THE EFFECT OF DRYING PROCESSES ON THE COLOR AND GEL STRENGTH OF BAKED WHOLE EGG AND MILK SLURRIES

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY

Joyce Ann Endres

1965

ABSTRACT

THE EFFECT OF DRYING PROCESSES ON THE
COLOR AND GEL STRENGTH
OF BAKED WHOLE EGG AND MILK SLURRIES

by Joyce Ann Endres

This study was initiated to determine the effects of freeze- and spray-drying on the gel strength and color of whole egg and milk gels. The effects of pH levels and end temperature were also investigated. The pH levels included the unadjusted pH of the egg-milk mixture (approximately 7.0) and the adjusted pH of 6.6. Selected end temperature ranges were 81-82°C and 84-85°C. Four replications of each of the twelve treatment combinations were baked.

Gel strength was measured using the upper assembly of the fixed blade cell of the Allo-Kramer Shear Press by both maximum force, using three defined peaks, and area-under-the-curve. Drainage due to syneresis was also investigated as a possible indication of gel strength. Objective color evaluations were determined by the Gardner Color Difference Meter and subjective evaluations by a color panel indicating difference in color and preference.

Results indicated that the drying processes brought about the following highly significant changes: a decrease in gel strength and a decrease in Gardner Color Difference Meter values for lightness and yellowness. In addition, the spray-drying process caused a decrease in Gardner Color Difference Meter values for greenness. Differences due to drainage, significant only at the 5 per cent level of probability, showed spray-dried egg gels to have less drainage than gels from frozen eggs.

Of the two drying processes, spray-drying had the most adverse effect on the gel strength and color indicating that spray-drying is more harmful to egg proteins and color components than is freeze-drying. Color panel difference scores also indicated the drying processes caused highly significant differences in the color of the baked slurries, and that color of the spray-dried egg gels differed more markedly from the control egg gels than did the freeze-dried egg gels. However, the color panel preference scores indicated changes due to freeze-drying were not objectionable although those due to spray-drying were.

Reducing the pH of the egg-milk mixture from approximately 7.0 to 6.6 caused the following significant differences: a decrease in gel strength, an increase in color lightness, a decrease in greenness and yellowness, a decrease in color panel preference scores, and an increase in color panel difference scores. Increasing the end baking temperature from 81-82°C to 84-85°C resulted in the following highly significant changes: an increase in gel strength; a decrease in lightness and yellowness values, but an increase in greenness values. Significant differences in drainage were not observed nor did the color panel observe any color differences or indicate any preferences for color related to end baking temperature.

All four shear press measurements correlated indicating the reliability of this instrument to measure the firmness of the gels. Although significant correlations were found between shear press gel strength measurements and drainage measurements, it was concluded that drainage, as a possible indicator of gel strength, was not a sufficiently sensitive method of measurement. It appeared that factors

other than gel strength affect drainage. Very highly significant correlations occurred between all four of the following evaluations of color: color panel difference scores, color panel preference scores, Gardner a_L values, and Gardner b_L values. These correlations indicated that the Gardner Color Difference Meter is a valid measure of color differences in egg-milk gels, with the b_L value being most sensitive.

Results of this investigation led to these suggestions for further research: 1) a search for the factors causing syneresis and a more sensitive method of determining drainage due to syneresis, 2) a study to establish the most accurate shear press measure of gel strength, and 3) an investigation to define more clearly the way in which the color pigment is changed by the drying processes.

THE EFFECT OF DRYING PROCESSES ON THE COLOR AND GEL STRENGTH OF BAKED WHOLE EGG AND MILK SLURRIES

By

Joyce Ann Endres

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Foods and Nutrition

1965

ACKNOWLEDGMENTS

Warm appreciation and sincere gratitude are expressed to Mrs. Mary Ellen Zabik for her generous advice, encouragement, and time throughout this investigation. Deep appreciation is also extended to Dr. Kaye Funk for her interest and advice in this study.

Recognition is due to M.R. Kudlick, Allo Precision Metals Engineering, Inc., Rockville, Md., for loan of the fixed blade assembly of the standard shear-compression cell which was used on the Allo-Kramer Shear Press. Grateful acknowledgment is expressed to Seymour Foods Co., Topeka, Kansas, for processing of the frozen and spray-dried eggs under specified conditions, to the Midwest Research Institute, Kansas City, Missouri, for processing the freeze-dried eggs, and to Jianas Bros. Candy Company, Kansas City, Missouri, for packaging the dried eggs.

The writer expresses appreciation to the Food Science Department at Michigan State University for use of the Gardner Color Difference Meter and to Dr. Clifford Bedford for his technical assistance and advice in operation of this instrument.

The writer is indebted to Dr. Pearl Aldrich, Miss Mary Coleman, Miss Carolyn Friedemann, Dr. Kaye Funk, Dr. Theodore Irmiter, Miss Mary Morr, Miss Jenny Lou Taylor, and Dr. Modesto Yang for serving on the color panel.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF LITERATURE	4
Egg Composition	4
Yolk and albumen constituents	4
pH values of egg	6
Types of Processed Eggs	7
Frozen egg	7
Spray-dried egg	8
Spray-drying process	8
Problems concerned with the stability of spray-dried eggs	9
1. Glucose-protein reactions	9
2. Lipid reactions	10
Methods of stabilizing dried egg	10
1. Acidification	10
2. Glucose removal	11
3. Addition of carbohydrate	12
4. Low temperature storage	12
5. Low moisture	13
6. Gas packing	13
Freeze-dried Egg	14
Freeze-drying process	14
Advantages of freeze-dried foods	14
Disadvantages of freeze-dried foods	15
Effect of freeze-drying on functional properties of eggs	15
Coagulation of Egg Protein	15
Theories of denaturation	15
Causes of denaturation	17

TABLE OF CONTENTS (Cont.)

	Page
Theory of gel formation	17
Syneresis	18
Use of baked custards to test gel strength	18
Gelation temperature	19
Effect of protein concentration	20
Effect of sugar	20
Effect of acid or alkali	20
Effect of salts	20
Effect of processing techniques	21
Changes in pH of custard after baking	22
Color of Egg	23
Egg yolk color	23
Influence of feed on color of yolk	23
Influence of drying process on color of yolk.	24
Objective Measurements	25
Gel strength measurements	25
Penetrometer	25
Curd tension	26
Shear press	26
Color measurements	28
Color charts and disks	28
Spectrophotometer	29
Photoelectric colorimeter	29

TABLE OF CONTENTS (Cont.)

Page

EXPERIMENTAL PROCEDURE 32

Preliminary Investigation 32

Design of Experiment 35

Processing of Whole Egg 36

Preparation of egg prior to processing 36

Spray-drying 37

Freeze-drying 37

Packaging, shipment, and storage 38

Basic Formula 39

Formula modification 39

Milk source 40

Preparation 41

Dried egg slurries 41

Control egg slurries 42

pH adjustment 43

Baking Procedure 43

Objective Measurements 47

pH of baked slurry 47

Shear press gel strength measurement 48

Syneresis 50

Color measurement 51

Subjective Evaluation 52

Color preference judging 52

Color difference judging 53

Analysis of Data 53

TABLE OF CONTENTS (Cont.)

	Page
RESULTS AND DISCUSSION	54
pH of the Slurries before and after Baking	54
Length of Baking Time	55
Time-Temperature Relationships	56
Objective Measurements of Gel Strength of Baked Whole Egg and Milk Slurries	57
Gel strength measured using the shear press	60
Gel strength variance within egg processes	60
Gel strength variance within pH levels	66
Gel strength variance within temperature ranges	66
Gel strength variances among the twelve treatment combinations	67
Gel strength measured by percentage of drainage due to syneresis	70
Drainage variance within egg processes	70
Drainage variance within pH levels	73
Drainage variance within end temperature ranges	73
Drainage variance among the twelve treatment combinations	73
Objective Measurement of Color of Baked Whole Egg and Milk Slurries	75
Color variance within egg processes	75
Color variance within pH levels	80
Color variance within end temperature ranges	80
Color variance among the twelve treatment combinations	81
Subjective Measurements of Color of Baked Whole Egg and Milk Slurries	84

TABLE OF CONTENTS (Cont.)

Page

Color variance within egg processes 84

Color variance within pH levels 87

Color variance within end temperature ranges . . . 88

Color variance among the twelve treatment combinations 88

Correlations for Objective and Subjective Measurements of Baked Whole Egg and Milk Slurries 90

Correlations for gel strength 90

Correlations for color 93

Reliability of objective measurements 94

SUMMARY AND CONCLUSIONS 95

LITERATURE CITED 100

APPENDIX 106

LIST OF TABLES

TABLE		Page
1	Approximate percentage of water, protein, fat, ash, and glucose in egg	4
2	Principal constituents of egg albumen	5
3	Principal components of egg yolk	5
4	Shear press value means and standard deviations using two levels of egg and two shear press cells	34
5	Formulas used in preparation of baked slurries	40
6	Analysis of variance for baking times of whole egg-milk slurries baked in both custard cups and pans	56
7	Analysis of variance for shear press measurements of baked whole egg-milk slurries	61
8	Rank order of significant differences for gel strength measured by the shear press among conglomerate averages for egg processes, pH levels, and end temperature ranges of baked whole egg-milk slurries	63
9	Rank order of significant differences for gel strength measured by the shear press among slurries prepared from frozen, freeze-dried,and spray-dried eggs baked at each combination of pH and end baking temperature	65
10	Rank order of significant differences in gel strength measured by the shear press among means for each treatment combination of slurries made from freeze-dried, spray-dried, and frozen eggs at two pH levels and baked to two end temperature ranges	68
11	Analysis of variance for drainage due to syneresis of whole egg-milk slurries	71
12	Rank order of significant differences for drainage due to syneresis among conglomerate averages for egg processes and pH levels of baked whole egg-milk slurries.	71
13	Rank order of significant differences for drainage due to syneresis among slurries prepared from frozen, freeze-dried, and spray-dried eggs baked at each combination of pH and end baking temperature	72

LIST OF TABLES (Cont.)

TABLE		Page
14	Rank order of significant differences in gel strength measured by drainage due to syneresis among means for each treatment combination of slurries made from freeze-dried, spray-dried, and frozen eggs at two pH levels and baked to two end temperature ranges	74
15	Analysis of variance for Gardner Color Difference Meter measurements of baked whole egg-milk slurries	76
16	Rank order of significant differences for color measured by the Gardner Color Difference Meter among conglomerate averages for egg processes, pH levels, and end baking temperatures of baked whole egg-milk slurries	77
17	Rank order of significant differences for color measured by the Gardner Color Difference Meter among slurries prepared from frozen, freeze-dried, and spray-dried eggs baked at each combination of pH and end baking temperature	79
18	Rank order of significant differences for color measured by the Gardner Color Difference Meter among means for each treatment combination of slurries made from freeze-dried, spray-dried, and frozen eggs at two pH levels and baked to two end temperature ranges.	82
19	Analysis of variance for color panel scores of baked whole egg-milk slurries	85
20	Rank order of significant differences for color panel scores among conglomerate averages for egg processes and pH levels of baked whole egg-milk slurries	86
21	Rank order of significant differences for color panel scores among slurries prepared from frozen, freeze-dried, and spray-dried eggs baked at each combination of pH and end baking temperature.	87
22	Rank order of significant differences for color panel scores among means for each treatment combination of slurries made from freeze-dried, spray-dried, and frozen eggs at two pH levels and baked to two end temperature ranges	89
23	Significant correlation coefficients of measurements related to gel strength of baked whole egg-milk slurries.	91

LIST OF TABLES (Cont.)

TABLE		Page
24	Significant correlation coefficients of measurements related to color of baked whole egg-milk slurries	92
25	Replication averages for pH values for before and after baking of whole egg-milk slurries baked in custard cups .	110
26	Replication averages for pH values for before and after baking of whole egg-milk slurries baked in pans	111
27	Replication averages and mean values, pH level and end baking temperature conglomerate averages, and standard deviations for baking times (minutes) for frozen, freeze-dried, and spray-dried egg-milk slurries baked simultaneously in cups or pans	112
28	Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for end baking temperatures (^{o}C) of whole egg-milk slurries baked in custard cups	113
29	Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for end baking temperatures (^{o}C) of whole egg-milk slurries baked in loaf pans	114
30	Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for shear press maximum force values for peak I (lbs.) of baked whole egg-milk slurries	115
31	Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for shear press maximum force values for peak II (lbs.) of baked whole egg-milk slurries	116
32	Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for shear press maximum force values for peak III (lbs.) of baked whole egg-milk slurries . .	117
33	Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for shear press area-under-the-curve values (cm^2) of baked whole egg-milk slurries	118

LIST OF TABLES (Cont.)

TABLE Page

34 Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for drainage due to syneresis of baked whole egg-milk slurries 119

35 Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for Gardner Color Difference Meter L values of baked whole egg-milk slurries 120

36 Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for Gardner Color Difference Meter a_L values of baked whole egg-milk slurries 121

37 Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for Gardner Color Difference Meter b_L values of baked whole egg-milk slurries 122

38 Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for Gardner Color Difference Meter a_L/b_L ratios of baked whole egg-milk slurries 123

39 Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for color panel difference scores of baked whole egg-milk slurries 124

40 Replicate averages and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for color panel preference scores of baked whole egg-milk slurries 125

41 Correlation coefficients of measurements related to gel strength evaluation 126

42 Correlation coefficients of measurements related to color evaluation 127

LIST OF FIGURES

FIGURE		Page
1	Shear press graphs when the succulometer piston and fixed blades were used	34
2	Specially designed baking apparatus for the support of the loaf pans and thermocouples	44
3	Specially designed baking apparatus for the support of the custard cups and thermocouples	46
4	Shear press in operation during measurement of the gel strength of a baked egg-milk slurry	49
5	Typical gel strength curve obtained using fixed blade cell showing three defined points	50
6	Mean time-temperature relationships during baking of slurries prepared with three types of eggs at the unadjusted pH level	58
7	Mean time-temperature relationships during baking of slurries prepared with three types of eggs at the adjusted pH level	59
8	General instructions for color panel members	107
9	Score sheet for preference evaluation of color	108
10	Score sheet for difference evaluation of color	109

INTRODUCTION

Production of a dehydrated egg which maintains the high quality of the fresh egg would benefit both homemakers and commercial users. Dried eggs offer potential advantages of convenience, minimum requirements for refrigeration, substantial reduction in weight and volume resulting in decreased storage and transportation costs, and extended shelf life. Currently spray-drying is the only commerically used process for the dehydration of eggs; however, newer dehydrating processes including freeze-drying are being investigated.

Contradictory reports concerning the effect of spray-drying on the functional properties and color of eggs appear in the literature. Ary and Jordan (1945) and Schlosser (1961) concluded the coagulative ability of high quality spray-dried eggs was not impaired whereas the findings of Jordan and Sisson (1945) and Miller et al.(1959a) suggested spray-drying decreases the coagulating functions of the egg. In contrast to the report by Miller et al. (1959a) which also stated the color of custards prepared with spray-dried eggs was undesirable, Mastic (1959) found no significant differences between the body color of custards prepared from fresh or spray-dried eggs. In addition improvements in the spray-drying techniques initiated by industry since the time of these investigations may have led to the production of a dried egg which better maintains its original quality.

Freeze-drying has been used successfully to dehydrate meats and vegetables, but its use for the dehydration of eggs is still in the experimental stages. Although the coagulative functional property of freeze-dried eggs has not been reported in the literature, Rolfes

et al. (1955) found freeze-drying had no detrimental effect on the whipping qualities but did impair the emulsifying properties of the egg.

No comparative studies of the effect of freeze-drying and spray-drying of eggs appear in the literature. Such an investigation using a common source of eggs for both the drying processes and the control eggs should elucidate the way in which and the extent to which each drying process affects the color, flavor, and acceptability of the product. Moreover, such a thorough investigation of the functional properties of dried eggs might hasten their acceptance and realization of their potential advantages by commercial users and homemakers.

The present investigation was concerned only with the coagulative ability of whole dried egg and the color of the product produced from it. To eliminate any interacting effects of additional ingredients on the thickening ability of egg proteins, simple systems of milk and whole egg baked to two end temperature ranges were used for evaluation. The slurries were prepared at two pH levels: unadjusted and adjusted to 6.6. A slightly acidic pH level was chosen since coagulation is often desired in products containing citric juices which lower the normal neutral pH of custard. The particular pH level of 6.6 was chosen as it is the pH at which milk proteins are most stable and, therefore, should eliminate any effect of milk proteins per se on the results obtained.

The primary purpose of this investigation was to determine the effect of spray- and freeze-drying on the color and gel strength of baked milk and whole egg slurries. A secondary purpose was to determine the effect of altering the pH and end baking temperature on the

same qualities and to determine whether the effect of processing was similar at each pH-end temperature combination. The investigator examined the data to see which, if any, combination of drying process, pH, and end baking temperature produces a baked slurry which is comparable in color and gel strength to that of the control.

REVIEW OF LITERATURE

Egg Composition

The principal components of egg (Table 1) are water, protein, and fat with smaller quantities of carbohydrate and ash (Sweetman and MacKellar, 1959; Ziemba, 1955a). The ash of egg includes small amounts of phosphorus, magnesium, potassium, sulfur, and copper.

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

	Component				
	Water	Protein	Fat	Ash	Glucose
Whole Egg	74.0	12.8	11.5	1.0	0.32
Yolk	49.4	16.3	31.9	1.7	0.17
Albumen	87.8	10.7	0.0	1.6	0.38

Yolk and albumen constituents

The yolk is primarily lipid and lipoprotein, whereas the albumen is almost entirely a dispersion of proteins. Egg yolk proteins possess characteristics similar to those of milk proteins. Both are composed of small amounts of a mixture of water soluble proteins, collectively referred to as livetin, plus larger amounts of phosphoproteins which are present as lipid conjugates or lipoproteins. Early workers considered egg albumen to be composed of a single protein. However, Meyer (1960) stated eight different proteins have presently been established while Feeney and Hill (1960) suggested additional proteins may be identified by future research. The principal constituents and

some of their properties of egg yolk and albumen are listed in Tables 2 and 3, respectively (Feeney and Hill, 1960; Fevold, 1951).

Table 2. Principal constituents of egg albumen.

Constituent	Approx. amount (%)	Approx. isoelectric point	Unique properties
Ovalbumin	54.0	4.6	Denatures easily.
Conalbumin	13.0	6.0	Complexes iron.
Ovomucoid	11.0	4.3	Resistant to denaturation.
Lysozyme	3.5	10.7	Antimicrobial.
Ovomucin	1.5	?	Least soluble.
Flavo-protein	0.8	4.1	Binds riboflavin.
Avidin	0.05	9.5	Binds biotin.
Unidentified proteins	8.0		Mainly globulins.
Others	8.0		Primarily glucose and salts.

Table 3. Principal components of egg yolk.

Constituent	Approx. amount (%)	Unique properties
Fats		
Neutral glycerides	42	Acids vary with diet.
Phospholipids	20	Lecithin and cephalin.
Sterols	2	Primarily cholesterol.
	(64)	
Proteins		
Livetin	5	Contains egg enzymes.
Phosvitin	7	Contains 10% phosphorus.
Lipoproteins	21	Emulsifiers.
Lipovitellin		
Lipovitellinin		
	(33)	
Others		
Primarily salt and sugar	3	

The protein composition of egg is of primary interest because of the functional role proteins serve in cookery. Egg albumen proteins contribute to the important functional properties of foaming and coagulating, while egg yolk proteins exhibit coagulating, emulsifying, and binding abilities. The functional properties of whole eggs are primarily those contributed by the yolk proteins, although albumen does contribute to the coagulative property while serving primarily as a proteinaceous diluent (Feeney and Hill, 1960).

pH values of egg

The pH of shell eggs is difficult to determine because the alkalinity increases rapidly after laying due to loss of carbon dioxide. The metabolic processes of the hen produce carbon dioxide which is dissolved in the egg to form carbonic acid and bicarbonates that act as buffers. However, during storage carbon dioxide diffuses through the shell until it is in equilibrium with the carbon dioxide in the air (Griswold, 1962). Initially the pH value of fresh egg albumen is approximately 7.6 and the yolk is around 6.0 (Feeney and Hill, 1960). Under normal storage conditions egg albumen can reach a pH of 8.9 or higher, whereas yolk may reach a pH of 7.0 (Sweetman and MacKellar, 1959). Lowe (1955) stated egg white may even reach a pH of 9.7 and is the most alkaline of any food used.

Change in pH also results when egg is subjected to drying processes. Knowles (1962) pointed out freshly dried whole egg is more alkaline than the egg from which it was made; liquid whole egg of pH 7.2-7.6 would increase in alkalinity to a figure of 7.6-8.6 or higher during drying. Lowe (1955) also reported an increase in the pH of dried eggs,

and stated dried whole egg has a pH of about 8.5. Knowles (1962) noted during storage the pH of dried eggs drops due to liberation of free fatty acids and to a reaction of glucose with amino groups.

Types of Processed Eggs

Treatment of egg to maintain quality is accomplished by many preservation methods. Common methods for preserving shell eggs are low temperature storage, addition of carbon dioxide to the storage atmosphere, thermostabilization, and treatment in an oil dip. Processes of concern in this study are those in which the liquid egg is separated from the shell and include freezing, spray-drying, and freeze-drying.

Frozen egg

Freezing is used for preserving whole egg magma, albumen, and yolks. Lowe (1955) stated freezing does not appreciably alter the physical characteristics of egg albumen but that yolks become pasty upon thawing. This gelation of yolk during freezing, believed to be due to some alteration of lipoproteins, has been lessened by the addition of salt, sucrose, honey, or corn syrup. Powrie *et al.* (1963) found the addition of cysteine to yolk prior to freezing inhibited the increase in viscosity caused by freezing and thawing. Jordan *et al.* (1952) reported the addition of salt, sugar, and corn syrup to yolks and whole eggs before freezing did not affect the functional properties necessary for the eggs to perform satisfactorily in custards or in plain cakes.

Winter (1952) reported the safety of frozen egg has been greatly improved by pasteurization and the main benefits of pasteurization include destruction of possible pathogenic bacteria and improvement in keeping qualities of frozen egg. Miller and Winter (1950) found pasteurization of liquid whole egg for four minutes killed more than 99 per cent of the standard and coliform bacteria. They also observed that shell, frozen, and pasterurized frozen whole eggs produced no significant differences in quality characteristics for sponge cakes or scrambled eggs. They concluded pasteurization and/or freezing does not alter the functional properties of whole eggs.

Spray-dried egg

The dehydration process for eggs was introduced in the 1890's. However, the availability of cheaper eggs from China limited the early expansion of the egg drying industry in the United States. Only after an import tax in the 1920's and an outbreak of a civil war in the 1930's caused a stoppage of the shipping of eggs from China, did the dried egg industry in the United States have a chance to grow. However, dried eggs were not produced in large quantities in the United States until World War II when large quantities of eggs were required for feeding the armed forces. The public attention brought about by this massive use of dried egg stimulated research programs which have led to the production of dehydrated egg of improved quality.

