THE EFFECT OF PASTEURIZATION, SELECTED ADDITIVES AND FREEZING RATE ON THE GELATION OF FROZEN-DEFROSTED EGG YOLK

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by

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INTRODUCTION

Frozen storage of liquid eggs has become a popular commercial method of preserving egg quality. In 1965 368,309,000 pounds of liquid egg were frozen. Of this amount 191,196,000 pounds were frozen as whole egg magma, 96,713,000 pounds as yolk, and 80,400,000 pounds as white (Anonymous, 1966).

Frozen storage of whole egg magma and egg yolk is complicated by a phenomenon referred to as gelation. When yolk is frozen and defrosted, it does not regain its original fluidity. Instead it becomes an extremely viscous, rubbery mass. The mechanism responsible for the increase in the apparent viscosity of the yolk is unknown. Gelation does not occur in egg white. The phenomenon is less evident in whole egg magma than in yolk since the yolk is diluted by the white in the magma.

Commercial egg handlers presently add up to 10% sodium chloride or sucrose to the yolk prior to freezing to retard gelation (Mitchell, 1966). Although these additives are effective in reducing gelation, they alter the flavor of the yolk or whole egg magma.

In 1966 the Federal government enacted a law requiring that liquid whole egg, yolk, and white; frozen whole egg, yolk, and white; and dried whole egg, yolk, and white be pasteurized or otherwise treated so as to destroy all viable Salmonella microorganisms (Goddard, 1966). It is postulated that the application of heat during pasteurization may affect the yolk constituents responsible for gelation, thereby altering the susceptibility of the yolk to gelation. The effectiveness of gelation-inhibiting additives may also vary between unpasteurized and pasteurized yolk. Little research was found in the literature on the gelation of yolk pasteurized prior to freezing.

The objective of this study was to investigate the effects of pasteurization, selected additives, and freezing rate on the gelation of frozen-defrosted egg yolk. Additional physical characteristics and functional properties of the frozen-defrosted yolk were also investigated.

REVIEW OF LITERATURE

Gelation of Egg Yolk

Functional properties. Contradictory results are presented regarding the effect of gelation on the functional properties of egg yolk. Forsythe *et al.* (1953) stated that commercial bakers generally assume that frozen-defrosted egg products must have a thick, gel-like consistency before satisfactory functional performance can be expected. However, studies by these investigators revealed little, if any relationship between the body of frozen-defrosted whole egg products and their performance in sponge cakes. Musil and Vitezslav (1957) also detected no difference in quality between sponge cakes made with unfrozen whole eggs and with thoroughly mixed whole eggs frozen at -10° to -23°C and stored 3.5 to 6 days.

In contrast, egg magma or yolk frozen without a protective agent was found by Urbain and Miller (1930) to be unsuitable for use by bakers, salad dressing manufacturers, and others who required a product that could be intimately incorporated in such carriers as milk and oil.

Jordan *et al.* (1952a) reported that sponge cakes made with frozen-defrosted yolk mixed with unfrozen egg white in the proportion of whole egg were smaller in volume than cakes made with unfrozen shell eggs. The cakes made with frozen-defrosted yolk and unfrozen white scored lower on crumb than the unfrozen shell egg cakes because undesirable small yellow particles were visible; they also scored lower on moistness, tenderness, and flavor. In preparing the batter the thick, gummy, gelled yolk did not disperse readily.

Whereas frozen-defrosted yolk was not desirable for use in sponge cakes, frozen-defrosted whole egg magma produced sponge cakes of good quality.

Baked custards made with frozen-defrosted yolk were found unsatisfactory by Jordan *et al.* (1952b) because of their softness, high liquid content, thick crusts, and objectionable yellow lumps. The extremely viscous yolks did not combine well with the sugar and milk.

Lopez *et al.* (1954) reported that the texture of frozen-defrosted yolk fried in Crisco was rubbery and its color bleached as compared to fried unfrozen yolk. The flavor was flat, but no off-flavor was detected.

Theories of gelation. The mechanism responsible for gelation of egg yolk has not been determined although several theories have been proposed. The lipoproteins of yolk are implicated in most of these theories. According to Fisher and Gurin (1964) and Lovelock (1957), lipoproteins, such as lipovitellin, the most abundant lipoprotein of egg yolk, are held together largely by weak forces such as electrostatic and hydrophobic bonds rather than by covalent bonds alone. Because of the tenuous nature of these binding forces, these complexes are inherently unstable and may dissociate under the altered physical conditions encountered in the frozen state.

The first investigation of the apparent viscosity changes in egg yolk resulting from freezing and defrosting was conducted by Moran (1925). The investigator observed that shell eggs frozen and stored at temperatures between -0.65°C (the freezing point of yolk) and -6°C regained normal fluidity when defrosted after several months of storage. Gelation occurred only in eggs frozen and/or stored at temperatures below -6°C, a temperature well below the freezing point of yolk. A time factor was also found necessary for gelation. To complete the irreversible change at -11°C, a period of at least 24 hours was required after shell eggs were frozen at -5°C.

Moran theorized that the lecitho-vitellin of egg yolk was the causative agent in gelation. This lipoprotein was soluble in a 10% sodium chloride solution and was precipitated by the addition of more water. The freezing point of a 10% sodium chloride solution was -6°C, the critical temperature for gelation. This investigator suggested that when yolk was frozen to a temperature below -6°C, the lecitho-vitellin of the yolk was dissolved by the concentrated salt solution formed as the water in the yolk was converted to ice crystals. When the yolk was defrosted, enough water was contributed by the melting ice crystals to precipitate the lecitho-vitellin; thus, the original fluidity of the yolk was not regained.

Urbain and Miller (1930) repeatedly washed frozen-defrosted egg yolk with distilled water until only a ropy mass, identified as lecithin, remained. Thus, these investigators concluded that gelation resulted from the separation and precipitation of lecithin. Yolk frozen 15 months was found to have physical characteristics similar to those of yolk frozen 72 hours, indicating that gelation occurred either during freezing or defrosting and not in the frozen state.

Lipovitellin isolated from unfrozen egg yolk was denatured by freezing as judged by the loss of solubility in a 15% sodium chloride solution and the release of lipid from the complex, according to Lea and Hawke (1952). The rate of denaturation was much slower in lipovitellin frozen at -65°C and stored at -20°C than in lipovitellin frozen at -65°C and stored at -3°C. This finding indicated that lipovitellin was less sensitive to the more concentrated sodium chloride solution present at -20°C than to the less concentrated solution present at -3°C. The lipovitellin was denatured to a greater extent at both temperatures when the pH of the suspending sodium chloride solution was lowered from 6.8 to 5.2. Mechanisms by which the pH of egg yolk could be lowered upon freezing include the increase in the hydrogen ion concentration, the precipitation of sparingly soluble buffer salts, and the increase in the acidity of protein solutions whose isoelectric points are on the acid side of neutrality. Lea and Hawke proposed that gelation was caused by a lowering of pH by these mechanisms and the subsequent effects on lipovitellin.

Lea and Hawke (1952) and Lovelock (1957) stated that modern theories of lipoprotein structure include water as an integral part of the molecule. According to Musil and Vitezslav (1957), the affinity of the adhered lecithin and vitelline molecules was weakened as water was removed from the lecithovitellin complex by freezing. As a result, the yolk emulsion deteriorated and gelation occurred. Powrie et al. (1963) suggested that the breakdown of the water shells surrounding the protein molecules promoted rearrangement and aggregation of yolk lipoproteins upon freezing. The observation of Moran (1925) that gelation did not occur in eggs supercooled at -11°C for 7 days supports these theories.

Powrie et al. (1963) observed that the viscosity of a crude lipovitellin suspension isolated from yolk was altered after freezing and defrosting. In addition, the electrophoretic migration of the lipovitellenin fraction of yolk was altered after freezing and defrosting, indicating that both lipovitellin and lipovitellenin may be involved in gelation.

Effect of sugars. Inhibition of gelation by treatment with additives prior to freezing was first investigated by Moran (1925). This investigator observed that yolk treated with 10% sucrose underwent almost no change in fluidity after being frozen at -11°C and defrosted. His explanation for the protective action of sucrose on colloids was that a definite percentage of the sucrose, depending on its concentration, was adsorbed by the colloid.

Powrie et al. (1963) found that the degree of apparent viscosity change in yolk frozen at -14°C and defrosted decreased as the sucrose concentration was increased from 0.001 to 0.014 moles per 100 g of yolk. However, the apparent viscosity changes were not completely inhibited even at the 0.014 mole sucrose per 100 g yolk level. This author suggested that the protective effect of sucrose may be attributed to inhibition of denaturation or aggregation of the yolk proteins.

The apparent viscosity of frozen-defrosted yolk treated with 8% sucrose was almost equal to that of unfrozen, untreated yolk, according to Pearce and Lavers (1949). Increasing the amount of sucrose added from 1 to 8% had a progressively greater effect in retaining the foaming volume of frozen-defrosted yolk mixed with unfrozen white in the proportion of whole egg.

Marion and Stadelman (1958) stated that the addition of up to 36.7% sucrose did not affect the apparent viscosity of unfrozen yolk. However, a two-fold decrease in the apparent viscosity of frozen-defrosted yolk treated with 4.8% sucrose as compared to frozen-defrosted untreated yolk was observed and a six-fold decrease was observed when 9.1% sucrose was added. Gelation was completely inhibited by the addition of 36.7% sucrose.

Assuming that gelation was caused by the separation and coagulation of lecithin, Urbain and Miller (1930) reported that essentially 100% of the lecithin isolated from yolk was coagulated when no protective agent was employed during freezing and defrosting and that 98.8, 0.8 , and 0.6% was coagulated when 10% sucrose, 10% dextrose, and 10% levulose, respectively, was added. These results indicated that dextrose and levulose were more effective in inhibiting gelation than an equal amount of sucrose. None of these sugars formed permanent combinations with the lecithin or other yolk components.

Equimolar quantities of sucrose (1.0% by weight) and dextrose (0.53% by weight) were added to egg yolk by Thomas and Bailey (1933). The additives produced quantitatively the same effect in reducing gelation of the yolk.

Studies by Godeton (1934) indicated that frozen-defrosted yolk treated with 7% sucrose produced sponge cakes of better volume and organoleptic score than did frozen-defrosted untreated yolk. Jordan et al. (1952a) also reported that frozen-defrosted yolk treated with approximately 7.5 and 14.0% sucrose and mixed with unfrozen white in the proportion of whole egg produced sponge cakes of greater volume and palatability than did frozen-defrosted untreated yolk. According to Jordan et al. (1952b), the flavor of plain cakes made with frozen-defrosted yolk treated with approximately 7.5 and 14.0% sucrose was judged somewhat better than the flavor of plain cakes made with frozen-defrosted untreated yolk. Plain cakes made with unfrozen untreated yolk, frozen-defrosted untreated yolk, and frozen-defrosted yolk treated with 7.5 and 14.0% sucrose did not differ significantly in volume, grain, tenderness, or velvetiness. Custards made with frozen-defrosted yolk treated with these levels of sucrose were of high quality.

Meyer and Woodburn (1965) observed that the addition of 0.0286 moles of fructose per 100 g of yolk decreased the apparent viscosity of both unfrozen and frozen-defrosted yolk. Electrophoretic findings indicated that the migration pattern of the lipovitellin and lipovitellenin fraction of the frozen-defrosted fructose-treated yolk was more similar to that of unfrozen, untreated yolk than to that of frozen-defrosted untreated yolk. Of possible importance, as suggested in the study of Meyer and Woodburn, are the findings of Charley et al. (1963) on the chelation of iron by sugars. The relative sequestering ability of fructose was greater than that of sucrose, lactose, maltose, or galactose. Meyer and Woodburn suggested that the sequestering action of fructose on the iron and possibly the copper of yolk would lessen the cross-bonding of protein molecules and thus the apparent viscosity would not be increased as greatly.

Lopez et al. (1954) investigated the gelation inhibiting ability of arabinose, galactose, cellobiose, lactose, maltose, and raffinose, using sucrose and dextrose as controls. Yolk treated with 10% arabinose or galactose had a lower apparent viscosity after 7 days of frozen storage than yolk treated with 10% sucrose or dextrose. However, arabinose and galactose imparted an objectionable sweet flavor to the yolk. The inability of the other sugars tested to inhibit gelation suggested that sugars do not retard the increase in viscosity merely by lowering the freezing point of the water present in yolk.

Effect of salts. Sodium chloride and certain other salts also have been found effective in inhibiting gelation of egg yolk. Frensdorff et al. (1953) suggested that if salt linkages play an important role in the aggregation of protein molecules, electrolytes such as sodium chloride would be expected to inhibit aggregation since they stabilize the charged groups of the proteins. The same theory on the role of salts in gelation inhibition was presented by Moran (1926).

In addition to decreasing the apparent viscosity of frozen-defrosted yolk, sodium chloride and certain other salts increase the apparent viscosity of unfrozen yolk. Zawadski (1933) demonstrated that the monovalent salts, sodium chloride and potassium chloride, markedly increased the apparent viscosity of a 50% water-50% yolk solution. The divalent salts, calcium chloride and magnesium chloride, produced an even greater increase in the apparent viscosity of the yolk solution.

The addition of up to 0.5% sodium chloride to unfrozen yolk decreased the apparent viscosity of the yolk, according to Lopez et al. (1954). However, the viscosity of the unfrozen yolk increased when the sodium chloride concentration was 0.8% or higher.

The ratio of the apparent viscosity of unfrozen yolk treated with 5% sodium chloride to that of untreated, unfrozen yolk was found by Jordan and Whitlock (1955) to be 4.8 to 1. These authors theorized that sodium chloride added to yolk may cause the lipovitellin to take up water, thereby permitting an increase in particle size with consequent increase in the apparent viscosity of the yolk. In addition, ionic bonding of sodium and chloride ions to protein molecules may be of sufficient strength to increase the apparent viscosity. The addition of 1 to 5% sodium chloride to whole egg magma and yolk also rendered the magma and yolk more translucent and orange in color.

The addition of 4.8% sodium chloride resulted in a ten-fold increase in the apparent viscosity of unfrozen yolk, according to Marion and Stadelman (1958). The increase in apparent viscosity was even greater when 9.1% sodium chloride was added. The addition of 4.8% sodium chloride was as effective in reducing gelation of frozen-defrosted yolk as the addition of 9.1% sucrose. No significant decrease in the apparent viscosity of frozen-defrosted yolk was observed upon increasing the sodium chloride concentration from 4.8 to 9.1%.

Meyer and Woodburn (1965) observed that the addition of 0.0055 moles of sodium chloride per 100 g yolk increased the apparent viscosity of unfrozen yolk and decreased the apparent viscosity of frozen-defrosted yolk. The electrophoretic migration of the lipovitellin and lipovitellenin fractions of frozen-defrosted salt-treated yolk was more similar to that of unfrozen salt-treated and unfrozen untreated yolk than to that of frozen-defrosted untreated yolk.

