International Egg Pasteurization Manual

Prepared in cooperation with

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by

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TRIBUTES

(see complete letters in Appendix B)

"The Office of Food Safety believes in science as basis for enhancing food safety and encourages collaborative efforts by industry and the scientific community to achieve this. The Egg Pasteurization Guidelines developed by scientists at the University of Nebraska and Oklahoma State University, through work supported by the egg products industry, are a good example of how such cooperation can work to the benefit of consumers."

— *Dr. Elisa A. Murano*
Under Secretary, Food Safety
US Department of Agriculture

"FSIS believes the data from the University of Nebraska study provide a reliable source of information for use in developing models for predicting the lethality of *Salmonella spp.* for pasteurization treatments, and thus can be considered in developing guidelines."

— *William J. Hudnall*
Acting Administrator
US Department of Agriculture

"FSIS believes that this study is the most extensive of its kind on liquid egg products with respect to the number of types of products covered, and thus, the results will be an important contribution to the scientific literature. The contribution is further enhanced because of the good repeatability of the results that were obtained from three independent replications performed for each product type studied. Thus, FSIS believes that these data could and should be used in considering time-temperature guidelines for pasteurization of liquid egg products."

— *Judith W. Riggins*
Associate Deputy Administrator
Office of Policy, Program Development and Evaluation
US Department of Agriculture

"The pasteurization manual will provide the stakeholders a valuable resource in their current and future research and marketing activities."

— *Elliot Gibber*
Chairman, United Egg Association

— *Al Pope*
President, United Egg Association

"This important work has updated our knowledge of effective pasteurization and will be of great value to the egg products industry worldwide as we all seek to achieve the highest standards of food safety."

— *Clive Frampton*
Chairman, International Egg Commission

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INTRODUCTION

In 1969, the first Egg Pasteurization Manual (USDA, 1969) reviewed research available at that time to develop present pasteurization requirements. This led to the Egg Products Inspection Act of 1970 (FDA, 1971). Although egg pasteurization was first utilized by the egg products industry in the 1930s, this Act required that all egg products be *Salmonella* free through use of approved pasteurization methods. Cunningham (1995) provides an excellent review of pasteurization methods used by the egg industry.

Pasteurization methods used by the egg products industry have served the industry and the consumer well. There have been no *Salmonella* outbreaks from pasteurized eggs. Nevertheless, there have been some significant changes in recent years that may impact the effectiveness of egg pasteurization. The purposes of the revision of the Egg Pasteurization Manual are:

1. To review the impact of modern egg production and egg processing practices on the effectiveness of existing egg products pasteurization methods.
2. To validate or propose new egg pasteurization guidelines where necessary.
3. To provide a tool for processing plants to select adequate pasteurization processes according to their performance standards.

BACKGROUND

Although most eggs at the time of lay are sterile, research has now indicated that transovarian infection by *Salmonella enteritidis* into the shell egg may be a potential health hazard (Duguid and North, 1991; Gast and Beard, 1990, 1992). Research has shown that naturally infected flocks have a low incidence of infection of less than 0.03% (Schlosser et al., 1995; Kinde et al., 1996). Most naturally infected eggs contain less than 10 cells per egg (Humphrey et al., 1989). However, occasionally eggs are reported to have much larger *Salmonella enteritidis* numbers (Humphrey et al., 1991). *Salmonella enteritidis*, particularly phage type 4, is also reported to be more heat resistant (Humphrey et al., 1990). Although numbers of *Salmonella enteritidis* have been low, there is concern that counts may grow during storage and the heat resistance may pose problems during pasteurization. Gast and Holt (2000) observed much less multiplication of *Salmonella enteritidis* at temperatures of 10 to 17.5°C than that noted at 25°C. Level of inoculum greatly influenced the growth rate at different temperatures. With regard to the effect of storage temperature, the USDA has now amended regulations to require that shell eggs intended for consumption be stored and transported under refrigeration at an ambient temperature of 7.2°C.

Substantial changes in the egg industry have occurred since 1969. Egg production and egg handling methods are much different. In 1969, eggs were produced in more small flocks with less control over washing, handling and refrigeration practices. At that time, many eggs were washed on the farm under poor sanitary conditions. Also, many farms did not have refrigeration facilities and often eggs did not reach the processing plant until several days after being laid.

Today, eggs usually are picked up from the producer 3 or 4 times a week. Often, eggs arrive at the breaking plant on the same day they are laid. Eggs are gathered often on automatic belts and refrigerated on the farm. All eggs are washed at the breaking plant under closely controlled temperature conditions using approved detergent sanitizers. These changes have greatly enhanced the retention of egg quality and reduced the incidence of bacterial spoilage. The higher quality at the time of breaking has led to some pasteurization concerns, especially for egg white. Eggs reaching the breaking plant often have an egg white with a lower pH. *Salmonella* is somewhat more heat resistant in egg white at a lower pH. Freshly laid eggs have an egg white pH of about 7.6. After laying, the egg white pH will increase from 7.6 to 9.4. Depending on temperature of storage, this increase may take 7 to 10 days. Therefore, improved albumen quality and lower pH values may raise questions relative to the adequacy of present day pasteurization guidelines. Obviously, the egg processing industry must continue to maintain high albumen quality goals. Thus, pasteurization guidelines must work within today's improved quality assurance programs.

Updated Characteristics and Composition of Liquid Eggs Which May Affect Pasteurization Guidelines

NUTRITIVE COMPOSITION

Several production factors have been shown to affect the egg's composition. Breed, strain, age, diet of bird, environmental temperatures, storage conditions and processing have been observed to affect the composition of liquid egg products (Stadelman and Pratt, 1989).

Strain, breed and age of the bird affect the egg size and consequently the relative amounts of yolk and white. The proportion of yolk and white will have a large effect on the total solids of liquid egg. When hens first come into production, they will produce small eggs with a higher proportion of yolk. As the age of the hen and egg size increases, the relative amount of yolk decreases, thereby decreasing the solids content (Forsythe, 1963). Cotterill and Geiger (1977) monitored solids content of whole eggs from 1966 through 1976 and observed a decrease in solids from 24.7% to 24.2%. These differences probably were related largely to strain and changes in handling methods. Perhaps, such production changes as forced molting could also have been a factor in these trends. Cunningham et al. (1960) found that season had a highly significant effect on sodium, calcium and chlorine content while having little influence on potassium, phosphorous and protein content of eggs. The age of the hen also significantly influenced phosphorous, chlorine and protein content of the eggs.

Diet of the hen greatly affects certain nutrients in the egg (Stadelman and Pratt, 1989). Fatty acid composition, fat soluble vitamins, certain water soluble vitamins and some minerals (iodine, fluorine and manganese) are affected by the diet of the hen. Watkins (1991) reported that dietary linoleic acid may affect yolk size and weight.