Spray-drying process (Forsythe and Miyahara, 1959; Knowles, 1962; Lineweaver and Feeney, 1950-51). Prior to spray-drying, high quality eggs are thoroughly blended by churning and homogenization, after which

the mass is flash pasteurized at 60-62°C for 3-4 minutes. The liquid egg is then pumped under high pressure (2,000-8,000 p.s.i.) through 4 to 12 nozzles into a large drier chamber. A stream of filtered hot air (121-177°C) is passed through the drier to dry the egg in seconds. The outlet temperature ranges from 60-82°C. The bulk of the powder settles to the bottom of the chamber, while the remaining powder is trapped in primary and secondary collectors. The powder is rapidly cooled to below 37.8°C on a conveyor, then sifted, and packed into drums.

Problems concerned with the stability of spray-dried eggs. The acceptance of dried egg powders has been hindered because of several undesirable changes in the egg solids. The most detrimental defects are due to glucose-protein reactions and lipid reactions.

1. Glucose-protein reactions. Glucose-protein reactions are characterized by both visible browning and loss in protein solubility. Brown ing, also referred to as the Maillard reaction, results in a brown, smelly egg product which retains very few of its functional properties. It is caused by a reaction of the reducing groups in glucose and the free amino groups of the egg proteins.

In addition to color and odor changes, glucose-protein reactions are characterized by loss of solubility which causes decreased functional performance. Stuart et al. (1942a) and Ary and Jordan (1945) confirmed there is a direct correlation between solubility of dried egg powder and quality of food products prepared from the egg powders. In general, higher solubility indexes of the egg powder result in less impairment of the functional properties than do lower indexes.

Loss of solubility is thought to take place in two stages. A condensation between reducing groups of glucose and free amino groups of proteins is involved in the first stage. The second stage involves changes in the product of the first reaction (Lightbody and Fevold, 1948).

The rate of decrease of solubility is a function of drying and storage conditions, the first being more detrimental than the second. Lightbody and Fevold (1948) suggested the decrease in solubility is due to excessive heating during drying. Conrad et al. (1948) pointed out that egg proteins subjected to high temperature storage became less soluble, while Stuart et al. (1942b) concluded a high percentage of moisture resulted in powder of low solubility.

2. Lipid reactions. Since 70 per cent of the lipids present in the yolk are unsaturated, rapid oxidation takes place which causes deterioration unless protected by gas packing or low moisture drying (Ziemba, 1955a). Investigations by Kline et al. (1951b) suggest there may be a glucose-cephalin interaction, and it may be this reaction which is responsible for the development of off-flavors.

Methods of stabilizing dried egg. Researchers have investigated methods of stabilization which would maintain the color, flavor, and functional properties of the dried eggs. The most successful methods are acidification, glucose removal, presence of carbohydrate, low temperature storage, low moisture, and gas packing.

1. Acidification (Mitchell, 1954). Acidification, which reduces the browning reaction, is usually done after pasteurization and before the drying process. An edible acid, such as hydrochloric acid, is added

to reduce the pH to around 5.5 prior to drying. After drying, sodium bicarbonate is added to return the reconstituted egg to a pH between 7 and 9.

2. Glucose removal (Kline et al.,1951a; Kline et al.,1951b). Removal of reducing sugars is necessary to prevent browning and loss of solubility caused by the Maillard reaction and also to prevent the formation of glucose-cephalin complexes which result in flavor deterioration. Since glucose is the only reducing sugar present in measurable amounts, its removal eliminates visible browning, development of fluorescence in the phospholipid fraction, and losses of measurable amino groups. Removal of glucose does not impair the nutritive value since glucose constitutes only 1 per cent of the dried egg solids.

Glucose removal is accomplished by either fermentation or enzymatic action. Fermentation is done with cell yeasts such as Torula monosa or Saccharomyces cerevisiae (Kline, 1951a) or by bacteria such as Aerobacter aerogenes and Streptococcus lactis (Ayres, 1958) which reduce glucose to alcohol and carbon dioxide. The enzyme commonly used is glucose oxidase which converts glucose to gluconic acid. Kline et al. (1954) reported these two desugaring processes were equally effective in minimizing dried egg deterioration as measured by chemical, functional, and flavor tests.

Kline et al. (1951b) reported glucose-free powders stored for six months at 37.8°C showed little browning, and theorized the removal of glucose prevented loss of baking quality which normally occurs in glucose-containing powders during high temperature storage. Palatability retention after high temperature storage was also much greater

for glucose-free than glucose-containing dried egg. Although it is evident that glucose-free powders have a much longer shelf life, Miyahara and Bergquist (1961) indicated glucose is not removed from whole egg and yolk unless the eggs are going to be held for extended periods at high temperatures.

Comparisons of glucose-free and acidified dried eggs indicated the glucose-free egg stored at 37.8°C at 2 per cent moisture is more than four times more stable than acidified dried egg (Hanson, 1954; Mitchell, 1954). Thus, although acidification retards glucose-induced protein reactions, it is not nearly as effective in stabilizing the egg as glucose removal.

3. Addition of carbohydrate. (Conrad et al. 1954; Lowe, 1955). The addition of 10-20 per cent sucrose or 10 per cent lactose to egg before drying extends the shelf life of the dehydrated egg. Sugar, with its abundance of hydroxyl groups, replaces the protective coating of water which normally surrounds the lipoprotein in shell eggs. Dried whole egg with added carbohydrate retains excellent foaming abilities and is dispersed more readily. One disadvantage, however, is that an interaction may occur between sucrose and lipids in the yolk resulting in development of off-flavors. The use of corn syrup products as a substitute for sucrose may eliminate this reaction. Acidification is harmful to sugared egg as it increases its susceptibility to oxidative change.

4. Low temperature storage. Since egg proteins subjected to high temperature during storage lose their solubility and do not retain their

flavor or cooking quality, low temperature storage is advocated. Dawson et al. (1945) found dried eggs with 3-5 per cent moisture content should be stored at temperatures of 15.6°C or lower in order to maintain quality for storage periods longer than six months. Ziemba (1955b) stated a storage temperature of 4.4°C gives best results when eggs are to be stored longer than a year.

5. Low moisture. Stuart et al. (1942a) reported changes in solubility of spray-dried eggs are much more pronounced when the moisture content of the powder is greater than 5 per cent than when it is less than that amount. Lowe (1955) stated low moisture powders of 3 per cent or less have longer shelf life than those with high moisture content. Lowering the moisture content from 5 per cent to 2 per cent was very effective in retarding loss in functional properties of the dried egg (Kline et al., 1951b). Kline et al. (1951b) indicated the reduction of moisture greatly reduced the glucose-protein interaction but had very little effect on the glucose-cephalin interaction. Mitchell (1954) concluded moisture content is a more critical factor in influencing stability in acidified egg than in glucose-free egg.

6. Gas packing. Many of the lipids present in egg are unsaturated and undergo deterioration unless protected from oxygen in the air. Shelf life is increased significantly when egg powder is packed in nitrogen or carbon dioxide (Lowe, 1955). Mitchell (1954) found a mixture of carbon dioxide and nitrogen was no more effective than nitrogen alone.

Freeze-dried egg

The freeze-drying process is used more extensively for meats and fruits, although eggs are being freeze-dried experimentally. Since freeze-dried eggs are not produced commercially, they have received less attention than spray-dried eggs have received.

Freezing-drying process (Harpor and Tappel, 1957). The basic principle involved in freeze-drying is the removal of water by sublimation from material in the frozen state. Thus, the water reaches the gaseous state without going through the intermediate formation of a liquid. Liquid egg is blended, frozen, and placed in a vacuum chamber where pressure is lowered considerably below the vapor pressure of ice. The egg must be kept under a constant vacuum since a rise in pressure would reduce the rate of sublimation. The heat for sublimation is supplied by both conduction and radiation at the surface of the frozen material; however, the rate of heating is controlled so that the temperature of the material will not raise to its melting point. Freeze-drying takes place in two stages. During the first stage the ice phase disappears but the product is still at a low temperature and holds water vapor in equilibrium with the vapor pressure. The second stage involves raising the temperature of the product to drive off the adsorbed water.

Advantages of freeze-dried foods (Harpor and Tappel, 1957). Keeping materials frozen until they are dehydrated greatly reduces chemical reactions and extensive denaturation of proteins. Freeze-dried products rehydrate more easily and quickly, retain color to a high degree, require no refrigeration, and retain true flavor since desirable volatile constituents are not lost.

Disadvantages of freeze-dried foods. Lipid oxidation is particularly severe in freeze-dried foods because of the large surface areas present and low moisture contents achieved. Freeze-dried foods must be packed under nitrogen with less than 1 per cent oxygen if reductions in oxidation are to be of value (Goldblith et al., 1963). Kline et al. (1951b) found nitrogen packing alone was an effective means of stabilization for lypholized powders stored at 15.6°C and glucose removal was not necessary. Presently, the cost of freeze-dried eggs is relatively high in comparison to spray-dried eggs primarily because freeze-drying of eggs is still in the experimental stages.

Effect of freeze-drying on functional properties of egg. The effect of freeze-drying on the functional properties of egg proteins has received little attention. Rolfes et al. (1955) reported freeze-drying of eggs had no detrimental effect on their functional properties as measured by angel cake volume, but the functional properties of freeze-dried yolk and whole egg were impaired as measured by mayonnaise stability and sponge cake volume.

Coagulation of Egg Protein

An important functional property of egg protein is its ability to coagulate or thicken. Coagulation, which Lowe (1955) defines as rendering the proteins insoluble, is closely related to denaturation.

Theories of denaturation

Haurowitz (1963) defined denaturation as an alteration of protein chain conformation; during this alteration the peptide chains may become

unfolded, refolded, or changed to some other formation due to the action of a denaturing agent. Likewise, Meyer (1960) defined denaturation as an alteration of the structure of the protein due to the unfolding of the protein molecule. The theory that denaturation is accomplished through an unfolding mechanism is indicated by the more intense color reactions of the denatured proteins. The higher reactivity of denatured proteins indicates some of the reactive groups which are normally inaccessible to different reagents in the native protein become accessible as the protein unfolds. These reactive groups include the sulfhydryl (-SH), disulfide (-S-S-), and phenolic groups.

Colvin (1964) indicated recent research has established protein denaturation occurs in systems which do not contain long polypeptide chains, and "changes grouped under denaturation may be regarded as the result of phase changes or of transconformation in any high polymer and that the phenomena are not restricted in principle to proteins." Feeney and Hill (1960) say "denaturation is that change in the protein which causes an alteration in the physical and/or biological properties without breaking a primary chemical bond." Thus, all reactions which break peptide bonds or any other internal chemical bonds are excluded by this definition of denaturation.

Although it is evident that denaturation is not clearly defined, it is correct to state that there is a loss of certain specific properties of the native protein. These changes include a decrease in solubility usually at the isoelectric point, an increase in reactive sulfhydryl, disulfide, and phenolic groups, and changes in viscosity. The rate of denaturation is low at the isoelectric point of the protein and

increases in either more acid or alkaline solutions.

Causes of denaturation. The causes of denaturation most commonly encountered in food preparation are: heat, mechanical action, freezing, and dehydration. Heat denaturation occurs during cooking, sterilization, or pasteurization of foods, and may be often desired before the food is eaten as in the case of the coagulation of egg proteins. Mechanical action, such as stirring or whipping, may cause the formation of interfacial areas which result in surface denaturation. Mechanical denaturation can be desirable as in the case of egg white foams. However, undesirable surface denaturation may occur during spray-drying if large areas are exposed at warm temperatures for long times (Feeney and Hill, 1960).

Freezing can damage proteins either by surface action or dehydration. Feeney and Hill (1960) postulated ice crystal formation causes rupture of physical structures and denatures protein either by surface phenomena at the ice solution interfaces or by removing water essential for normal structure. The drying processes may damage egg proteins if faulty drying techniques, including use of too high a drying temperature or too severe a shear force, are used.

Theory of gel formation

Meyer (1960) summarized the three theories of gel formation currently supported by colloidal chemists. These include solvent adsorption, formation of a three-dimensional network, and particle orientation. She further stated the pH and salt dependency of egg gels suggest these gels are formed through a three-dimensional network bonded by nonspecific

attractions between sections of the molecule or along the entire molecule. She theorized that gel formation depends on both denaturation and gelation. During denaturation a fibrous material is formed, which is followed by the formation of the three-dimensional network. Gelation results from a balance of forces of attraction and repulsion; that is, solute molecules are attracted at some spots but are separated by the attraction of solvent molecules along other spots. Too strong an attraction between solute molecules or solvent molecules would result in conditions incapable of gel formation.

Syneresis. Liquid sometimes seeps from coagulated protein gels upon standing. This process of liquid separation is termed syneresis and is related to the stability and gel strength of protein gels. Ferry (1948) pointed out a high percentage of drainage usually indicates a relatively coarse structured gel, and the incidence of syneresis can be explained by large pools of solvent which are readily squeezed out as the network is compacted. As the attractive forces between chains of denatured protein become smaller, the slower the second step of the gelation process takes place. Accordingly, this results in the formation of a higher concentration of long chain molecules occurring as an intermediacy in the gelation process and the formation of a finer network. Thus, low attractive forces are correlated with fineness of structure and a relatively small amount of drainage.

Use of baked custards to test gel strength

Baked custard is commonly used to test the thickening ability of eggs since gelation of the custard is due primarily to the presence of

egg proteins. Although milk proteins are also present, only 0.75 per cent of these proteins are heat coagulable (Lowe, 1955).

Gelation temperature. The coagulation temperature of custard depends on protein concentration, presence of other ingredients, rate of cooking, and pH of the mix. Thus, no specific end temperature can be given although Griswold (1959) stated the end point temperature for baked custards ranges from 86° to 92°C. Miller et al. (1959a) reported the gel strength of custards increased as the end baking temperature was raised from 86° to 90°C. Mastic (1959) observed similar trends while studying the effect of increasing the temperature from 88° to 92°C. These findings are in agreement with Lowe's (1955) statement that as the temperature is elevated the firmness of custard increases until at a definite temperature, depending on the rate of heating, an optimum consistency is reached. Overheating, either from too high an end temperature or too high a baking temperature, may result in an overcooked custard which is porous or curdled and shows excessive drainage upon standing.

When a custard is cooked slowly it thickens at a lower temperature than it does when cooked rapidly (Lowe, 1955). Because the coagulation process is endothemic, the internal temperature remains constant as the thickening point is reached, indicating gelation of the custard is occurring. When a slower rate of cooking is used, thickening occurs over a wider temperature range as compared to the short thickening temperature range obtained with a fast rate of cooking. Cooking custards with a fast rate of heating causes coagulation to occur over such a short temperature

range and makes it difficult to determine when optimum coagulation has been reached before curdling takes place. Griswold (1962) reported an oven temperature of 177°C gives best results.

Effect of protein concentration (Lowe, 1955). The temperature necessary to produce coagulation is increased as the protein is diluted. Decreasing the proportion of egg to milk in a custard mix not only lowers the coagulation temperature but produces a less firm product.

Effect of sugar (Lowe, 1955). Since sugar has a peptizing effect on protein, its addition elevates the coagulation temperature and reduces the firmness of the custard. The effects of sugar are proportional to the amount added.

Effect of acid or alkali. The addition of acid or alkali affect the gel strength depending on the resulting pH in relation to the isoelectric point of the egg proteins. Proteins coagulate readily at their isoelectric point. Addition of acid, until the isoelectric point is reached, usually lowers the coagulation temperature and reduces the gel strength. Chick and Martin (1910) found acid hastens the coagulation process but that the effect is relatively small at first. However, with each successive addition of acid, the influence of the acid becomes disproportionately greater. Chick and Martin (1912-13) also reported that if the egg solution is highly alkaline the agglutination or coagulation phase will not take place.

Effect of salts. Gel formation of an egg-milk mixture requires the presence of certain salts or ions. If distilled water is substituted

for milk in a custard, flocculation rather than gelation occurs. This indicates that the ions present in milk are necessary for coagulation. Lowe (1955) stated the extent of coagulation caused by the ions is dependent on the kind of ion present, the concentration, and the ion's valence. As the valence of the ion is increased, the amount which is required to bring about gelation is lowered.

Effect of egg processing techniques. Jordan et al. (1952) reported pasteurization and/or freezing did not impair the functional ability of whole egg to produce a satisfactory custard. Miller and Winter (1950) cited similar findings.

Jordan and Sisson (1943) found baked custards made from good quality dried eggs were as desirable as custards made from fresh eggs. However, their studies indicated the dried egg custards received the highest flavor scores, whereas the fresh egg custards were significantly firmer. Ary and Jordan (1945) reported the desirability of custards prepared from high quality spray-dried egg powder was comparable to that of custards prepared with fresh eggs but that dried eggs of low solubility produced custards which were less firm than those made from fresh eggs. Dawson et al. (1945) also found that as the egg powder became less soluble it produced a less firm custard. Schlosser et al. (1961) observed dried egg powder stored at 4.4°C or 21.1°C for several months produced custards which had flavor and texture qualities similar to custards prepared with shell eggs. Miller et al. (1959a) indicated custards baked to one end temperature and prepared with spray-dried eggs were less firm and somewhat less desirable than comparable custards prepared with fresh or frozen eggs.

Kelly et al. (1962) observed that the flavor of custards prepared from spray-dried egg was preferred over the flavor of custards from freeze-dried, fresh, or frozen egg, and that the flavor of custards prepared from freeze-dried egg was preferred over the flavor of custards prepared from frozen egg. No reports were found in the literature concerning the gel strength of custards made from freeze-dried eggs.

The reconstitution procedures used in the reconstitution of whole egg solids is also an important factor in the functional performance of eggs in custards, although there is little agreement among research workers regarding the optimum conditions for reconstitution. Jordan and Sisson (1945) reconstituted the dried egg, which was to be used in custards, 18 hours before mixing and just prior to mixing. These workers observed that the egg which had been reconstituted for 18 hours produced a firmer custard than that which was reconstituted just prior to mixing. Miller et al. (1959b) found the addition of water in three portions at 21-45°C to egg solids produced a significantly lower per cent dispersibility than the addition of egg solids to the total quantity of water (21-45°C) or the incorporation of water with the egg solids in one or two equal portions. The addition of water at 13°C produced low dispersibility for all methods of mixing. These workers also reported the addition of sucrose or the aeration of the egg solids before adding water produced no significant difference in per cent dispersibility of whole egg solids.

Changes in pH of custard after baking. Miller et al. (1959a) reported the pH of the baked custard is more alkaline than the pH of the mix from fresh, dried, or frozen eggs. This is in agreement with findings

reported by Lowe (1955). However, Longree et al. (1961) found pH values were slightly lower after baking for custards prepared from dried eggs.

Color of Egg

Color is extremely important because it is not only a measure of quality and economic worth but also determines whether or not a food product will be accepted or rejected. Color is so important that researchers have shown that even different tints of the same food will be considered by judges to differ in flavor (Birren, 1963). Food coloring may be the result of natural occurring pigment or artificial coloring additives.

Egg yolk color

The natural carotenoid pigments in egg yolk are mostly xanthophylls with small amounts of luten and zeaxanthin (Bunnell and Bauernfeind, 1962). The Federal Food and Drug Administration governs egg yolk color by a Standard of Identity which indicates that no artificial coloring may be added to yolks (Forsythe, 1963). Yolk color is, however, influenced to a great extent by the diet of the hen. Wilcke (1938) reported that heredity influences yolk color only slightly. Egg processing techniques may have detrimental effects on yolk color.

Influence of feed on color of yolk. Due to a demand for yolks with dark yellow color, studies have been undertaken to determine which feeds will give the desired yellow color. It is known that an increased consumption of green foods causes yolk color to become deeper yellow. However, hens no longer have free range in grassy covered fields,

thus other feed sources which impart a rich yellow color to the yolk are desired.

Carlson (1961) reported a diet of alfalfa meal at the level of 20 per cent and yellow corn imparted a desirable dark yellow color to the yolk. However, carrot oil concentrates and xanthophyll concentrates did not influence yolk color. Jensen (1963) found the addition of 3-7 per cent of seaweed meal to the diet increased the carotenoid content of the yolks. Frompton et al. (1962) observed the effects of cottonseed meal in the diet caused adverse effects on yolk color. Deethardt et al. (1965) found diets containing 18 and 20 per cent alfalfa meal, 3 per cent algae meal, and 6-9 per cent grass and clover meal produced yolks with a more intense yellow color, whereas diets with xanthophyll concentrate and beta-apo-8'-carotenal produced light colored yolks. Carlson (1961) and Mackey (1963) observed the yellowness of the yolk increased when a small amount of paprika was added to the diet. On the contrary, Deethardt et al. (1965) found diets containing paprika resulted in poor yolk color. The addition of paprika is not approved by the Food and Drug Administration.

Influence of drying process on color of egg. As mentioned previously, dried eggs undergo the Maillard reaction, resulting in undesirable browning. Removal of glucose reduces greatly the development of brown substances. Browning usually increases as the moisture content increases and as the storage temperature increases. Whole dried eggs may also darken to an undesirable color as a result of the oxidative destruction of carotenoid pigments.

Miller et al. (1959a) reported custards made from spray-dried egg solids were significantly different and less desirable in color and flavor than shell or frozen egg custards, but that differences in the color or flavor of shell and frozen egg custards were not significant. On the other hand, Mastic (1959) found the color of the body of custards prepared with dried egg was not significantly different from the color of custards prepared with fresh egg. No studies have been reported on the color of custards prepared with freeze-dried eggs.

Objective Measurements

Food is often evaluated by measures other than the human senses. Objective measures are employed to reduce the possibility of error in sensory methods and to eliminate differences in individual senses. The results of any objective test must be reproducible and accurate. The validity of any objective device depends on whether or not it is in agreement with results of sensory testing.

Gel strength measurements

The gel strength or firmness of custards is commonly measured by a penetrometer or curd tension meter. Because of limitations and difficulties in obtaining accurate readings with these two instruments, attention is being given to the possibility of using the shear press to measure the firmness of gels.

Penetrometer. The penetrometer measures the distance a specified free falling force applied for a specified time penetrates into the gel structure. Depending on the type of product being tested, a cone,

disc, or needle is used. Readings are recorded in millimeters penetration. Both MacDougall (1953) and Bittner (1954) reported correlations between panel scores for crust tenderness and penetrometer readings of custards with the crusts on. However, neither worker found correlations between panel scores for firmness and penetrometer readings for firmness of custards with the crusts removed. On the other hand, Mastic (1959) observed close agreement between penetrometer values, curd tention values, and panel scores for firmness of custards.

Curd tension. Although the curd tension meter was designed to measure the hardness of the curd in milk, it has been modified to judge the firmness of custards. It measures the force, in grams, required for the cutting blades of the instrument to cut through the custard. MacDougall (1953) and Bittner (1954) found high correlations between panel scores and curd tension meter readings for firmness and concluded the curd tension meter was a better measure of gel strength than the penetrometer.

Shear press. Around 1950, Lee Kramer developed a shear press for measuring the tenderness and texture of products. The shear press, which operates on the principle of resistance to force, consists of a motor-driven hydraulic system for moving a piston at a predetermined rate of speed (Kramer, 1961). This eliminates uneven application of pressure and varying speeds which have limited the use of other objective devices. Measurement of the force applied to the product being tested is provided by the compression of a proving ring dynamometer (Decker et al., 1957). Any possible frictional error is eliminated by attaching the test cell to the proving ring. These rings are available in

sizes which range from 100 pounds for measurements on soft materials to 5000 pounds for hard products. Force readings are obtained through the transformation of the mechanical energy of shearing force into electrical energy which is then recorded on an electronic recording attachment. Complete time-force curves are obtained, and results may be read either as maximum force or total work. Maximum force, recorded in pounds, is the peak shear value; work is determined by measuring the area under the curve. In addition the slope of the curve, the shear angle, and peak compression may also be of value.