Erikson and Boyden (1955) noted that the addition of 1, 2, and 4% sodium chloride reduced gelation of frozen-defrosted yolk; however, the differences in the effectiveness of the three levels were not significant. Pearce and Lavers (1949) reported that the addition of 2% sodium chloride had a marked effect in retaining the foaming volume of frozen-defrosted yolk. Increasing the sodium chloride level to 8% had only a slight additional effect.

Gelation was found by Powrie et al. (1963) to be almost completely retarded by the inclusion of 0.1 moles of sodium chloride per 100 g yolk. On a molar basis, the ionic sodium chloride was not as effective an inhibitor as nonpolar sucrose. Thomas and Bailey (1933) stated that sodium chloride and sucrose appeared to have the same effect in inhibiting gelation when present in amounts which lowered the freezing point of the yolk to the same extent.

Jordan et al. (1952a) observed that sponge cakes made with frozen-defrosted yolk treated with approximately 2.5 and 5.0% sodium chloride were larger in volume than cakes made with frozen-defrosted untreated yolk. Sponge cakes made with yolk treated with the higher level of sodium chloride were too salty in flavor to be desirable. Jordan et al. (1952b) reported that custards made with frozen-defrosted yolk treated with 2.5 and 5.0% sodium chloride were also undesirably salty in flavor.

Effect of enzymes. Feeney et al. (1954) stated that the crotoxin (lecithinase A)-treated yolk (1 mg enzyme per 1 ml yolk and 10 mg enzyme per 1 ml yolk) had only 10 to 20% as much gelation as untreated yolk. Gelation was reduced when the yolk was incubated with crotoxin either before or after freezing and defrosting. These results supported the theory that gelation is related to changes involving the lipoproteins of egg yolk; the lipovitellin and lipovitellenin fractions were attacked by the enzyme and the resultant lysophospholipoproteins had an altered solubility in water.

Papain mixed with unfrozen yolk in a concentration of 0.05% and incubated

15 to 20 minutes inhibited gelation, according to Lopez et al. (1955). The flavor of the uncooked and cooked yolk was not affected. Trypsin and Rhozyme also inhibited gelation of yolk; however, these enzymes produced off-flavors and off-odors in the yolk. Gelation was not reduced by pancreatin, erepsin, and lipase. These results indicated that gelation-inhibiting enzymes broke down the component or components responsible for gelation. Since only proteolytic enzymes were found effective, the authors concluded that a protein complex was partly or totally responsible for gelation of yolk. Marion and Stadelman (1958) reported that 0.01 and 0.02% ribonuclease was not effective in reducing gelation.

Effect of cysteine. Meyer and Woodburn (1965) and Powrie et al. (1963) observed that the addition of 0.0055 moles of cysteine per 100 g of yolk reduced gelation. Powrie et al. speculated that cysteine might rupture the intramolecular disulfide bonds in lipoproteins, thereby bringing about a partial uncoiling of the protein molecules and lessening the increase in apparent viscosity.

Effect of miscellaneous additives. The effect of selected emulsion stabilizers and destabilizers was investigated by Lopez et al. (1954). None of the substances tested decreased gelation. These investigators also observed that the addition of 3% trisodium citrate, which prevents coagulation of blood, to yolk inhibited gelation; however, it imparted a strong citrate flavor to the yolk. In an attempt to determine whether metallic ions have a direct influence on gelation, Lopez et al. (1954) added a chelating agent, sequestrene Na_3, to yolk in concentrations of 0.05 to 1.0%. Gelation was not inhibited. Meyer and Woodburn (1965) reported that gelation was not inhibited by the addition of 2, 3 dimercapto 1 propanol (0.0055 moles per 100 g yolk), a chelating and reducing agent.

Effect of water. The addition of 4% water reduced gelation slightly, according to Marion and Stadelman (1958). A somewhat stepwise decrease in the apparent viscosity was noted as the amount of water added was increased from 0 to 4%, suggesting that dilution of yolk affects gelation. Lopez et al. (1954) observed that the addition of water to yolk had no influence on gelation until additions of 70 to 100% were made. The 70 and 100% dilutions were liquid probably due to dispersion of yolk particles. The addition of 5.5 ml distilled water per 100 g of yolk was found by Meyer and Woodburn (1965) to partially reduce gelation.

Effect of pH. Lopez et al. (1954) reported that changing the pH of egg yolk from 6.2 to 6.6 and 7.0 by the addition of sodium hydroxide and to 5.1, 4.6, and 3.2 by the addition of sulfuric acid did not prevent gelation. Lea and Hawke (1952) observed that lipovitellin isolated from yolk and dispersed in a 15% sodium chloride solution gave up lipid to ether (an indication of denaturation) extremely slowly at pH values above 5.5. However, up to one-third of the lipid could be extracted rapidly from more acid sodium chloride solutions in which the lipovitellin was much less soluble. These results suggested that damage to lipovitellin could be easily produced by the lowering of the pH which occurs as egg yolk is frozen.

Mechanical treatment. Colloid milling was observed by Lopez et al. (1954) to reduce gelation. The viscosity of yolk colloid milled prior to freezing and defrosting was approximately the same as that of yolk treated with 5% sodium chloride or 10% sucrose prior to freezing and defrosting. The flavor, color, and texture of frozen-defrosted colloid milled samples were similar to that of fresh yolk. The addition of up to 10% sodium chloride to the yolk before colloid milling resulted in a frozen-defrosted yolk with a higher degree of gelation than frozen-defrosted colloid milled samples with no added sodium chloride. The apparent viscosity of frozen-defrosted yolk diluted with 5 and 15% water before colloid milling was as great as that of the frozen-defrosted untreated control.

Frozen-defrosted hand-stirred yolk and yolk homogenized at zero pounds pressure did not differ significantly in apparent viscosity from frozen-defrosted controls, according to Marion and Stadelman (1958). The apparent viscosity of frozen-defrosted yolk homogenized at zero pounds pressure was significantly greater than that of frozen-defrosted yolk homogenized at 1000, 2000, and 3000 pounds pressure. Increasing the pressure above 1000 pounds resulted in no additional decrease in apparent viscosity.

Heating prior to freezing. A high degree of gelation was noted by Lopez et al. (1954) in 15 g samples of egg yolk immersed in water at 55° to 100°C for 15 to 20 seconds before being frozen. Thus, slight heating prior to freezing did not inhibit gelation.

Freezing rate. Pearce and Lavers (1949) reported that reducing the freezing time of egg yolk from 39 to 0.2 hours resulted in a progressive decrease in gelation. According to Lea and Hawke (1952), the solubility of lipovitellin isolated from yolk was changed less by rapid freezing at temperatures of -65° to -183°C than by slower freezing at temperatures up to -1°C.

Rapid freezing of yolk by immersion in an acetone-carbon dioxide mixture (temperature approximately -70°C) and liquid nitrogen partially inhibited gelation in a study by Lopez et al. (1954). Marion and Stadelman (1958) stated that the apparent viscosity of yolk frozen in an alohol-carbon dioxide mixture was lower than that of yolk frozen in either a freezer cooled by a 26% sodium chloride solution (-19 ± 1°C) or a still air freezer (-21°C). No difference was found in the apparent viscosity of yolk frozen by the last two methods. These results indicated that gelation of yolk was a function of freezing rate up to a certain point.

A physical examination of the effect of freezing rate on the color of yolk by Pearce and Lavers (1949) revealed that yolk frozen in 10 minutes was light yellow in color. After a freezing time of 100 hours, the color was dark orange. The foaming volume of frozen-defrosted yolk was affected by freezing rate. A 100 hour freezing period produced a product which, when mixed with unfrozen white in the proportion of whole egg, had a foaming volume of about 300 ml; yolk frozen in 10 min and mixed with unfrozen white had a foaming volume of only about 200 ml. Moran (1925) reported that yolk frozen in liquid air and defrosted at room temperature was finer in texture than yolk frozen more slowly.

Defrosting rate. Moran (1925) observed that yolk frozen in liquid air became pasty when defrosted at room temperature, but if defrosted in mercury at 30°C, it regained its original fluidity. From this and previous observations on the effect of freezing rate, Moran concluded that gelation may occur either during freezing or defrosting and occurs in neither if the rate of temperature change is high enough.

A decrease in defrosting time from 24 to 0.03 hours was observed by Pearce and Lavers (1949) to result in a decrease in the apparent viscosity of yolk frozen at -12°C. The degree of gelation was similar in yolk frozen at -12°C and defrosted in 24 or 48 hours. Yolk defrosted in 4 hours produced sponge cakes of greater volume than yolk defrosted in 0.03, 24, or 48 hours.

The decrease in the apparent viscosity of yolk upon reduction of defrosting time from 143 to 21 minutes was equally effective regardless of freezing rate, stated Marion and Stadelman (1958). According to Lopez et al. (1954), both quicker freezing and quicker defrosting independently decreased the degree of gelation of frozen-defrosted yolk. Faster freezing and faster defrosting, when combined, were more effective than either of the two used separately.

Lea and Hawke (1952) noted that the solubility of lipovitellin isolated from yolk and frozen at -65°C was best preserved by rapid defrosting in water at 37°C rather than at lower temperatures.

Storage time and temperature. In 1925 Moran reported that the pastiness of shell eggs frozen at -11°C increased in proportion to the length of frozen storage up to approximately 24 hours. According to Thomas and Bailey (1933), the period of increasing gelation of whole egg magma stored at -18° to -20°C extended from 60 to 120 days, with the majority of the samples reaching their maximum degree of gelation before 90 days. This observation was in contradiction to the statement by Urbain and Miller (1930) that gelation occurred either during freezing or defrosting or during both of these phases and not in the frozen state.

Powrie et al. (1963) noted a rapid increase in the apparent viscosity of yolk during the first few hours of storage at -10° and -14°C. Pearce and Lavers (1949) stated that frozen storage of yolk up to 8 months at -10°C caused no increase in apparent viscosity if the yolk were frozen or defrosted in 4 hours or less, but increasing the length of storage from 0 to 8 months increased the apparent viscosity of yolk frozen or defrosted in longer time periods.

Jordan et al. (1952a) observed that the average volume of sponge cakes made with frozen-defrosted untreated yolk and frozen-defrosted yolk treated with 2.5 and 5% sodium chloride and 7.5 and 15% sucrose and stored 6 months was significantly higher than that of cakes made with similarly treated yolk stored one week, two months, or four months. The breaking strength values for the sponge cakes were significantly lower after the one week and six month storage periods than after the two and four month periods.

Lea and Hawke (1952) froze lipovitellin isolated from yolk at -65°C, stored the samples at -29°, -20°, -10°, and -3°C, and defrosted the samples in a 37°C hot water bath after three months of storage. Denaturation of the lipovitellin was practically 0% at -29°C and increased with increasing storage temperature to almost complete denaturation at -3°C. At all four temperatures most of the denaturation occurred during the first ten days of storage.

Pasteurization of Egg Yolk

Heat-induced apparent viscosity changes. Coagulation is the limiting factor controlling heat treatment of egg products. According to Winter (1952), it was generally assumed prior to 1952 that it was impossible to heat liquid egg products at a high enough temperature for a long enough time to kill bacteria without causing coagulation of the proteins or otherwise impairing the culinary properties of the egg.

Payawal et al. (1946) observed no change in the apparent viscosity of yolk heated at 58°C for as long as 800 seconds. At 62.5°C the apparent viscosity of yolk was a linear function of the time of heating up to 300 seconds. After 300 seconds the apparent viscosity decreased. The apparent viscosity rapidly increased upon heating at 65°C until a maximum apparent viscosity was observed at 200 seconds. Further heating at 65°C resulted in a sharp decrease in the apparent viscosity to approximately 475 seconds. Almost immediately thereafter, the yolk coagulated. A possible explanation for the apparent viscosity decrease after 400 seconds was deterioration of the fat emulsion of the yolk.

Hanson et al. (1947) noted a certain amount of physically altered material in whole eggs pasteurized at 60°C for 3 to 10.5 minutes to 70°C for 0.1 to 0.5 minutes, the amount increasing as the time and/or temperature of heating increased. At 70°C coagulation occurred extremely rapidly.

Miller and Winter (1950) pasteurized liquid whole egg at 60 to 61°C for 4 minutes. The apparent viscosity of frozen-defrosted pasteurized eggs was four to seven times greater than that of unfrozen, unpasteurized eggs, but less than half that of frozen-defrosted unpasteurized eggs.

Influence of heating on functional properties. No difference was noted by Miller and Winter (1950) in the stability of oil and water foams made with frozen-defrosted unpasteurized whole eggs and frozen-defrosted whole eggs pasteurized at 60° to 61°C for 4 minutes. Pasteurization and freezing of whole eggs had no significant effect on sponge cake volume, crumb color, texture, grain, tenderness, moistness, or flavor. No significant difference was noted in the stiffness, color, texture, odor, and flavor of baked and stirred custards made with unfrozen and unpasteurized, frozen and unpasteurized, and frozen and pasteurized whole eggs.

Hanson et al. (1947) observed that the volume of sponge cakes made with whole eggs pasteurized at 60° to 61°C for 1.5 to 6.5 minutes was approximately 5% less than that of cakes made with unpasteurized whole eggs. The cakes made with pasteurized eggs were somewhat less desirable in texture and shape than those made with unpasteurized eggs. Pasteurization did not impair the value of whole eggs for scrambling or making mayonnaise.

EXPERIMENTAL METHODS AND MATERIALS

Source of the Egg Yolk

Unfrozen, unpasteurized egg yolk and unfrozen, pasteurized egg yolk were obtained from Seymour Foods, Inc., a commercial producer of frozen and dried egg products located in Topeka, Kansas. The shell eggs had been broken out and separated the previous day in the Seymour branch plant in Yankton, South Dakota. The separated yolk and white had been transported in refrigerated tank trucks to the Topeka plant the same day. The temperature of the yolk and white was maintained at approximately 4°C during the 8 hours of transport. Since the eggs had been collected from a number of farms near Yankton, the breed, age, and ration of the hens varied and were unknown.

In the Topeka plant the yolk, which was held at 4°C or slightly less, was uniformly blended and the chalazae and broken shell bits were filtered out. The unpasteurized yolk was obtained prior to passage through the pasteurizing unit. The pasteurized yolk was obtained immediately after it had been pasteurized and cooled. Pasteurization was accomplished by heating the yolk at 61° to 62.3°C for 3.5 to 4 minutes. The temperature of the yolk was lowered to 4°C within 30 seconds after completion of pasteurization. The solids content of the unpasteurized and pasteurized yolk was approximately 45%.

The yolk was transported from Topeka to Kansas State University in Manhattan, Kansas, in two 30 pound tin containers. The two containers of yolk were stored 18 hours in a walk-in cooler at 4.5°C before the yolk was treated with additives and frozen.