"Specialty" eggs in which the omega 3 highly unsaturated fatty acids are increased through the diet of the hen have become increasingly popular. These eggs are generally modified by feeding flaxseed or flaxseed oil to increase omega 3 fatty acids (Cherian and Sim, 1991). Flaxseed is high in α-linolenic acid which can be converted in humans to longer chain polyunsaturated fatty acids such as eicosapentaenoic (EPA) and docosahexaenoic acids (DHA). Feeding of flaxseed does not affect layer performance or egg quality. Also, off-flavors are minimized when feeding flaxseed. Feeding of fish meal also effectively increases omega 3 fatty acids in the eggs but fishy off-flavors are a problem (Hargis et al., 1991).

Current composition data for egg products are shown in Table 1 (USDA, ARS, 2000). As indicated, there are differences in pure yolk and commercial yolk. These differences reflect an average of approximately 15% white, which becomes a part of the yolk during the breaking operation. This also accounts for the present 43% solids specification (FDA, CFR 21, 2002a) for commercially broken egg products. Cholesterol content of 425mg/100g is substantially lower than that reported in the 1960s. This is largely attributed to improved analytical methods for determining cholesterol values. Other factors affecting composition likely may be attributed to genetic selection of the layers and feed. Actually, the composition of today's eggs remains fairly steady with minimum fluctuations from year to year. The exception would be the specialty eggs discussed earlier.

TABLE 1. COMPOSITION OF EGG PRODUCTS (USDA, ARS, 2000)

		Liquid/Frozen (per 100g)				Dehydrated		
Nutrient	Unit	Whole	White	Pure Yolk	Commercial Yolk	Plain Whole	Stab White	Plain Yolk
Water	g	75.33	87.81	48.81	56.20	3.10	8.54	2.95
Energy	Kcal	149.00	50.00	358.00	303.00	594.00	376.07	666.00
Protein	g	12.49	10.52	16.76	15.50	47.35	82.40	34.25
Lipid	g	10.02	—	30.87	25.60	40.95	—	55.80
Carbohydrate	g	1.22	1.03	1.78	1.15	4.95	4.47	3.60
Ash	g	0.94	0.64	1.77	1.55	3.65	4.55	3.40
Minerals								
Calcium	mg	49.00	6.00	137.00	138.00	231.00	89.4	284.00
Iron	mg	1.44	0.03	3.53	3.34	6.79	0.240	5.42
Magnesium	mg	10.00	11.00	9.00	9.00	42.00	71.84	13.00
Phosphorous	mg	178.00	13.00	488.00	417.00	831.00	89.40	920.00
Potassium	mg	121.00	143.00	94.00	118.00	493.00	1115.10	244.00
Sodium	mg	126.00	164.00	43.00	67.00	523.00	1238.40	135.00
Zinc	mg	1.10	0.01	3.11	2.88	5.28	0.160	4.93
Copper	mg	0.014	0.006	0.025	0.024	0.196	0.170	0.012
Manganese	mg	0.024	0.004	0.069	0.062	0.125	0.050	0.119
Selenium	mg	30.80	17.60	45.20	41.80	119.60	125.10	86.80
Vitamins								
Thiamin	mg	0.062	0.006	0.170	0.155	0.195	0.037	0.290
Riboflavin	mg	0.508	0.452	0.639	0.520	1.54	2.316	1.88
Niacin	mg	0.073	0.092	0.015	0.045	0.305	0.723	0.095
Pantothenic acid	mg	1.26	0.119	3.807	3.530	5.905	1.958	7.765
Vitamin B_6	mg	0.139	0.004	0.392	0.345	0.388	0.024	0.66
Folate	mcg	47.00	3.00	146.00	116.00	171.00	95.70	244.00
Vitamin B_{12}	mcg	1.00	0.20	3.11	1.82	3.95	0.528	5.33
Vitamin A	Iu	635.00	—	1945.11	1410.00	900.00	—	1315.00
Vitamin D	Iu	52.00	—	148.00	N/A*	188.00	—	—
Vitamin E	mg	1.05	—	3.16	2.50	4.38	—	6.42
Cholesterol	mg	425.00	—	1281.00	1075.00	1715.00	—	2335.00

*Not available

CHEMICAL AND PHYSICAL PROPERTIES

The egg has several heat-sensitive proteins that become an important factor when establishing pasteurization guidelines. This is particularly true in egg white. Egg white proteins and their denaturation temperature are presented in Table 2. As indicated, ovotransferrin is one of the most heat-sensitive egg white proteins. Its heat stability has been observed to be improved by adding multivalent metal ions, such as aluminum and adjusting the pH to 7.5 (Cunningham and Lineweaver, 1965). At pH 9.0, egg white increases in viscosity when heated from 56.7°C to 57.2°C and coagulates at 60°C (Cunningham, 1995). Whole egg increases in viscosity at temperatures from 56°C to 66°C and coagulates at 73°C. Egg yolk shows an increase in viscosity beginning at 65°C and a progressive increase in rigidity to 85°C (Nakamura et al., 1982).

TABLE 2. PROTEINS IN EGG ALBUMEN[1]

Protein	% of Albumen Proteins	Denaturation Temperature °C
Ovalbumin	54	84.0
Ovotransferrin	12	61.0
Ovomucoid	11	79.0
Ovomucin	3.5	—
Lysozyme	3.4	75.0
G2 Globulin	4.0	92.5
G3 Globulin	4.0	—
Ovoinhibitor	1.5	—
Ovoglycoprotein	1.0	—
Ovoflavoprotein	0.8	—
Ovomacrogloblin	0.5	—
Cystatin	0.05	—
Avidin	0.05	85

[1]LiChan et al., 1995.

Other scientists have investigated the effect of heat on egg proteins. Woodward and Cotterill (1983) utilized polyacrylamide electrophoresis to evaluate stability of proteins in heated egg mixtures containing yolk and albumen. Livetins, lysozyme, ovomacroglobulin and ovoglobulin G3 were observed to be the least heat stable while ovotransferrin, ovoinhibitor and ovoglobulin G2 were found to be the most heat stable. Both salt and sugar increased the heat stability of heat-sensitive proteins. Dixon and Cotterill (1981) further noted that 10% salted yolk could be pasteurized at 63.3°C to 68.0°C without substantial damage to protein fractions.

