	23.9±0.35	23.2±0.28	22.9±0.43	22.4±0.52

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