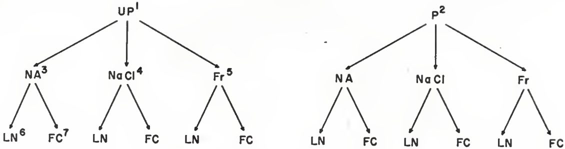
Statistical Methods

The statistical design employed in this study was a 2 x 2 x 3 factorial design as shown in plan 6.9 in Cochran and Cox (1957). The design as applied to this study is presented in Table 29 in the Appendix. Three replications were necessary. The derivation of the 12 treatments per replication is shown in Fig. 1. The design was an incomplete block design in that only 6 of the 12 samples in a replication were tested on any one day.

The analysis used to analyze the data was presented by Yates (1937). The sources of variation in the analysis of variance are shown in Table 1. The least significant difference (LSD) ($P \leq 0.5$) was calculated when the F-value for treatments or blocks was significant. The variation among treatments was partitioned into the single component sources of treatment variation. The significance or non-significance of treatments and treatment interactions, which accounted for eight of the eleven treatment degrees of freedom, was determined. The three remaining treatment degrees of freedom were attributed to the confounding of block effects.

Preparation of the Samples

Addition of additives. The unpasteurized and pasteurized yolk was divided into 215 g samples 18 hours after transporting from Topeka to Manhattan. Six and one half percent by weight A.C.S. grade sodium chloride (14.9465 g per 215 g yolk or 0.2555 moles per 215 g yolk) was added to one third of the unpasteurized samples and to one third of the pasteurized samples. Six and one half percent by weight fructose (14.9465 g per 215 g yolk or 0.0830 moles per 215 g yolk) was added to another one third of the unpasteurized samples and to another one third of the pasteurized samples. No additive was added to the



1 - Unpasteurized.
2 - Pasteurized.
3 - No additive.
4 - Sodium chloride added.
5 - Fructose added.
6 - Frozen in liquid nitrogen.
7 - Frozen on freezer coils.

Figure 1. Derivation of the twelve treatments.

Table 1. The sources of variation in the analysis of variance.

Source of Variation	Degrees of Freedom	
Treatments	11	
Pasteurization		1
No additive versus some additive		1
Sodium chloride versus fructose		1
Freezing method		1
Pasteurization X no additive versus some additive interaction		1
Pasteurization X sodium chloride versus fructose interaction		1
No additive versus some additive X freezing method interaction		1
Sodium chloride versus fructose X freezing method interaction		1
Interactions partially confounded with block differences		3
Blocks	5	
Error	19	
Total	35	

final third of the unpasteurized samples and the final third of the pasteurized samples.

The 6.5% level of additive was selected as a result of preliminary studies. It was observed that gelation was only partially inhibited by this level of additive. It is believed that decreases in gelation resulting from differences in the freezing rate could also be detected.

Each yolk sample was blended 90 seconds with a Hamilton Beach hand mixer, model 55, set at low speed. Two hundred grams of each blended sample was weighed into a 5" x 4" x $1\frac{1}{2}$" aluminum freezer container with a snap-on aluminum lid. The edges of the containers were sealed with freezer tape.

Freezing methods. One half of the unpasteurized sodium chloride-treated samples, one half of the pasteurized sodium chloride-treated samples, one half of the unpasteurized fructose-treated samples, one half of the pasteurized fructose-treated samples, one half of the unpasteurized untreated samples, and one half of the pasteurized untreated samples were frozen in liquid nitrogen (temperature approximately -196°C). To prevent leakage of the liquid nitrogen into the freezer containers, each sample frozen in liquid nitrogen was enclosed in a pouch constructed of a polyethylene-mylar laminate (2 ml polyethylene - 1 ml mylar). The liquid nitrogen was held in an insulated stainless steel container 11" tall with a total diameter of 11" and an internal diameter of 8". A three tier rack was constructed to hold the samples while they were submerged in the liquid nitrogen.

Freezing was accomplished by immersing two laminate-wrapped samples at a time in the liquid nitrogen for a period of 12 minutes. Preliminary studies indicated that the yolk was completely frozen within this time interval. After the samples were removed from the liquid nitrogen, the laminate pouches were removed and the samples were immediately placed in a Hotpoint upright household freezer (-20 ± 2°C). They were stored in the freezer until their removal for testing.

The remaining half of the samples were placed unfrozen in the same upright freezer and allowed to freeze. The freezer coils in the freezer were located in the shelves on which the samples were stored. Thus, freezing was accomplished at a faster rate than would have been possible in a freezer in which the coils were located in the walls of the unit. Since these samples were not submerged in a liquid, it was not necessary to enclose them in the laminate pouches. The samples remained in the freezer until they were removed for testing.

Six additional samples - one unpasteurized and treated with sodium chloride, one pasteurized and treated with sodium chloride, one unpasteurized and treated with fructose, one pasteurized and treated with fructose, one unpasteurized and untreated, and one pasteurized and untreated - were prepared to investigate the freezing rate of samples frozen on the freezer coils of the freezer. Thermocouples were inserted through holes drilled in the center of the freezer container lids and positioned in the center of each egg yolk mass. The temperature of the yolk was recorded at 5 minute intervals during the freezing process using a YST scanning tele-thermometer, model 47, until the temperatures of the six samples remained relatively constant.

Length of storage. The number of days the samples in each replication were stored in the freezer before removal for testing is shown in Table 2. As mentioned previously, it was necessary to use an incomplete block design. Therefore, only six of the twelve samples within a replication were tested on any one day.

Defrosting. All samples were defrosted in a hot water bath at 35 ± 2°C. Preliminary work indicated that the sodium chloride-treated yolk reached room

Table 2. Number of days the samples were stored in the freezer before their removal for testing.

Replication	Length of storage period in days
1a[1]	33
1b	35
2a	40
2b	42
3a	47
3b	49

[1]a and b refer to the first and second halves, respectively, of each of the three replications.

temperature (25°C) approximately 35 minutes after being placed in the hot water bath, the fructose-treated yolk reached 25°C after approximately 45 minutes and the untreated yolk after approximately 50 minutes. Since pasteurization and freezing rate did not appear to influence defrosting rate to nearly as great an extent as did the presence or absence of an additive, the samples were defrosted for 35, 45, or 50 minutes depending on whether they contained sodium chloride, fructose, or no additive, respectively. All tests were made on yolk at room temperature (25 $\pm$ 1°C).

Measurements of Physical Characteristics and Functional Properties

Apparent viscosity. The apparent viscosity of the frozen-defrosted egg yolk was measured with a Fisher Improved MacMichael viscosimeter, model 90, within 45 minutes after the samples were removed from the hot water bath. The yolk was placed in a cylindrical container and a spindle into which a certified wire was inserted was suspended in the yolk. The unit containing the sample was rotated at a known speed. The reading was taken when the spindle ceased rotating and remained relatively stationary.

The depth of the yolk sample, the rotational speed of the unit containing the yolk sample, and the gauge of the certified wire inserted in the spindle had been determined by preliminary studies. The temperature of the oil bath surrounding the unit in which the sample was contained was maintained at 25°C.

The formula used to determine the apparent viscosity of the yolk was

$$\mu = \frac{NA}{4 \pi h} \cdot \frac{1}{w}$$

where μ equals apparent viscosity in poises, N equals the torsional moment of the certified wire in dyne-cm or: 981 x the g-cm/°M resistance of the wire (its certification constant) x the rotation of the wire in °M, A equals $\frac{1}{r_1^2} - \frac{1}{r_2^2}$ where r_1 equals the outer radius of the plunger (lower part of the spindle) in cm and r_2 equals the inner radius of the sample cup in cm, h equals the depth of immersion of the plunger in cm, and w equals the speed of revolution of the cup in radians per second; 1 rev/sec equals 2 π radians/sec.

The certification constants of the certified wires used were 0.091800 g-cm/°M for the 26 gauge wire, 0.032130 g-cm/°M for the 28 gauge wire, 0.013005 g-cm/°M for the 30 gauge wire, and 0.003060 g-cm/°M for the 34 gauge wire. The rotation of the wire in °M was indicated by the reading obtained from the viscosimeter. r_1 was equal to 0.5 cm; r_2 was equal to 1.5 cm. The value of h was either 2 or 3 cm. w was equal to 0.8357, 3.1416, or 4.8316 radians/sec.

Color difference. A Gardner color difference meter, model AC-2a, was used to investigate color differences among the yolk samples. The "Rd" value (reflectance), the "-a" value (greenness), and the "+b" value (yellowness) of duplicate 30 g aliquots of yolk contained in the standard clear plastic cells were measured. The color difference meter was standardized against a yellow tile with a "Rd" value of 70.2, an "a" value of -6.22, and a "b" value of +27.05.

ΔE. Comparisons were made of the total color difference between selected treatments. In accomplishing this, the "Rd" values, "-a" values, and "+b" values were converted into the corresponding "L", "a_L", and "b_L" values using the conversion table in the Gardner color difference meter instruction manual. The total color difference (Δ E) was calculated using the following formula (Judd, 1952):

$$\Delta E = (\Delta a_L^2 + \Delta b_L^2 + \Delta L^2)$$

where Δa_L^2 = the square of the difference in the greenness values for the two treatments being compared

Δb_L^2 = the square of the difference in the yellowness values for the two treatments being compared

ΔL^2 = the square of the difference in the visual lightness (i.e., blackness or whiteness) for the two treatments being compared

The following scale was used to judge the magnitude of the color difference:

$\Delta E = 0.50$ - difference very small, easily confused

$\Delta E = 1.00$ - considered acceptable commercial matches

$\Delta E = 3.00$ - differences very visible

pH. The pH of the yolk was recorded from the expanded scale of a Beckman pH meter, model 76. The duplicate 30 g aliquots per sample tested for color differences were combined and the pH measurement was made on this yolk.

Total solids. The method employed to determine total solids was a modification of the A.O.A.C. method (1965). Duplicate aliquots weighing approximately 5 g were weighed into pyrex watch glasses 2.5" in diameter. The yolk was dried in a Precision vacuum oven, model 524, at -25 in Hg and 100°C for 48 hours. Preliminary studies indicated that the yolk attained a constant temperature after 36 hours of drying. The drying time was extended to 48 hours to provide a safety margin. At the end of the 48 hour period the samples were removed from the vacuum oven and cooled to room temperature in a desiccator containing calcium chloride for 45 minutes. The yolks were then reweighed and total solids were determined.

Emulsifying ability. Emulsions were prepared consisting of 8.5 g yolk, 11.0 g Mazola corn oil, and 46.0 ml deionized water. All ingredients were at room temperature. The ingredients for each emulsion were weighed and measured into a 175 ml Virtis pyrex homogenizing flask and emulsified for 90 seconds with a Virtis "45" hi speed homogenizer set at medium speed. Duplicate emulsions were prepared for each yolk sample.

The emulsions were poured into 100 ml graduated cylinder and allowed to set at room temperature for 3 hours. At 30 minute intervals, the emulsions were checked to determine whether any separation of the oil and aqueous phases was evident and the approximate time of breakage was recorded for those emulsions which did "break". The total percentage of separation was determined at the end of the three hour period.

Sponge cakes. Sponge cakes were baked in which egg yolk was a major ingredient. The following recipe, which was adapted from a recipe presented in

Practical Cookery (Dept. of Foods and Nutrition, 1966), was used:

60 g frozen-defrosted egg yolk

41 ml boiling water

0.375 g table salt (NaCl)

62.5 g granulated sugar

42 g cake flour

1.350 g S.A.S. baking powder

Twenty five g of sugar was sifted three times with 24 g of flour. The baking powder was sifted three times with the remaining flour. The boiling water and the salt were added to the egg yolk and the yolk-water-salt mixture was beaten 5 minutes with a Kitchen Aid mixer, model 3C, set at speed 8. Thirty seven and one half g of sugar was added to the egg-water-salt mixture, one tablespoon at a time, as the mixture was beaten an additional 1.5 minutes at speed 8. The sifted flour-sugar mixture was added, one tablespoon at a time, as the batter was beaten 1 minute at speed 1. The batter was beaten 1 minute at speed 1 while the flour-baking powder mixture was added. The batter was beaten an additional 2 minutes at speed 1. One hundred and thirty five grams of the batter was poured into a $7\frac{1}{2}$" x $3\frac{1}{2}$" x $2\frac{1}{2}$" aluminum loaf pan lined on the bottom with silicone-treated baking paper and baked in a rotary oven at 375°F for 35 minutes. The cakes were inverted immediately after their removal from the oven and cooled on wire cooling racks. When completely cooled, they were removed from the loaf pans.

The specific gravity of the sponge cake batter was measured by filling a metal specific gravity cup 1 5/8" in height and 1 3/4" in diameter with batter, leveling the batter in the cup with a spatula, and weighing the cup filled with batter. The formula used to determine the specific gravity was obtained from Griswold (1957):

$$\text{Specific gravity} = \frac{\text{weight filled container (g) - weight container (g)}}{\text{volume container (ml)}}$$

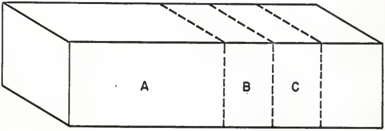
where volume container (ml) = weight container (g) + water (g) - weight container (g).

A panel of three judges scored the exterior of the whole sponge cakes for shape, crust, and degree of brownness on the same day the cakes were baked. The score card for the exterior of the sponge cakes is shown in Fig. 14 in the Appendix. A scoring range of 7 (excellent) to 1 (very poor) was used for the shape and color; a scoring range of 7 (extremely dark golden brown) to 1 (extremely light golden brown) was used for the degree of brownness.

The volume of the sponge cakes was determined by rapeseed displacement. The volume in ml of rapeseed required to fill a $8\frac{1}{2}$" x $4\frac{1}{2}$" x 2 3/4" loaf pan was determined. The difference between the ml of rapeseed required to fill the loaf pan when it did not and did contain a sponge cake was equal to the volume in ml of the cake being tested.

After the cakes were scored and volumes determined, they were placed in the $7\frac{1}{4}$" x $3\frac{1}{2}$" x $2\frac{1}{4}$" loaf pans, which were then completely wrapped in vinyfilm, and stored at room temperature until the next morning (approximately 18 hours). At that time the cakes were sliced according to the sampling diagram presented in Fig. 2. One inch cubes of cake were presented to a panel of 9 judges. The judges scored the interior of the cakes for grain, texture, color of crumb, flavor, and over-all acceptability using a 7-point scale ranging from excellent (7) to very poor (1). The score card for the interior of the sponge cake is presented in Fig. 15 in the Appendix.

A Precision Bloom Gelometer was employed to measure the compressibility of one inch slices of the sponge cakes. Two slices from each cake were tested. Compressibility was a function of the weight in grams required to depress the



A - Organoleptic measurements

B and C - Compressibility measurements

Figure 2. Sampling diagram for the sponge cakes.

interior surface of the cake 4 mm.

RESULTS AND DISCUSSION

Measurements Relating to the Physical Characteristics of the Egg Yolk

Physical measurements of the egg yolk included the freezing rate, apparent viscosity, total solids, and pH. Color differences were estimated by the "Rd", "-a", and "+b" values. The three color difference measurements were also studied collectively as an index of the total color difference between selected treatments. The original data for the physical characteristics are presented in Tables 30 and 31 in the Appendix. The analyses of variance of these data are presented in Table 36 in the Appendix.