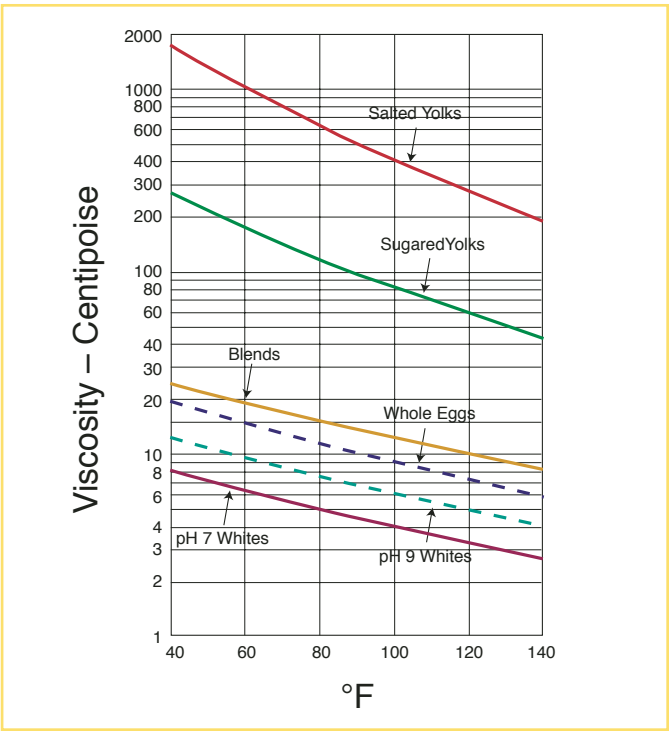
Cunningham (1995) further indicated that several carbohydrates including sucrose, glucose, fructose, arabinose, mannitol and xylose will protect proteins from denaturation during pasteurization. He further noted that sugars have a marked stabilizing effect on egg white proteins during pasteurization.

These studies show that heat does affect the properties of egg proteins. Some scientists investigated the effect of heat on isolated proteins while others reported denaturation values of proteins in the intact egg system. These differences likely account for some of the varying denaturation rates of egg proteins reported by various research scientists.

Physical properties of egg products become important in ascertaining optimum conditions for egg pasteurization. Density of whole egg, white and yolk is 1.035 at room temperature (Romanoff and Romanoff, 1949). Density of 10% salted yolk and whole egg has been reported to be 1.10 while 10% sugared yolks and whole eggs were reported as 1.07 (USDA, 1969). Blended egg products with 32 to 35% solids were indicated to have a density 1.05. Density has been shown to slightly decrease about 1.5% when blended egg products were heated from 21°C to 60°C. Mixing, pumping, dissolved gas evolution and gas generated by chemical reactions may create gas bubbles which may reduce density 10% or more.

Viscosity of liquid egg products becomes an important variable when calculating flow rates. USDA (1969) developed viscosity-temperature curves for egg products. Approximately 150 egg product samples were measured in commercial plants. Viscosity was measured using a Brookfield viscometer on samples taken directly from pasteurizing lines. Samples included both raw and pasteurized products that had not been frozen. The logarithms of the values were plotted against the reciprocal of the absolute temperature and the straight-line curves are shown in Figure 1.

FIGURE 1. THE VISCOSITY OF SEVERAL COMMERCIAL EGG PRODUCTS AT 4.4°C (40°F) TO 60°C (140°F). THE VISCOSITY OF PLAIN YOLKS IS SIMILAR TO THAT OF SUGARED YOLKS (USDA, 1969).



When measuring samples from different lots of the same sample, viscosities varied as much as 50% above and 40% below values shown with 20% variation being more common. Scalzo et al. (1970) reported similar results when using a capillary viscometer (Table 3). They also measured density, which would be of value for measuring flow characteristics. It is known that viscosity of each product may be influenced by mixing and homogenation, percent solids, pH and pasteurization methods.

Flow of egg products in tubes may be either laminar, turbulent or a combination of these types of flow (USDA, 1969). Laminar flow is most commonly straight, parallel and steady. When considering straight tubes, laminar flow involves concentric cylinders of fluid with those closer to the center traveling at higher velocities. If this straight line is followed, the center of the tube flows twice as fast as the average and holding time at the pasteurization temperatures would be only half as long. In turbulent flow, the line of flow is broken and there is continuous mixing over the entire cross-section of flow. Since egg pasteurizer holding tubes have turns at the end of straight-line tubes, the minimum holding time should be determined by experimental means. Kaufman et al. (1968) investigated various test methods for measuring minimum holding times. A dye may be injected into egg white to measure absorption as it passes through the holding tube. Other methods include a "cold shot" and a fluorocarbon tracer.

ANTIBACTERIAL COMPONENTS

Except for *Salmonella enteritidis*, most of the bacterial contamination of the egg occurs after laying. After laying, eggs are exposed to the environment, feces and moisture. Thus, several bacterial species may become possible contaminants, including *Salmonella* (Board and Tranter, 1995). The shell egg has both physical and chemical barriers to microorganisms. The cuticle of the egg shell prevents some invasion of bacteria but it is usually removed during washing. Also, the egg shell has between 9,000 to 10,000 pores about 10-30 µm in diameter, which readily allows bacterial penetration. Sauter and Petersen (1974) indicated that higher shell thickness reduced the rate of *Salmonella* penetration.

TABLE 3. VISCOSITY, DENSITY, pH, AND WATER CONTENT (W.C.) OF VARIOUS EGG PRODUCTS FROM THREE SOURCES OF SUPPLY (SCALZO ET AL., 1970)

		Ohio		Illinois		California	
Product	Temperature °C	Viscosity cps	Density g/cc	Viscosity cps	Density g/cc	Viscosity cps	Density g/cc
Stabilized egg white		(w.c. = 88%,[1] pH 7.1[2])		(w.c. = 87%, pH 7.2)		(w.c. = 87%, pH 7.1)	
(pH 7)	5	4.8	1.041	7.4	1.039	5.5	1.041
	30	2.7	1.036	—	1.035	2.8	1.035
	40	1.9	1.033	2.3	1.031	2.3	1.032
	50	1.7	1.031	2.0	1.028	1.9	1.028
Whole egg		(w.c. = 75%, —)		(w.c. = 76%, pH 7.4)		(w.c. = 76%, pH 7.6)	
	6	19	1.044	12	1.045	14	1.045
	30	6.4	1.042	6.3	1.032	6.0	1.031
	40	5.5	1.027	5.2	1.024	4.4	1.023
	50	4.1	1.027	4.0	1.023	3.5	1.022
	60	3.1	1.020	2.7	1.020	3.2	1.017
Sugared yolk		(w.c. = 50%, pH 6.3)		(w.c. = 52%, pH 6.5)		(w.c. = 51%, pH 6.5)	
(10% sucrose by weight)	5	180	1.086	210	1.070	180	1.085
	30	56	1.068	64	1.072	64	1.067
	40	40	1.065	46	1.060	39	1.064
	50	31	1.056	35	1.057	29	1.061
	60	27	1.054	27	1.052	26	1.055
Plain yolk		(w.c. = 55%, pH 6.8)		(w.c. = 56%, pH 6.4)		(w.c. = 55%, pH 6.5)	
	5	310	1.042	230	1.048	240	1.044
	30	92	1.040	80	1.030	79	1.037
	40	70	1.032	58	1.023	57	1.026
	50	54	1.030	46	1.018	44	1.021
	60	48	1.027	37	1.012	0	1.015
Salted yolk		(w.c. = 50%, pH 6.0)		(w.c. = 50%, pH 6.2)		(w.c. = 51%, pH 6.0)	
(10% salt by weight)	5	1600	1.120	2300	1.103	1800	1.099
	30	400	1.100	500	1.093	300	1.096
	40	250	1.089	340	1.092	220	1.089
	50	180	1.081	240	1.078	150	1.082
	60	140	1.077	180	1.072	120	1.080