Two types of forces which can be applied using the shear press are shearing and compression. Shearing is measured by a standard test cell consisting of a series of blades which simulate the shearing action of the teeth. Compression is measured by a succulometer cell which simulates the sensory reaction of juiciness and can be used to measure the consistency of gels, allowing the sample to be extruded around the cell.

The shear press has been used successfully to evaluate quality characteristics of fruits and vegetables such as, asparagus spears, strawberries, pineapple, beans, and peas (Sidwell and Decker, 1959). Kramer and Cooler (1962) reported that it is rapid and accurate for determining the tenderness-maturity factor of corn. Techniques have also been developed to measure quality factors of other food products as well. The shear press has been used successfully for testing quality of macaroni and spaghetti (Emory, 1960), and of jelly candy drops and marshmallows (Meschter, 1960). Funk et al. (1965) indicated it has use in measuring tenderness, compressiblity, and tensile strength of angel

cake. Burrill et al. (1962) found it can be used successfully for tenderness measurements of beef, however, Wells et al. (1962) reported the shear press had limitations when measuring the tenderness of freeze-dried poultry. Englar and Kudlich (1964) found by using the back extrusion method, the shear press was successful in measuring mashed potato texture.

Use of the shear press for measurement of gel strength has only recently received attention. Presently Kramer (1964) is investigating the use of the shear press to measure characteristics of fruit jellies and synthetic gels. He is recording the peak force as gel strength and height of the curve as firmness. Complete results have not yet been published.

Color measurements

The color of custards is most often determined by panelists. However, because it is difficult for each individual to carry in his mind the same standard by which to score a product and because of differences in sensitivity characteristics of the eye viewing the object, an objective measurement of color is desirable. Among the most common methods of color determination are color charts, spectrophotometers, and photoelectric colorimeters.

Color charts and disks (Triebold and Aurand, 1963). Two important color systems include the Munsell charts which contain 982 colors and the Mærz and Paul Dictionary of color which contains 7056 colors. The Munsell system can be represented mathematically, whereas the Maerz and Paul values cannot be treated mathematically unless they are first converted into the Munsell values.

The Maxwell Spinning Disks, essentially an additive visual colorimeter, consist of spinning standardized colored disks at a speed sufficient to make them appear as a solid color which is derived from the composite of the areas of each of the color disks exposed. The Munsell system of notation is commonly used in this method. By varying the area of the disks exposed it is possible to match the color of the sample being tested. This method still requires visual perception to match the color comparisons and does not eliminate the error of difference in sensitivity of the human eye.

Spectrophotometer (Mackinney and Chichester, 1954). The spectrophotometer is an analytical instrument capable of measuring total reflectance as a function of wave length. The American Standards Association require "the spectrophotometer shall be recognized as the basic instrument in the fundamental standardization of color." It is the most unambiguous specification of color since the spectrophotometric curve is a plot of intensity versus wave length. The use of a nonrecording spectrophotometer is extremely time consuming and laborious for testing large numbers of samples.

Photoelectric colorimeter (Gardner Color Meter). This instrument measures color using three separate scales to determine the color of an object in comparison with the color of a standard plate. This instrument possesses a light source which strikes the sample at a 45^{0} angle of incidence. The light is then diffused perpendicularly from the sample and is passed out to each of three filter photocell combinations to create a current proportional to the light's intensity which can be measured (Bedford, 1964).

Color is measured by three scales, the L, a_L, and b_L. The L scale measures lightness and is such that an object which the human eye judges as halfway between black and white will have a value of 50. The a_L and b_L readings are rectangular coordinates of color which intersect the color solid perpendicular to the white-black axis. Both the a_L and b_L measurements are recorded in plus or minus values. Plus values for the a_L scale indicate redness and minus values greenness, while plus values for the b_L scale indicate yellowness and minus values blueness.

For a comparison between the color of two or more products to be meaningful, it is necessary to use the color attribute or attributes responsible for the difference in color. In determining the color of food stuffs the use of more than one coordinate has been found to give a more accurate measurement of color for many food products. For example, the a_L/b_L ratio is commonly used to evaluate the redness of tomato juice color. Francis (1963) described this ratio as a tangential function which should be used only when it is close to unity. Saturation or purity is measured by $\sqrt{a^2 + b^2}$. Even greater accuracy may be obtained by computations involving all three coordinates. However, Francis (1963) stated this increase in accuracy may not justify the lengthy computations involved.

Numerous studies in the literature report the successful use of the color difference meter to measure the color of such foods as tomato juice (Robinson et al., 1952), citrus juices (Huggart and Wenzel, 1955), and peach puree (Wilson et al., 1957). Longree et al. (1961), using the color difference meter to determine the differences in color of

custards prepared with various egg concentrations, observed the values of the interior of the custard were lower and the reflectance values were higher for custards with a low egg concentration than values obtained for custards with a high egg concentration.

EXPERIMENTAL PROCEDURE

Preliminary Investigation

Lack of information in the literature regarding use of the shear press for testing gels prompted an investigation into the possibility of using this instrument to measure the gel strength of baked custards. Both Lowe (1955) and Griswold (1962) state that the firmness of baked custards is increased with increasing amounts of egg. Thus, in order to produce custards of varying gel strength, three levels of egg protein were used: 48 g , 72 g , and 96 g of whole shell egg per 244 g of milk and 25 g of sugar. Custards prepared under standardized conditions from the three levels of egg protein were baked to an end temperature of 86°C in a 177°C oven. Tenderness of the custards was measured by four different methods including a taste panel, the Micrometer Penetrometer, the Allo-Kramer Shear Press using the upper assembly of the fixed blade cell, and the Allo-Kramer Shear Press using the piston of the succulometer cell. Maximum force values and area-under-the-curve values were determined for both types of shear press measurements. The custard mixtures were baked both in 400-ml beakers and in rectangular loaf pans (5 in. x 3 1/2 in. x 2 1/4 in.) to obtain the desired shapes and sizes for testing on the shear press with the succulometer piston and fixed blade cell, respectively.

Analysis of variance revealed highly significant differences in the gel strength of the custards made from three levels of egg protein for all four testing methods. Each of the four methods indicated the expected results showing the lowest concentration of egg produced the

most tender custard, whereas the highest concentration produced the least tender custard.

Coefficients of linear correlation were calculated for all three egg protein levels combined. Significant correlations were found for all combinations of the four measurements. The highly significant correlation coefficients between the taste panel and the shear press (maximum force) for gel strength, using both the fixed blade cell and the succulometer piston, were -0.837 and -0.883, respectively. The correlation coefficients ($p < 0.01$) between the taste panel and the shear press (area-under-the-curve), using both the fixed blade and the succulometer piston, were -0.902 and -0.854 respectively. Thus, use of the shear press with either of the two cells investigated appeared to be a valid measure of the gel strength of custards. Furthermore, gel strength measurements determined by use of either cell correlated equally well with taste panel evaluations.

Standard deviations were calculated between replication averages for custards made with the two lower concentrations of egg. Results are listed in Table 4. The slight differences in the standard deviations obtained by use of the different cells also indicated use of either cell to be equally effective.

The shape of the curves drawn by the electronic recorder (Figure 1) varied consistently depending on the particular cell used. Use of the fixed blade assembly to measure gel strength resulted in an initial peak followed by a reduction in force required to shear the custard which was in turn followed by an additional build up of force reading. However, use of the succulometer piston produced a graph with approximately

Table 4. Shear press value means and standard deviations using two levels of egg and two shear press cells.

Grams of egg per 244 g of milk	Cell	Mean	Standard Deviation
48	fixed blades	2.60	± 0.29
72	fixed blades	5.09	± 0.54
48	succulometer piston	2.30	± 0.26
72	succulometer piston	5.37	± 0.48

Figure 1. Shear press graphs when the succulometer piston (left) and fixed blades (right) were used.

the same force readings throughout each individual test. Observation of these recorded patterns led to the postulation that the initial peak obtained using the fixed blade assembly represented the shearing of the surface crust; following the shearing of the crust, the amount of force required dropped off to a point representative of the force

required to shear the gel structure per se. The force readings then increased as the blades penetrated deeper into the slurry due to increased surface area of the blades coming in contact with the gel. When the succulometer piston was used to determine gel strength, the gel extruded up around the piston as it moved deeper into the gel resulting in similar force readings throughout the testing. The flat bottom of the piston did not shear the surface crust except at the circumference and thus did not produce a distinguishable initial reading. Although the results of shear press evaluations using both cells were found to be valid when compared to taste panel evaluations, use of the fixed blade cell was arbitrarily chosen for use in the actual investigation since it was hoped further information concerning the actual consistency could be determined from the defined peaks produced by this method.

Design of Experiment

To determine the effect of drying processes on the coagulating ability and on the color of egg proteins, a milk-whole egg slurry was prepared and baked to a gel-type product. These slurries were prepared with frozen, freeze-dried, and spray-dried eggs, and a slurry made with the frozen eggs served as the control.

Two pH levels were used: one was the unadjusted pH of the mix and the other level was a pH of 6.6. The pH value of 6.6 was chosen, because a pH lower than 6.6 might have caused coagulation of the milk proteins and a pH higher than the original pH of approximately 7.0 has no practical application in cookery.

The slurries were baked to two end temperature ranges of 81-82°C and 84-85°C. Gelation of the milk-egg slurries was found to occur from 80° to 86°C. From these temperatures, the two end temperatures were arbitrarily selected so that the lower range was at least 1C° above the temperature at which gelation was noted, and the higher range was 1 C° below the temperature at which curdling was observed. A 2 C° range was used because slurries baked in the same water bath, regardless of oven position or type of egg, did not reach the same end temperature simultaneously.

The experiment was divided into two series: the first series was baked in aluminum loaf pans and used to determine gel strength with the shear press; the second series was baked in conventional custard cups and used for color and drainage determinations. Four replications of each series were baked.

Processing of Whole Egg

To eliminate possible variation in egg composition, sufficient eggs from one controlled source were procured for processing both types of dried eggs as well as for the frozen control. The whole eggs were obtained from a common source through a commercial food company.[1]

Preparation of eggs prior to processing (Gorman, 1965)

The shell eggs were machine broken, strained to remove shell fragments and membranes, and churned to insure product homogeneity. Corn

[1]Seymour Foods Company, Topeka, Kansas.

syrup solids were added to the liquid blend of whole egg on the basis of 31.5 ± 0.5 per cent carbohydrate in the dried product. The egg mixture was pasteurized at 60°C for 3 1/2 - 4 minutes. Following pasteurization, the mixture was placed in 30-pound metal containers, commercially frozen, and held at -40°C until further processing and/or shipment. A third of the frozen mixture was allocated for use as the control. Another third was used for spray-drying and the remaining third for freeze-drying.

Spray-drying (Gorman, 1965)

The portion of whole egg to be used for spray-drying was thawed, blended, and spray-dried using a 12-nozzle Roger's Drier under an atomizing pressure of about 2500 pounds.[2] The egg was sprayed into a drying chamber through which air of 149-163°C was passing. The exhaust temperature was 66-71°C. After drying, the product was screened through a 16 mesh USBS screen and cooled to a temperature of about 29°C.

Freeze-drying (Wells, 1964)

The frozen eggs for the freeze-drying process were shipped to the appropriate processor[3] and held at -40°C until the final processing. Prior to freeze-drying, the frozen egg mixture was thawed at room temperature, during which time the temperature of the product did not exceed 15.6°C. The thawed product was mixed and poured into dryer pans of a RePP Industries sublimator No. 42 where it was frozen to

---

[2]Seymour Foods Company, Topeka, Kansas.

[3]Midwest Research Institute, Kansas City, Missouri.

-45.5°C. Chamber pressure was maintained at 10 microns. Heat was supplied by both conduction and radiation. Although the temperature of the platens was 60°C, the temperature of the product never exceeded 49°C. Upon completion of the 18-hour drying cycle, the chamber vacuum was broken with air. The egg was removed, allowed to reach room temperature, and then sealed into five gallon tins until final packaging.

Packaging, shipment, and storage

Both the spray-dried and freeze-dried eggs were similarly packaged.[4] One-pound flexible laminated-foil pouches were used for both types of eggs. The pouches consisted of the following materials: polyethylene terephthalete (.005 thickness), foil aluminum (.001 thickness), and polyethylene (.002 thickness). The packaging process involved drawing 27 inches of vacuum, purging the eggs with nitrogen twice, and sealing on the third vacuum. The eggs were held at 20.6°C both before and after the packaging process. Following shipment to Michigan State University the dried egg packages were frozen and held at -23.3°C for the 6 to 7 months period prior to use.

The frozen eggs were shipped to Michigan State University in 30-pound tins packed in dry ice. Upon arrival the mixture was thawed by placing the tins under running water, subdivided into appropriate amounts, and placed in round plastic-lined, pint-size cardboard containers. During this repackaging, the temperature of the eggs did not exceed 4-5°C. The eggs were then blast frozen at -40°C and held at -23.3°C for 6 to 7 months prior to their use.

---

[4]Jianas Bros. Candy Company, Products Packaging Division, Kansas City 8, Missouri.

Just prior to each baking series the one-pound packages containing the freeze-dried egg were opened and the freeze-dried egg was pulverized using the grinder attachment of the Hobart Kitchen-Aid mixer, Model K5-A. After the mix was pulverized, the powder passed through a fine wire screen (18 wires per in.). The freeze-dried eggs were ground to simulate powder conditions of the spray-dried eggs. The ground freeze-dried eggs and also the one pound packages of spray-dried eggs were then portioned into the 60-g amounts required for each replication, heat sealed in heat sealable pouches, and refrozen at -23.3°C until day of use.

Basic Formula

A standard basic custard formula commonly used in experimental work with eggs (Lowe, 1955) consists of 1 cup of milk (244 g), 1 egg (48 g), and 2 tablespoons sugar (25 g). Flavorings are usually omitted to avoid any effect they may have on flavor or color.

Formula modification

Since the addition of sucrose to an egg-milk mixture affects the gel strength of a baked custard (Lowe, 1955; Griswold, 1962), sugar was omitted in this investigation so that the effects of drying processes *per se* on the egg proteins could be identified more clearly. To obtain a gel structure firm enough to invert for testing purposes, the proportion of egg was increased from 48 g to 72 g per 244 g milk (approximately 1 1/2 eggs per cup of milk).

The amount of whole eggs solids and the quantity of water equal to that in the liquid control egg mixture were calculated on the basis

of the average moisture content (69.4 per cent) for the frozen eggs as determined by the AOAC vacuum oven method 16.3 (a) (1955). The actual weight of the dried egg solids used was corrected for variance in moisture content of the dried eggs, which was calculated by the AOAC method 16.3 (b) (1955). The amounts of dried egg used increased and the amount of water for reconstitution decreased as the moisture content of the dried egg powder increased. The weights of the ingredients used in the baked slurries are listed in Table 5.

Table 5. Formulas used in preparation of baked slurries.[a]

Ingredients	Frozen Egg Slurry	Dried Egg Slurries	
		Spray-dried Egg	Freeze-dried Egg
	g	g	g
Frozen egg	180.0	-	-
Spray-dried egg	-	57.8 - 58.5	-
Freeze-dried egg	-	-	56.2 - 56.9
Dried milk	65.2	65.2	65.2
Distilled water for:			
Milk reconstitution	545.0	545.0	545.0
Egg reconstitution	-	121 - 122	123 - 124

[a]The amount of dried egg and distilled water was corrected for variance in moisture between packages.

Milk source

Dried whole milk in nitrogen packed No. 10 cans was purchased from a common lot. Just prior to each baking series it was portioned into amounts needed for each replication and heat sealed into heat sealable pouches. The dried milk was stored at 4-5°C from the time it was purchased until needed for use.

Preparation

Preparation for each day consisted of two bakings of slurries, each of which contained a separate batch prepared with each of the three types of processed eggs. Each baking represented one replication, one end temperature, and one pH level.

The frozen eggs were thawed at 4-5°C for approximately 15-22 hours prior to using. The dried egg samples were thawed at room temperature about 15 minutes before preparation. All ingredients were weighed on the day of preparation.

Dried egg slurries

The eggs and milk for the dried egg slurries were weighed to the nearest 0.1 g on a triple beam balance (1.6 kg capacity) and placed together in a labeled stainless steel 5-qt. mixing bowl. The powders were dry-blended for 30 seconds on a Hobart Kitchen-Aid mixer, Model K5-A, using a whip attachment at speed 4 (132 rpm). The bowl was then scraped, and the powders were blended for an additional 30 seconds.

Complete reconstitution of the dried mixture was accomplished by first making a paste of the egg-milk powders and a small portion of distilled water, followed by two additions of the remaining liquid. The distilled water was warmed to 40-50°C prior to use according to company recommendations for reconstitution of the milk powder. Eighty ml of the distilled water was blended with the mixture of dried milk and egg for 30 seconds at speed 4 (132 rpm) using a paddle attachment. The bowl and paddle attachment were scraped to loosen unmoistened

particles, and then mixing was continued for an additional 30 seconds. The remaining water was added in two equal portions. The first addition was followed by a mixing period of 30 seconds at speed 2 (87 rpm), scraping, and an additional 30-second mixing period. The final addition of water was followed by a 30-second mixing period at speed 2, scraping, and a final 3-minute mixing period. Upon removal from the mixer, the mixture was strained through a fine wire household strainer (25 wires per in.) into a labeled pouring pitcher. A small portion of the strained mixture was removed for pH determination with a Beckman Zeromatic pH Meter.

Control egg slurries

The dried milk for the control slurries was weighed to the nearest 0.1 g on the triple beam balance and combined in a 5-qt. stainless steel mixing bowl with the amount of distilled water (40-50°C) required for reconstituting to average composition for fluid whole milk. The mixture was blended with the paddle attachment on the Hobart Kitchen-Aid mixer at speed 1 (69 rpm) for 30 seconds. At this time any large lumps of undispersed milk powder were broken with a rubber spatula, and the mixing was continued for another minute. A portion of the milk was removed for pH determination and then returned to the bowl. The liquid egg was weighed to the nearest gram on a Toledo balance (4.5 kg capacity) into a labeled mixing bowl. The reconstituted milk was added to the defrosted egg and mixed for 5 minutes on speed 2 (87 rpm) with the paddle attachment. Using the same procedure described previously, the control egg mix was strained into a labeled pouring pitcher and a pH determination was made.

pH adjustment

The preparation of the slurries which involved addition of acid was similar to the previously described methods except that 75 ml of the distilled water was held back from the final addition of water and the final mixing time was reduced by 1 minute. The mixture was removed from the mixer, poured into a 1000-ml beaker and the pH determined. Lowering of the slurry to pH 6.6 was accomplished by gradually adding 0.1 N hydrochloric acid during a 5-minute stirring period, using a magnetic stirrer set at medium speed. The pH adjusted mixture was returned to the mixing bowl and distilled water was added in an amount equal to the difference between the 75 ml of water withheld and the milliliters of acid added. A final 1-minute mixing period at speed 2 followed, after which the mixture was strained back into the 1000-ml beaker and the adjusted pH value recorded.

Baking Procedure

The egg-milk slurries were baked in two different types of containers to facilitate selected objective tests. Slurries for gel strength determinations were baked in 5 in. x 3 1/2 in. x 2 1/4 in. aluminum loaf pans to provide samples of the desired size and shape for testing with the Allo-Kramer Shear Press. Each loaf pan contained 350 ml of mix, which filled it to a depth of 4.1 cm. Duplicate samples of each of the three types of egg slurries were baked simultaneously. A perforated stainless steel frame was used to support the individual loaf pans in the large aluminum baking pan (18 5/8 in. x 3 3/4 in. x 3 1/2 in.) which served as the water bath. Specially designed thermocouple supports (Figure 2) were clamped to each individual pan to insure

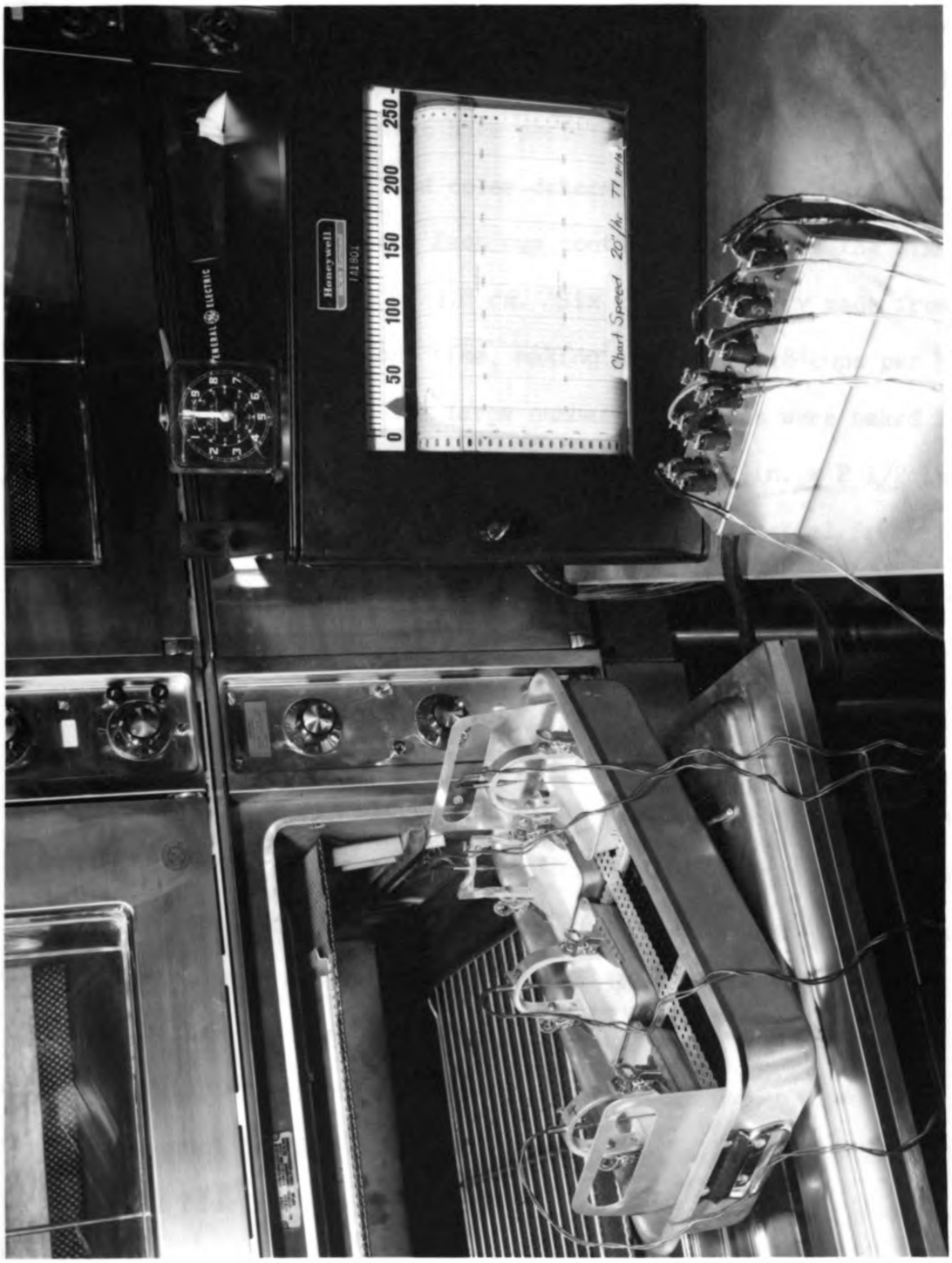

Figure 2. Specially designed baking apparatus for the support of the loaf pans and thermocouples.

that the thermocouple remained securely positioned in the center of the slurry at a depth of 1.6 cm. The slurries were baked in a predetermined randomized order so that the slurries prepared with each type of egg were baked in right- and left-oven bake positions and in front-, middle-, and rear-oven bake positions.