Freezing rate. The decline in the temperature of the egg yolk containing no additive and frozen on freezer coils was arrested temporarily at approximately -3.0°C (Fig. 3). This temporary arrest can be attributed to the liberation of latent heat from the yolk, indicating that the state of the yolk changed from liquid to solid at approximately this temperature. This phenomenon was observed at approximately -4.5°C in the yolk treated with fructose (0.386 moles per liter) and at approximately -10.0° and -10.6°C in the unpasteurized and pasteurized yolk, respectively, treated with sodium chloride (1.186 moles per liter). The differences in the freezing rate between unpasteurized and pasteurized yolk treated identically in respect to additives were slight. The temperature of the frozen yolk became relatively constant at approximately 23 ± 1°C (temperature of the freezer was approximately 20 ± 2°C).

The differences in the temperature at which the temperature decline of the yolk was temporarily arrested can be explained by the colligative characteristics of the freezing point of the yolk. The moles of sodium chloride added

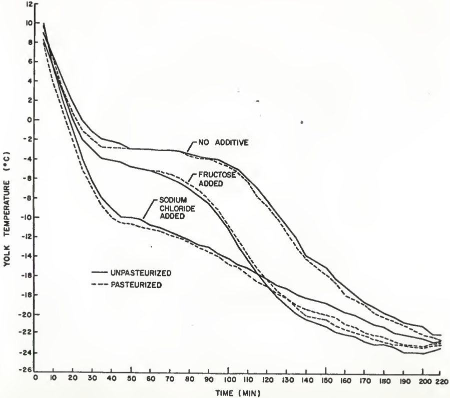


Figure 3. The freezing rate of the egg yolk frozen on the freezer coils.

to the yolk was greater than the moles of fructose. The dissociation of the ionic sodium chloride molecules further increased the number of particles added to the yolk treated with this additive.

The yolk samples frozen on the freezer coils changed from liquid to solid approximately 40 to 70 minutes after being placed in the freezer. Preliminary studies indicated that the yolk frozen in liquid nitrogen became completely solid within 12 minutes after immersion in the liquid nitrogen. Thus, the freezing rate was estimated to be at least three to five times more rapid when the yolk was frozen in liquid nitrogen as compared to on the freezer coils.

Apparent viscosity. The apparent viscosity of the frozen-defrosted yolk varied with the presence or absence of an additive ($P \leq 0.001$) (Table 3). The increase in the apparent viscosity of the yolk upon freezing and defrosting was significantly reduced by the addition of fructose or sodium chloride (Table 4). Whereas the differences in apparent viscosity between yolk containing no additive and yolk containing either fructose or sodium chloride were significant, the differences in apparent viscosity between fructose-treated yolk and sodium chloride-treated yolk were not significant.

A lessening of the increase in the apparent viscosity of yolk by the addition of fructose prior to freezing was also reported by Meyer and Woodburn (1965). These investigators observed that the addition of 0.0286 moles of fructose per 100 g of yolk retarded the apparent viscosity increase resulting from freezing and defrosting.

The apparent viscosity of the frozen-defrosted yolk containing 0.2555 moles of sodium chloride per 215 g yolk was similar to that of unfrozen, untreated yolk. This observation is in agreement with the finding of Powrie et al. (1963) that the increase in apparent viscosity of yolk upon freezing and

Table 3. The analyses of variance of the apparent viscosity, pH, and total solids of the egg yolk.

Source of variation	Apparent viscosity	Total solids	pH
Treatments	***	***	***
Pasteurization	ns	ns	ns
No additive versus some additive	***	***	***
Sodium chloride versus fructose	ns	na	***
Freezing method	***	ns	ns
Pasteurization X no additive versus some additive interaction	ns	ns	ns
Pasteurization X sodium chloride versus fructose interaction	ns	na	ns
Freezing method X no additive versus some additive interaction	***	ns	ns
Freezing method X sodium chloride versus fructose interaction	ns	na	ns
Blocks	ns	ns	ns

na - Not applicable.
ns - Not significant.
* - Significant at the 0.05 probability level
** - Significant at the 0.01 probability level
*** - Significant at the 0.001 probability level.

Table 4. The mean apparent viscosity of the egg yolk in poises for each treatment.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
678.33	1511.37	830.35	1473.26	17.62	19.69	19.57	16.71	6.66	37.78	82.67	47.09
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		—	—	—	—	—	—	—	—	—	—
			—	—	—	—	—	—	—	—	—

[1]LSD = 77.75.
[2]Underlined values differ significantly from the first underlined value in the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

defrosting was almost completely retarded by the addition of 0.1000 moles of sodium chloride per 100 g yolk.

In contrast to the effect of sodium chloride on frozen-defrosted yolk, it was observed that the apparent viscosity of unfrozen yolk was slightly increased by the addition of sodium chloride. No similar effect on the apparent viscosity of unfrozen yolk was noted for fructose. Jordan and Whitlock (1955), Marion and Stadelman (1958), and Meyer and Woodburn (1965) also reported that the apparent viscosity of unfrozen yolk was increased by the addition of sodium chloride.

The freezing method had a statistically significant effect on the apparent viscosity of the frozen-defrosted yolk ($P \leq 0.001$). The apparent viscosity of yolk containing no additive and frozen in liquid nitrogen was significantly less than that of yolk treated with no additive and frozen on the freezer coils. Lopez et al. (1954), Marion and Stadelman (1958), and Pearce and Lavers (1949) also reported that increasing the freezing rate decreased the change in apparent viscosity of yolk containing no additive. Although the differences in apparent viscosity were not statistically significant, the fructose-treated yolk frozen in liquid nitrogen was consistently less viscous than the fructose-treated yolk frozen on freezer coils. In contrast, the apparent viscosity of the sodium chloride-treated yolk frozen on freezer coils in relation to that of sodium chloride-treated yolk frozen in liquid nitrogen varied among replications, as indicated in Table 30 in the Appendix.

The interaction between the presence versus the absence of an additive and the freezing method was significant ($P \leq 0.001$) (Table 3). Freezing the yolk in liquid nitrogen as compared to on freezer coils was more effective in retarding the increase in apparent viscosity of the yolk containing no additive than of the yolk containing either fructose or sodium chloride (Fig. 4).

Although the interaction between the addition of sodium chloride versus

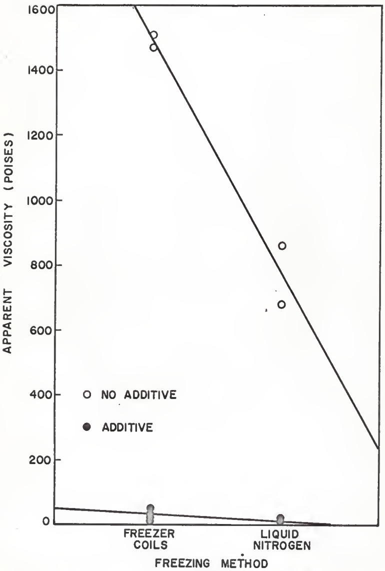

Figure 4. The interaction between the effects of freezing method and the presence versus the absence of an additive on the apparent viscosity of the egg yolk.

fructose and the freezing method was not significant, the differences in the apparent viscosity of the yolk treated with sodium chloride or fructose and frozen by both methods were quite evident in handling the yolk. Of interest is the finding that the apparent viscosity of yolk treated with sodium chloride and frozen either in liquid nitrogen or on freezer coils was less than that of fructose-treated yolk frozen on the freezer coils, but greater than the apparent viscosity of fructose-treated yolk frozen in liquid nitrogen. The apparent viscosity of sodium chloride-treated samples frozen in liquid nitrogen or on freezer coils appeared to be more similar to that of unfrozen, untreated yolk than did the apparent viscosity of yolk containing no additive or fructose and frozen by either method.

The apparent viscosity of the frozen-defrosted yolk was not affected by pasteurization as compared to no pasteurization. The interaction between pasteurization versus no pasteurization and the presence versus the absence of an additive and the interaction between pasteurization versus no pasteurization and the addition of sodium chloride versus fructose were not significant.

Total solids. The method employed to determine total solids of the yolk was not applicable to yolk treated with fructose since this monosaccharide was oxidized in the 100°C temperature of the vacuum oven. Therefore, total solids were determined only for yolk containing no additive and yolk containing sodium chloride.

The total solids content was not significantly affected by pasteurization, freezing method or the interactions between pasteurization and additives or freezing method and additives (Table 3). The only significant source of variation was the presence versus the absence of an additive ($P \leq 0.001$). The addition of 6.5% sodium chloride resulted in an increase in total solids of approximately 3.5% (Table 5).

It may be assumed that the total solids of the yolk treated with fructose was approximately equal to that of the yolk treated with sodium chloride since the amount of each additive contained in the yolk was 6.5% by weight.

pH. The only analyzed sources of variation significantly affecting the pH of the yolk were the presence versus the absence of an additive ($P \leq 0.001$) and the addition of sodium chloride versus fructose ($P \leq 0.001$) (Table 3). The effects of pasteurization, freezing method, and the interactions among additives, pasteurization, and freezing method were not significant.

Whereas the difference in pH between yolk containing fructose and yolk containing no additive was not significant, the difference in pH between yolk treated with sodium chloride and yolk containing no additive was significant (Table 6). The pH difference between fructose-treated yolk and sodium chloride-treated yolk was also significant. The results indicated that the ionic sodium chloride was more effective in reducing the pH of the yolk than the nonionic fructose.

Color changes in the yolk. Visual observations of the color of the yolk prior to freezing indicated that the addition of sodium chloride caused the yolk to become oranger in color, darker, and more translucent. Similar results were reported by Jordan and Whitlock (1955). The yolk became somewhat darker and oranger in color upon the addition of fructose, but the color change caused by fructose was much less evident than the change caused by sodium chloride. All color changes observed in the unfrozen yolk were evident in the frozen-defrosted yolk. More specific information about the color differences in the frozen-defrosted yolk (reflectance, greenness, and yellowness) was obtained with the Gardner color difference meter.

Table 5. The mean total solids content (%) of the egg yolk containing no additive and the egg yolk containing sodium chloride.[1,2]

UP[3] NA[5] LN[7]	UP NA FC[8]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC
44.53	45.10	45.06	44.86	48.03	48.97	48.59	48.08
———				———	———	———	———
	———			———	———	———	———
		———		———	———	———	———
			———	———	———	———	———
				———	———		
					———		———

[1]LSD = 0.68.
[2]Underlined values differ significantly from the first underlined value on the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Frozen in liquid nitrogen.
[8]Frozen on freezer coils.

Table 6. The mean pH of the egg yolk for each treatment.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
6.917	6.932	6.931	6.921	6.900	6.895	6.900	6.894	6.928	6.920	6.922	6.927
___				___	___	___	___				
	___			___	___	___	___				
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			___	___	___	___	___				
				___				___	___	___	___
					___			___	___	___	___
						___		___	___	___	___
							___	___	___	___	___

[1]LSD = 0.016.
[2]Underlined values differ significantly from the first underlined value on the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

"Rd" value. "Rd" (reflectance) is a measure of the lightness or darkness of a sample. A "Rd" value of 100.00 indicates complete reflectance of light by a sample; a "Rd" value of 0.00 indicates complete absorbance of light by a sample.

The effects of the presence versus the absence of an additive ($P \leq 0.001$) and of the addition of fructose versus sodium chloride ($P \leq 0.001$) on the "Rd" value were significant (Table 7). The reflectance of the fructose-treated yolk was significantly less than that of yolk containing no additive (Table 8). The reflectance of the sodium chloride-treated yolk was significantly less than that of the yolk with no additive and the fructose-treated yolk. These results support the visual observations that the sodium chloride-treated yolk was darker than the fructose-treated yolk and the yolk with no additive and that the fructose-treated yolk was lighter than the sodium chloride-treated yolk, but darker than the yolk with no additive.

Reflectance was affected by the freezing method ($P \leq 0.05$). The effect of freezing method on the "Rd" value was more evident in the yolk containing no additive than in the yolk containing either sodium chloride or fructose. The reflectance of yolk containing no additive and frozen in liquid nitrogen was significantly less than the reflectance of yolk containing no additive and frozen on freezer coils. These results are in contradiction to findings reported by Pearce and Lavers (1949). These investigators noted that yolk frozen in 10 minutes was lighter in color than yolk frozen in 100 hours. The only other instance in which a significant difference in "Rd" value was observed between two treatments identical except for freezing method involved the pasteurized sodium chloride-treated yolk. For this yolk the "Rd" value was greater when the yolk was frozen in liquid nitrogen as compared to on freezer coils.

Table 7. The analyses of variance of the "Rd" values, the "-a" values, and the "+b" values of the egg yolk.

Source of variation	"Rd" value	"-a" value	"+b" value
Treatments	***	***	***
Pasteurization	ns	ns	ns
No additive versus some additive	***	***	***
Sodium Chloride versus fructose	***	**	***
Freezing method	*	**	ns
Pasteurization X no additive versus some additive interaction	ns	ns	ns
Pasteurization X sodium chloride versus fructose interaction	ns	ns	ns
Freezing method X no additive versus some additive interaction	***	***	*
Freezing method X sodium chloride versus fructose interaction	*	ns	ns
Blocks	ns	ns	ns

ns - Not significant.
* - Significant at the 0.05 probability level.
** - Significant at the 0.01 probability level.
*** - Significant at the 0.001 probability level.

Table 8. The mean "Rd" value of the egg yolk for each treatment.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr LN	UP Fr[7] FC	P Fr LN	P Fr FC
41.08	44.60	40.73	44.95	24.53	22.82	25.38	23.20	37.07	37.02	33.65	34.85
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[1]LSD = 2.02.
[2]Underlined values differ significantly from the first underlined value in the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

The interaction between freezing method and the presence versus the absence of an additive ($P \leq 0.001$) and the interaction between freezing method and the addition of sodium chloride versus fructose ($P \leq 0.05$) were both significant. The reflectance of yolk containing no additive was decreased whereas the reflectance of yolk treated with fructose or sodium chloride was increased when the freezing rate was more rapid (Fig. 5). The effect of the freezing method was also dependent on the additive present (Fig. 6). When the yolk was frozen in liquid nitrogen as compared to on the freezer coils, reflectance decreased slightly when the additive was fructose and increased when the additive was sodium chloride.

The effects of pasteurization and the interactions between pasteurization and additives were not significant.

The correlation coefficient (r) between the pH and the "Rd" value was 0.7613, indicating a direct relationship between these two factors. The r^2 value was 0.5796; therefore, 57.96% of the variability in the "Rd" value can be explained by the variability in the pH of the yolk.

<u>"-a" value</u>. The redness or greenness of a sample is indicated by the "a" value. The "a" value becomes more positive as the sample becomes redder and more negative as the sample becomes greener.