[1]w.c. = water content by weight.
[2]The variation of temperature between 5°C and 60°C was less than 4% for all products and sources of supply.

The two shell membranes are the most important single physical barriers to penetration of microorganisms into the egg. Haines and Moran (1940) indicated that the shell membranes act as bacterial filters. Several investigators have observed that the inner shell membrane is more effective in preventing bacterial penetration than the outer shell membrane (Garibaldi and Stokes, 1958; Florian and Trussell, 1957; Liftshitz et al., 1964, 1965). It is possible that albumen proteins, such as lysozyme, may contribute to the shell membranes resistance of microbes (Brooks and Taylor, 1955). Some have reported that enzymatic breakdown of membranes may enhance bacterial penetration, but Wedral et al. (1971) indicated that enzymes did not change permeability of *Salmonella*.

The albumen has both mechanical and chemical defenses against microbial growth (Board and Tranter, 1995). Viscosity of the thick albumen, which results from the ovomucin fibers, impedes movement of bacteria from the albumen to the yolk. Also, the thick albuminous sac centers the yolk, providing a greater distance for bacteria to move after they migrate through the shell membrane.

With reference to chemical defenses, the albumen has several proteins which have antimicrobial properties (Table 4). Lysozyme lyses the bacterial cell wall of gram-positive bacteria. Wang and Shelef (1991) observed that lysozyme was an effective inhibitor of *Listeria monocytogenes*. They further indicated that this antilisterial activity of lysozyme was enhanced by ovomucoid, conalbumin and alkaline pH. Gast and Holt (2000) inoculated egg white with *Salmonella enteritidis* and noted little growth at any temperature (10°C, 17.5°C or 25°C) for 3 days. Although lysozyme is largely ineffective against gram negative bacteria, such as *Salmonella*, a combination of other proteins, such as ovotransferrin (conalbumin), which chelates metal cations, may delay growth. Also, an alkaline pH (9.3 to 9.5) will enhance the chelation potential of ovotransferrin (Board and Tranter, 1995).

Several other egg white proteins may inhibit bacterial growth by enzyme or vitamin inhibition (Table 4). The effect of these proteins depends on the nutrient requirements of the bacteria in question.

Although the shell, shell membranes and albumen offer barriers to microbial growth, the yolk is a good nutrient medium for growth of *Salmonella enteritidis* (Bradshaw et al., 1990; Humphrey, 1990). Gast and Holt (2000) observed that *Salmonella enteritidis* grew rapidly in egg yolk at temperatures of 17.5°C and 25°C but growth was much slower at 10°C. This gives further support for the new USDA requirement that shell eggs be stored and transported at an ambient temperature of no more than 7°C (USDA, 1998).

TABLE 4. ANTIMICROBIAL PROTEINS IN EGG ALBUMEN

Protein	Mode of Action	Significance
Lysozyme	Hydrolysis of β (1-4) glycosidic bonds in bacterial cell wall	Effective against gram positive organisms but not *Salmonella*
Ovotransferrin	Chelates metal cations (Fe, Cu, Mn, Zn) making them unavailable to microorganisms	Particularly effective against spoilage bacteria
Avidin	Binds biotin making it unavailable to bacteria	Depends on bacterial requirement for this vitamin
Ovomucoid	Inhibits trypsin	Role unknown
Ovoinhibitor	Inhibits trypsin, chymotrypsin, subtilisin, elastin	Role unknown
Ovomacroglobulin	Inhibits trypsin, papain	Role unknown
Cystatin	Inhibits papain, bromelain, ficin	Role unknown
Flavoprotein	Binds riboflavin making it unavailable to bacteria	Depends on bacterial requirement

MAINTAINING QUALITY OF SHELL EGGS FOR LIQUID EGG PROCESSING

In order to minimize bacterial contamination and maintain high egg quality, it is important to have a quality assurance program starting at the production unit. Today, many commercial egg production units have inline collection systems which move the eggs to a central area where eggs are placed on filler flats and palletized for cooling at the farm. Three or four times a week, eggs are delivered to the breaking plant. The eggs are washed and flash candled at the breaking plant. In other cases, more processing steps may be accomplished at the production unit, including gathering, washing, candling, sizing, packaging and cooling. Some production units are dedicated totally to egg products.

Several factors affect the quality of the newly laid egg. After laying, the eggs should be moved from the production unit several times during the day to the cooler. It is well known that rapid cooling of the egg controls growth of *Salmonella enteritidis* and reduces egg quality deterioration. As indicated earlier, keeping shell eggs at an ambient temperature of 7°C in market channels is required for shell eggs destined for the ultimate consumer (FDA, CFR, 21, 2002; USDA, 1998). Recently, new rapid methods of cooling eggs are receiving emphasis. Curtis et al. (1995) have developed a patented procedure for cooling shell eggs with cryogenic gases (N_2 gas, CO_2 gas). Their cooling method improved shell quality and reduced aerobic plate counts. Refrigeration retards egg white thinning and yolk membrane strength deterioration. A strong yolk membrane is important in the egg breaking operation, especially when separating egg white on today's new high-speed breaking machines. If excessive yolk breakage occurs, yolk contamination of the whites becomes a problem.

A good indicator of egg quality is pH. As the egg ages, it loses CO_2 through the shell and the pH of egg albumen increases from 7.6 to 9.3. Ovomucin provides the egg white structure. Thinning appears to be related to changes in the ovomucin-lysozyme complex (Li-Chan et al., 1995). When the pH reaches greater than 8.8, egg white thinning and decreased yolk membrane strength become greatly accelerated. Higher storage temperatures contribute to the rate of pH increase (Table 5). Eggs stored at 7.2 °C to 12.7°C will reach a pH of 9.0 in about 7 days. If eggs are oiled to seal the pores, the rate of pH elevation will be greatly decreased and albumen thinning will also be delayed (Froning and Swanson, 1962; Schwall et al., 1961).