Slurries for drainage and color determinations were baked in conventional 5-oz custard cups. Each cup contained 110 ml of the mix which filled it to a depth of 3.8 cm. Six cups of slurry made from each type of egg were baked at one time, making a total of 18 cups per baking period. Because of the large number, nine cups were baked in each of two separate baking pans (15 1/2 in. x 8 1/2 in. x 2 1/2 in.). The cups were held in place by a perforated stainless steel frame, which was also used to support the thermocouples positioned at a depth of 1.9 cm in the center of the slurries used for drainage determinations (Figure 3). The baking positions of the cups were also rotated with respect to front-, middle-, and rear-, and inside- and outside-oven bake positions. The six slurries used for drainage determinations were baked in the same rows in the water bath each day because of the fixed position of the thermocouples. However, the slurries used for the color determinations were rotated with respect to row in the two water baths.

Just before the pans containing the slurries were placed in the oven, tap water at approximately 20°C was poured into the baking pans to a level equal to that of the mix. The slurries were baked at 177°C in a General Electric 30-in. compact oven, Model CN 16, with a damper half-way closed and the grids set at medium. Oven temperature was controlled with a Minneapolis-Honeywell Versatronik Controller which

Figure 3. Specially designed baking apparatus for the support of the custard cups and thermocouples.

was installed to replace the normal oven thermostat to reduce the normal oven cycling from 177 ± 20°C to 177 ± 7°C. The water bath containing the slurries was centered in the oven on a metal rack 3/8 in. high which had been placed on the floor of the oven. Removal of the center deck allowed ample room in the oven for the baking apparatus. A dark metal shield was installed in the top of the oven to further equalize heat distribution and to reduce surface browning.

Temperature readings were recorded using a Brown Electronic 12-point recording potentiometer which made it possible to record temperatures of each slurry every three minutes. As soon as the selected end temperature range of either 81-82°C or 84-85°C was reached, the water bath was removed from the oven. The containers supported by the stainless steel frame were removed from the water bath and placed on a wire rack to cool at room temperature for 1 hour. Thermocouples were then removed and the slurries were refrigerated uncovered for approximately 24 hours prior to objective testing.

Objective Measurements

On the day following preparation, objective tests were performed to determine pH, gel strength, syneresis, and color. The samples were removed from the refrigerator just prior to objective testing.

pH of baked slurry

The pH was determined on 15-g samples obtained from baked slurries after tests for gel strength and drainage had been performed. Fifty ml of distilled water were added to each slurry sample, and this mixture

was blended for 15 seconds on an Osterizer set at low speed. The pH value was then obtained using a Beckman Zeromatic pH meter. Each pH value recorded was the average of two trials.

Shear press gel strength measurement

The upper assembly of the fixed blade cell of the Allo-Kramer Shear Press, Model SP 12, was used to determine the gel strength of the baked slurries. The lower portion of the cell was not used because the baked slurry could not be transferred into the standard cell box without damage to the gel structure. For the gel strength determinations a 100 pound proving ring, with a range of 10 pounds and a pressure of 5 pounds, was used.

Just prior to testing, the baked slurries were removed from the refrigerator so that the internal temperature of the slurries ranged from 6-8°C during testing. Each slurry was placed directly under the upper assembly where the cell box was normally positioned. Using a full downstroke speed of 30 seconds, the fixed blade cell was lowered into the baked slurry to a depth of 3.8 cm while readings were recorded on an electronic Recorder Indicator, Model E2 (Figure 4). Before tests of each slurry were made, the cell blades were rinsed with lukewarm water to remove gel particles.

Gel strength of the slurries was determined by the number of pounds required to shear through the gel. This was calculated from the three points on the curved graph drawn by the electronic recorder (Figure 5). The pounds force required to shear through the baked slurry was computed by multiplying separately the range used times the peak

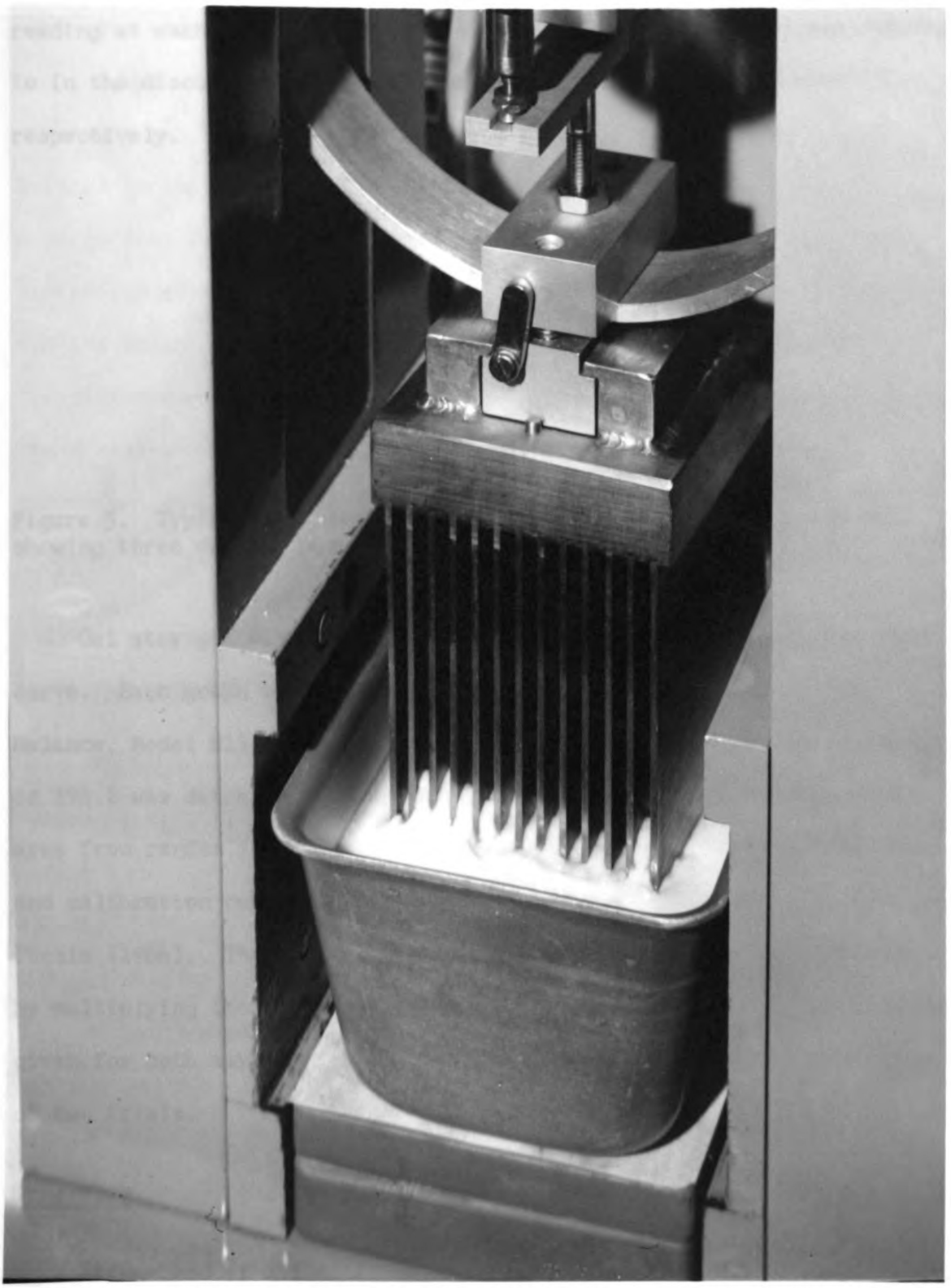

Figure 4. Shear press in operation during measurement of the gel strength of a baked egg-milk slurry.

reading at each of the three indicated points. These values are referred to in the discussion of the results as peak I, peak II, and peak III, respectively.

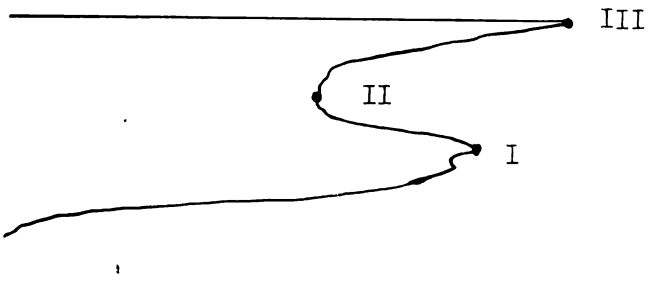

Figure 5. Typical gel strength curve obtained using fixed blade cell showing three defined peaks.

Gel strength was also determined by computing the area-under-the-curve. Each graph was carefully cut out and weighed on a Mettler Balance, Model H15. To convert the weight to area, a conversion factor of 174.2 was determined by weighing multiple squares of varying known area from random locations on similar chart paper. The numerical data and calibration curve for derivation of this factor appeared in Brown's Thesis (1964). The area-under-the-curve for gel strength was calculated by multiplying the curve weight times the conversion factor. The values given for both maximum force (lbs.) and area (cm^2) represent an average of two trials.

Syneresis

The method of Miller et al. (1959a) was used to determine the drainage of the baked slurries. The gel was carefully loosened from the custard cup with a metal spatula and inverted, crust down, on fine

wire screening (18 wires per in.) positioned over a petri dish. Before the gel was inverted, the combined weight of the petri dish and wire screening was obtained. The dish, screen, and inverted sample were weighed to the nearest 0.1 g on the triple beam balance, covered with a large bowl to prevent evaporation, and allowed to stand for 1 hour. At the end of this period, the gel was removed from the wire screening, and the weight of the drainage was recorded to the nearest 0.1 g from the difference in weights of the petri dish and screen before and after the drainage period. Percentage drainage was calculated by dividing the weight of the drainage by the weight of the baked slurry before drainage and multiplying by 100. Each value represents an average of two trials.

Color measurement

Color of the baked slurries was measured by a Gardner Color Difference Meter, Model AC-1. The instrument was standardized with the yellow tile (L, 78.7; a_L, -1.8; b_L, +22.7) in preparation for determining the L (lightness), a_L (greenness), and b_L (yellowness) values of the gel samples. After each sample was loosened with a 1/4-in. spatula, the gel was inverted on a plate and a slice approximately 1/4 inch thick was removed from the original bottom of the gel. The gel was then placed on a clear flat piece of high quality plate glass (4 3/4 in. x 3 5/8 in. x 1/8 in.) so that the cut edge of the gel was against the glass surface. The glass and slurry were placed over the viewing area of the Gardner Color Difference Meter, and two sets of readings were obtained from different gel positions by moving the glass supporting the gel. Analysis of color was based on L, a_L, and b_L values and the

a_L/b_L ratio. Each value given represents an average of four readings, two readings for each of two baked slurries.

Subjective Evaluation

Inside color was the only attribute for which the slurries were subjectively evaluated. A panel of seven judges scored each replication of baked slurries on the basis of color preference and color difference. Tests were administered to each judge by using AO H-R-R Pseudoisochromatic Plates to establish that no color blindness existed in the yellow-blue or red-green areas. Directions given to the judges at the time of scoring appear in the Appendix.

Color preference judging

Six slurries were examined during each judging period. These consisted of slurries made from each of the three types of egg at both pH levels. The gels were carefully loosened from the sides of the custard cups and inverted on clear glass plates 7 1/2 inches in diameter. A 1/4-in. slice was removed from the original bottom of each slurry so that both objective and subjective evaluations were made from the same area of the gel. The prepared samples were coded with previously determined randomized numbers, placed on a dull white background, and examined under fluorescent lighting produced by 15 watt cool white light bulbs. Each judge was asked to score the slurries on a 7-point hedonic scale, ranging from very poor to excellent. A score sheet appears in the Appendix.

Color difference judging

Slurries made from the three types of eggs at both pH levels were also evaluated for color differences. The preparation of the six slurries was similar to that described above. However, the slurry prepared from the frozen egg at the unadjusted pH level was labeled as the control, and it was this slurry with which the other slurries were compared. The slurries were judged on a 4-point scale ranging from no difference to extreme difference. A score sheet appears in the Appendix.

Analysis of Data

The data obtained from all of the tests was evaluated by use of two computer programs on the CDC 3600 Computer at Michigan State University. The Rand Routine (Option 3) was used to calculate analysis of variance and the Core Routine was used to determine simple correlations. Significant differences among types of egg, pH levels, end baking temperatures, and individual treatment combinations were evaluated through use of the Studentized range tests (Duncan, 1955).

RESULTS AND DISCUSSION

This study was undertaken to determine the effect of spray- and freeze-drying on the gel strength and color of baked whole egg and milk slurries prepared at two pH levels and baked to two end temperature ranges. Twelve treatments combining each egg type, pH level, and end baking temperature were prepared.

The study was divided into two series: 1) slurries to be used for gel strength measured by the shear press were baked in loaf pans; 2) slurries to be used for gel strength measured as the percentage of drainage due to syneresis and for color, measured by both objective and subjective methods, were baked in conventional custard cups. The slurries were prepared using standardized procedures. Time-temperature relationships were recorded during the baking period. In addition data regarding the pH of the slurries, both before and after baking, and the length of baking time were collected.

pH of the Slurries before and after Baking

The pH values of the slurries before and after baking appear in the Appendix. The results indicate that the pH of the unadjusted mix, regardless of the type of egg used, ranged from 7.0 to 7.1. Although the pH of the mix was adjusted to 6.6, the pH consistently increased to 6.7 during the 1-minute mixing period on the Hobart Kitchen-Aid mixer after the acid had been added. However, the pH meter used was accurate only to a pH 0.1.

In all cases the pH of the slurry increased during baking. The slurries made from the mix at the unadjusted pH generally increased in pH to values of 7.2 to 7.4; whereas, those made from the mix which was adjusted to a pH of 6.6 increased in pH to values of 7.0 to 7.1. These findings are in agreement with observations by Lowe (1955) and Miller et al. (1959a), but differ from those reported by Longree et al. (1961).

Length of Baking Time

The baking times required to reach the designated end temperature ranges for each combination of pH and end temperature range are in the Appendix. The difference in the length of baking times for each replication of a particular treatment ranged from 2 minutes to 8 minutes. Analysis of variance for the baking times (Table 6) showed the differences in length of baking time to be very highly significant for both baking series. These differences may be due to any one or combination of the following factors. Differences in oven cycling or the time of the cycle at which the slurries were placed in the oven may have altered the baking time. Slight variations in the length of time required to position the baking pans and thermocouples in the oven may have lowered the oven temperature slightly more at the beginning of the baking period for one replication than for another. The initial temperature of the mix as it went into the oven varied from 24-26°C among replications, although examination of the time-temperature charts did not indicate any relationship between the initial temperature and the length of baking time. The existence of these very highly significant differences among baking times may be a possible explanation for the

significant differences which occurred between replications for some of the objective measurements.

Table 6. Analysis of variance for baking times of whole egg-milk slurries baked in both custard cups and pans.

Source of Variance	Degrees of Freedom	Cups Mean Square	Pans Mean Square
Total	47		
Replication	3	34.50***	86.69***
Egg Process	2	0.00	0.00
pH	1	3.00	136.69***
End Temperature	1	270.75***	1912.69***
EP x pH	2	0.00	0.00
EP x ET	2	0.00	0.00
pH x ET	1	18.75*	9.18
EP x pH x ET	2	0.00	0.00
Error	33	3.64	2.91

*Significant at 5 per cent level of probability.

**Significant at 1 per cent level of probability.

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

Time-Temperature Relationships

The time-temperature relationships (Figures 6 and 7) show that the inside temperature of all three types of egg slurries increased at the same rate for approximately three quarters of the baking period. However, as the slurries approached the coagulation temperature, the time-temperature curves exhibited slight variation among the three types of

eggs. Generally the spray-dried eggs showed the slowest rise in temperature and the control egg slurries exhibited the fastest rise in temperature. This was true for slurries prepared from mix at both the unadjusted and adjusted pH levels, although there was a greater variation in the adjusted mix than in the unadjusted mix.

Although end temperatures with a 2-degree range were selected, all slurries did not always reach the same end temperature simultaneously. Thus, slurries were removed from the oven when the end temperatures of the majority of the containers of the slurries fell within the designated end temperature range. The end temperatures of the slurries for each replication appear in the Appendix. Examination of the replicate mean values indicated that the slurries prepared from the spray-dried eggs were approximately 1-2C^{0} lower in end temperature when removed from the oven than were the slurries prepared from the freeze-dried or frozen eggs. This difference in end temperature may have been a possible explanation for differences which appear among the gel strength values of the spray-dried egg slurries when they were compared with the freeze-dried or frozen egg slurries.

Objective Measurements of Gel Strength of Baked Whole Egg-Milk Slurries

Gel strength of the baked slurries was measured by two objective methods: the firmness of the gels was determined by the Allo-Kramer Shear Press, and the percentage of drainage due to syneresis was measured by inverting the baked gel on fine wire screening. The discussion of each objective test is accompanied by tables of values which include

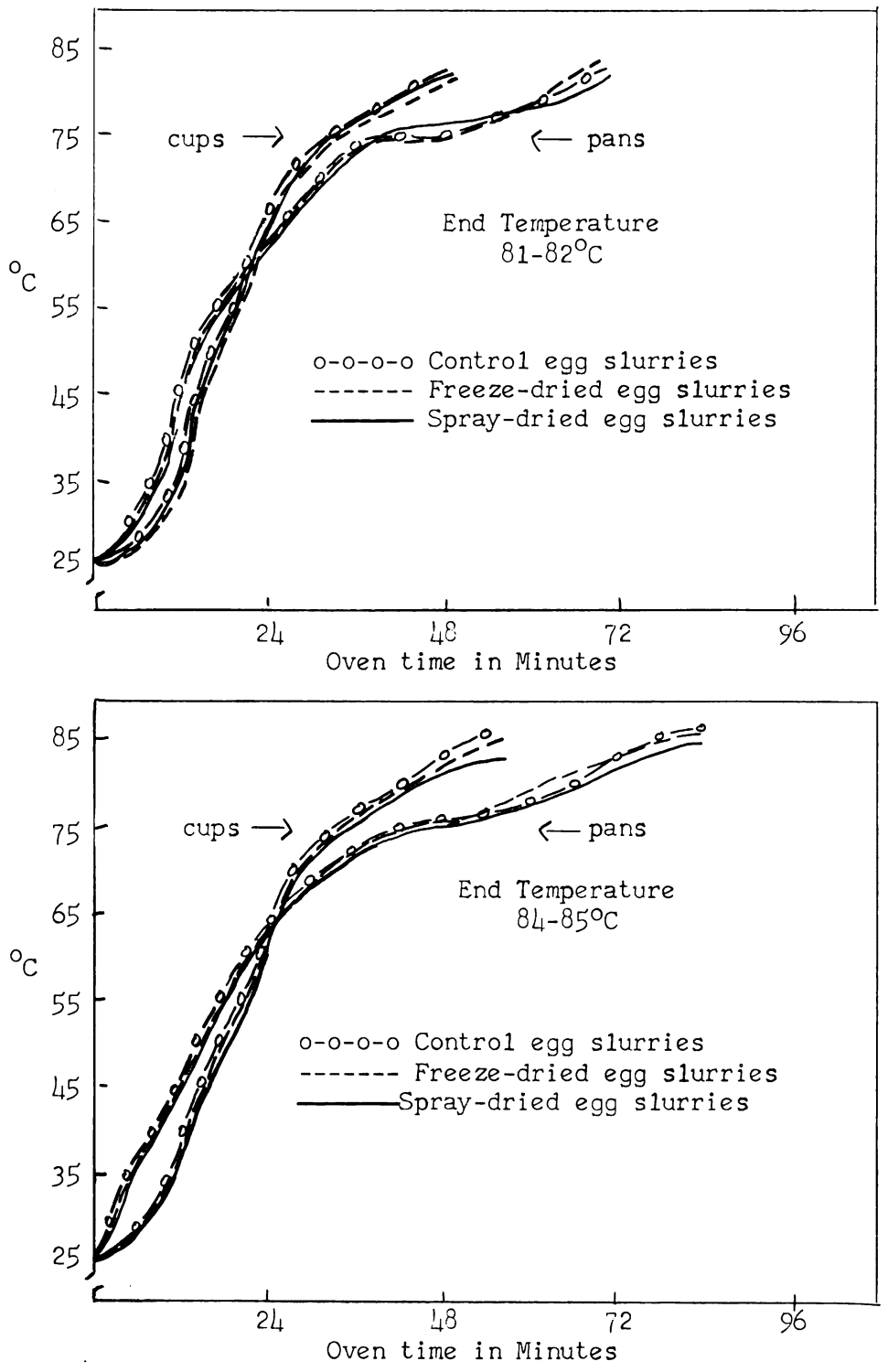

Figure 6. Mean time-temperature relationships during baking of slurries prepared with three types of eggs at the unadjusted pH level.