The effects of no additive versus an additive ($P \leq 0.001$) and the effects of the addition of sodium chloride versus fructose ($P \leq 0.01$) on the "-a" value were both significant (Table 7). The "-a" values for yolk containing no additive were significantly more negative than the "-a" values for yolk treated with fructose or sodium chloride (Table 9). Several of the "-a" values for the fructose-treated yolk were significantly more negative than the "-a" values for the sodium chloride-treated yolk.

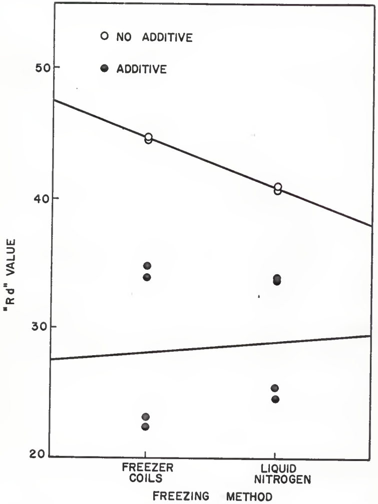

Figure 5. The interaction between the effects of freezing method and the presence versus the absence of an additive on the "Rd" value of the egg yolk.

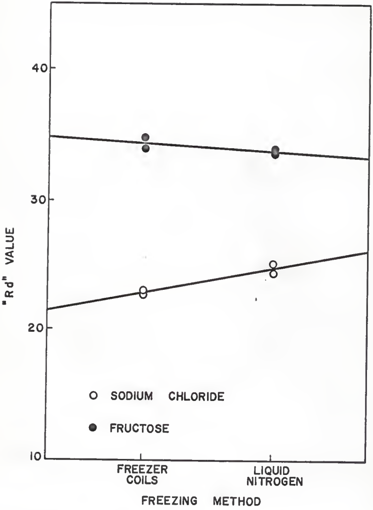

Figure 6. The interaction between the effects of freezing method and the addition of sodium chloride versus fructose on the "Rd" value of the egg yolk.

Table 9. The mean "-a" value of the egg yolk for each treatment.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
34.70	38.45	34.73	38.67	28.63	28.87	29.23	28.00	29.92	29.35	30.22	30.80
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[1]LSD = 1.66.
[2]Underlined values differ significantly from the first underlined value in the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

The "-a" value was affected by the freezing method ($P \leq 0.01$). The "-a" value of yolk containing no additive was more negative when the yolk was frozen on the freezer coils as compared to in the liquid nitrogen. Among the samples containing sodium chloride or fructose, none of the differences between samples treated identically except for freezing method were significant.

Whereas the interaction between freezing method and the addition of sodium chloride versus fructose was not significant, the interaction between freezing method and the presence versus the absence of an additive was significant ($P \leq 0.001$). The "-a" value became less negative for yolk containing no additive and slightly more negative for yolk treated with sodium chloride or fructose when the freezing rate was increased (Fig. 7).

The effect of pasteurization and its interaction with additives was not significant.

The correlation coefficient (r) between the pH and the "-a" value was 0.5506, somewhat less than the correlation coefficient between pH and the "Rd" value. The r^2 value of 0.3032 indicated that only 30.32% of the variability in the "-a" value can be explained by variability in the pH of the yolk.

"+b" value. The "b" value is a measure of the yellowness or blueness of a sample. The "b" value becomes more positive as the sample becomes more yellow and more negative as the sample becomes bluer.

Significant sources of variation in the "+b" value included the presence versus the absence of an additive ($P \leq 0.001$) and the addition of sodium chloride versus fructose ($P \leq 0.001$) (Table 7). The "+b" value for yolk treated with fructose was significantly less positive than the "+b" value for yolk containing no additive (Table 10). The "+b" value for yolk treated with sodium chloride was significantly less positive than that for yolk containing

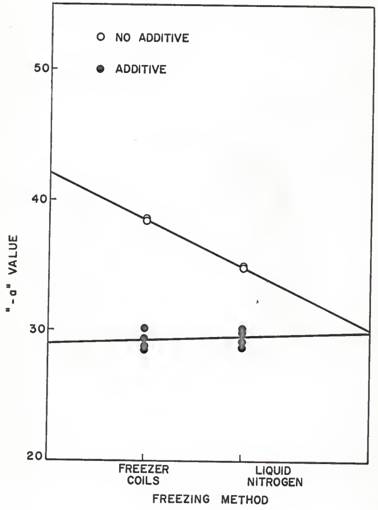

Figure 7. The interaction between the effects of freezing method and the presence versus the absence of an additive on the "-a" value of the egg yolk.

Table 10. The mean "+b" value of the egg yolk for each treatment.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
39.62	40.10	39.65	40.15	31.10	29.83	31.58	30.08	37.23	37.47	38.18	37.77
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[1] LSD = 1.27.
[2] Underlined values differ significantly from the first underlined value on the same row.
[3] Unpasteurized.
[4] Pasteurized.
[5] No additive.
[6] Sodium chloride added.
[7] Fructose added.
[8] Frozen in liquid nitrogen.
[9] Frozen on freezer coils.

no additive or yolk treated with fructose.

Although the effect of the freezing method was not significant, the interaction between the presence versus the absence of an additive and the freezing method was significant ($P \leq 0.05$). An increase in freezing rate was accompanied by a slight decrease in the "+b" value of yolk containing no additive and an increase in the "+b" value of yolk treated with sodium chloride or fructose (Fig. 8).

The "+b" value was not significantly affected by the interaction between the freezing method and the addition of sodium chloride versus fructose, pasteurization or the interactions between pasteurization and additives.

The correlation coefficient (r) between pH and the "+b" value was 0.8262. The correlation between pH and the "+b" value was greater than that between pH and either the "Rd" value or the "-a" value. The r^2 value was 0.6825. Thus, 68.25% of the variability in the "+b" value can be explained by the variability in the pH of the yolk.

ΔE. The ΔE (total color difference) was calculated between samples treated identically except for the freezing method and between samples frozen by the same method, but differing in pasteurization and/or additives. The color differences between samples treated identically except for freezing method were smallest when the yolk contained fructose (0.56 for unpasteurized yolk, 1.26 for pasteurized yolk), largest when it contained no additive (4.80 for unpasteurized yolk, 5.29 for pasteurized yolk) and intermediate when it contained sodium chloride (2.24 for unpasteurized yolk, 4.12 for pasteurized yolk) (Table 11). A tendency for these differences to be somewhat more pronounced for the pasteurized yolk than for the unpasteurized yolk was noted.

The ΔE was less than 3.00 for all comparisons between samples frozen by

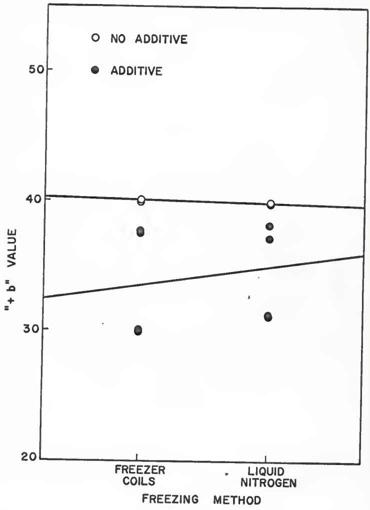

Figure 8. The interaction between the effects of freezing method and the presence versus the absence of an additive on the "+b" value of the egg yolk.

Table 11. The color difference (ΔE) between samples treated identically except for freezing method.

Treatments			ΔE
UP[1], NA[3], LN[6]	vs	UP, NA, FC[7]	4.80
P[2], NA, LN	vs	P, NA, FC	5.29
UP, Fr[4], LN	vs	UP, Fr, FC	0.56
P, Fr, LN	vs	P, Fr, FC	1.26
UP, NaCl[5], LN	vs	UP, NaCl, FC	2.24
P, NaCl, LN	vs	P, NaCl, FC	4.12

[1]Unpasteurized.
[2]Pasteurized.
[3]No additive.
[4]Fructose added.
[5]Sodium chloride added.
[6]Frozen in liquid nitrogen.
[7]Frozen on freezer coils.

the same method and containing the same additive (Table 12). This observation indicated that the color differences between unpasteurized and pasteurized yolk were small enough for the yolk to be described as acceptable commercial matches. The color differences between yolk differing only in the presence or absence of an additive were greatest when the additive was sodium chloride (19.34 and 17.92 for unpasteurized and pasteurized yolk, respectively, frozen in liquid nitrogen and 25.50 and 26.74 for unpasteurized and pasteurized yolk, respectively, frozen on freezer coils) and smallest when the additive was fructose (8.37 and 8.00 for unpasteurized and pasteurized yolk, respectively, frozen in liquid nitrogen and 13.41 and 12.17 for unpasteurized and pasteurized yolk, respectively, frozen on freezer coils). With the exception of the sodium chloride-treated yolk frozen on the freezer coils, the color differences between yolk with and without an additive were somewhat greater when the yolk was unpasteurized rather than pasteurized.

Measurements Relating to the Functional Properties of the Egg Yolk

The functional properties of the egg yolk were investigated in emulsions and sponge cakes. Objective measurements of the sponge cakes included the specific gravity of the batter and the volume and compressibility of the cakes. Subjective evaluation of the exterior of the cakes included shape, crust, and brownness. The interior of the cakes was evaluated for flavor, texture, grain, crumb color, and over-all acceptability. The original data on the functional properties are presented on Table 32 to 35 in the Appendix. The analyses of variance of these data are presented in Table 36 in the Appendix.

Emulsifying ability. The stability of the egg yolk, oil, and water emulsions was a measure of the emulsifying ability of the frozen-defrosted yolk. Emulsion stability was inversely related to the percentage of separation of the

Table 12. The color difference (ΔE) between samples frozen by the same method.

Treatments			ΔE
Comparisons of samples frozen on freezer coils			
UP[1], NA[3], FC[6]	vs	P[2], NA, FC	0.36
UP, Fr[4], FC	vs	UP, NA, FC	13.41
P, Fr, FC	vs	P, NA, FC	12.17
P, Fr, FC	vs	UP, Fr, FC	1.69
UP, NaCl[5], FC	vs	UP, NA, FC	25.50
P, NaCl, FC	vs	P, NA, FC	26.74
P, NaCl, FC	vs	UP, NaCl, FC	1.22
Comparisons of samples frozen in liquid nitrogen			
UP, NA, LN[7]	vs	P, NA, LN	0.28
UP, Fr, LN	vs	UP, NA, LN	8.37
P, Fr, LN	vs	P, NA, LN	8.00
P, Fr, LN	vs	UP, Fr, LN	0.94
UP, NaCl, LN	vs	UP, NA, LN	19.34
P, NaCl, LN	vs	P, NA, LN	17.92
P, NaCl, LN	vs	UP, NaCl, LN	1.24

[1]Unpasteurized.
[2]Pasteurized.
[3]No additive.
[4]Fructose added.
[5]Sodium chloride added.
[6]Frozen on freezer coils.
[7]Frozen in liquid nitrogen.

oil and aqueous phases of the emulsions.

The effects of the presence versus the absence of an additive on emulsion stability were not significant (Table 13). However, the emulsifying ability of the yolk varied with the addition of sodium chloride versus fructose ($P \leq 0.001$).

The observation that none of the emulsions made with sodium chloride-treated yolk "broke" indicates that the emulsifying ability of the yolk was greater when it contained sodium chloride rather than no additive (Table 14). Jordan (1962) also reported that the addition of 3.3 to 4.8% sodium chloride to yolk increased the stability of emulsions made with the unfrozen yolk, corn oil, and deionized water.

In contrast to the effect of sodium chloride, emulsion stability was decreased when the yolk contained fructose rather than no additive. Approximately two ml of the aqueous phase separated from the emulsions made with fructose-treated yolk within 30 minutes at room temperature after the emulsions were formed. Only approximately one ml of the aqueous phase separated from the emulsions made with yolk containing no additive within this time interval. A curdled appearance was also evident after the first 30 minutes in the emulsions made with fructose-treated yolk and yolk containing no additive. Of interest is the observation that when the emulsifying period was increased from 90 to 105 seconds, the emulsions made with fructose-treated yolk "broke" while being emulsified with the Virtis homogenizer. The nonionic fructose therefore decreased the emulsifying ability of the yolk whereas the ionic sodium chloride increased the emulsifying ability.

The emulsifying ability of the yolk was affected by the method of freezing the yolk ($P \leq 0.01$). The separation of emulsions made with unpasteurized yolk containing no additive and unpasteurized fructose-treated yolk increased from 7.76 to 12.96% and 18.59 to 26.73%, respectively, when the freezing rate was

Table 13. The analyses of variance of the emulsifying ability of the egg yolk, the specific gravity of the sponge cake batter, and the volume of the sponge cakes.

Source of variation	Emulsifying ability	Specific Gravity	Volume
Treatments	***	***	***
Pasteurization	ns	ns	ns
No additive versus some additive	ns	***	***
Sodium chloride versus fructose	***	*	***
Freezing method	**	***	**
Pasteurization X no additive versus some additive interaction	ns	ns	ns
Pasteurization X sodium chloride versus fructose interaction	ns	ns	ns
Freezing method X no additive versus some additive interaction	ns	*	ns
Freezing method X sodium chloride versus fructose interaction	*	*	ns
Blocks	*	ns	*

ns - Not significant.
* - Significant at the 0.05 probability level.
** - Significant at the 0.01 probability level.
*** - Significant at the 0.001 probability level.

Table 14. The mean values for the separation (%) of the emulsions.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
12.97	7.76	8.61	8.72	0.00	0.00	0.00	0.00	26.73	18.59	22.17	19.42
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[1]LSD = 3.99.
[2]Underlined values differ significantly from the first underlined value on the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

increased. The effect of freezing rate was not significant for pasteurized yolk containing no additive, pasteurized, fructose-treated yolk and pasteurized and unpasteurized sodium chloride-treated yolk.

The interaction between the freezing method and the addition of sodium chloride versus fructose was significant ($P \leq 0.05$). The stability of emulsions made with sodium chloride-treated yolk remained constant and the stability of emulsions made with fructose-treated yolk decreased when the yolk was frozen in liquid nitrogen as compared to on freezer coils (Fig. 9).

Emulsion stability was not affected by pasteurization of the egg yolk. The interactions between pasteurization and additives and between the freezing method and the presence versus the absence of an additive were not significant.

The differences in emulsion stability among blocks were significant ($P \leq 0.05$). The emulsions made with unpasteurized yolk containing no additive and frozen in liquid nitrogen, pasteurized yolk containing no additive and frozen on freezer coils, unpasteurized, fructose-treated yolk frozen on freezer coils, and pasteurized, fructose-treated yolk frozen in liquid nitrogen exhibited greater separation when the storage time was increased from 35 to 47 days (Table 32). The percentage of separation of emulsions made with pasteurized, fructose-treated yolk frozen on freezer coils decreased when the storage time was increased from 33 to 49 days.

The correlation coefficient (r) between the emulsion separation (%) and the pH was 0.6604. The r^2 value of 0.4361 indicated that 43.61% of the variability in emulsion stability can be explained by the variability in the pH of the yolk.