TABLE 5. CHANGES IN pH DURING STORAGE

Hr	Schwall et al., 1961[1]	Froning and Swanson, 1961[2]	Heath, 1977[3]
0	7.90	7.80	8.00
4		8.04	
8		8.04	
24	8.5	8.5	8.65
48		8.75	
72	8.80		9.10
96			
168	9.00	9.30	

[1]7.2°C - 12.7°C
[2]12.7°C
[3]22°C

Prior to breaking, all eggs are washed in the United States. Egg wash water must be at least 11°C higher than the egg temperature, and the water temperature should be at least 35°C for adequate cleaning (Wesley and Beane, 1967). Today's egg washers are much more efficient than the immersion washers formerly used (Stadelman, 1995). Eggs are sprayed with water rather than immersing them. Egg washers have separate sections for detergent and sanitizer (most processors use chlorine compounds as a sanitizer). Washers rotate eggs during washing and use low pressure sprays and oscillating brushes. The rinse water is warmer than the wash water. After washing, eggs are flash candled prior to breaking to remove any eggs with defects (e.g. dirts, blood spots or other loss-type eggs, such as cracks, rots, etc.).

EFFECT OF PASTEURIZATION ON FUNCTIONAL PROPERTIES

Eggs are multi-functional and are used widely as an ingredient in many food applications (Yang and Baldwin, 1995). Functional attributes provided by eggs include the properties of coagulation and binding, flavor, color, foaming, emulsifying and prevention of crystallization in confectionary products.

Coagulation and binding are important in such foods as surimi, cooked meat products and custards. Major proteins contributing to coagulative attributes include conalbumin, globulins, ovalbumin and lysozyme.

The superior foaming properties of eggs are difficult to duplicate with other ingredients. Eggs produce foams with excellent volume and stability that coagulate with heat for such foods as angel food cakes, sponge cakes, meringues, souffles and omelets. Several egg proteins contribute to the foaming properties. Globulins increase the viscosity and lower surface tension. Ovalbumin and conalbumin provide heat-setting properties. Ovomucin forms an insoluble film which stabilizes the foam.

Eggs provide emulsification properties to mayonnaise, salad dressings and cream puffs. A combination of components, including lipoproteins, phospholipids and cholesterol, all contribute to the optimum emulsifying ability of eggs. Egg yolk proteins such as lipovitellin, livetin and lipovitellenin function as surface active agents to stabilize film around the oil globule to form an emulsion.

Cotterill et al. (1963) observed that egg white inhibited the growth of sugar crystals in candy. They further found that egg white prevented syneresis, excessive evaporation and fluidity due to the inversion of sucrose.

Pasteurization can adversely affect the functional properties of egg products depending on the time and temperature used. Egg white proteins are particularly susceptible to heat damage. It has been shown that pasteurization temperatures between 54°C to 60°C will damage the foaming properties of egg white (Cunningham, 1995). Heating above 57°C will damage egg white and increase whipping time, but heating yolk-contaminated egg white will improve foaming properties. Whipping agents, such as triethyl citrate and sodium lauryl sulfate, may help restore some foaming properties of heat-damaged egg white.

Studies have indicated that pasteurization of whole egg at 61°C for 3 minutes did not affect performance in custards but slightly impaired the quality of sponge cakes (Cunningham, 1995). Commercially pasteurizing whole egg at 60°C has been shown not to adversely affect baking properties. Pasteurization temperatures for whole egg in excess of 60°C may adversely affect sponge cake volume. Herald and Smith (1989) observed that pasteurization of whole egg between 60°C to 68°C decreased pie filling expansion.

Pasteurization of egg yolk products appears to have minimal effects on emulsifying properties (Cunningham, 1995). Pasteurization of salted yolk at 62°C to 64°C also did not adversely affect performance of mayonnaise and cream puffs. Other studies have indicated that sugared yolks pasteurized from 60°C to 64°C perform well in sponge cakes, chiffon cakes and yellow layer cakes.

Egg Pasteurization Methods

Pasteurization requirements for various liquid egg products are shown in Table 6. These USDA requirements provide minimum temperatures and holding times (FDA, CFR 9, 2002; USDA, 1980). Whole egg pasteurization requirements for other countries are 66°C to 68°C for Poland; 63.3°C for 2.5 minutes for China; 62°C for 2.5 minutes for Australia; and 65°C for 90 to 180 seconds in Denmark (Cunningham, 1995). Great Britain requires 64.4°C for 2.5 minutes (Statutory Instruments, 1963). There are other equivalent methods that have also been approved. Detailed present-day pasteurization methods for liquid egg products are provided in the following discussion.

TABLE 6. USDA PASTEURIZATION REQUIREMENTS (FDA CFR 9:590,570; USDA, 1980)

Liquid Egg Product	Minimum Temperature °C	Minimum Holding Time Requirement Minutes
Albumen (without use of chemicals)	56.7	3.5
	55.6	6.2
Whole egg	60.0	3.5
Whole egg blends (less than 2% added non-egg ingredients)	61.1	3.5
	60.0	6.2
Fortified whole egg and blends (24-38% solids, 2-12% added non-egg ingredients)	62.2	3.5
	61.1	6.2
Salted whole egg (with 2% or more salt added)	63.3	3.5
	62.2	6.2
Sugared whole egg (with 2% or more sugar added)	61.1	3.5
	60.0	6.2
Plain yolk	61.1	3.5
	60.0	6.2
Sugared yolk (2% or more sugar added)	63.3	3.5
	62.2	6.2
Salted yolk (2-12% salt added)	63.3	3.5
	62.2	6.2

EGG WHITE PASTEURIZATION

Heat Without Chemicals

The approved methods using heat alone are 56.7°C for 3.5 minutes or 55.6°C for 6.2 minutes. As mentioned earlier, egg white proteins are particularly heat sensitive, requiring these lower temperatures. The effectiveness of eliminating *Salmonella* at these temperatures has been shown to be improved at higher pH values (Cotterill, 1968). The research generally indicated a much better *Salmonella* kill using the approved methods when the albumen pH was greater than 8.9.