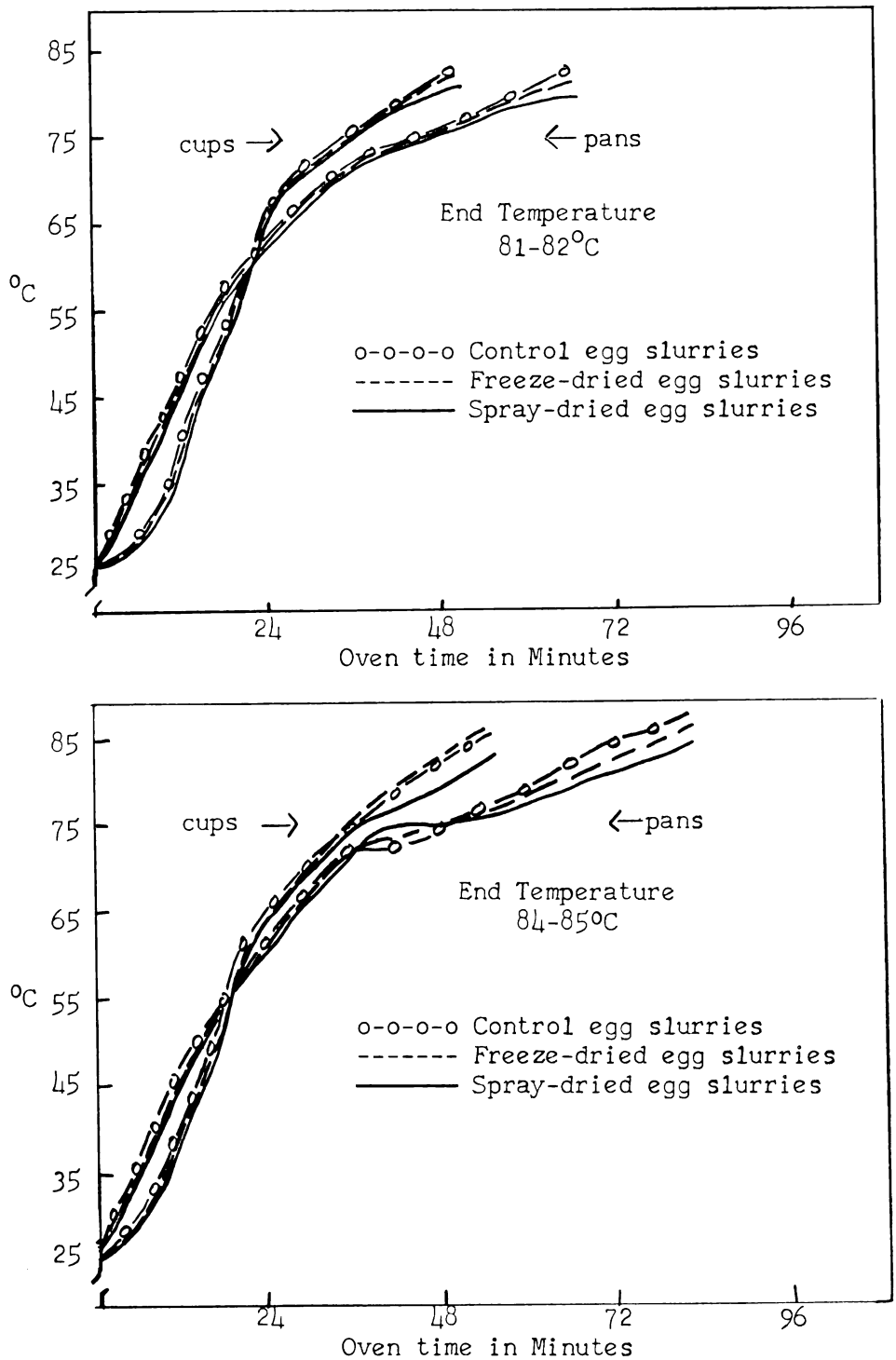

Figure 7. Mean time-temperature relationships during baking of slurries prepared with three types of eggs at the adjusted pH level.

the results of both a three-way analysis of variance and Studentized multiple range tests (Duncan, 1955). Tables of values which include averages and mean values for replication, conglomerate averages for egg process, temperature, and pH, and standard deviations for each of the objective tests are given in the Appendix.

Gel strength measured using the shear press

Gel strength was measured on the Allo-Kramer Shear Press by both the number of pounds required to shear through the gel and by the area-under-the-curve (cm^2). The pounds of force required for shearing was recorded from three defined points on the curved graph and are referred to as peak I, peak II, and peak III (Figure 5, page 50). It was postulated that the peak I reading was the force required to shear through the crust of the slurry; whereas, peak II was assumed to represent the amount of force required to shear through the gel structure. Peak III was regarded as representative of the increase in shear force caused by increased surface area of the fixed blades coming in contact with the gel as the blades penetrated deeper into the baked gel. The area-under-the-curve was assumed to represent a composite measure of total surface and body gel strength. The data were analyzed for significance of variance within drying processes, pH levels, and end temperature ranges, and among the twelve treatment combinations.

Gel strength variance within egg processes. Analysis of variance for gel strength measured by the maximum force (peak I, peak II, and peak III) and area-under-the-curve, as shown in Table 7, revealed very highly significant differences which could be traced to processing of

Table 7. Analysis of variance for shear press measurements of baked whole egg-milk slurries.

Source of Variance	Degrees of Freedom	Peak I Mean Square	Peak II Mean Square	Peak III Mean Square	Area Mean Square
Total	47				
Replication	3	0.74**	0.12	1.13**	1.51
Egg Process	2	7.93***	2.31***	4.11***	42.83***
pH	1	39.24***	12.77***	30.25***	200.21***
End Temperature	1	11.17***	1.64***	24.07***	59.12***
EP x pH	2	0.32	0.20*	0.05	2.04
EP x ET	2	1.19**	0.16	0.16	1.82
pH x ET	1	0.18	0.00	0.00	1.11
EP x pH x ET	2	0.08	0.03	0.08	0.28
Error	33	0.14	0.05	0.24	0.63

*Significant at 5 per cent level of probability.

**Significant at 1 per cent level of probability.

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

the egg. At the 1 per cent level of probability, comparisons of egg process means (Table 8) for all four measurements revealed that baked slurries prepared from the frozen control eggs were firmer than those prepared from either freeze-dried or spray-dried eggs. In addition at the 1 per cent level of probability, both the area-under-the-curve and peak I maximum force readings disclosed that the use of freeze-dried eggs produced a stronger surface and/or firmer gel than the use of spray-dried eggs. The same trend was observed for peaks II and III maximum force readings, although these differences were significant only at the 5 per cent level of probability.

The data from peak I readings indicates that the frozen control eggs produced a baked slurry with a tougher crust than did the freeze-dried eggs, which in turn produced a tougher crust than the spray-dried eggs. The data for peaks II and III indicate that the differences in inside gel tenderness of the dried egg slurries was not as significant as differences in crust tenderness. The highly significant interaction (Table 7) between egg processing and end temperature indicates not all processes were reacting the same to different end baking temperatures. Comparison of peak I force readings listed in the Appendix revealed the magnitude of increase in peak I readings by increasing the end baking temperature from 81-82°C to 84-85°C was considerably lower for slurries prepared with frozen eggs than for slurries prepared with spray-dried eggs. The magnitude of increase for slurries from freeze-dried eggs was intermediate.

A comparison of egg process means for each combination of temperature and pH revealed the same trends as did the conglomerate means for

Table 8. Rank order of significant differences for gel strength measured by the shear press among conglomerate averages for egg processes, pH levels, and end temperature ranges of baked whole egg-milk slurries.

Objective Measure	Source of Variance	Significant Differences[a] at 1% level	additional at 5% level
Shear Press Maximum Force	Egg Process	FROZ > FD > SPD[b]	None
	Temperature	84-85°C > 81-82°C	None
Peak I	pH	pH 7.0 > pH 6.6	None
Shear Press Maximum Force	Egg Process	FROZ > FD = SPD	FD > SPD
	Temperature	84-85°C > 81-82°C	None
Peak II	pH	pH 7.0 > pH 6.6	None
Shear Press Maximum Force	Egg Process	FROZ > FD = SPD	FD > SPD
	Temperature	84-85°C > 81-82°C	None
Peak III	pH	pH 7.0 > pH 6.6	None
Shear Press Area-under-the-curve	Egg Process	FROZ > FD > SPD	None
	Temperature	84-85°C > 81-82°C	None
	pH	pH 7.0 > pH 6.6	None

[a]Significantly greater than those that follow. (Duncan, 1955).

[b]FROZ denotes frozen egg slurries.
FD denotes freeze-dried egg slurries.
SPD denotes spray-dried egg slurries.

egg process (Table 9). However, there were fewer significant differences at the 1 per cent level of probability for egg process means at each combination of temperature and pH than there were for the conglomerate means of the egg processes, with the exception of the peak II measurements for the slurries prepared from the unadjusted pH and baked to 81-82°C. It is interesting to note that for peak III maximum force readings the adjusted pH level and end baking temperature range of 81-82°C was the only combination for which there were no significant differences in gel strength among the three types of baked egg slurries. However, since this was true for only the peak III measurements and since the investigator judged the appearance of the baked gels at this treatment combination to be the least acceptable, it should not be concluded from this investigation that a pH of 6.6 and an end temperature of 81-82°C produces acceptable coagulums for all three types of egg processes.

Analysis of variance for peak I and peak II measurements (Table 7) revealed significant differences between replication averages at the 1 per cent level of probability. This may have been due to variations in baking conditions caused by oven cycling or variations in length of baking time required to reach the designated end temperature. Although these significant differences between replications were present, the F values for peak I were less than 1/10 the F values for egg process, and the F values for peak II were approximately 1/4 the F values for egg process. Because of the differences in magnitude of the F values, it seems certain that there were differences due to egg processing even though significant differences among replications exist.

Table 9. Rank order of significant differences for gel strength measured by the shear press among slurries prepared from frozen, freeze-dried, and spray-dried eggs baked at each combination of pH and end baking temperature.

Objective Measure	Treatment Combination	Significant Differences[a] at 1% level	additional at 5% level
Shear Press Maximum Force	pH 7.0, 81-82°C	FROZ > FD > SPD[b]	None
	pH 6.6, 81-82°C	FROZ = FD > SPD	FROZ > FD
Peak I	pH 7.0, 84-85°C	FROZ FD SPD	FD > SPD
	pH 6.6, 84-85°C	None	FROZ FD SPD
Shear Press Maximum Force	pH 7.0, 81-82°C	FROZ > FD > SPD	None
	pH 6.6, 81-82°C	FROZ > FD = SPD	None
Peak II	pH 7.0, 84-85°C	FROZ FD SPD	FROZ > FD > SPD
	pH 6.6, 84-85°C	FROZ SPD FD	FROZ > SPD
Shear Press Maximum Force	pH 7.0, 81-82°C	None	FROZ > FD
	pH 6.6, 81-82°C	None	None
Peak III	pH 7.0, 84-85°C	FROZ FD SPD	None
	pH 6.6, 84-85°C	FROZ FD SPD	FROZ > FD
Shear Press Area-under-the-curve	pH 7.0, 81-82°C	FROZ > FD > SPD	None
	pH 6.6, 81-82°C	FROZ > FD = SPD	FD > SPD
	pH 7.0, 84-85°C	FROZ > FD = SPD	FD > SPD
	pH 6.6, 84-85°C	FROZ > FD = SPD	None

[a]Significantly greater than those that follow. Underlining denotes no significant difference (Duncan, 1955).

[b]FROZ denotes frozen egg slurries.
FD denotes freeze-dried egg slurries.
SPD denotes spray-dried egg slurries.

These results indicate that both freeze-drying and spray-drying reduce the coagulating ability of whole eggs as measured by the gel strength of baked whole egg and milk slurries. However, the differences between the freeze-dried egg gels when compared to the control and spray-dried egg gels were not always significant. Thus, freeze-drying had the less detrimental effect on gel strength. These findings for the reduction of the coagulating ability of spray-dried eggs are in agreement with those reported by Jordan and Sisson (1943) and Miller et al. (1959a), but are not in agreement with those reported by Ary and Jordan (1945), Dawson et al. (1945), and Schlosser et al. (1961).

Gel strength variance within pH levels. Analysis of variance (Table 7) for gel strength as measured by maximum force (peak I, peak II, and peak III) and area-under-the-curve revealed very highly significant differences in slurries prepared from the two pH levels. Slurries prepared from the mix at the adjusted pH level were less firm than those prepared at the unadjusted pH level (Table 8) with differences significant at the 1 per cent level of probability. Such results might be expected because of the peptizing action of the acid on the egg proteins.

Gel strength within temperature ranges. Analysis of variance (Table 7) revealed very highly significant differences in gel strength between the slurries baked to end temperature ranges of 81-82°C and those baked to 84-85°C. Comparisons of end temperature means (Table 8) for maximum force (peak I, peak II, and peak III) and area-under-the-curve indicated that for each measurement, the slurries baked to an internal temperature of 84-85°C were firmer than those baked to 81-82°C ($p < 0.01$). These

findings are in agreement with those reported by Griswold (1962), Lowe (1955), Mastic (1959), and Miller et al. (1959a).

Gel strength variances among the twelve treatment combinations. The rank order of significant differences (Table 10) shows that the slurries prepared from the frozen eggs at the unadjusted pH level and baked to 84-85°C were the firmest. However, mean values for peaks I, II, and III indicate that the slurries prepared under the same conditions from the freeze-dried eggs were not significantly different from the frozen egg slurries. At the 1 per cent level of probability results for peak I, peak III, and area-under-the-curve indicate that slurries prepared from both freeze-dried and spray-dried eggs at the unadjusted pH level and baked to 84-85°C were similar to those prepared from the frozen eggs at the unadjusted pH level and baked to 81-82°C. Likewise, for all four shear press measurements, with the exception of peak III maximum force readings, slurries prepared from the freeze-dried and spray-dried eggs at the adjusted pH level and baked to 84-85°C were similar in gel strength to those prepared from the frozen eggs at the adjusted pH level and baked to 81-82°C. From these data it is evident that freeze-dried and spray-dried eggs can produce a slurry equivalent in gel strength to a frozen egg slurry if a higher end temperature is used for the dried egg slurries. Miller et al. (1959a) suggested that this might be feasible after observing that dried egg custards baked to 90°C were comparable in firmness to shell and frozen egg custards baked to 86°C.

Despite the similarities just described, other treatment combinations produced slurries of similar gel strength. The means for peak I

Table 10. Rank order of significant differences[a] in gel strength measured by the shear press among means for each treatment combination of slurries made from freeze-dried, spray-dried, and frozen eggs at two pH levels and baked to two end temperature ranges.

Objective test: Shear Press-Peak I

1 per cent level

FROZ[b] pH 7.0 84-85°	FD pH 7.0 84-85°	FROZ pH 7.0 81-82°	SPD pH 7.0 84-85°	FD pH 7.0 81-82°	FROZ pH 6.6 84-85°	FROZ pH 6.6 81-82°	FD pH 6.6 84-85°	SPD pH 6.6 84-85°	SPD pH 7.0 81-82°	FD pH 6.6 81-82°	SPD pH 6.6 81-82°
6.71	6.30	6.23	5.60	5.12	4.68	4.24	4.09	4.05	4.00	3.47	2.58

5 per cent level

6.71	6.30	6.23	5.60	5.12	4.68	4.24	4.09	4.05	4.00	3.47	2.58

Objective test: Shear Press-Peak II

1 per cent level

FROZ pH 7.0 84-85°	FROZ pH 7.0 81-82°	FD pH 7.0 84-85°	SPD pH 7.0 84-85°	FD pH 7.0 81-82°	FROZ pH 6.6 84-85°	SPD pH 7.0 81-82°	FROZ pH 6.6 81-82°	SPD pH 6.6 84-85°	FD pH 6.6 84-85°	FD pH 6.6 81-82°	SPD pH 6.6 81-82°
4.24	4.16	3.88	3.55	3.42	3.15	2.97	2.89	2.77	2.65	2.36	2.21

5 per cent level

4.24	4.16	3.88	3.55	3.42	3.15	2.97	2.89	2.77	2.65	2.36	2.21

Objective test: Shear Press-Peak III

1 per cent level

FROZ pH 7.0 84-85°	FD pH 7.0 84-85°	SPD pH 7.0 84-85°	FROZ pH 7.0 81-82°	FROZ pH 6.6 84-85°	FD pH 7.0 81-82°	FD pH 6.6 84-85°	SPD pH 7.0 81-82°	SPD pH 6.6 84-85°	FROZ pH 6.6 81-82°	FD pH 6.6 81-82°	SPD pH 6.6 81-82°
7.55	7.00	6.32	6.12	6.03	5.39	5.23	5.13	4.86	4.30	3.88	3.67

5 per cent level

7.55	7.00	6.32	6.12	6.03	5.39	5.23	5.13	4.86	4.30	3.88	3.67

Objective test: Shear Press-Area-under-the-curve

1 per cent level

FROZ pH 7.0 84-85°	FD pH 7.0 84-85°	FROZ pH 7.0 81-82°	SPD pH 7.0 84-85°	FD pH 7.0 81-82°	FROZ pH 6.6 84-85°	FROZ pH 6.6 81-82°	SPD pH 7.0 81-82°	FD pH 6.6 84-85°	SPD pH 6.6 84-85°	FD pH 6.6 81-82°	SPD pH 6.6 81-82°
16.97	15.20	15.14	13.73	12.66	12.23	10.61	10.53	10.25	10.24	8.91	7.46

5 per cent level

16.97	15.20	15.14	13.73	12.66	12.23	10.61	10.53	10.25	10.24	8.91	7.46

[a]Significantly firmer than those that follow. Underlining denotes no significant difference (Duncan, 1955).

[b]FROZ denotes frozen egg slurries. FD denotes freeze-dried egg slurries. SPD denotes spray-dried egg slurries.

Table 11. Analysis of variance for drainage due to syneresis of baked whole egg-milk slurries.

Source of Variance	Degrees of Freedom	Mean Square
Total	47	
Replication	3	0.037
Egg Process	2	0.161*
pH	1	1.744***
End Temperature	1	0.009
EP x pH	2	0.008
EP x ET	2	0.085
pH x ET	1	0.104
EP x pH x ET	2	0.057
Error	33	0.042

*Significant at 5 per cent level of probability.

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

Table 12. Rank order of significant differences for drainage due to syneresis among conglomerate averages for egg processes and pH levels of baked whole egg-milk slurries.

Objective Measure	Source of Variance	Significant Differences[a] at 1% level	additional at 5% level
Syneresis	Egg Process	None	FROZ[b] FD SPD
	pH	pH 6.6 > pH7.0	None

[a]Significantly greater than those that follow. Underlining denotes no significant differences. (Duncan, 1955).

[b]FROZ denotes frozen egg slurries.
FD denotes freeze-dried egg slurries.
SPD denotes spray-dried egg slurries.

freeze-dried eggs. The slurries prepared with freeze-dried eggs were not significantly different from those prepared with spray-dried eggs.

A comparison of egg process means for each combination of temperature and pH (Table 13) revealed the same results at the 5 per cent level of probability as did the conglomerate means for egg processes with one exception: for the slurries prepared at pH 6.6 and baked to 84-85°C the frozen and freeze-dried egg slurries had significantly more drainage than did the spray-dried egg slurries, although the freeze-dried and spray-dried egg slurries did not differ significantly from each other. It is interesting to note that no other treatment combination produced significant differences at the 5 per cent level of probability.

Table 13. Rank order of significant differences for drainage due to syneresis among slurries prepared from frozen, freeze-dried, and spray-dried eggs baked at each combination of pH and end baking temperature.

Objective Measure	Treatment Combination	Significant Differences[a] at 5% level
Syneresis	pH 7.0, 81-82°C	None
	pH 6.6, 81-82°C	None
	pH 7.0, 84-85°C	None
	pH 6.6, 84-85°C	FROZ[b] FD SPD

[a] Significantly greater than those that follow. Underlining denotes no significant differences. (Duncan, 1955).

[b] FROZ denotes frozen egg slurries.
FD denotes freeze-dried egg slurries.
SPD denotes spray-dried egg slurries.

Drainage variance within pH levels. Analysis of variance for drainage due to syneresis (Table 11) revealed very highly significant differences in slurries prepared from the two pH levels. Rank order for significant differences due to syneresis indicated drainage was significantly greater for the slurries prepared from the mix with the adjusted pH of 6.6 (Table 12) than for the slurries prepared from the mix with the unadjusted pH level.

Drainage variance within end temperature ranges. Analysis of variance (Table 11) revealed no significant differences between slurries baked to two end temperature ranges of 81-82°C and 84-85°C.

Drainage variance among the twelve treatment combinations. The rank order of differences (Table 14), significant at the 1 per cent level of probability, shows that the slurries prepared with the dried eggs at the unadjusted pH level and baked to 84-85°C had the least amount of drainage. However, a further examination of the data showed no significant differences between the frozen control egg slurries, the spray-dried egg slurries, and the freeze-dried egg slurries at the unadjusted pH level and baked to either end temperature range.

Thus, drainage due to syneresis disclosed very few significant differences attributable to processing or end temperature and are in contrast to the results obtained using the shear press. This may indicate that gel strength is not the only factor which affects drainage. Ferry (1948) postulated that drainage is related to the fineness of the gel. He theorized that lower attractive forces produced finer gels, and decreased ease of syneresis. The data for drainage may also be an indication that measurement of drainage is not a very sensitive

Table 14. Rank order of signficant differences[a] in gel strength measured by drainage due to syneresis among means for each treatment combination of slurries made from freeze-dried, spray-dried, and frozen eggs at two pH levels and baked to two end temperature ranges.

Objective test: Syneresis

1 per cent level

FROZ[b] pH 6.6 84-85°	FD pH 6.6 84-85°	SPD pH 6.6 81-82°	FROZ pH 6.6 81-82°	FD pH 6.6 81-82°	SPD pH 6.6 84-85°	FROZ pH 7.0 81-82°	FROZ pH 7.0 84-85°	FD pH 7.0 81-82°	SPD pH 7.0 81-82°	FD pH 7.0 84-85°	SPD pH 7.0 84-85°
0.92	0.71	0.66	0.65	0.56	0.43	0.40	0.34	0.32	0.29	0.16	0.15

5 per cent level

0.92	0.71	0.66	0.65	0.56	0.43	0.40	0.34	0.32	0.29	0.16	0.15

[a]Significantly greater than those that follow. Underlining denotes no significant difference (Duncan, 1955).

[b]FROZ denotes frozen egg slurries.
FD denotes freeze-dried egg slurries.
SPD denotes spray-dried egg slurries.

test. The relatively high standard deviations substantiate this view. This view is in agreement with Garlick (1964) and Miller et al. (1959a) both of whom concluded that this method of determining the percentage of drainage did not represent true measurements of syneresis.

Objective Measurement of Color of Baked Whole Egg and Milk Slurries

Differences in color of the slurries were determined on the Gardner Color Difference Meter by the L (lightness), a_L (greenness), and b_L (yellowness) values and the a_L/b_L ratio. The data were analyzed for variance within drying processes, pH levels, end temperature ranges, and among the twelve treatment combinations. The average and mean values for replication, conglomerate averages for egg process, pH level, and end temperature range, and standard deviations for the L, a_L, and b_L values and the a_L/b_L ratio are summarized in the Appendix.

Color variance within egg processes

Analysis of variance for color differences measured by L, a_L, and b_L values, as shown in Table 15, revealed very highly significant differences which could be attributed to processing of the eggs. Comparisons of egg process means (Table 16) showed the following differences were significant at the 1 per cent level of probability. Slurries prepared from the frozen eggs were lighter (L values) and more yellow (b_L values) than were the slurries prepared from the freeze-dried eggs; slurries prepared from the freeze-dried eggs were in turn lighter and more yellow than those prepared from the spray-dried eggs. Slurries prepared from the frozen and freeze-dried eggs showed no significant

differences in greenness (a_L values). However, both the freeze-dried and frozen egg slurries were significantly greener than the slurries prepared from the spray-dried eggs. Although the a_L/b_L ratios were calculated, the significant differences revealed were not consistent with those for the L, a_L, and b_L values, and from this it was concluded that the a_L/b_L ratio which is meaningful in evaluating red colors is not a useful measure of color differences for yellowness of the egg-milk gels.

Table 15. Analysis of variance for Gardner Color Difference Meter measurements of baked whole egg-milk slurries.

Source	Degrees of Freedom	L Mean Square	a_L Mean Square	b_L Mean Square	a_L/b_L Mean Square
Total	47				
Replication	3	0.02	0.08	0.37**	0.0003
Egg Process	2	1.18***	0.95***	14.62***	0.0008**
pH	1	4.94***	0.61***	2.80***	0.0003
End Temperature	1	0.24**	0.52***	1.69***	0.0035***
EP x pH	2	0.05	0.02	0.02	0.0003
EP x ET	2	0.04	0.01	0.11	0.0000
pH x ET	1	0.00	0.14	1.02***	0.0001
EP x pH x ET	2	0.00	0.02	0.01	0.0000
Error	33	0.03	0.04	0.06	0.0001

*Significant at 5 per cent level of probability.