<u>Ease of incorporation of the yolk into the batter.</u> Difficulty was encountered in distributing the yolk containing no additive uniformly throughout the sponge cake batter. When the yolk, water, and sodium chloride mixture

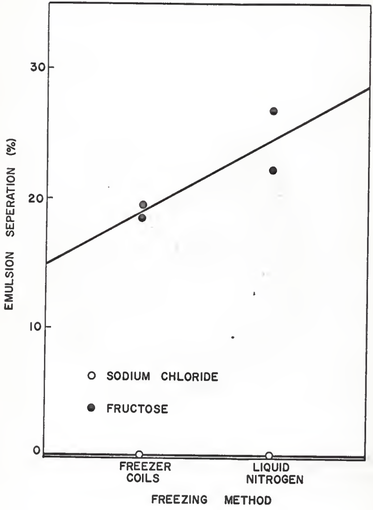

Figure 9. The interaction between the effects of freezing method and the addition of sodium chloride versus fructose on the separation of the emulsions.

was beaten with the Kitchen Aid mixer, part of the yolk remained on the sides and bottom of the mixing bowl. After the remaining ingredients were added and mixing was completed, some yolk was still visible on the sides of the bowl and small flecks of yolk were observed in the batter.

The difficulty in incorporating the yolk into the batter was, in part, a result of the increased apparent viscosity of the frozen-defrosted yolk. Since the apparent viscosity of the yolk containing no additive decreased as the freezing rate increased, the yolk frozen in liquid nitrogen was more easily incorporated into the batter than the yolk frozen on freezer coils.

No difficulty was encountered in incorporating the sodium chloride-treated and fructose-treated yolk into the batter.

Specific gravity. The presence versus the absence of an additive in the yolk ($P \leq 0.001$) and the addition of sodium chloride versus fructose to the yolk ($P \leq 0.05$) affected the specific gravity of the sponge cake batter (Table 13). The specific gravity of batter made with sodium chloride-treated yolk was significantly less than that of batter made with yolk containing no additive (Table 15). The specific gravity of batter made with fructose-treated yolk was significantly less than that of batter made with either sodium chloride-treated yolk or yolk containing no additive.

The effect of the method of freezing the yolk on the specific gravity of the batter was significant ($P \leq 0.001$). When the batter was made with yolk containing no additive or fructose-treated yolk, the specific gravity was less when the yolk was frozen in liquid nitrogen as compared to on freezer coils. The differences in the specific gravity of batter made with sodium chloride-treated yolk frozen by both methods were not significant.

The interaction between the freezing method and the presence versus the absence of an additive ($P \leq 0.05$) and the interaction between the freezing

Table 15. The mean specific gravity values for the sponge cake batter.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
.4707	.5263	.4805	.5194	.4427	.4433	.4467	.4512	.4117	.4467	.4209	.4524
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[1]LSD = 0.0256.
[2]Underlined values differ significantly from the first underlined value in the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

method and the addition of sodium chloride versus fructose ($P \leq 0.05$) were significant. The decrease in the specific gravity of the batter with an increase in freezing rate was greater when the batter was made with yolk containing no additive as compared to yolk treated with sodium chloride or fructose (Fig. 10). An increase in freezing rate resulted in a slight decrease in the specific gravity of batter made with sodium chloride-treated yolk and a greater decrease in the specific gravity of batter made with fructose-treated yolk (Fig. 11).

The effects of pasteurization and the interactions between pasteurization and additives were not significant. The correlation coefficient (r) between specific gravity of the sponge cake batter and the apparent viscosity of the frozen-defrosted yolk was 0.8904. The r^2 value was 0.7928. Thus, 79.28% of the variability in the specific gravity can be explained by the variability in the apparent viscosity.

Volume. Significant sources of variation in the volume of the sponge cakes included the presence versus the absence of an additive ($P \leq 0.001$), the addition of sodium chloride versus fructose ($P \leq 0.001$), and the freezing method ($P \leq 0.01$) (Table 13).

Cakes made with sodium chloride-treated yolk were largest in volume whereas those made with yolk containing no additive were smallest in volume (Table 16). The fructose-treated yolk produced cakes intermediate in volume. Jordan et al. (1952a) also observed that sponge cakes made with frozen-defrosted yolk treated with 2.5 and 5.0% sodium chloride were larger in volume than cakes made with frozen-defrosted untreated yolk.

The volume of cakes made with pasteurized yolk containing no additive and unpasteurized, fructose-treated yolk was greater when the yolk was frozen in

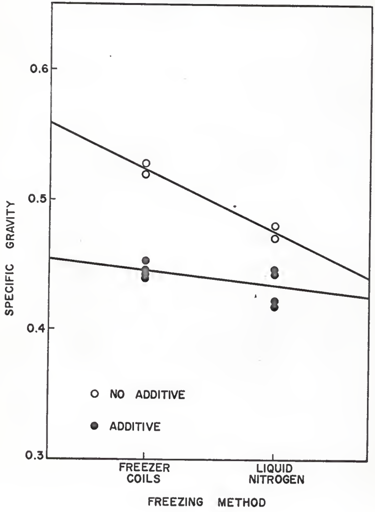

Figure 10. The interaction between the effects of freezing method and the presence versus the absence of an additive on the specific gravity of the sponge cake batter.

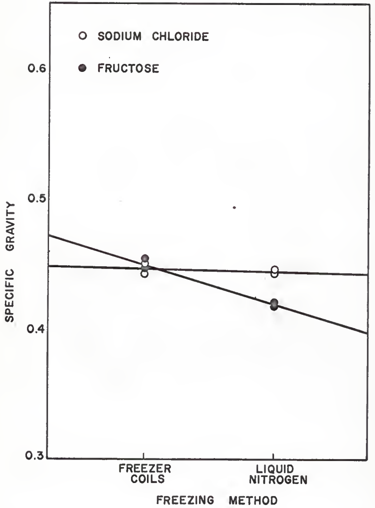

Figure 11. The interaction between the effects of freezing method and the addition of sodium chloride versus fructose on the specific gravity of the sponge cake batter.

Table 16. The mean values for the volume (ml) of the sponge cakes.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
548.33	530.00	560.00	525.00	660.00	661.67	671.67	648.33	610.00	573.33	600.00	598.33
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[1] LSD = 29.25.
[2] Underlined values differ significantly from the first underlined value in the same row.
[3] Unpasteurized.
[4] Pasteurized.
[5] No additive.
[6] Sodium chloride added.
[7] Fructose added.
[8] Frozen in liquid nitrogen.
[9] Frozen on freezer coils.

liquid nitrogen as compared on freezer coils. Other differences in the volume of cakes made with yolk treated identically except for freezing method were not significant.

The effects of pasteurization and the interactions between pasteurization and additives and between freezing method and additives were not significant.

The variations among blocks were significant ($P \leq 0.05$); no definite trend was observed in these variations (Table 32).

Shape. The analysis of variance revealed that the differences in the shape of the sponge cakes were not significant. However, when the total variability attributed to treatments was partitioned into the single component sources of variation, the effects of the presence versus the absence of an additive ($P \leq 0.01$) and of the addition of sodium chloride versus fructose were significant ($P \leq 0.05$) (Table 17).

The scores for the shape of the cakes made with sodium chloride-treated yolk were highest, the scores for the cakes made with yolk containing no additive were lowest, and the scores for the cakes made with fructose-treated yolk were intermediate (Table 18). As indicated previously, none of these differences were statistically significant.

The variation among blocks was significant ($P \leq 0.001$). The scores for the shape of the cakes tended to decrease as the storage time of the yolk increased (Table 33). No explanation is available for these results.

Crust. The scores for the crust of the sponge cakes varied with the presence versus the absence of an additive ($P \leq 0.001$) and the addition of sodium chloride versus fructose ($P \leq 0.001$) (Table 17). The crust of cakes made with sodium chloride-treated yolk was most acceptable, the crust of cakes made with yolk containing no additive was least acceptable, and the crust of

Table 17. The analyses of variance of the shape, crust, and brownness of the whole sponge cakes.

Source of Variation	Shape	Crust	Brownness
Treatments	ns	**	**
Pasteurization	ns	ns	ns
No additive versus some additive	**	***	***
Sodium chloride versus fructose	*	***	*
Freezing method	ns	ns	ns
Pasteurization X no additive versus some additive interaction	ns	ns	ns
Pasteurization X sodium chloride versus fructose interaction	ns	ns	ns
Freezing method X no additive versus some additive interaction	ns	ns	ns
Freezing method X sodium chloride versus fructose interaction	ns	ns	ns
Blocks	***	ns	ns

ns - Not significant.
* - Significant at the 0.05 probability level.
** - Significant at the 0.01 probability level.
*** - Significant at the 0.001 probability level.

Table 18. The mean values for the shape of the sponge cakes.[1]

UP[2] NA[4] LN[7]	UP NA FC[8]	P[3] NA LN	P NA FC	UP NaCl[5] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[6] LN	UP Fr FC	P Fr LN	P Fr FC
4.72	5.17	5.50	4.83	5.67	5.67	5.50	5.50	5.39	5.00	5.28	5.33

[1]LSD not significant.
[2]Unpasteurized.
[3]Pasteurized.
[4]No additive.
[5]Sodium chloride added.
[6]Fructose added.
[7]Frozen in liquid nitrogen.
[8]Frozen on freezer coils.

cakes made with fructose-treated yolk was intermediate in acceptability (Table 19). The crust of the cakes made with sodium chloride-treated yolk was coarser in appearance than the crust of the other cakes.

The effects of pasteurization and the method of freezing the yolk and the interactions between pasteurization and additives and between the method of freezing the yolk and additives were not significant.

Brownness. The presence versus the absence of an additive ($P \leq 0.001$) and the addition of sodium chloride versus fructose ($P \leq 0.05$) were significant sources of variation in the scores for the brownness of the sponge cakes (Table 17). The judges tended to describe the color of the cakes made with yolk containing no additive as medium golden brown, the color of the cakes made with sodium chloride-treated yolk as dark golden brown, and the color of the cakes made with fructose-treated yolk as very dark golden brown (Table 20). Possible explanations for the greater brownness of the latter cakes include carmelization of the fructose and the Maillard reaction acting either singly or in combination with each other.

The scores for the brownness of the cakes were not significantly affected

Table 19. The mean values for the crust of the sponge cakes.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
4.00	3.78	4.28	3.39	5.50	5.44	5.44	5.72	4.44	4.06	4.67	4.61
———				———	———	———	———				
	———			———	———	———	———				
		———		———	———	———	———				
			———	———	———	———	———			———	———
				———					———		
					———				———		
						———			———		
							———	———	———		

[1]LSD = 1.12.
[2]Underlined values differ significantly from the first underlined value in the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

Table 20. The mean values for the brownness of the sponge cakes.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
4.56	4.28	4.61	4.28	5.33	5.00	5.33	5.39	5.94	5.89	5.72	5.61
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	—			—		—	—	—	—	—	—
		—						—	—	—	—
			—	—		—	—	—	—	—	—

[1]LSD = 0.98.
[2]Underlined values differ significantly from the first underlined value in the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

by pasteurization or the freezing method. The interactions between pasteurization and additives and between freezing method and additives were not significant.

Compressibility. The compressibility of the one inch slices of the sponge cakes was significantly affected by the presence versus the absence of an additive ($P \leq 0.001$) and the addition of sodium chloride versus fructose ($P \leq 0.001$) (Table 21). The weight required to depress the surface of the cake slice four mm was greatest for the cakes made with yolk containing no additive (Table 22). Decreasingly less weight was required when the cakes were made with yolk treated with fructose and sodium chloride, respectively.

The compressibility of the cakes was not significantly affected by pasteurization or the method of freezing the yolk. However, the interactions between pasteurization and the presence versus the absence of an additive ($P \leq 0.05$) and

Table 21. The analyses of variance of the compressibility, texture, and grain of the sponge cakes.

Source of variation	Compressibility	Texture	Grain
Treatments	***	ns	ns
Pasteurization	ns	ns	ns
No additive versus some additive	***	*	*
Sodium chloride versus fructose	***	ns	ns
Freezing method	ns	ns	ns
Pasteurization X no additive versus some additive interaction	*	ns	ns
Pasteurization X sodium chloride versus fructose interaction	ns	ns	ns
Freezing method X no additive versus some additive interaction	**	ns	ns
Freezing method X sodium chloride versus fructose interaction	ns	ns	ns
Blocks	*	ns	**

ns - Not significant.
* - Significant at the 0.05 probability level.
** - Significant at the 0.01 probability level.
*** - Significant at the 0.001 probability level.

Table 22. The mean values for the compressibility (g) of the sponge cakes.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
212.00	214.50	209.33	244.33	145.00	138.33	132.67	138.50	170.83	166.83	171.83	169.33
___		___	___	___	___	___	___	___	___	___	___
	___		___	___	___	___	___	___	___	___	___
		___	___	___	___	___	___	___	___	___	___
			___	___	___	___	___	___	___	___	___
				___				___	___	___	___
					___			___	___	___	___
						___		___	___	___	___
							___	___	___	___	___

[1]LSD = 16.46.
[2]Underlined values differ significantly from the first underlined value in the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

between the method of freezing the yolk and the presence versus the absence of an additive ($P \leq 0.01$) were significant. An increase was noted in the compressibility values of cakes made with yolk containing no additive and a decrease was noted in the compressibility values of cakes made with yolk containing an additive when the yolk was pasteurized rather than unpasteurized (Fig. 12). When the yolk was frozen in liquid nitrogen rather than on freezer coils, the compressibility values decreased for cakes made with yolk containing no additive and increased slightly for cakes made with yolk containing an additive (Fig. 13).

The interactions between pasteurization and the addition of sodium chloride versus fructose and between the freezing method and the addition of sodium chloride versus fructose were not significant.

The variation in the compressibility values among replications was significant ($P \leq 0.05$). However, no definite trend was noted in these differences (Table 37).

Texture. The variation in the organoleptic scores for the texture of the cakes among treatments was not statistically significant (Table 21). However, a partitioning of the total variation attributed to treatments into the component sources of variation indicated that the effect of the presence versus the absence of an additive in the yolk was significant ($P \leq 0.05$). The scores for the texture of the cakes made with yolk containing an additive were higher than those for cakes made with yolk containing no additive (Table 23). However, the differences in these scores were not statistically significant.

The scores for the texture of the cakes were not significantly affected by the addition of sodium chloride versus fructose, pasteurization or freezing method. The interactions between pasteurization and additives and between

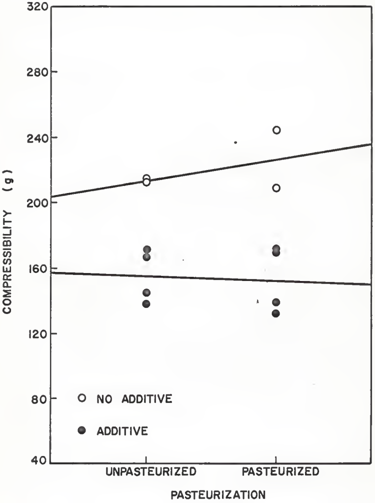

Figure 12. The interaction between pasteurization and the presence versus the absence of an additive on the compressibility of the sponge cakes.