Recently, there have been other studies to re-evaluate present egg white pasteurization guidelines. Palumbo et al. (1996) determined survival of a six-strain mixture of *Salmonella enteritidis*, *Salmonella typhimurium* and *Salmonella senftenberg* (not 775 W) in egg white using a submerged vial technique. As reported by previous workers, these scientists also reported that *Salmonella* is much more heat resistant at low albumen pH. Log reductions using a 3.5-minute holding time at 56.6°C were 0.97 at pH 7.8, 1.64 at pH 8.2, 2.20 at pH 8.8 and 3.24 at pH. 9.3. Michalski et al. (1999) determined D values for a five-strain cocktail of *Salmonella enteritidis* in egg white at pH 9.0 using 100µl capillary tubes. They reported a 7.5 D reduction which was considerably higher than that reported by Palumbo et al. (1996). Schuman et al. (1997) observed that capillary tubes gave more accurate D values as compared to test tubes which may account for some of the differences in Palumbo's and Michalski's data.

Michalski et al. (1999) observed a reduction of greater than 9 D at 56.7°C for 3.5 minutes when using a plate pasteurizer, which was somewhat higher than the reduction found using the capillary tubes. Palumbo et al. (1996) also reported a better kill when using a plate pasteurizer, which they attributed to better mixing due to turbulent flow in the right-angle turns in the holding tube of the plate pasteurizer.

Lactic Acid-Aluminum Sulfate

Lineweaver and Cunningham (1966) patented a process which stabilized liquid egg whites prior to pasteurizing at 60°C to 61.7°C for 3.5 to 4.0 minutes. When egg white is adjusted to a neutral pH (6.8 to 7.3) using lactic acid, the ovalbumin, lysozyme, ovomucoid and ovomucin are more heat stable. Also, metallic ions (aluminum salts) are added to form a heat-stable complex with conalbumin (ovotransferrin). Stabilization of the egg white prior to pasteurization is accomplished by adding aluminum sulfate and lactic acid. A whipping aid may also be added to the stabilizing solution.

Heat Plus Hydrogen Peroxide

Hydrogen peroxide has been shown to eliminate *Salmonella* in egg white at room temperature (Ayres and Slosberg, 1949). After treatment, catalase is added to decompose hydrogen peroxide to water and oxygen. Armour developed a patent which utilized this technology (Lloyd and Harriman, 1957).

The Armour method involves heating to 51.7°C and holding for 1.5 minutes to inactivate the natural catalase in the egg white. Hydrogen peroxide (10% solution) is then metered into the holding tube at a level of 0.5 lb per 100 lb of egg white. The mixture is held at 51.7°C for 2 minutes, after which the pasteurized product is cooled to 7°C and catalase added to remove residual hydrogen peroxide.

Standard Brands (USDA, 1969) later modified the hydrogen peroxide method. After leaving the regenerator section and before entering the heating section, a 10% solution of hydrogen peroxide is injected at a level of 0.875 lb per 100 lb of egg white. The mixture is then heated to 51.7°C for 3.5 minutes. After cooling, catalase is added to remove residual hydrogen peroxide.

The hydrogen peroxide method is extensively utilized by the industry today. It allows for the pasteurization of egg white at a lower temperature to minimize damage to heat-sensitive proteins.

Heat Plus Vacuum

The Ballas Egg Products Corp. developed a method for pasteurizing egg whites at 56.7°C with a 3.5-minute holding time (USDA, 1969). A vacuum chamber with 17 to 20 inches of vacuum is placed in the line after the egg white has passed through the regenerator. Ballas Egg Products indicated that the vacuum chamber reduces "cooking" of egg white on plates.

Hot Room Treatment of Dried Egg White

Heat treatment of dried egg white was proposed and further investigated as a method for destroying *Salmonella* (Ayres and Slosberg, 1949; Banwart and Ayres, 1956). Moisture content should be 6% for the adequate destruction of *Salmonella*. The bulk-packaged egg white solids should be heated to at least 54.4°C and be held at that temperature for 7 to 10 days until *Salmonella* negative. This pasteurization method has also been shown to improve whipping properties of egg solids.

Bergquist (1961) patented a combined liquid egg white pasteurization and hot room treatment of egg white solids. This process produced egg white solids with a low bacterial count.

WHOLE EGG PASTEURIZATION

USDA pasteurization requirements for yolk, whole eggs, whole egg blends, fortified whole eggs and blends, salted yolk, salted whole egg, sugared yolk and sugared whole egg are shown in Table 6. Minimum temperatures and holding times are shown. Recently, Michalski et al. (1999), using a plate pasteurizer, reported a greater than 9 D reduction of *Salmonella enteritidis* in whole egg at 60.0°C for 3.5 minutes.

Ball et al. (1987) developed an ultrapasteurized and aseptically packaged process to extend shelf life. Whole egg was heated to temperatures ranging from 63.7°C to 72.2°C for 2.7 to 192.2 seconds. This process gave a shelf life of 4 to 24 weeks at 4°C and was later patented (Swartzel et al., 1989).

YOLK PASTEURIZATION

USDA minimum pasteurization requirements for plain yolk, salted yolk and sugared yolk are presented in Table 6. *Salmonella* is more resistant in yolk, but yolk is less sensitive to higher temperatures as it affects functional properties. Thus, higher pasteurization temperatures are practical for yolk products. Addition of salt or sugar further increases the heat resistance (Garibaldi et al., 1969; Cotterill and Glauert, 1971) of yolk products. Thermal resistance of *Salmonella* in salted yolk products has been of special concern.

Recently, Palumbo et al. (1995) determined effectiveness of present pasteurization procedures used for egg yolk and egg yolk products by heating in a closed vial. The D value for plain yolk at 61.1°C was 0.57. The D values for 10% sugared yolk at 63.3°C was 0.72 while 10% salted yolk had an observed D value of 11.50 at 63.3°C. They indicated that present pasteurization methods for yolk and 10% sugared yolk were adequate, but suggested that current minimum pasteurization processes for 10% to 20% salted yolk would allow survival of *Salmonella* if initial levels were high. However, Michalski et al. (1999) observed an 8 D reduction in 10% salted yolk at 63.3°C and a 1 D reduction in egg yolk containing both 5% salt and 5% sugar using capillary tubes. Here again, these different results may be partially explained by the use of capillary tubes which largely eliminate the come-up time and the effect of viscosity (Schuman et al., 1997).

OTHER METHODS OF PASTEURIZATION

Irradiation

Radiation pasteurization has been studied extensively. Many of the earlier research efforts in the 1950s and 1960s have been reviewed in the 1968 Egg Pasteurization Manual (USDA, 1968). Gamma irradiation was emphasized at that time. Gamma radiation has excellent penetration, particularly in frozen egg products. Yolk-containing egg products were noted to have off-flavors which were largely volatized during spray drying. Egg white was less prone to off-flavor development during gamma irradiation. Kijowski et al. (1994) recently observed that gamma irradiation of frozen whole egg at 2.5 KGy did not adversely affect functional or sensory properties. They obtained a D value of 0.39 KGy.