**Significant at 1 per cent level of probability.

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

Table 16. Rank order of significant differences for color measured by the Gardner Color Difference Meter among conglomerate averages for egg processes, pH levels, and end baking temperature ranges of baked whole egg-milk slurries.

Objective Measure	Source of Variance	Significant Differences[a] at 1% level	additional at 5% level
Gardner Color Difference Meter	Egg Process	FROZ > FD > SPD[b]	None
	Temperature	81-82°C > 84-85°C	None
L value	pH	pH 6.6 > pH 7.0	None
Gardner Color Difference Meter	Egg Process	FROZ = FD > SPD	None
	Temperature	84-85°C > 81-82°C	None
a_L value	pH	pH 7.0 > pH 6.6	None
Gardner Color Difference Meter	Egg Process	FROZ > FD > SPD	None
	Temperature	81-82°C > 84-85°C	None
b_L value	pH	pH 7.0 > pH 6.6	None
Gardner Color Difference Meter	Egg Process	FD = SPD > FROZ	None
	Temperature	84-85°C > 81-82°C	None
a_L/b_L ratio	pH	pH 7.0 = pH 6.6	None

[a] Significantly greater than those that follow. Underlining denotes no significant differences. (Duncan, 1955).

[b] FROZ denotes frozen egg slurries.
FD denotes freeze-dried egg slurries.
SPD denotes spray-dried egg slurries.

A comparison of egg process means for each combination of temperature and pH revealed the same trends as did the conglomerate means for egg process (Table 17). However, except for the b_L values there were fewer differences significant at the 1 per cent level of probability for egg process means at each combination of temperature and pH than for the conglomerate means for the egg processes. The significant differences were consistent among egg process means for each combination of end temperature and pH level for the b_L values. From this relationship it was hypothesized by the investigator that the b_L value is not only the most sensitive but also the most useful measure for determining differences in the color of egg-milk gels.

These results indicated that drying processes reduce the lightness of the baked slurries. This may be due to browning in the dried powders caused by the Maillard reaction since glucose was not removed. The drying processes also altered the pigment present since the values for yellowness and greenness were lowest for the slurries prepared from the dried egg powder, although greenness was not significantly different between the frozen and freeze-dried egg slurries. Since the L, a_L, and b_L values were significantly lower for the spray-dried egg slurries than the freeze-dried egg slurries, it appears that the freeze-drying process is less detrimental to the pigment of the eggs than is the spray-drying process.

The reduced color values are in agreement with results reported by Kline *et al.* (1959a) in which he concluded that both glucose-protein interactions and oxidative destruction of the caratenoid pigments were responsible for color changes of the dried powders. If the same reactions

Table 17. Rank order of significant differences for color measured by the Gardner Color Difference Meter among slurries prepared from frozen, freeze-dried, and spray-dried eggs baked at each combination of pH and end baking temperature.

Objective Measure	Treatment Combination	Significant Differences[a] at 1% level	additional at 5% level
Gardner Color Difference Meter	pH 7.0, 81-82°C	FROZ = FD > SPD[b]	None
	pH 6.6, 81-82°C	FROZ FD SPD	None
L value	pH 7.0, 84-85°C	FROZ > FD = SPD	FD > SPD
	pH 6.6, 84-85°C	FROZ FD SPD	FROZ > FD
Gardner Color Difference Meter	pH 7.0, 81-82°C	None	FD > SPD
	pH 6.6, 81-82°C	FROZ FD SPD	FD > SPD
a_L value	pH 7.0, 84-85°C	FROZ FD SPD	None
	pH 6.6, 84-85°C	FD = FROZ > SPD	None
Gardner Color Difference Meter	pH 7.0, 81-82°C	FROZ > FD > SPD	None
	pH 6.6, 81-82°C	FROZ > FD > SPD	None
b_L value	pH 7.0, 84-85°C	FROZ > FD > SPD	None
	pH 6.6, 84-85°C	FROZ > FD > SPD	None
Gardner Color Difference Meter	pH 7.0, 81-82°C	None	SPD FD FROZ
	pH 6.6, 81-82°C	None	FD SPD FROZ
a_L/b_L ratio	pH 7.0, 84-85°C	None	None
	pH 6.6, 84-85°C	None	FD SPD FROZ

[a] Significantly greater than those that follow. Underlining denotes no significant differences (Duncan, 1955).

[b] FROZ denotes frozen egg slurries.
FD denotes freeze-dried egg slurries.
SPD denotes spray-dried egg slurries.

are operative in the present study, this may be an indication that the spray-drying process accelerates these reactions more than the freeze-drying process.

Color variance within pH levels

Analysis of variance for color differences measured by the L, a_L, and b_L values, as shown in Table 15, revealed very highly significant differences which could be attributed to pH levels. Comparison of egg process means (Table 16) disclosed the slurries which were adjusted to pH 6.6 were lighter, at a highly significant level of probability, than the slurries which were prepared from the unadjusted mix. Also, slurries prepared from the mix adjusted to 6.6 had decreased values for yellowness and greenness, significant at the 1 per cent level of probability. Thus, these findings indicate that the addition of acid decreases the values for yellow and green pigment but increases the value for lightness. These results are in agreement with color changes by Norris *et al.* (1965) in which these workers found the addition of acid increased the lightness of liquid whole egg.

Color variance within end temperature ranges

Analysis of variance for color differences measured by the a_L and b_L values, as shown in Table 15, revealed very highly significant differences which could be attributed to end temperature ranges, while analysis of variance for color differences measured by the L values revealed highly significant differences attributable to end temperature ranges. Comparisons of end temperature means (Table 16) showed the

higher end temperature caused an increase in greenness values but a decrease in yellowness values and lightness values.

Color variance among the twelve treatment combinations

The rank order of significant differences (Table 18) showed that the addition of acid was more influential in increasing the lightness than were egg processes or end temperature ranges. The rank order of significant differences for the a_L and b_L values revealed that differences observed were caused by egg processes more so than by pH level or end baking temperature. For both measurements the frozen egg slurries had the highest values and the spray-dried egg slurries had the lowest values. However, there were few differences among the treatment combinations for the a_L values significant at the 1 per cent level of probability. Data for the b_L values indicated that these values showed the most consistent differences in color at the 1 per cent level of probability. Slurries made from each type of egg for all treatment combinations showed no significant differences among treatment combinations for each egg process with the exception of slurries at pH 7.0 and baked to 81-82°C. It is interesting to note that for all three egg processes, the gels at the unadjusted pH which were baked to 81-82°C appeared more yellow in color than gels at any other combination of pH and end baking temperature.

Examination of the rank order of significant differences for the a_L/b_L ratios revealed few consistent results when compared to the other Gardner Color Meter readings. These data supported the conclusion made previously that the a_L/b_L ratio is not a valid measure of the differences in color of the baked egg-milk gels.

Table 18. Rank order of significant differences[a] for color measured by the Gardner Color Difference Meter among means for each treatment combination of slurries made from freeze-dried, spray-dried, and frozen eggs at two pH levels and baked to two end temperature ranges.

Objective test: Gardner Color Difference Meter-L values

1 per cent level

FROZ[b] pH 6.6 81-82°	FROZ pH 6.6 84-85°	FD pH 6.6 81-82°	SPD pH 6.6 81-82°	FD pH 6.6 84-85°	FROZ pH 7.0 84-85°	FROZ pH 7.0 81-82°	SPD pH 6.6 84-85°	FD pH 7.0 81-82°	FD pH 7.0 84-85°	SPD pH 7.0 81-82°	SPD pH 7.0 84-85°
79.85	79.80	79.65	79.50	79.50	79.28	79.28	79.28	79.08	78.85	78.73	78.53

5 per cent level

79.85	79.80	79.65	79.50	79.50	79.28	79.28	79.28	79.08	78.85	78.73	78.53

Objective test: Gardner Color Difference Meter-a_L values

1 per cent level

FROZ pH 7.0 84-85°	FROZ pH 7.0 81-82°	FD pH 6.6 84-85°	FROZ pH 6.6 84-85°	FD pH 7.0 84-85°	FD pH 7.0 81-82°	SPD pH 7.0 84-85°	FROZ pH 6.6 81-82°	FD pH 6.6 81-82°	SPD pH 7.0 81-82°	SPD pH 6.6 84-85°	SPD pH 6.6 81-82°
-7.28	-7.10	-7.10	-7.08	-7.05	-7.03	-6.78	-6.75	-6.70	-6.68	-6.57	-6.35

5 per cent level

-7.28	-7.10	-7.10	-7.08	-7.05	-7.03	-6.78	-6.75	-6.70	-6.68	-6.57	-6.35

Objective test: Gardner Color Difference Meter-b_L values

1 per cent level

FROZ pH 7.0 81-82°	FROZ pH 7.0 84-85°	FROZ pH 6.6 84-85°	FROZ pH 6.6 81-82°	FD pH 7.0 81-82°	FD pH 7.0 84-85°	SPD pH 7.0 81-82°	FD pH 6.6 84-85°	FD pH 6.6 81-82°	SPD pH 6.6 81-82°	SPD pH 7.0 84-85°	SPD pH 6.6 84-85°
21.75	21.15	20.98	20.90	20.63	20.03	19.90	19.80	19.80	19.25	19.10	18.93

5 per cent level

21.75	21.15	20.98	20.90	20.63	20.03	19.90	19.80	19.80	19.25	19.10	18.93

Objective test: Gardner Color Difference Meter-a_L/b_L ratio

1 per cent level

FD pH 6.6 84-85°	SPD pH 7.0 84-85°	FD pH 7.0 84-85°	SPD pH 6.6 84-85°	FROZ pH 7.0 84-85°	SPD pH 7.0 81-82°	FROZ pH 6.6 84-85°	FD pH 7.0 81-82°	FD pH 6.6 81-82°	SPD pH 6.6 81-82°	FROZ pH 7.0 81-82°	FROZ pH 6.6 81-82°
-0.36	-0.36	-0.35	-0.35	-0.35	-0.35	-0.34	-0.34	-0.34	-0.33	-0.33	-0.32

5 per cent level

-0.36	-0.36	-0.35	-0.35	-0.35	-0.35	-0.34	-0.34	-0.34	-0.33	-0.33	-0.32

[a]Significantly greater than those that follow. Underlining denotes no significant difference (Duncan, 1955).

[b]FROZ denotes frozen egg slurries. FD denotes freeze-dried egg slurries. SPD denotes spray-dried egg slurries.

Subjective Measurements of Color of Baked Whole Egg-Milk Slurries

Color was the only attribute for which the slurries were subjectively scored. A panel of seven members scored the slurries on the basis of both difference and preference. Differences were determined by comparing the slurries prepared from the three types of eggs at both pH levels to a labeled control slurry prepared from the frozen egg at the unadjusted pH. Preferences among the three processing types of egg slurries at both pH levels were determined by using a 7-point hedonic scale.

The data were analyzed for variance within drying processes, pH levels and end baking temperature ranges, and among the twelve treatment combinations. Studentized multiple range tests were used to identify more explicitly the significant differences disclosed by the analyses of variance (Duncan, 1955). Tables of values which include averages and mean values for replication, conglomerate averages for egg process, temperature, and pH, and standard deviations for each of the objective tests are given in the Appendix.

Color variance within egg processes

Analysis of variance for color differences and preferences, as shown in Table 19, revealed very highly significant differences which could be traced to processing of the egg. Comparisons of egg process means at the 1 per cent level of probability (Table 20) showed the panel scored the spray-dried egg gels different in color from the freeze-dried egg gels, which in turn were different from the frozen egg gels.

These findings are similar to the differences found with the Gardner Color Meter, for which the spray-dried egg gels had the lowest values for lightness, greenness, and yellowness, whereas the frozen egg gels had the highest values. Comparison of egg process means for color panel preferences revealed no significant differences, significant at the 1 per cent level of probability (Table 20), between the slurries prepared from the frozen and freeze-dried eggs; but both were preferred over the slurries prepared from the spray-dried eggs.

Table 19. Analysis of variance for color panel scores of baked whole egg-milk slurries

Source of Variance	Degrees of Freedom	Difference Mean Square	Preference Mean Square
Total	47		
Replication	3	0.08	0.16**
Egg Process	2	4.18***	0.50***
pH	1	4.56***	1.51***
End Temperature	1	0.02	0.00
EP x pH	2	0.03	0.07
EP x ET	2	0.01	0.10
pH x ET	1	0.07	0.05
EP x pH x ET	2	0.00	0.03
Error	33	0.04	0.03

*Significant at 5 per cent level of probability.

**Significant at 1 per cent level of probability.

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

Table 20. Rank order of significant differences for color panel scores among conglomerate averages for egg processes and pH levels, of baked whole egg-milk slurries.

Subjective Measure	Source of Variance	Significant Differences[a] at 1% level	additional at 5% level
Color Panel Differences	Egg Process	SPD > FD > FROZ[b]	None
	pH	pH 6.6 > pH 7.0	None
Color Panel Preferences	Egg Process	FROZ = FD > SPD	None
	pH	pH 7.0 > pH 6.6	None

[a]Significantly greater than those that follow. (Duncan, 1955).

[b]FROZ denotes frozen egg slurries.
FD denotes freeze-dried egg slurries.
SPD denotes spray-dried egg slurries.

A comparison of egg process means for each combination of temperature and pH revealed the same trends as did the conglomerate means for egg process (Table 21). However, fewer differences were found to be significant at the 1 per cent level of probability for both the color difference and color preference scores.

Thus, these results indicated that the spray-drying and freeze-drying processes, when compared to the freezing of eggs, do cause a difference in color of baked egg slurries. Color panel preferences indicated that the color changes of eggs due to spray-drying are detrimental, but that color changes due to freeze-drying are not objectional. These results, indicating adverse color changes for slurries prepared with spray-dried eggs, agree with those reported by Miller et al. (1959a) but are in contrast to those reported by Mastic (1959).

Table 21. Rank order of significant differences for color panel scores among slurries prepared from frozen, freeze-dried, and spray-dried eggs baked at each combination of pH and end baking temperature.

Subjective Measure	Treatment Combination	Significant Differences[a] at 1% level	additional at 5% level
Color Panel Differences	pH 7.0, 81-82°C	SPD = FD > FROZ[b]	None
	pH 6.6, 81-82°C	SPD > FD > FROZ	None
	pH 7.0, 84-85°C	SPD = FD > FROZ	SPD > FD
	pH 6.6, 84-85°C	SPD > FD > FROZ	None
Color Panel Preferences	pH 7.0, 81-82°C	None	None
	pH 6.6, 81-82°C	None	None
	pH 7.0, 84-85°C	FROZ = FD > SPD	None
	pH 6.6, 84-85°C	None	FROZ FD SPD

[a]Significantly greater than those that follow. Underlining denotes no significant difference (Duncan, 1955).

[b]FROZ denotes frozen egg slurries.
FD denotes freeze-dried egg slurries.
SPD denotes spray-dried egg slurries.

Color variances within pH levels

Analysis of variance for color differences and preferences, as shown in Table 19, revealed very highly significant differences among the pH levels. Comparison of pH level means for color panel preferences (Table 20) disclosed that the slurries prepared from the mix with the unadjusted pH were preferred over those prepared from the mix with the adjusted pH, with differences significant at the 1 per cent level of probability.

Thus, these findings indicated that the addition of acid produces significant differences in the color of the slurries. Furthermore, the addition of acid has a detrimental effect on the color as determined by color panel preference ratings.

Color variance within end temperature ranges

Analysis of variance for color differences, as shown in Table 19, revealed no significant differences among the end temperature ranges. Likewise analysis of variance for color preferences disclosed no significant differences among end temperature ranges.

Color variances within the twelve treatment combinations

Results of the Studentized range test (Table 22) for color panel differences at the 1 per cent level of probability disclosed that no treatment combination of drying process, pH level, and end baking temperature produced a slurry similar in color to the slurries prepared from the frozen egg at the unadjusted pH and baked to either end temperature range. However, results of the Studentized range tests at the 1 per cent level of probability for color panel preference scores indicated the color of gels at the unadjusted pH level with the exception of the gels prepared from spray-dried eggs and baked to an internal temperature of 84-85°C received higher preference ratings than the color of the gels with an adjusted pH. However, the color of all the gels was described as good to very good by the panel members.

Table 22. Rank order of significant differences[a] for color panel scores among means for each treatment combination of slurries made from freeze-dried, spray-dried, and frozen eggs at two pH levels and baked to two end temperature ranges.

Subjective test: Color Panel - Differences

1 per cent level

SPD pH 6.6 81-82°	SPD pH 6.6 84-85°	FD pH 6.6 81-82°	FD pH 6.6 84-85°	SPD pH 7.0 84-85°	SPD pH 7.0 81-82°	FROZ pH 6.6 81-82°	FD pH 7.0 84-85°	FD pH 7.0 81-82°	FROZ pH 6.6 84-85°	FROZ pH 7.0 84-85°	FROZ pH 7.0 81-82°
2.73	2.63	2.28	2.18	2.08	1.98	1.75	1.70	1.70	1.60	1.00	1.00

5 per cent level

2.73	2.63	2.28	2.18	2.08	1.98	1.75	1.70	1.70	1.60	1.00	1.00

Subjective test: Color Panel - Preferences

1 per cent level

FROZ pH 7.0 84-85°	FROZ pH 7.0 81-82°	FD pH 7.0 84-85°	FD pH 7.0 81-82°	SPD pH 7.0 81-82°	FROZ pH 6.6 84-85°	FD pH 6.6 84-85°	FD pH 6.6 81-82°	FROZ pH 6.6 81-82°	SPD pH 7.0 84-85°	SPD pH 6.6 81-82°	SPD pH 6.6 84-85°
6.00	5.93	5.85	5.80	5.68	5.55	5.53	5.50	5.38	5.35	5.28	5.25

5 per cent level

6.00	5.93	5.85	5.80	5.68	5.55	5.53	5.50	5.38	5.35	5.28	5.25

[a]Significantly greater than those that follow. Underlining denotes no signficant differences (Duncan, 1955)

[b]FROZ denotes frozen egg slurries; FD denotes freeze-dried egg slurries; SPD denotes spray-dried egg slurries.

Correlations for Objective and Subjective Measurements of Baked Whole Egg-Milk Slurries

Simple correlation coefficients were calculated between appropriate combinations of the data. The significant correlations for measurements related to gel strength are found in Table 23; those related to color are found in Table 24. A complete list of all correlations appears in the Appendix.

Correlations for gel strength

Very highly significant positive correlations were found between the shear press measurements for peaks I, II, and III and area-under-the-curve. These correlations indicate that as crust toughness increased, body firmness and overall gel strength increased also. Since all four measurements correlated positively, this suggests that all four methods may be reliable determinations of gel strength. The use of the shear press to evaluate gel strength of custards was validated using a taste panel during the preliminary investigation.

Shear press measurements correlated at the 0.1 per cent level of probability with end baking temperature, pH before and after baking, and baking times. These correlations indicate that gel firmness increased as baking temperature, pH, and length of baking time increased.

Highly significant negative correlations were found between shear press measurements and percentage of drainage, suggesting that as gel firmness increased, percentage of drainage decreased. The percentage of drainage correlated at the 0.1 per cent level of probability with pH, indicating that as the pH was lowered the percentage of drainage

Table 23. Significant correlation coefficients of measurements related to gel strength of baked whole egg-milk slurries.[a]

Objective Measurements	Shear Press Peak I	Shear Press Peak II	Shear Press Peak III	Shear Press Area-under-the-curve	Drainage %	End Baking Temperature	pH Before Baking	pH After Baking	Baking Times
Shear Press Peak I		.962***	.903***	.969***	-.437**	.528***	.674***	.475***	.548***
Shear Press Peak II	.962***		.855***	.958***	-.419**	.412**	.729***	.572***	.459**
Shear Press Peak III	.903***	.855***		.902***	-.358***	.666***	.572***	.356**	.731***
Shear Press Area-under-the-curve	.969***	.958***	.902***		-.397**	.538***	.679***	.507***	.545***
% Drainage	-.437**	-.419**	-.358**	-.397**			-.662***	-.628***	
End Baking Temperature	.528***	.412**	.666***	.538***					.758***
pH Before Baking	.674***	.729***	.572***	.679***	-.662***			.818***	
pH After Baking	.475***	.572***	.356**	.507***	-.628***		.818***		
Baking Times	.548***	.459**	.731***	.545***		.758***			

[a]Nonsignficant values were omitted to more readily identify those measurements which correlated.

*Significant at 5 per cent level of probability.

**Significant at 1 per cent level of probability.

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

Table 24.[a] Significant correlation coefficients of measurements related to color of baked whole egg-milk slurries.

	Gardner L values	Gardner a_L values	Gardner b_L values	Gardner a_L/b_L Ratio	Color Panel Differences	Color Panel Preferences	End Baking Temperature	pH Before Baking	pH After Baking	Baking Times
Gardner L value			.299*	-.377**				-.757***	-.738***	
Gardner a_L Value			.511***	.454**	-.684***	.470***	.444**	.360**		
Gardner b_L Value	.299*	.511***		-.468***	-.840***	.587***				
Gardner a_L/b_L Ratio	-.377**	.454**	-.468***				.402**			.375**
Color Panel Difference		-.684***	-.840***			-.664***		-.559***	-.450**	
Color Panel Preference		.470***	.587***		-.664***			.583***	.428**	
End Baking Temperature		.444**		.402**						.683***
pH Before Baking	-.757***	.360**			-.559***	.583***			.891***	
pH After Baking	-.738***				-.450**	.428**		.891***		
Baking Times				.375**			.683***			

[a]Nonsignificant values were omitted to more readily identify those measurements which correlated.

*Significant at 5 per cent level of probability.

**Significant at 1 per cent level of probability.

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

increased. No significant correlations were revealed between precentage of drainage and end baking temperature. There were no significant correlations found between pH and length of baking time, indicating that the change in pH did not alter the amount of time required to reach the designated end temperature.

Correlations for color

Very highly significant positive correlations were found between the Gardner a_L (greenness) and b_L (yellowness) values, indicating that as greenness increased so did yellowness. Further findings include a significant positive correlation between the L (lightness) and b_L value, suggesting that as yellowness increased the lightness increased slightly.

Very highly significant positive correlations existed between the Gardner a_L and b_L values and the color panel scores for preference. These correlations indicate that as the values for yellowness and greenness increased, the panel's preference ratings increased, suggesting that the panel preferred the slurries with the greater amount of yellow and green pigment. Very highly significant negative correlations were found between the Gardner a_L and b_L values and the color panel scores for difference. These correlations suggest that the panel was making its primary judgments based on yellowness and greenness. Lightness did not correlate with either panel preference or difference scores.

A highly significant positive correlation was found between panel preference scores and pH values; a highly significant negative correlation was found between color panel difference scores and pH values.

These correlations suggest that as the pH was decreased the panel's rating for differences increased, and that a decrease in pH caused a decrease in the panel's preference of the slurry color.