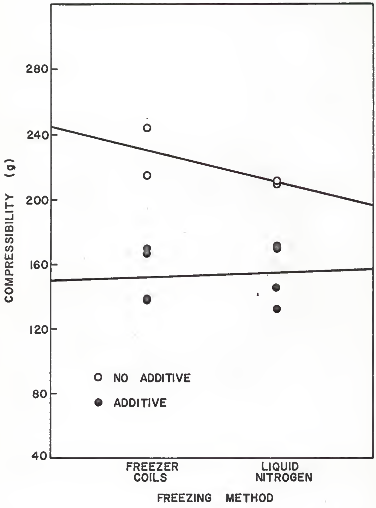

Figure 13. The interaction between the effects of the freezing method and the presence versus the absence of an additive on the compressibility of the sponge cakes.

Table 23. The mean values for the texture of the sponge cakes.[1]

UP[2] NA[4] LN[7]	UP NA FC[9]	P[3] NA LN	P NA FC	UP NaCl[5] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[6] LN	UP Fr FC	P Fr LN	P Fr FC
5.36	4.79	4.71	4.92	5.24	5.27	5.06	4.92	5.44	5.02	5.46	5.16

[1]LSD not significant.
[2]Unpasteurized.
[3]Pasteurized.
[4]No additive.
[5]Sodium chloride added.
[6]Fructose added.
[7]Frozen in liquid nitrogen.
[8]Frozen on freezer coils.

freezing method and additives were also not significant.

The correlation coefficient between the texture scores and the compressibility values was -0.2587, indicating a relatively weak inverse relationship between these factors.

Grain. The analysis of variance indicated that the variation in the scores for the grain of the cakes attributed to treatments was not significant. Of the component sources of variation among treatments, the presence versus the absence of an additive was significant ($P \leq 0.05$) (Table 21). Although the differences were not statistically significant, the scores for the grain of the cakes made with yolk containing no additive were slightly higher than those for cakes made with yolk containing fructose (Table 24). The sodium chloride-treated yolk produced cakes with the least desirable grain.

The effects of the addition of sodium chloride versus fructose, pasteurization, and freezing method and the interactions between pasteurization and additives and between freezing method and additives were not significant.

The differences in the scores for the grain of the cakes among replications were significant ($P \leq 0.01$). The scores tended to increase as the

Table 24. The mean values for the grain of the sponge cakes.[1]

UP[2] NA[4] LN[7]	UP NA FC[8]	P[3] NA LN	P NA FC	UP NaCl[5] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[6] LN	UP Fr FC	P Fr LN	P Fr FC
5.40	5.09	4.85	5.39	4.79	4.80	4.59	5.25	4.99	5.13	5.03	4.95

[1]LSD not significant.
[2]Unpasteurized.
[3]Pasteurized.
[4]No additive.
[5]Sodium chloride added.
[6]Fructose added.
[7]Frozen in liquid nitrogen.
[8]Frozen on freezer coils.

storage period of the yolk became longer (Table 37). No explanation is available for these results.

Color of the crumb. The differences in the scores for the color of the sponge cake crumb were not statistically significant (Tables 25 and 26). The variation in the color of the frozen-defrosted yolk was not evident in the cakes. As indicated previously, small flecks of yolk were noticeable in the sponge cake batter made with yolk containing no additive. Flecks of yolk were also slightly visible in the cakes made with this batter.

The variation in the scores for crumb color desirability among blocks was significant ($P \leq 0.001$). A tendency for the scores to increase as the length of storage increased was noted (Table 25). No explanation is available for this observation.

Flavor. Significant sources of variation in the scores for the flavor of the sponge cakes were the presence versus the absence of an additive in the yolk ($P \leq 0.001$) and the addition of sodium chloride versus fructose to the yolk ($P \leq 0.001$) (Table 25). Although the differences were not statistically

Table 25. The analyses of variance of the crumb color, flavor, and over-all acceptability of the sponge cakes.

Source of variation	Crumb Color	Flavor	Over-all Acceptability
Treatments	ns	***	***
Pasteurization	ns	ns	ns
No additive versus some additive	ns	***	***
Sodium chloride versus fructose	ns	***	***
Freezing method	ns	ns	ns
Pasteurization X no additive versus some additive interaction	ns	ns	ns
Pasteurization X sodium chloride versus fructose interaction	ns	ns	ns
Freezing method X no additive versus some additive interaction	ns	ns	ns
Freezing method X sodium chloride versus fructose interaction	ns	ns	ns
Blocks	***	ns	*

ns - Not significant.
* - Significant at the 0.05 probability level.
** - Significant at the 0.01 probability level.
*** - Significant at the 0.001 probability level.

Table 26. The mean value for the color of the crumb of the sponge cakes.[1]

UP[2] NA[4] LN[7]	UP NA FC[8]	P[3] NA LN	P NA FC	UP NaCl[5] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[6] LN	UP Fr FC	P Fr LN	P Fr FC
5.91	5.89	5.89	5.81	5.88	5.80	5.73	5.96	5.80	5.88	5.83	5.76

[1]LSD not significant.
[2]Unpasteurized.
[3]Pasteurized.
[4]No additive.
[5]Sodium chloride added.
[6]Fructose added.
[7]Frozen in liquid nitrogen.
[8]Frozen on freezer coils.

significant, the scores for the flavor of the cakes made with yolk containing no additive were slightly higher than those for the cakes made with fructose-treated yolk (Table 27). The fructose imparted an extremely sweet flavor to the cakes containing this additive. The scores for cakes made with yolk containing no additive and fructose-treated yolk were significantly higher than those for the cakes made with sodium chloride-treated yolk. The sodium chloride in the yolk caused the cakes to be undesirably salty in flavor. Jordan et al. (1952a) also reported that the flavor of sponge cakes made with frozen-defrosted yolk treated with 5% sodium chloride was too salty to be acceptable.

The scores for flavor were not significantly affected by pasteurization or the freezing method. The interactions between pasteurization and additives and between freezing method and additives were also not significant.

Over-all acceptability. The over-all acceptability scores for the sponge cakes were significantly affected by the presence versus the absence of an additive in the yolk ($P \leq 0.001$) and by the addition of sodium chloride versus fructose to the yolk ($P \leq 0.001$) (Table 25). The scores for the over-all acceptability of the cakes made with yolk containing no additive and

Table 27. The mean value for the flavor of the sponge cakes.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
5.43	5.21	4.89	5.02	2.64	2.50	2.70	2.92	4.76	5.00	4.75	4.91
———				———	———	———	———				
	———			———	———	———	———				
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			———	———	———	———	———				
				———				———	———	———	———
					———			———	———	———	———
						———		———	———	———	———
							———	———	———	———	———

[1]LSD = 0.77.
[2]Underlined values differ significantly from the first underlined value in the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No Additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

fructose-treated yolk were significantly higher than those for cakes made with sodium chloride-treated yolk (Table 28). The cakes made with yolk containing no additive were scored somewhat higher than were the cakes made with fructose-treated yolk. However, the latter differences were not statistically significant. The similarity in the scores for over-all acceptability and flavor suggests that flavor may have been the major factor in evaluating the over-all acceptability of the sponge cakes.

The effects of pasteurization and the method of freezing the yolk and the

Table 28. The mean values for the over-all acceptability of the sponge cakes.[1,2]

UP[3] NA[5] LN[8]	UP NA FC[9]	P[4] NA LN	P NA FC	UP NaCl[6] LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr[7] LN	UP Fr FC	P Fr LN	P Fr FC
5.57	5.01	4.84	5.18	3.59	3.34	3.35	3.61	4.73	5.33	5.09	4.92
—		—		—	—	—	—	—			—
	—			—	—	—	—				
		—		—	—	—	—				
			—	—	—	—	—				
				—				—	—	—	—
					—			—	—	—	—
						—		—	—	—	—
							—	—	—	—	—

[1]LSD = 0.65.
[2]Underlined values differ significantly from the first underlined value in the same row.
[3]Unpasteurized.
[4]Pasteurized.
[5]No additive.
[6]Sodium chloride added.
[7]Fructose added.
[8]Frozen in liquid nitrogen.
[9]Frozen on freezer coils.

interactions between pasteurization and additives and between freezing method and additives were not significant. The differences in the over-all acceptability scores among replications were significant ($P \leq 0.05$). No trend was noted in the variations, however (Table 35).

SUMMARY

Gelation (i.e., the increase in apparent viscosity) of the frozen-defrosted egg yolk was reduced by the addition of 6.5% sodium chloride or fructose prior to freezing. Increasing the freezing rate was more effective in reducing the gelation of yolk containing no additive than of yolk treated with an additive.

The addition of 6.5% sodium chloride increased the total solids of the yolk by approximately 3.5%. The pH of the yolk was reduced by the addition of sodium chloride and to a lesser extent by the addition of fructose.

The yolk containing an additive, especially sodium chloride, was oranger in color and darker than yolk containing no additive. Yolk containing no additive was oranger and darker when frozen in liquid nitrogen as compared to being frozen on the freezer coils of a household type freezer.

The emulsifying ability of the yolk was increased by sodium chloride and decreased by fructose. Increasing the freezing rate decreased the emulsifying ability of unpasteurized yolk containing no additive or fructose.

Yolk treated with an additive produced a sponge cake batter of lower specific gravity than did yolk containing no additive. The specific gravity of the batter was lower when the yolk containing no additive and the yolk treated with fructose was frozen in liquid nitrogen as compared to being frozen on freezer coils.

The volume of sponge cakes was largest when the yolk contained sodium chloride, smallest when it contained no additive, and intermediate when it contained fructose. The crust of cakes made with yolk treated with an additive as compared to yolk containing no additive was more desirable and darker in color. Yolk containing no additive or fructose produced cakes of greater over-all acceptability than did yolk treated with sodium chloride. Fructose imparted an extremely sweet flavor and sodium chloride an undesirably salty

flavor to the cakes. The compressibility of cakes made with fructose-treated yolk and especially sodium chloride-treated yolk was greater than that of cakes made with yolk containing no additive. The differences in the scores for shape, texture, grain, and crumb color were not statistically significant.

Pasteurization of the yolk did not affect the physical characteristics and functional properties investigated.

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APPENDIX

Explanation of Abbreviations and Symbols in the Appendix

Treatments

UP	- Unpasteurized
P	- Pasteurized
NA	- No additive
NaCl	- Sodium chloride added
Fr	- Fructose added
LN	- Frozen in liquid nitrogen
FC	- Frozen on freezer coils

Significance of the F values

ns	- Not Significant
*	- Significant at the 0.05 probability level
**	- Significant at the 0.01 probability level
***	- Significant at the 0.001 probability level

Apparent viscosity, total solids, "Rd", "-a", +b", and compressibility values presented are the averages of duplicate measurements.

Table 29. The 2 x 2 x 3 factorial design, indicating which 6 samples of each replication were tested in each block.

Block					
1a[1]	1b	2a	2b	3a	3b
001	000	000	001	000	001
100	101	101	100	101	100
010	011	011	010	010	011
111	110	110	111	111	110
020	021	020	021	021	020
121	120	121	120	120	121

Treatment	Symbol
Unpasteurized, no additive, liquid nitrogen	000
Unpasteurized, no additive, freezer coils	001
Unpasteurized, sodium chloride, liquid nitrogen	010
Unpasteurized, sodium chloride, freezer coils	011
Unpasteurized, fructose, liquid nitrogen	020
Unpasteurized, fructose, freezer coils	021
Pasteurized, no additive, liquid nitrogen	100
Pasteurized, no additive, freezer coils	101
Pasteurized, sodium chloride, liquid nitrogen	110
Pasteurized, sodium chloride, freezer coils	111
Pasteurized, fructose, liquid nitrogen	120
Pasteurized, fructose, freezer coils	121

[1]a and b refer to the first and second halves, respectively, of each of the three replications.

	1	2	3	4	5	6	Comments
Shape - regular, slightly rounded							
Crust - not too smooth, crusty, or sticky; free from spots; not moist, shiny appearance; free from cracks							
Degree of brownness							

Scale for crust and shape:

7 - Excellent
6 - Very good
5 - Good
4 - Fairly good
3 - Fair
2 - Poor
1 - Very poor

Scale for degree of borwnness:

7 - Extremely dark golden brown
6 - Very dark golden brown
5 - Dark golden brown
4 - Medium golden brown
3 - Light golden brown
2 - Very light golden brown
1 - Extremely light golden brown

Figure 14. Score card for the exterior of sponge cakes.

	1	2	3	4	5	6	Comments
Grain - cells small, uniform and with thin walls; free from large air spaces, no compact layer							
Texture - tender, moist, feathery, light in weight for size, not compact or soggy							
Color of orumb - light yellow with no flecks of yellow, not grey or off-oolor							
Flavor - light, delioate							
Over-all acceptability							

7 - Excellent
6 - Very Good
5 - Good
4 - Fairly Good

3 - Fair
2 - Poor
1 - Very Poor

Figure 15. Soore card for the interior of sponge cakes.

Table 30. The apparent viscosity (poises), total solids (%) and pH of the egg yolk.[1]

Replication	Treatment											
	UP NA LN	UP NA FC	P NA LN	P NA FC	UP NaCl LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr LN	UP Fr FC	P Fr LN	P Fr FC
Apparent viscosity												
1	597.44	1562.17	864.14	1371.67	15.07	17.70	23.24	17.90	5.04	51.07	8.60	46.52
2	650.77	1493.58	866.81	1508.81	24.60	23.31	16.55	13.52	8.05	31.26	8.20	37.04
3	786.78	1478.36	760.10	1539.30	13.18	18.05	18.92	18.71	6.88	31.01	8.00	57.71
Mean	678.33	1511.37	830.35	1473.26	17.62	19.69	19.57	16.71	6.66	37.78	8.27	47.09
Total solids												
1	44.88	45.32	44.92	44.96	47.93	48.46	48.84	47.80	45.29	44.74	44.85	44.67
2	44.39	44.53	44.82	44.78	47.92	48.78	48.37	48.23	45.35	45.54	44.45	44.96
3	43.79	45.46	45.45	44.83	48.23	49.68	48.57	48.21	45.83	44.54	44.97	44.45
Mean	44.35	45.10	45.06	44.86	48.03	48.97	48.59	48.08	45.49	44.94	44.76	44.69
pH												
1	6.92	6.94	6.94	6.91	6.91	6.89	6.90	6.88	6.93	6.92	6.92	6.94
2	6.92	6.93	6.93	6.92	6.89	6.90	6.91	6.89	6.93	6.92	6.93	6.93
3	6.91	6.93	6.92	6.92	6.91	6.90	6.89	6.91	6.93	6.92	6.92	6.91
Mean	6.92	6.93	6.94	6.92	6.90	6.90	6.90	6.89	6.93	6.92	6.92	6.93

[1] For explanation of abbreviations, see page 91.

Table 31. The Gardner color difference meter "Rd", "-a", and "+b" values of the egg yolk[1].