Other research on use of electron beam irradiation has stimulated new interest in this technology (Wong et al., 1996; Huang et al., 1997; Serrano et al., 1997). Electron beam irradiation generates no radioactivity when the accelerator is switched off. Also, there is no radioactive waste which is a problem when using Co-60 as a gamma source. However, electron beam radiation has a low penetration and is limited to use in foods of limited thickness (3 cm at a beam power of 8.1 KW).

Serrano et al. (1997) inoculated shell eggs and whole liquid egg with five strains of *Salmonella enteritidis* and irradiated using an electron beam accelerator. They found that a 0.5 KGy dose was sufficient to eliminate all isolates on the shell surface. On the basis of D values obtained, an irradiation dose of 1.5 KGy was sufficient to reduce *Salmonella* counts by 4 logs in both shell eggs and liquid eggs.

Wong et al. (1996) found that electron beam irradiation of liquid egg white at 2.5 to 3.3 KGy destroyed an inoculum of 10^7 cells per milliliter of the nalidixic acid-resistant strain of *Salmonella typhimurium*. Irradiated egg white samples had 47% lower foam drainage and more stable viscosity than thermally pasteurized egg white. Also, volume of angel food cakes from irradiated samples was significantly higher than that from thermally pasteurized liquid egg white.

Huang et al. (1997) utilized electron beam irradiation at 2.5 KGy to pasteurized liquid egg yolk. Irradiation did not cause any significant effect on physical, chemical and functional properties of egg yolk. Percent soluble protein was not significantly affected, indicating minimal protein denaturation.

The FDA (2000) approved the use of ionizing irradiation for the reduction of *Salmonella* in fresh shell eggs. It was claimed that the absorbed dose of 3 KGy would result in some changes in viscosity and color. However, they indicated no affect on chemical composition. It was emphasized that this dosage would reduce, but not eliminate, *Salmonella*.

Irradiation may have potential for pasteurization of liquid eggs. Electron beam irradiation probably may be worth pursuing for eliminating *Salmonella* in egg white which is quite heat sensitive. However, acceptance of irradiation by consumers is presently a concern.

Alternative Methods

The Institute of Food Technologists (2000) has published a special supplement reviewing several alternative methods for pasteurizing food products. These include microwave and radio-frequency processing, ohmic heating, high-pressure processing, pulsed electric field, high-voltage arc discharge, pulsed-light technology, oscillating magnetic fields, ultrasound and pulsed x-rays. Some of these may have future commercial application, but presently they are largely experimental.

Re-evaluation of Liquid Egg Pasteurization Guidelines

EGG WHITE, SALTED OR SUGARED YOLK, SALTED OR SUGARED WHOLE EGG AND BLENDED EGG PRODUCTS

Objective

The objective of this project was to determine the heat resistance of *Salmonella spp.* in a variety of liquid egg products. The data were used to evaluate the effectiveness of pasteurization time/temperature requirements in destroying *Salmonella spp.* Five organisms were used in a cocktail to determine the survival curves of *Salmonella spp.* in the various liquid egg products at 4 predetermined temperatures for each product (Table 7). This study utilized a wider temperature range than reported previously in the literature. These treatments should provide the information for newly recommended temperatures and holding times for pasteurization of liquid egg products.

Methods

Fresh shell eggs were obtained from the University of Nebraska poultry farm. Prior to separation of the white from the yolk, the shells were disinfected with 200 ppm hypochlorite solution. Preparation varied as to product type. Separation of yolk from white was done aseptically. Products were blended for 2 minutes using a small sterile stainless steel container on a Waring blender attached to a variable speed rheostat set at 20 rpm and 120 v to prevent foaming. The various liquid egg products were inoculated, mixed thoroughly and filtered through sterile gauze to assure an even distribution of inoculum with no lumps from the liquid egg product or the inoculum. With each new batch of eggs and prior to each experiment, total plate counts were done on the liquid egg product before inoculation, to give some indication of competitive organisms.

The pH and A_w were determined in triplicate on each heating menstrum, prior to the heat treatment. The pH was measured with a Ross pH electrode on an Orion SA 720 pH meter. The A_w was measured with a Decagon CX-1 water activity meter at 22 ± 0.5°C. Percent solids, A_w and pH of all egg products are presented in Table 8.

Egg White Products. To obtain egg whites with pH values of 7.8 and 8.2, fresh eggs were used. For pH values of 8.8 and 9.3, the shell eggs were held at 5°C for one and 2 weeks respectively. Adjustments for the pH treatments were accomplished with the addition of 1N hydrochloric acid (HCL) or 1N sodium hydroxide (NaOH) after the white was collected. Some adjustment of the pH was needed immediately after inoculation and filtration. Enumeration was done on inoculated filtered liquid egg just prior to thermal treatments to determine the initial populations, as explained later in the methods section.

TABLE 7. INDIVIDUAL EGG PRODUCTS AND TEMPERATURES USED TO DETERMINE D VALUES FOR EACH PRODUCT WITH A COCKTAIL MIXTURE OF (5) *SALMONELLA* STRAINS

Egg Product	Temperatures °F (°C)
Egg white, pH 7.8	130(54.4), 132(55.5), 134(56.7), 135(57.7)
Egg white, pH 8.2	130(54.4), 132(55.5), 134(56.7), 135(57.7)
Egg white, pH 8.8	130(54.4), 132(55.5), 134(56.7), 135(57.7)
Egg white, pH 9.3	130(54.4), 132(55.5), 134(56.7), 135(57.7)
Salted egg yolk, 10%, Initial time (0 h)	146(63.3), 150(65.6), 154(67.8), 158(70.0)
Salted egg yolk, 10%, Hold time (96 h)	146(63.3), 150(65.6), 154(67.8), 158(70.0)
Salted whole egg, 10%, Initial time (0h)	142(61.1), 146(63.3), 150(65.6), 154(67.8)
Salted whole egg, 10%, Hold time (96 h)	142(61.1), 146(63.3), 150(65.6), 154(67.8)
Sugared egg yolk, 10%, Initial time (0 h)	142(61.1), 146(63.3), 150(65.6), 154(67.8)
Sugared egg yolk, 10%, Hold time (96 h) 2 runs	142(61.1), 146(63.3), 150(65.6), 154(67.8)
Sugared egg yolk, 10% Hold time (96 h) 2 runs	138(58.9), 142(61.1), 146(63.3), 150(65.6)
Sugared whole egg, 10%, Initial time (0 h)	140(60.0), 144(62.2), 148(64.4), 152(66.7)
Sugared whole egg, 10%, Hold time (96 h)	136(57.8), 140(60.0), 144(62.2), 148(64.4)
USDA scrambled egg mix (#1)	140(60.0), 144(62.2), 148(64.4), 152(66.7)
Scrambled egg high solids (#2)	136(57.8), 140(60.0), 144(62.2), 148(64.4)
Fortified whole egg "Tex" (#4)	140(60.0), 144(62.2), 148(64.4), 152(66.7)
Fortified egg yolk "Tex" (#6)	142(61.1), 146(63.3), 150(65.6), 154(67.8)
Imitation egg product	130(54.4), 134(56.7), 138(58.9), 142(61.1)