Reliability of objective measurements

Very highly significant correlations were found between the shear press measurements for peaks I, II, and III, and area-under-the-curve. Very highly significant positive correlations were also found between the Gardner a_L and b_L values and the color panel preference scores, while very highly significant negative correlations were found between the Gardner a_L and b_L values and the color panel difference scores. These correlations may indicate the reliability of the Allo-Kramer Shear Press to judge the firmness of gels and the Gardner Color Difference Meter to determine the color of these products.

SUMMARY AND CONCLUSIONS

The primary purpose of this investigation was to determine the effect of egg drying processes on the coagulating ability and color of milk and whole egg gels. In addition, the effects of pH and end baking temperature on the above mentioned properties were also studied. Whole eggs used for the drying processes were obtained from a common source and either freeze-dried or spray-dried; frozen eggs from the same source served as the control. The eggs were commercially processed, the dried eggs were packaged similarly, and all eggs were held in frozen storage to minimize change before evaluation.

To evaluate the coagulating ability and color of the eggs, whole egg and milk slurries made from the freeze-dried, spray-dried, and frozen eggs were prepared as similarly as feasible and baked to form a gel-type product. The two pH levels included the unadjusted pH of the egg-milk mixture (approximately 7.0) and an adjusted pH level of 6.6 which was chosen because a lower pH might have caused coagulation of the milk proteins and a pH higher than the original had no practical application in cookery. The slurries were baked to two end temperature ranges, 81-82°C and 84-85°C. Each of the twelve treatment combinations was replicated four times.

The study was divided into two phases: (1) slurries used for gel strength determinations were baked in metal loaf pans; (2) slurries used for drainage and color measurements were baked in conventional pyrex custard cups. Gel strength was determined by using the fixed blade assembly of the Allo-Kramer Shear Press, from which readings

were recorded as both maximum force, using three defined peaks, and area-under-the-curve. Gel strength was also measured by the amount of drainage due to syneresis. Measurement of color was determined objectively with a Gardner Color Difference Meter and subjectively using a color panel to evaluate difference in color among the gels and to indicate color preferences.

The results indicated the following significant differences attributable to the drying processes. The less firm gels prepared from the spray-dried eggs differed at the 1 per cent level of probability from the gels prepared from the frozen control eggs. Gels prepared from the freeze-dried eggs were less firm than those prepared from the frozen eggs but more firm than those prepared from the spray-dried eggs, although the differences were not significant for each of the treatment combinations. It was concluded that although both drying processes lessened the coagulating ability of egg proteins, the spray-drying process was more detrimental in this respect than the freeze-drying process. Results also indicate that the increase in end baking temperature for the dried egg slurries resulted in a gel which more closely approximated the firmness of the frozen egg gels at the lower temperature range.

Significant differences for drainage due to syneresis were found among the three types of eggs. However, comparisons of egg processes for each treatment combination revealed no significant differences except for the slurries prepared from the adjusted pH level and baked to 84-85°C. In this instance, slurries made from spray-dried eggs had a lower percentage of drainage due to syneresis than did those made from frozen eggs; slurries made from freeze-dried eggs were intermediate.

Very few significant differences attributable to known variables were found for drainage data in contrast to the many significant differences for shear press evaluations. From this the investigator concluded that drainage determinations did not represent a reliable method of evaluating gel strength or coagulating ability. It appeared that factors other than gel strength affected the drainage values.

Baked gels prepared with the spray-dried eggs had values on the Gardner Color Difference Meter for lightness, greenness, and yellowness which were significantly lower (1% level of probability) than did the gels prepared from the frozen eggs. Although the baked gels using frozen eggs were lighter, greener, and more yellow than the freeze-dried egg gels, not as many of the differences were significant as were the differences between the color of the frozen egg gels and the spray-dried egg gels. The results of this investigation indicated that the b_L values (yellowness) were the most sensitive measure of color differences in egg-milk gels. Differences for the b_L value at the 1 per cent level of probability showed that the frozen egg gels were more yellow than the freeze-dried egg gels which in turn were more yellow than the spray-dried egg gels. Also, at the 1 per cent level of probability the color panel found the frozen egg slurries were significantly different from the freeze-dried egg gels which in turn were significantly different from the spray-dried egg gels. However, the color panel indicated no preference between the frozen egg and freeze-dried egg gels, but preferred both of these types of gels over the spray-dried egg gels.

Lowering the pH from the unadjusted pH level to pH 6.6 produced the following significant changes: gel strength as measured by the

Allo-Kramer Shear Press was reduced, precentage of drainage due to syneresis was increased, and both greenness and yellowness values were decreased. The color panel not only detected highly significant differences between the slurries prepared at the two pH levels but preferred those at the unadjusted pH level.

Increasing the end temperature from 81-82°C to 84-85°C caused the following highly significant changes: gel strength was increased and crust toughness was increased although greater increases in crust toughness were observed for the gels prepared with the spray-dried eggs than for those prepared from the other two types of eggs; lightness and greenness values were decreased, while yellowness values were increased. No significant differences were found for drainage between the slurries baked to either end temperature, nor were differences found for color panel difference or color panel preference scores.

Correlations between the various measurements revealed highly significant correlations between the four shear press measurements and between the Gardner L and b_L values. Very highly significant correlations were found between all four of the following evaluations of color; color panel difference scores, color panel preference scores, Gardner a_L values, and Gardner b_L values. High significant correlations were found between the shear press and drainage measurements. The correlation between the Gardner L values and panel scores was not significant. Data indicated that the shear press measurements were the most reliable determinations for gel strength and that the b_L values were the most sensitive objective measure of color differences.

Results from this study point the need for further research in the following areas: 1) a search for further refinement for the method

of determining drainage due to syneresis, 2) a study to define more clearly the factors responsible for syneresis, 3) an investigation to determine which shear press measurement used in this study or other techniques used in interpreting shear press measurements in other investigations would give the most reliable method of determining gel strength, 4) an investigation to establish the way in which the color pigment is changed due to the drying process, and 5) a study to determine if the loss of color and coagulating ability occurs to the same extent in a baked coagulated food product such as custards.

LITERATURE CITED

AOAC. 1955. "Official Methods of Analysis." 8th ed. Assoc. Offic. Agr. Chemists. Washington, D.C.

Ary, J. E., and R. Jordan. 1945. Plain butter cakes and baked custards made from spray-dried whole egg powder. Food Research 10, 476-484.

Ayres, J. C. 1958. Methods for depleting glucose from egg albumen before drying. Food Technol. 12, 186-189.

Bedford, C. L. 1964. Information on the Gardner Color Difference Meter (Private communication). Michigan State University, East Lansing.

Birren, F. 1963. Color and human appetite. Food Technol. 17 (5), 45-57.

Bittner, B. A. 1954. The effect of various milks on the time-temperature relationships in baking custard, and on the quality of the product. M.S. Thesis. Michigan State University, East Lansing.

Brown, S. L. 1964. Effect of heat treatments on the physical and functional properties of liquid and spray-dried albumen. M.S. Thesis. Michigan State University, East Lansing.

Bunnell, R. H., and J. C. Bauernfeind. 1962. Chemistry, uses, and properties of carotenoids in foods. Food Technol. 16 (7), 36-43.

Burrill, L. M., D. Deethardt, and R. L. Saffle. 1962. Two mechanical devices compared with taste-panel evaluation for measuring tenderness. Food Technol. 16 (10), 145-146.

Carlson, C. W. 1961. Do you want dark colored egg yolks? Poultry Proc. and Mktg. 67, 14, 33, 34.

Chick, H., and C. J. Martin. 1910. On the "heat coagulation" of proteins. J. Physiol. 40, 404-430.

Chick, H., and C. J. Martin. 1912-13. On the "heat coagulation" of proteins. Part III. The influence of alkali upon reaction velocity. J. Physiol. 45, 61-69.

Colvin, J. R. 1964. Denaturation: A Requiem. In: "Symposium on Foods: Proteins and Their Reactions." H. W. Schultz and A. I. Anglemier, eds. The Avi Publishing Co., Inc., Westport, Connecticut.

Conrad, R. M., G. E. Vail, A. L. Olsen, G. L. Tinklin, J. W. Greene and C. Wagoner. 1948. Improved dried whole egg products. Kansas State College Agr. Expt. Sta. Bull. No. 64, 4-62.

Dawson, E. H., D. E. Shank, J. M. Lynn, and E. A. Wood. 1945. Effect of storage on flavor and cooking quality of spray-dried whole egg. U.S. Egg and Poult. Mag. 51, 154-161.

Decker, R. W., J. N. Yeatman, A. Kramer, and A. P. Sidwell. 1957. Modification of the shear-press for electrical indicating and recording. Food Technol. 11, 343-347.

Deethardt, D. E., L. M. Burrill, and C. W. Carlson. 1965. Quality of sponge cakes made with egg yolk of varying color produced by different feed additives. Food Technol. 19, 75-77.

Duncan, D. B. 1955. Multiple ranges and multiple F tests. Biometrics 11, 1-8.

Emory, J. 1960. Use of the shear press for in-plant control. Summaries of the First Regional Shear Press Symposium. L.E.E. Incorporated, Washington 1, D.C., 10-11.

Englar, W. J., and R. Kudlich. 1964. Application of the shear press for determining and controlling the texture of potato flakes. Paper presented at the 24th Annual Meeting of the Inst. of Food Technologists, Washington D.C., May 24-28.

Feeney, R., and R. M. Hill. 1960. Protein chemistry and food research. Advances in Food Research 10, 23-73.

Ferry, J. D. 1948. Protein gels. Advances in Protein Chemistry 4, 47-50.

Forsythe, R. 1963. Chemical and physical properties of eggs and egg products. Cereal Science Today 8 (9), 309-310, 312, 328.

Forsythe, R., and T. Miyahara. 1959. The use of modern egg solids in baking. Baker's Digest 33 (2), 56, 60-61, 64-65, 86.

Frampton, V. L., F. L. Carter, B. Piccolo, and B. W. Heywang. 1962. Food discolorations, cottonseed constituents, and discolorations in stored shell eggs. J. Agr. Food Chem. 10, 46-48.

Francis, F. J. 1963. Color control. Food Technol. 17 (5), 38-45.

Funk, K., M. E. Zabik, and D. M. Downs. 1965. Comparison of shear press measurements and sensory evaluation of angel cakes. J. Food Sci. (in press).

Garlick, M. E. 1964. Effect of color and flavor modification on the palatibility and gel structure of standard baked custard. M.S. Thesis. Michigan State University, East Lansing.

Goldblith, S. A., M. Karel, and G. Lirsk. 1963. The role of food science and technology in the freeze-dehydration of foods. Food Technol. 17, 139-144.

Gorman, J. M. 1965. Information on processing of spray-dried eggs (Private communication). Seymour Foods Company, Topeka, Kansas.

Griswold, R. M. 1962. "The Experimental Study of Foods." Houghton Mifflin Co., Boston.

Hanson, H. L. 1954. Comparison of glucose-free and acidified whole egg powders by sensory tests. In: "Stability of Dehydrated Eggs - A Symposium." M. S. Peterson and H. E. Goresline, eds. National Academy of Sciences - National Research Council, Washington D.C., 31-33.

Harpor, J. C., and A. L. Tappel. 1957. Freeze-drying of food products. Advances in Food Research 7, 171-234.

Haurowitz, F. 1963. "The Chemistry and Function of Proteins." Academic Press, New York. 161-166, 199-202.

Huggart, R. L., and F. W. Wenzel. 1955. Color differences of citrus juices and concentrates using the Hunter Color Difference Meter. Food Technol. 9, 27-29.

Jensen, A. 1963. The effect of seaweed carotenoids on egg yolk coloration. Poultry Sci. 42, 912-916.

Jianas, G. G. 1964. Information of packaging of dried eggs (Private communication). Jianas Bros. Candy Company, Kansas City 8, Missouri.

Jordan, R., B. N. Luginbill, L. E. Dawson, and C. J. Echterling. 1952. The effect of selected pretreatments upon the culinary qualities of eggs frozen and stored in a home-type freezer. I. Plain cakes and baked custards. Food Research 17, 1-7.

Jordan, R., and M. S. Sisson. 1943. Use of spray-dried eggs in baked custards. U.S. Egg and Poult. Mag. 49, 266-269, 287-288.

Kelly, J., J. L. Newcomer, and F. Borsenik. 1962. Freeze-dried whole egg solids, other processed eggs, and fresh eggs. J. Am. Dietet. Assoc. 40, 31-34.

Kline, L., J. E. Gegg, and T. T. Sonoda. 1951a. Role of glucose in the storage deterioration of whole egg powder. II. A browning reaction involving glucose and cephalin in dried whole egg. Food Technol. 5, 181-187.

Kline, L., H. L. Hanson, T. T. Sonoda, J. E. Gegg, R. E. Feeney, and H. Lineweaver. 1951b. Role of glucose in the storage deterioration of whole egg powder. III. Effect of glucose removal before drying on organoleptic, baking, and chemical changes. Food Technol. 5, 323-331.

Kline, L., T. T. Sonoda, and H. L. Hanson. 1954. Comparison of the quality and stability of whole egg powders desugared by yeast and enzyme methods. Food Technol. 8, 343-349.

Knowles, N. R. 1962. The preservation of eggs. Recent Advances in Food Science 2, 224,233.

Kramer, A. 1964. Measuring and recording rheological properties of gels. Paper presented at the 24th Annual Meeting of the Inst. of Food Technologists, Washington D.C., May 24-28.

Kramer, A. 1961. The shear press, a basic tool for the food technologist. The Food Scientist 5, 7-16.

Kramer, A., and J. C. Cooler. 1962. An instrumental method for measuring quality of raw and canned sweet corn. Proc. Am. Soc. Hort. Sci. 81, 421-427.

Lightbody, H. D., and H. L. Fevold. 1948. Biochemical factors influencing the shelf life of dried whole eggs and means for their control. Advances in Food Research 1, 149-202.

Lineweaver, H., and R. E. Feeney. 1950-51. Improving frozen and dried egg. In: USDA Yearbook of Agriculture. 642-647.

Longree, K., M. Jooste, and J. C. White. 1961. Time-temperature relationships of custards made with whole egg solids. J. Am. Dietet. Assoc. 38, 147-151.

Lowe, B. 1955. "Experimental Cookery." 4th ed. John Wiley and Sons, Inc., New York.

MacDougall, M. J. 1953. Cooking qualities of several concentrations or various types of nonfat dried milk solids. M.S. Thesis. Michigan State University, East Lansing.

Mackey, E., G. J. Mountney, and E. C. Naber. 1963. Yolk color resulting from different levels of paprika extract in the ration. Poultry Sci. 42, 32-37.

Mackinney, G., and C. O. Chichester. 1954. The color problem in foods. Advances in Food Research 5, 302-347.

Mastic, M. 1959. The effect of homogenization on gelation and palatability of baked custards prepared with dried whole egg solids. M.S. Thesis. Michigan State University, East Lansing.

Meschter, E. E. 1960. The need for objective methods to measure food quality. Summaries of the First Regional Shear Press Symposium. L.E.E. Incorporated, Washington 1, D.C., 1-2.

Meyer, L. H. 1960. "Food Chemistry," Reinhold Publishing Corporation, New York.

Miller, C., and A. R. Winter. 1950. The functional properties and bacterial content of pasteurized and frozen whole eggs. Poultry Sci. 29, 88-97.

Miller, G. A., E. M. Jones, and P. J. Aldrich. 1959a. A comparison of the gelation properties and palatability of shell eggs, frozen whole eggs, and whole egg solids in standard baked custard. Food Research 24, 584-594.

Miller, G. A., E. M. Jones, and P. J. Aldrich. 1959b. Some factors affecting the dispersibility of whole egg solids in water. Food Research 24, 579-583.

Mitchell, J. H., Jr. 1954. Comparative stability of acidified and glucose-free eggs. In: "Stability of Dehydrated Eggs - A Symposium." M. S. Peterson and H. E. Goresline, eds. National Academy of Sciences - National Research Council, Washington D.C. 19-26.

Miyahara, T., and D. Bergquist. 1961. Modern egg solids for the baker. II. Use of plain whole egg and yolk solids. Baker's Digest 35, (2), 71-73, 97.

Norris, M. E., M. Sebring, and O. J. Cotterill. 1965. Composition and performance of fractionated whole egg. Paper presented at the 25th Annual Meeting of the Inst. of Food Technologists, Kansas City, Mo., May 16-20.

Powrie, W. D., H. Little, and A. Lopez. 1963. Gelation of egg yolk. J. Food Sci. 28, 38-46.

Robinson, W. B., T. Wishnetsky, J. R. Ransford, W. L. Clark, and D. B. Hand. 1952. A study of methods for the measurement of tomato juice color. Food Technol. 6, 269-275.

Rolfes, T., P. Clements, and A. R. Winter. 1955. The physical and functional properties of lypholized whole egg, yolk, and white. Food Technol. 9, 569-572.

Schlosser, G. C., M. March, and E. Dawson. 1961. Flavor and cooking quality of stabilized dried whole egg solids. Poultry Proc. and Mktg. 67, 8-9, 32.

Sidwell, A. P., and R. W. Decker. 1959. Shear test indicates tenderness. L.E.E. Incorporated, Washington D.C.

Stuart, L. S., E. Grewe, and E. E. Dicks. 1942a. Solubility of spray-dried whole egg powder. U.S. Egg and Poult. Mag. 48, 498-503, 524-526.

Stuart, L. S., H. H. Hall, and E. E. Dicks. 1942b. Storage changes in spray-dried whole egg powder. U.S. Egg and Poult. Mag. 48, 629-633.

Sweetman, M. D., and I. MacKellar. 1959. "Food Selection and Preparation." 4th ed. John Wiley and Sons, New York.

Triebold, H. O., and L. W. Aurand. 1963. "Food Composition and Analysis." D. Van Nostrand Company, Inc., Princeton, New Jersey.

Wells, F. E. 1964. Information on processing of freeze-dried eggs (Private communication). Midwest Research Institute, Kansas City, Missouri.

Wells, G. H., K. N. May, and J. J. Powers. 1962. Taste-panel and shear-press evaluation of color and consistency in peach puree. Food Technol. 11, 479-481.

Wilke, H. L. 1938. Recent developments in studies of interior egg quality. U.S. Egg and Poult. Mag. 44, 16.

Wilson, D. E., J. C. Moyer, W. B. Robinson, and D. B. Hand. 1957. Objective evaluation of color and consistency in peach puree. Food Technol. 11, 479-481.

Winter, A. R. 1952. Production of pasteurized frozen egg products. Food Technol. 6, 414-415.

Ziemba, J. V. 1955a. Five egg-quality properties important to food processors. Food Eng. 27, 85, 191-192.

Ziemba, J. V. 1955b. Egg solids to forefront. Food Eng. 27, 77-80.

APPENDIX

GENERAL INSTRUCTIONS FOR COLOR PANEL MEMBERS

1. The purpose of this panel is to evaluate the color only of the baked slurries. Please disregard other factors, such as syneresis, sag, aroma, and flavor. The samples should not be cut during the evaluation, as there are several judges scoring the same product.

2. You will be provided with a written schedule of dates and times that the color panel will meet. We would prefer that you come at the time indicated on your schedule sheet so that you may get done as quickly as possible. However, any time between 12:45 p.m. and 2:00 p.m. will be suitable.

3. Please do not give any reactions such as grimace, smile, or vocal expression, as you evaluate the sample.

4. There will be two types of evaluation: One for preference and one for difference. Separate score sheets will be provided for each type of evaluation.

5. You are asked to do the preference test first. For this type of evaluation, the slurries are not to be compared with a control, but rather each sample is to be judged individually. Judge the inside color of the slurry only. The crust is not to be evaluated. Take into consideration any particles of off-color in your evaluation. If a low score is used, give the reasons for your choice.

6. After evaluating the baked slurries for preference, you are asked to score another set of slurries for differences between the samples and a labeled control. Judge only on the basis of color differences between each sample and the control and not on the basis of personal preference in this case.

Figure 8. General instructions for color panel members.

SCORE SHEET FOR COLOR OF BAKED SLURRIES

(Preference Evaluation)

Judge: _____ Date: _____

Code No.	7	6	5	4	3	2	1	Reasons

Score Key

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

If score of 1 or 2 is used, give reason for choice.

Figure 9. Score sheet for preference evaluation of color.

SCORE SHEET FOR COLOR OF BAKED SLURRIES

(Difference Evaluation)

Judge:_____ Date:_____

Code No	3	2	1	0

Score Key

3- Extremely different from control
2- Moderately different from control
1- Slightly different from control
0- No different from control

Figure 10. Score sheet for difference evaluation of color.

Table 25. Replication averages[a] for pH values for before and after baking of whole egg-milk slurries baked in custard cups.

End Baking Temperature		81-82°C				84-85°C			
pH		Unadjusted		Adjusted[b]		Unadjusted		Adjusted[b]	
		Before Baking	After Baking	Before Baking	After Baking	Before Baking	After Baking	Before Baking	After Baking
Egg Process	Rep								
Freeze-dried	1	7.0	7.4	6.6	7.1	7.0	7.3	6.6	7.0
	2	7.0	7.3	6.6	7.0	7.0	7.4	6.6	7.1
	3	7.0	7.4	6.6	7.1	7.0	7.4	6.6	7.1
	4	7.0	7.4	6.6	7.0	7.0	7.3	6.6	7.1
Spray-dried	1	7.0	7.3	6.6	7.1	7.0	7.3	6.6	7.0
	2	7.0	7.4	6.6	7.0	7.0	7.4	6.6	7.0
	3	7.0	7.4	6.6	7.1	7.0	7.3	6.6	7.0
	4	7.0	7.3	6.6	7.1	7.0	7.4	6.6	7.1
Frozen egg	1	7.0	7.0	6.6	7.1	7.0	7.3	6.6	7.1
	2	7.0	7.3	6.6	7.1	7.0	7.4	6.6	7.0
	3	7.0	7.4	6.6	7.1	7.0	7.3	6.6	7.1
	4	7.0	7.3	6.6	7.0	7.0	7.3	6.6	7.1

[a]Figure represents an average of two determinations.

[b]Mix was adjusted to pH 6.6 with 0.1N HCl.

Table 26. Replication averages[a] for pH values for before and after baking of whole egg-milk slurries baked in pans.

End Baking Temperature		81-82°C				84-85°C			
pH		Unadjusted		Adjusted[b]		Unadjusted		Adjusted[b]	
		Before Baking	After Baking	Before Baking	After Baking	Before Baking	After Baking	Before Baking	After Baking
Egg Process	Rep								
Freeze-dried	1	7.1	7.4	6.6	7.1	7.0	7.1	6.6	7.0
	2	7.1	7.2	6.6	6.9	7.1	7.2	6.6	7.0
	3	7.1	7.2	6.6	6.9	7.0	7.2	6.6	7.0
	4	7.1	7.3	6.6	7.0	7.0	7.1	6.6	7.0
Spray-dried	1	7.1	7.3	6.6	7.1	7.0	7.1	6.6	7.0
	2	7.1	7.2	6.6	6.9	7.0	7.1	6.6	7.0
	3	7.0	7.3	6.6	6.9	7.0	7.2	6.6	7.0
	4	7.0	7.3	6.6	7.1	7.0	7.1	6.6	7.0
Frozen	1	7.1	7.3	6.6	7.1	7.0	7.1	6.6	7.0
	2	7.1	7.3	6.6	6.9	7.0	7.2	6.6	7.0
	3	7.0	7.2	6.6	6.9	7.0	7.2	6.6	7.0
	4	7.0	7.4	6.6	7.1	7.1	7.1	6.6	6.9

[a]Figure represents an average of two determinations.