Replication	Treatment											
	UP NA LN	UP NA FC	P NA LN	P NA FC	UP NaCl LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr LN	UP Fr FC	P Fr LN	P Fr FC
"Rd" values												
1	40.90	43.80	40.04	44.15	24.10	22.55	26.80	22.30	33.95	34.30	32.50	35.05
2	41.30	44.15	41.15	45.60	27.50	23.35	25.85	23.80	34.35	33.40	33.85	34.90
3	41.05	45.85	41.00	45.10	22.00	22.55	23.50	23.50	33.90	34.35	34.60	34.60
Mean	41.08	44.60	40.73	44.95	24.53	22.82	25.38	23.20	34.07	34.02	33.65	34.85
"-a" values												
1	34.85	38.15	34.25	38.20	28.70	28.15	30.25	27.45	30.40	29.75	30.20	30.85
2	34.55	38.20	35.05	38.80	29.95	27.80	29.45	27.90	30.05	27.90	30.10	30.65
3	34.70	39.00	34.90	39.00	27.25	30.65	28.00	28.55	29.30	30.40	30.35	30.90
Mean	34.70	38.45	34.73	38.67	29.63	28.87	29.23	27.97	29.92	29.35	30.22	30.80
"+b" values												
1	39.55	39.70	39.55	40.05	31.15	30.00	32.75	29.15	37.15	37.45	38.80	37.70
2	39.90	40.25	39.80	40.00	33.00	30.10	31.80	30.30	37.60	37.40	37.70	38.10
3	39.40	40.35	39.60	40.40	29.15	29.40	30.20	30.80	37.10	37.55	38.05	37.40
Mean	39.62	40.10	39.65	40.15	31.10	29.83	31.58	30.08	37.28	37.47	38.18	37.17

[1] For explanation of abbreviations, see page 91.

Table 32. The separation (%) of the emulsions, the specific gravity of the sponge cake batter, and the volume (ml) of the sponge cakes[1]

Replication	Treatment											
	UP NA LN	UP NA FC	P NA LN	P NA FC	UP NaCl LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr LN	UP Fr FC	P Fr LN	P Fr FC
Emulsion separation												
1	9.90	8.17	9.63	6.66	0.00	0.00	0.00	0.00	27.10	13.08	15.10	20.73
2	14.19	6.81	8.58	9.71	0.00	0.00	0.00	0.00	25.44	20.25	25.26	19.62
3	14.81	8.31	7.62	9.80	0.00	0.00	0.00	0.00	27.64	22.44	26.14	17.91
Mean	12.97	7.76	8.61	8.72	0.00	0.00	0.00	0.00	26.73	18.59	22.17	19.42
Specific gravity												
1	0.4725	0.5034	0.4742	0.5051	0.4432	0.4415	0.4501	0.4518	0.4226	0.4673	0.4243	0.4621
2	0.4810	0.5206	0.4931	0.5360	0.4501	0.4347	0.4518	0.4432	0.4192	0.4415	0.4312	0.4501
3	0.4587	0.5549	0.4742	0.5171	0.4347	0.4536	0.4381	0.4587	0.3934	0.4312	0.4072	0.4550
Mean	0.4707	0.5263	0.4805	0.5194	0.4427	0.4433	0.4467	0.4512	0.4117	0.4467	0.4007	0.4525
Volume												
1	525.00	530.00	550.00	525.00	645.00	655.00	665.00	645.00	600.00	565.00	573.00	600.00
2	545.00	525.00	535.00	525.00	675.00	645.00	665.00	665.00	600.00	590.00	600.00	600.00
3	575.00	535.00	595.00	525.00	660.00	685.00	685.00	635.00	630.00	565.00	625.00	595.00
Mean	548.33	530.00	560.00	525.00	660.00	661.67	671.67	648.33	610.00	573.33	600.00	598.33

[1]For explanation of abbreviations, see page 91.

Table 33. The scores for the shape, crust, and brownness of the sponge cakes.[1]

Replication	UP NA LN	UP NA FC	P NA LN	P NA FC	UP NaCl LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr LN	UP Fr FC	P Fr LN	P Fr FC
Shape												
1	4.67	6.00	6.00	5.00	6.00	6.00	6.00	6.00	5.67	5.00	5.33	6.00
2	5.00	5.50	5.50	5.00	6.00	5.50	5.00	5.50	5.00	5.50	5.50	5.00
3	4.50	4.00	5.00	4.50	5.00	5.50	5.50	5.00	5.50	4.50	5.00	5.00
Mean	4.72	5.17	5.50	4.83	5.67	5.67	5.50	5.50	5.39	5.00	5.28	5.33
Crust												
1	4.00	5.33	5.33	2.67	5.00	5.33	5.33	5.67	5.33	4.67	5.00	5.33
2	4.00	3.50	3.50	4.00	6.00	5.50	5.50	6.00	3.50	4.50	4.50	4.50
3	4.00	2.50	4.00	3.50	5.50	5.50	5.50	5.50	4.50	3.00	4.50	4.00
Mean	4.00	3.78	4.28	3.39	5.50	5.44	5.44	5.72	4.44	4.06	4.67	4.61
Brownness												
1	4.67	3.33	3.33	4.33	4.00	5.00	5.00	4.67	6.33	5.67	5.67	6.33
2	4.50	5.50	5.50	4.50	6.00	5.00	5.00	6.00	5.50	6.00	6.00	5.50
3	4.50	4.00	5.00	4.00	6.00	5.00	6.00	5.50	6.00	6.00	5.50	5.00
Mean	4.56	4.28	4.61	4.428	5.33	5.00	5.33	5.39	5.94	5.89	5.72	5.61

[1]For explanation of abbreviations, see page 91.

Table 34. The compressibility (g) of the sponge cakes and the scores for the texture and grain of the sponge cakes[1]

Replication	UP NA LN	UP NA FC	P NA LN	P NA FC	UP NaCl LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr LN	UP Fr FC	P Fr LN	P Fr FC
Compressibility												
1	230.00	211.50	199.00	253.50	135.00	149.00	127.00	130.00	157.00	175.00	167.00	167.50
2	195.00	212.00	219.00	220.00	150.00	123.00	127.50	147.50	171.00	175.50	173.50	178.50
3	211.00	211.00	210.00	259.50	150.00	150.00	143.50	138.00	184.50	168.00	175.00	162.00
Mean	212.00	214.50	209.33	244.33	145.00	138.33	132.67	138.50	170.83	166.83	171.83	169.33
Texture												
1	4.50	4.75	4.63	4.75	5.00	5.50	5.25	5.13	5.50	5.13	5.13	5.25
2	5.78	4.63	4.63	5.22	5.13	5.44	4.78	4.63	5.33	4.63	5.25	5.22
3	5.80	5.00	4.87	4.80	5.60	4.87	5.16	5.00	5.50	5.30	6.00	5.00
Mean	5.36	4.79	4.71	4.92	5.24	5.27	5.06	4.92	5.44	5.02	5.46	5.16
Grain												
1	5.38	4.63	4.88	5.00	4.63	4.50	4.50	4.50	5.13	5.00	4.75	4.75
2	5.22	5.63	5.00	5.56	4.75	4.89	4.78	5.25	4.67	5.00	5.13	5.22
3	5.60	5.00	4.67	5.60	5.00	5.00	4.50	6.00	5.16	5.40	5.20	4.87
Mean	5.40	5.09	4.85	5.39	4.79	4.80	4.59	5.25	4.99	5.13	5.03	4.95

[1]For explanation of abbreviations, see page 91.

Table 35. The scores for the color of the crumb, flavor, and over-all acceptability of the sponge cakes[1].

Replication	UP NA LN	UP NA FC	P NA LN	P NA FC	UP NaCl LN	UP NaCl FC	P NaCl LN	P NaCl FC	UP Fr LN	UP Fr FC	P Fr LN	P Fr FC
Color of the crumb												
1	5.75	5.88	5.88	5.75	5.75	5.75	5.75	5.75	5.63	5.75	5.75	5.63
2	5.78	5.88	5.88	5.67	5.88	5.78	5.56	5.88	5.89	5.88	5.75	5.78
3	6.20	5.87	5.87	6.00	6.00	5.87	5.87	6.25	5.87	6.00	6.00	5.87
Mean	5.91	5.88	5.88	5.81	5.88	5.80	5.73	5.96	5.80	5.88	5.83	5.76
Flavor												
1	5.25	5.63	5.00	4.75	2.63	2.88	2.38	3.13	4.38	5.00	4.50	4.63
2	5.44	5.13	5.00	5.11	2.88	2.11	2.22	3.63	4.89	5.00	4.75	5.44
3	5.60	4.87	4.67	5.20	2.40	2.50	3.50	2.00	5.00	5.00	5.00	4.67
Mean	5.43	5.21	4.89	5.02	2.64	2.50	2.70	2.92	4.76	5.00	4.75	4.91
Over-all acceptability												
1	5.13	5.43	5.00	5.13	3.57	3.88	3.25	2.57	4.57	5.13	4.75	4.57
2	5.38	5.00	5.13	5.00	3.00	3.13	3.00	3.75	4.63	5.25	5.13	5.38
3	6.20	4.60	4.40	5.40	4.20	3.00	3.80	3.50	5.00	5.60	5.40	4.80
Mean	5.57	5.01	4.84	5.18	3.57	3.34	3.35	3.61	4.73	5.33	5.09	4.92

[1]For explanation of abbreviations, see page 91.

Table 36. The analyses of variance for the egg yolk, emulsions, and sponge cakes.

Source of variation	Degrees of freedom	Mean square	F-value	Significance[1]
Physical characteristics of the egg yolk				
Apparent viscosity				
Blocks	5	4131.04	2.00	ns
Treatments	11	1033721.40	499.36	***
Error	19	2070.10		
Total	35			
Total solids				
Blocks	5	0.46	2.90	*
Treatments	11	9.18	57.86	***
Error	19	0.16		
Total	35			
pH				
Blocks	5	0.00010	1.24	ns
Treatments	11	0.00057	6.96	***
Error	19	0.00008		
Total	35			
"Rd" value				
Blocks	5	83.82	0.60	ns
Treatments	11	19979.54	142.60	***
Error	19	140.11		
Total	35			
"a" value				
Blocks	5	28.66	0.31	ns
Treatments	11	4379.66	46.62	***
Error	19	93.94		
Total	35			
"b" value				
Blocks	5	69.59	1.27	ns
Treatments	11	5141.72	93.49	***
Error	19	55.00		
Total	35			
Functional properties of the yolk in emulsions and sponge cakes				
Emulsion separation				
Blocks	5	16.16	2.96	*
Treatments	11	271.49	49.76	***
Error	19	5.46		
Total	35			

Table 36. (Contd.)

Source of variation	Degrees of freedom	Mean square	F-value	Significance[1]
Specific gravity				
Blocks	5	0.00011	0.48	ns
Treatments	11	0.00363	16.23	***
Error	19	0.00022		
Total	35			
Volume				
Blocks	5	836.11	2.85	*
Treatments	11	8114.56	27.71	***
Error	19	292.88		
Total	35			
Shape				
Blocks	5	1.07	10.18	***
Treatments	11	3.19	1.85	ns
Error	19	0.11		
Total	35			
Crust				
Blocks	5	0.84	1.96	ns
Treatments	11	1.71	4.00	**
Error	19	0.43		
Total	35			
Brownness				
Blocks	5	0.89	2.74	ns
Treatments	11	1.12	3.44	**
Error	19	0.33		
Total	35			
Compressibility				
Blocks	5	300.51	3.24	*
Treatments	11	3931.56	42.38	***
Error	19	92.76		
Total	35			
Texture				
Blocks	5	0.27	2.74	ns
Treatments	11	0.15	1.49	ns
Error	19	0.10		
Total	35			
Grain				
Blocks	5	0.40	5.60	**
Treatments	11	0.13	1.76	ns
Error	19	0.07		
Total	35			

Table 36. (Contd.)

Source of variation	Degrees of freedom	Mean square	F-value	Significance[1]
Color of crumb				
Blocks	5	0.0977	12.06	***
Treatments	11	0.0052	0.64	ns
Error	19	0.0081		
Total	35			
Flavor				
Blocks	5	0.05	0.25	ns
Treatments	11	3.10	19.73	***
Error	19	0.20		
Total	35			
Over-all acceptability				
Blocks	5	0.43	2.99	*
Treatments	11	1.94	13.59	***
Error	19	0.14		
Total	35			

[1]For explanation, see page 91.

THE EFFECT OF PASTEURIZATION, SELECTED ADDITIVES AND FREEZING RATE ON THE GELATION OF FROZEN-DEFROSTED EGG YOLK

by

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B. S., Kansas State University, 1965

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ABSTRACT

Eighteen 215 g samples of unpasteurized egg yolk and 18 215 g samples of pasteurized egg yolk were treated with 6.5% sodium chloride, 6.5% fructose, or no additive. One half of the samples treated identically in respect to pasteurization or no pasteurization and additive or no additive were frozen in liquid nitrogen (-196°C). The other half of the samples were frozen on the freezer coils of an upright household freezer (-20 ± 2°C). After 33 to 49 days of frozen storage, the samples were defrosted in a hot water bath (35 ± 2°C). Selected physical characteristics and functional properties of the frozen-defrosted yolk were investigated.

Gelation (i.e., the increase in apparent viscosity) of the frozen-defrosted egg yolk was reduced by the addition of sodium chloride or fructose prior to freezing. Increasing the freezing rate was more effective in reducing the gelation of yolk containing no additive than of yolk treated with an additive.

The addition of sodium chloride increased the total solids of the yolk by approximately 3.5%. The pH of the yolk was reduced by the addition of sodium chloride and to a lesser extent by the addition of fructose.

The yolk containing an additive, especially sodium chloride, was oranger in color and darker than yolk containing no additive. Yolk containing no additive was oranger and darker when frozen in liquid nitrogen as compared to being frozen on the freezer coils of a household type freezer.

The emulsifying ability of the yolk was increased by sodium chloride and decreased by fructose. Increasing the freezing rate decreased the emulsifying ability of unpasteurized yolk containing no additive or fructose.

Yolk treated with an additive produced a sponge cake batter of lower specific gravity than did yolk containing no additive. The specific gravity of

the batter was lower when the yolk containing no additive and the yolk treated with fructose was frozen in liquid nitrogen as compared to being frozen on freezer coils.

The volume of sponge cakes was largest when the yolk contained sodium chloride, smallest when it contained no additive, and intermediate when it contained fructose. The crust of cakes made with yolk treated with an additive as compared to yolk containing no additive was more desirable and darker in color. Yolk containing no additive or fructose produced cakes of greater over-all acceptability than did yolk treated with sodium chloride. Fructose imparted an extremely sweet flavor and sodium chloride an undesirably salty flavor to the cakes. The compressibility of cakes made with fructose-treated yolk and especially sodium chloride-treated yolk was greater than that of cakes made with yolk containing no additive. The differences in the scores for shape, texture, grain, and crumb color were not statistically significant.

Pasteurization of the yolk did not affect the physical characteristics and functional properties investigated.