[b]Mix was adjusted to pH 6.6 with 0.1N HCl.

Table 27. Replication averages and mean values, pH level and end baking temperature conglomerate averages, and standard deviations for baking times (minutes) for frozen, freeze-dried, and spray-dried egg-milk slurries baked simultaneously in cups or pans.

End Baking Temperature	Rep	Slurries baked in cups			Slurries baked in pans		
		Unadjusted pH	Adjusted[a] pH	Temperature Conglomerate Average	Unadjusted pH	Adjusted[a] pH	Temperature Conglomerate Average
81-82°C	1	48	51	48 ± 1.80	69	65	67 ± 3.19
	2	47	48		69	66	
	3	49	45		71	67	
	4	47	50		66	60	
	Mean	48 ± 0.96	49 ± 2.65		69 ± 2.06	65 ± 3.11	
84-85°C	1	55	55	53 ± 2.72	79	74	79 ± 3.42
	2	51	53		79	81	
	3	53	47		85	82	
	4	56	53		79	75	
	Mean	54 ± 2.22	52 ± 3.46		81 ± 3.00	78 ± 4.08	
pH conglomerate average		51 ± 3.42	50 ± 3.26		75 ± 6.42	71 ± 7.61	

[a]Mix was adjusted to pH 6.6 with 0.1N HCl.

Table 28. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for end baking temperatures (°C) of whole egg-milk slurries baked in custard cups.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[b]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-Dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	82.0	81.0	81.8	83.0	82.0	82.0	81.56 ± 0.77
	2	81.3	81.0	82.0	81.5	81.3	81.5	
	3	80.5	81.0	83.5	80.3	81.8	82.3	
	4	80.5	80.8	81.5	82.3	81.5	81.0	
	Mean	81.1 ± 0.72	81.0 ± 0.10	82.2 ± 0.89	81.8 ± 1.16	81.7 ± 0.31	81.7 ± 0.57	
84-85	1	85.0	84.0	84.5	86.0	84.5	84.5	84.63 ± 0.97
	2	85.5	82.5	85.0	85.5	83.3	85.3	
	3	84.3	84.0	86.0	84.0	84.3	85.5	
	4	84.5	83.0	86.3	84.8	83.5	85.3	
	Mean	84.8 ± 0.54	83.4 ± 0.75	85.5 ± 0.84	85.1 ± 0.87	83.9 ± 0.59	85.2 ± 0.44	
pH Mean			82.98 ± 1.87			83.21 ± 1.71		

Egg Process Mean: Freeze-dried = 83.19 ± 1.99. Spray-dried = 82.47 ± 1.33. Frozen = 83.63 ± 1.86

[a]Figure represents an average of two temperature readings.

[b]Mix was adjusted to pH 6.6 with 0.1N HCl.

Table 29. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for end baking temperatures (°C) of whole egg-milk slurries baked in loaf pans.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[b]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	82.0	80.5	81.8	82.0	79.5	83.0	81.45 ± 1.23
	2	82.5	81.3	81.5	79.5	80.0	83.0	
	3	83.0	82.0	82.0	82.5	80.0	82.0	
	4	81.0	80.0	82.0	82.0	79.0	82.8	
	Mean	82.1 ± 0.85	81.0 ± 0.88	81.8 ± 0.24	81.5 ± 1.35	79.6 ± 0.48	82.7 ± 0.48	
84-85	1	85.5	83.5	84.5	86.8	80.5	85.5	85.12 ± 1.55
	2	84.8	84.8	87.5	85.0	84.0	88.5	
	3	85.5	85.0	85.5	85.5	84.0	85.0	
	4	84.5	85.0	86.0	85.5	83.5	87.0	
	Mean	85.1 ± 0.51	84.6 ± 0.72	85.9 ± 1.25	85.7 ± 0.77	83.0 ± 1.68	86.5 ± 1.58	
pH Mean			83.40 ± 2.02			83.17 ± 2.61		

Egg Process Mean: Freeze-dried = 83.6 ± 2.04. Spray-dried = 82.0 ± 2.17. Frozen = 84.2 ± 2.27.

[a] Figure represents an average of two temperature readings.

[b] Mix was adjusted to pH 6.6 with 0.1N HCl.

Table 30. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for shear press maximum force values for peak I (lbs.) of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[b]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	4.95	3.95	5.55	3.83	2.55	4.48	4.27 ± 1.24
	2	5.45	4.10	6.48	3.30	2.88	4.10	
	3	5.48	4.58	6.40	3.68	2.83	4.03	
	4	4.60	3.35	6.50	3.08	2.05	4.35	
	Mean	5.12 ± 0.42	4.00 ± 0.51	6.23 ± 0.46	3.47 ± 0.34	2.58 ± 0.38	4.24 ± 0.21	
84-85	1	6.80	6.15	6.75	4.20	3.45	4.68	5.24 ± 1.14
	2	6.60	5.78	6.88	4.35	4.75	5.23	
	3	5.60	5.60	6.70	4.18	4.05	5.00	
	4	6.20	4.88	6.50	3.63	3.95	3.80[c]	
	Mean	6.30 ± 0.53	5.60 ± 0.53	6.71 ± 0.16	4.09 ± 0.32	4.05 ± 0.54	4.68 ± 0.63	
pH Mean			5.66 ± 1.01			3.85 ± 0.78		

Egg Process Mean: Freeze-dried = 4.75 ± 1.17. Spray-dried = 4.06 ± 1.19. Frozen = 5.46 ± 1.13.

[a]Figure represents an average of two determinations.

[b]Mix was adjusted to pH 6.6 with 0.1N HCl.

[c]Figure represents only one determination.

Table 31. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for shear press maximum force values for peak II (lbs.) of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[b]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	3.50	2.85	3.68	2.63	2.15	3.00	3.00 ± 0.71
	2	3.50	2.80	4.40	2.23	2.40	2.98	
	3	3.38	3.48	4.10	2.38	2.43	2.65	
	4	3.30	2.75	4.45	2.20	1.85	2.93	
	Mean	3.42 ± 0.10	2.97 ± 0.34	4.16 ± 0.35	2.36 ± 0.20	2.21 ± 0.27	2.89 ± 0.16	
84-85	1	3.88	3.65	4.43	2.73	2.65	3.05	3.37 ± 0.62
	2	4.20	3.68	4.03	2.88	3.03	3.45	
	3	3.68	3.40	4.25	2.75	2.73	3.23	
	4	3.75	3.45	4.25	2.25	2.65	2.85[c]	
	Mean	3.88 ± 0.23	3.55 ± 0.14	4.24 ± 0.16	2.65 ± 0.28	2.77 ± 0.18	3.15 ± 0.26	
pH Mean			3.70 ± 0.50			2.67 ± 0.38		

Egg Process Mean: Freeze-dried = 3.08 ± 0.65. Spray-dried = 2.87 ± 0.54. Frozen = 3.61 ± 0.66.

[a] Figure represents an average of two determinations.

[b] Mix was adjusted to pH 6.6 with 0.1N HCl.

[c] Figure represents only one determination.

Table 32. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for shear press maximum force values for peak III (lbs.) of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[b]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	5.05	5.35	5.30	4.40	3.75	4.45	4.75 ± 1.04
	2	5.35	5.05	5.83	3.40	3.95	4.30	
	3	6.15	6.20	7.25	4.18	3.88	4.10	
	4	5.00	3.90	6.10	3.55	3.10	4.35	
	Mean	5.39 ± 0.53	5.13 ± 0.95	6.12 ± 0.82	3.88 ± 0.48	3.67 ± 0.39	4.30 ± 0.15	
84-85	1	7.50	6.60[c]	7.70	5.18	4.35	5.43	6.16 ± 1.05
	2	6.90	6.18	7.88	5.60	5.45	6.45	
	3	6.55	7.20	7.55	5.50	5.00	6.13	
	4	7.05	5.30	7.05	4.63	4.65	6.10[c]	
	Mean	7.00 ± 0.39	6.32 ± 0.80	7.55 ± 0.36	5.23 ± 0.44	4.86 ± 0.47	6.03 ± 0.43	
pH Mean			6.25 ± 1.05			4.66 ± 0.90		

Egg Process Mean: Freeze-dried = 5.37 ± 1.22. Spray-dried = 4.99 ± 1.15. Frozen = 6.00 ± 1.27.

[a]Figure represents an average of two determinations.

[b]Mix was adjusted to pH 6.6 with 0.1N HCl.

[c]Figure represents only one determination.

Table 33. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for shear press area-under-the-curve values (cm^2) of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[b]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	12.06	10.16	12.93	9.28	7.45	10.68	10.88 ± 2.65
	2	12.92	10.33	15.41	8.04	7.64	10.45	
	3	13.01	11.80	15.42	8.97	7.90	9.80	
	4	12.63	9.83	16.78	9.37	6.84	11.49	
	Mean	12.66 ± 0.43	10.53 ± 0.87	15.14 ± 1.60	8.92 ± 0.61	7.46 ± 0.45	10.61 ± 0.70	
84-85	1	14.93	14.37	15.92	10.04	8.91	11.68	13.10 ± 2.63
	2	16.33	13.48[c]	17.72	10.27	10.88	12.48	
	3	14.41	14.07	17.37	11.37	10.92	13.26	
	4	15.11	12.98	16.87	9.33	10.26	11.50[c]	
	Mean	15.20 ± 0.81	13.73 ± 0.62	16.97 ± 0.78	10.25 ± 0.85	10.24 ± 0.94	12.23 ± 0.81	
pH Mean			14.04 ± 2.26			9.95 ± 1.65		
Egg Process Mean: Freeze-dried = 11.75 ± 2.55. Spray-dried = 10.49 ± 2.39. Frozen = 13.74 ± 2.72								

[a]Figure represents an average of two determinations.

[b]Mix was adjusted to pH 6.6 with 0.1N HCl.

[c]Figure represents only one determination.

Table 34. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for percentage of drainage due to syneresis of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[b]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	0.47	0.40[c]	0.45	0.72	0.55	0.35	0.48 ± 0.26
	2	0.30	0.20	0.39	0.61	0.40[c]	0.67	
	3	0.30	0.24	0.30	0.10	1.23[c]	0.56	
	4	0.20	0.30[c]	0.45	0.80	0.46	1.01	
	Mean	0.32 ± 0.11	0.29 ± 0.09	0.40 ± 0.07	0.56 ± 0.31	0.66 ± 0.38	0.65 ± 0.28	
84-85	1	0.15	0.26	0.50	0.91	0.26	1.01	0.45 ± 0.32
	2	0.15	0.05	0.40	0.56	0.31	0.87	
	3	0.11	0.07	0.20	0.76	0.61	0.60	
	4	0.21	0.21	0.25	0.61	0.55	1.20	
	Mean	0.16 ± 0.04	0.15 ± 0.10	0.34 ± 0.14	0.71 ± 0.16	0.43 ± 0.17	0.92 ± 0.25	
pH Mean			0.28 ± 0.13			0.65 ± 0.28		
Egg Process Mean: Freeze-dried = 0.44 ± 0.28. Spray-dried = 0.38 ± 0.28. Frozen = 0.58 ± 0.30.								

[a] Figure represents an average of two determinations.

[b] Mix was adjusted to pH 6.6 with 0.1N HCl.

[c] Figure represents only one determination.

Table 35. Replication averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for Gardner Color Difference Meter L values of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[b]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	79.2	78.7	79.4	79.6	79.3	79.6	79.3 ± 0.41
	2	78.9	78.8	79.1	79.5	79.6	79.9	
	3	79.0[c]	78.5	79.1	79.8	79.6	80.0	
	4	79.2	78.9	79.5	79.7	79.5	79.9	
	Mean	79.1 ± 0.15	78.7 ± 0.17	79.3 ± 0.21	79.7 ± 0.13	79.5 ± 0.14	79.9 ± 0.17	
84-85	1	78.8	78.6	79.5	79.9	79.3	79.9	79.2 ± 0.44
	2	78.9	78.6	79.3	79.3	79.3	79.9	
	3	78.8	78.4	79.2	79.4	79.3	79.7	
	4	78.9	78.5	79.1	79.4	79.2	79.7	
	Mean	78.9 ± 0.06	78.5 ± 0.10	79.3 ± 0.17	79.5 ± 0.27	79.3 ± 0.05	79.8 ± 0.12	
pH Mean			79.0 ± 0.31			79.6 ± 0.25		

Egg Process Mean: Freeze-dried = 79.3 ± 0.36. Spray-dried = 79.0 ± 0.42. Frozen = 79.6 ± 0.32.

[a]Figure represents an average of two readings on each of two determinations.

[b]Mix was adjusted to pH 6.6 with 0.1N HCl.

[c]Figure represents an average of two readings on one determination.

Table 36. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for Gardner Color Difference Meter a_L values of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[b]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	-7.2	-7.0	-7.2	-6.7	-6.5	-6.8	-6.8 ± 0.31
	2	-7.0	-6.5	-7.3	-6.6	-6.3	-6.8	
	3	-6.8[c]	-6.3	-6.7	-6.6	-6.3	-6.8	
	4	-7.1	-6.9	-7.2	-6.9	-6.3	-6.6	
	Mean	-7.0 ± 0.17	-6.7 ± 0.33	-7.1 ± 0.27	-6.7 ± 0.14	-6.4 ± 0.10	-6.8 ± 0.10	
84-85	1	-6.9	-6.7	-7.2	-6.9	-6.2	-6.7	-7.0 ± 0.29
	2	-7.1	-6.8	-7.2	-7.4	-6.8	-7.3	
	3	-7.1	-6.7	-7.4	-6.9	-6.6	-7.1	
	4	-7.1	-6.9	-7.3	-7.2	-6.7	-7.2	
	Mean	-7.1 ± 0.10	-6.8 ± 0.10	-7.3 ± 0.10	-7.1 ± 0.24	-6.6 ± 0.26	-7.1 ± 0.26	
pH Mean			-7.0 ± 0.27			-6.8 ± 0.32		

Egg Process Mean: Freeze-dried = -7.0 ± 0.22. Spray-dried = -6.6 ± 0.26. Frozen = -7.1 ± 0.27.

[a] Figure represents an average of two readings on each of two determinations.

[b] Mix was adjusted to pH 6.6 with 0.1N HCl.

[c] Figure represents an average of two readings on one determination.

Table 37. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for Gardner Color Difference Meter b_L values of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[b]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	20.9	19.9	21.6	20.0	19.4	21.3	20.4 ± 0.93
	2	20.6	20.2	21.8	19.9	19.4	20.8	
	3	20.7[c]	20.0	21.9	19.7	19.0	20.6	
	4	20.3	19.5	21.7	19.6	19.2	20.9	
	Mean	20.6 ± 0.25	19.9 ± 0.29	21.8 ± 0.13	19.8 ± 0.18	19.3 ± 0.19	20.9 ± 0.29	
84-85	1	20.2	19.5	21.4	20.3	18.8	21.1	20.0 ± 0.81
	2	20.3	19.6	21.4	19.6	19.1	20.8	
	3	19.9	19.0	20.9	19.7	18.6	21.0	
	4	19.7	18.3	20.9	19.6	19.2	21.0	
	Mean	20.0 ± 0.28	19.1 ± 0.59	21.2 ± 0.29	19.8 ± 0.34	18.9 ± 0.28	21.0 ± 0.13	
pH Mean			20.4 ± 0.86			19.9 ± 0.92		

Egg Process Mean: Freeze-dried = 20.1 ± 0.42. Spray-dried = 19.3 ± 0.51. Frozen = 21.2 ± 0.40.

[a]Figure represents an average of two readings on each of two determinations.

[b]Mix was adjusted to pH 6.6 with 0.1N HCl.

[c]Figure represents an average of two readings on one determination.

Table 38. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for Gardner Color Difference Meter a_L/b_L ratios of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	-.34	-.35	-.34	-.34	-.34	-.32	-.33 ± 0.01
	2	-.33	-.35	-.34	-.33	-.33	-.33	
	3	-.33[c]	-.32	-.31	-.33	-.33	-.32	
	4	-.35	-.36	-.33	-.35	-.33	-.32	
	Mean	-.34 ± 0.01	-.35 ± 0.02	-.33 ± 0.01	-.34 ± 0.01	-.33 ± 0.01	-.32 ± 0.01	
84-85	1	-.34	-.34	-.34	-.35	-.33	-.32	-.35 ± 0.01
	2	-.35	-.35	-.34	-.38	-.36	-.35	
	3	-.36	-.36	-.36	-.35	-.36	-.34	
	4	-.36	-.38	-.35	-.37	-.35	-.34	
	Mean	-.35 ± 0.01	-.36 ± 0.02	-.35 ± 0.01	-.36 ± 0.02	-.35 ± 0.01	-.34 ± 0.01	
pH Mean			-.35 ± 0.02			-.34 ± 0.02		
Egg Process Mean: Freeze-dried = -.35 ± 0.01. Spray-dried = -.35 ± 0.02. Frozen = -.33 ± 0.01.								

[a]Figure represents an average of two readings on each of two determinations.

[b]Mix was adjusted to pH 6.6 with 0.1N HCl.

[c]Figure represents an average of two readings on one determination.

Table 39. Replicate averages[a] and mean values, egg process, pH levels, and end baking temperature conglomerate averages, and standard deviations for color panel difference scores[b] of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[c]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	1.6	2.1	1.0	2.1	2.6	1.7	1.9 ± 0.56
	2	1.6	1.7	1.0	2.0	2.7	1.9	
	3	1.6	2.0	1.0	2.4	2.9	1.7	
	4	2.0	2.1	1.0	2.6	2.7	1.7	
	Mean	1.7 ± 0.20	2.0 ± 0.19	1.0 ± 0.00	2.3 ± 0.28	2.7 ± 0.13	1.8 ± 0.10	
84-85	1	1.6	1.9	1.0	2.7	2.9	1.9	1.9 ± 0.56
	2	1.7	2.1	1.0	2.0	2.3	1.3	
	3	1.6	1.9	1.0	2.1	2.7	1.6	
	4	1.9	2.4	1.0	1.9	2.6	1.6	
	Mean	1.7 ± 0.14	2.1 ± 0.24	1.0 ± 0.00	2.2 ± 0.36	2.6 ± 0.25	1.6 ± 0.24	
pH Mean			1.6 ± 0.46			2.2 ± 0.47		
Egg Process Mean: Freeze-dried = 2.0 ± 0.36. Spray-dried = 2.4 ± 0.39. Frozen = 1.3 ± 0.37.								

[a] Figure represents an average of 7 panel member scores.

[b] Slurries were rated on a 4-point scale ranging from 1 (no difference) to 4 (extreme difference).

[c] Mix was adjusted to pH 6.6 with 0.1N HCl.

Table 40. Replicate averages[a] and mean values, egg process, pH level, and end baking temperature conglomerate averages, and standard deviations for color panel preference scores[b] of baked whole egg-milk slurries.

End Baking Temp. (°C)	Rep	Unadjusted pH			Adjusted pH[c]			Temp. Mean (°C)
		Egg Process			Egg Process			
		Freeze-dried	Spray-dried	Frozen	Freeze-dried	Spray-dried	Frozen	
81-82	1	5.7	5.9	6.1	5.6	5.3	5.7	5.6 ± 0.28
	2	5.9	5.6	6.0	5.6	5.4	5.3	
	3	5.9	5.6	5.9	5.4	5.0	5.4	
	4	5.7	5.6	5.7	5.4	5.4	5.1	
	Mean	5.8 ± 0.12	5.7 ± 0.15	5.9 ± 0.17	5.5 ± 0.12	5.3 ± 0.19	5.4 ± 0.25	
84-85	1	5.9	5.7	5.9	5.7	5.6	5.7	5.6 ± 0.34
	2	5.7	5.0	5.9	5.4	5.0	5.6	
	3	6.1	5.6	6.3	5.6	5.1	5.6	
	4	5.7	5.1	5.9	5.4	5.3	5.3	
	Mean	5.9 ± 0.19	5.4 ± 0.35	6.0 ± 0.20	5.5 ± 0.15	5.3 ± 0.26	5.6 ± 0.17	
pH Mean			5.8 ± 0.29			5.4 ± 0.21		
Egg Process Mean: Freeze-dried = 5.7 ± 0.21. Spray-dried = 5.4 ± 0.28. Frozen = 5.7 ± 0.32.								

[a] Figure represents an average of 7 panel member scores.

[b] Slurries were scored on a 7-point hedonic scale with a rating of 7 being most preferred.

[c] Mix was adjusted to pH 6.6 with 0.1N HCl.

Table 41. Correlation coefficients of measurements related to gel strength of baked whole egg-milk slurries.

Objective Measurement	Maximum Force Peak I	Maximum Force Peak II	Maximum Force Peak III	Area-Under-the-curve	% Drainage	End Baking Temperature	pH Before Baking	pH After Baking	Baking Time
Maximum Force Peak I		.962***	.903***	.969***	-.437**	.528***	.674***	.475***	.548***
Maximum Force Peak II	.962***		.855***	.958***	-.419**	.412**	.729***	.572***	.459***
Maximum Force Peak III	.903***	.855***		.902***	-.358**	.666***	.572***	.356**	.731***
Area-under-the-curve	.969***	.958***	.902***		-.397**	.538***	.679***	.507***	.545***
% Drainage	-.437**	-.419**	-.358**	-.397**		.111	-.662***	-.628***	-.082
End Baking Temperature	.528***	.412**	.666***	.538***	.111		.000	-.161	.758***
pH before Baking	.674***	.729***	.572***	.679***	-.662***	.000		.818***	.170
pH after Baking	.475***	.572***	.356**	.507***	-.628***	-.161	.818***		-.051
Baking time	.548***	.459***	.731***	.545***	-.082	.758***	.170	-.051	

*Significant at 5 per cent level of probability.

**Significant at 1 per cent level of probability.

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

Table 42. Correlation coefficients of measurements related to color of baked whole egg-milk slurries.

Objective Measurement	Gardner L value	Gardner a_L value	Gardner b_L value	Gardner a_L/b_L ratio	Panel Scores Difference	Panel Scores Preference	End Baking Temperature	pH Before Baking	pH After Baking	Baking Time
Gardner L value		-.013	.299*	-.377**	.077	-.216	.018	-.757***	-.738***	-.200
Gardner a_L value	-.013		.511***	.454**	-.684***	.470***	.444***	.360**	.270	.205
Gardner b_L value	.299*	.511***		-.468***	-.840***	.587***	.048	.271	.201	-.139
Gardner a_L/b_L ratio	-.377**	.454**	-.468***		.122	-.096	.402**	.148	.117	.375**
Panel Scores Difference	.077	-.684***	-.840***	.122		-.664***	-.203	-.559***	-.450**	-.036
Panel Scores Preference	-.216	.470***	.587***	-.096	-.664***		.186	.583***	.428**	.104
End Baking Temperature	.018	.444***	.048	.402**	-.203	.186		-.065	-.066	.683***
pH before Baking	.757***	.360**	.271	.148	-.559***	.583***	-.065		.891***	.076
pH after Baking	-.738***	.270	.201	.117	-.450**	.428**	-.066	.891***		.044
Baking time	-.200	.205	-.139	.375**	-.036	.104	.683***	.076	.044	

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

**Significant at 1 per cent level of probability.