TABLE 8. WATER ACTIVITY (A_W), pH AND SOLIDS OF ALL EGG PRODUCTS

Egg Product	A_w	Solids %	pH
Egg white, pH 7.8	0.997	11.59	7.8
Egg white, pH 8.2	1.000	12.34	8.2
Egg white, pH 8.8	0.993	12.31	8.8
Egg white, pH 9.3	0.997	12.62	9.3
Salted egg yolk	0.866	50.42	5.89
Salted whole egg	0.912	32.36	7.08
Sugared egg yolk	0.982	49.10	6.24
Sugared whole egg	0.985	32.17	7.35
USDA scrambled egg mix (#1)	0.992	29.68	6.93
Scrambled egg mix (#2)	0.996	22.54	6.84
Fortified whole egg "Tex" (#4)	0.987	22.73	7.06
Fortified egg yolk "Tex" (#6)	0.976	48.94	6.59
Imitation egg product	0.997	11.56	8.88

TABLE 9. BLENDED EGG PRODUCTS (SCRAMBLED MIXES, "TEX" PRODUCT FORMULATIONS AND IMITATION EGG PRODUCT)

Ingredient	Percentage	Solids
Scrambled Egg Mix – USDA (#1)		
Whole egg – 24.2% solids	66.30	16.05
Nonfat dry milk – 95% solids	9.60	9.12
Vegetable oil	4.80	4.80
Salt	0.30	0.30
Water	19.00	
Total	100.00	30.27
Scrambled Egg Mix – High Solids – pH 6.5 to 6.8 (#2)		
Whole egg – 24.2% solids	81.20	19.65
Nonfat dry milk – 95% solids	2.60	2.47
Xanthan gum	0.18	0.18
Citric acid	0.13	0.13
Water	15.89	
Total	100.00	22.43
Fortified Whole Egg – "Tex" Product (#4)		
Whole egg – 24.2% solids	71.68	17.35
Egg yolk – 43% solids	20.00	8.60
36 DE corn syrup solids	6.46	6.14
Salt	0.40	0.40
Water	1.46	
Total	100.00	32.49
Fortified Egg Yolk – "Tex" Product (#6)		
Egg yolk – 43% solids	82.00	35.26
Corn syrup – 80% solids	16.00	12.80
Salt	0.80	0.78
Water	1.20	
Total	100.00	48.84
Imitation Egg Product		
Egg whites	95.50	11.46
Nonfat dry milk	3.59	3.41
Soybean oil	0.50	0.50
Modified food starch	0.20	0.20
Xanthan gum	0.20	0.20
Color (beta carotene)	0.01	0.01
Total	100.00	15.78

Yolk and Whole Egg Products. For yolk products, egg white was added back to the separated yolk to acquire a solids content of 43.3% (normal for industry breaking machines). Very fine commercial salt or sugar was added to the yolk or whole egg products on a 10% weight basis (i.e., 10 g salt or sugar/90 g liquid egg product). The salted and sugared yolk and whole egg products were tested at 0 and 4 days. The product being held for 4 days was held at 6°C. Thermal stability of *Salmonella spp.* in salted egg yolk or whole egg, after 4 days storage, needed further verification (Flowers et al., 1992).

Blended Egg Products. Egg yolk and whole egg used in blended egg products were tested at 1 day. Egg white at pH 8.8 was utilized in the imitation egg product. Otherwise, all other variables were the same as reported earlier. Formulations for various blended egg products are shown in Table 9.

Organisms and Culture Conditions. Five cultures were used in an inoculum cocktail: *Salmonella enteritidis* (phage types 4 and 13, *Salmonella typhimurium* TM-1, *S Salmonella blockley,* and *Salmonella heidelberg.* Criteria for selecting appropriate cultures included their frequency of occurrence in the field and their heat resistance. For example, *Salmonella blockley* was utilized since it is known to be more heat resistant. These cultures were kept frozen at -70°C in Brain Heart Infusion broth (BHI) with 10% glycerol. The day before each run, individual cultures of each strain were grown separately to the stationary phase in BHI (35°C for 20 hours). For all pH levels, egg white product for each culture was centrifuged, washed twice with 10 ml of triple-strength peptone water that had been adjusted to a pH close to the final pH desired for the particular egg white product and resuspended in 5 ml of that egg white product. This resulted in 25 ml of inoculated egg white product. This cocktail was kept on ice and the final pH adjusted immediately. For whole egg and egg yolk products, each culture was grown individually, as was done with the whites. The only change was that the pellets of each spun culture were washed with 10 ml of regular or 1% peptone water and centrifuge tubes combined or eliminated until one was left. This kept the addition of excess liquid to the product at a minimum, and egg white or whole egg was used to rinse the pellet from the final centrifuge tube. The inoculated yolk or whole egg product was mixed thoroughly, filtered and placed on ice like the egg white products.

Thermal Death Time. TDT testing was done by a modification of procedures outlined by the National Canners Association (1968). Capillary tubes were used to minimize temperature come-up times, since they had a small diameter (0.80-1.1 mm ID x 90 mm long). Previous published research has shown that the use of sealed capillary tubes provides more accurate data than can be obtained using larger tubes or flasks (Schuman et al., 1997). Cells of the inoculum cocktail were diluted in 25-50 ml of egg product to a concentration of $1x10^9$ colony-forming units per milliliter (CFU/ml). Suspensions were distributed in 0.05 ml aliquots to sterile capillary tubes using a sterile syringe. Capillary tubes were cut to eliminate the large head space and sealed with hot wax. Sealed tubes were placed in a strip of screen material (3.5 x 0.5 in) that was tied onto individual glass rods with heavy thread, in preparation for immersion in a heated circulating water bath (4 tubes per strip/4 time intervals/4 set temperatures). The heating treatments were done immediately to avoid pH changes related to metabolic activity of the inocula. Temperature data were collected with Omega hypodermic thermocouples inserted directly in the capillary tubes containing liquid egg product and verified by a calibrating thermometer. Data from the thermocouples were recorded continuously on a Campbell Scientific CSI datalogger. All tubes for a single temperature were immersed at the same time (16 tubes). At the end of each time interval, a rod containing 4 replicates was removed and the tubes immediately immersed in an ice water bath for 5 minutes, followed by a transfer to hypochlorite (200 ppm), at room temperature for 2 minutes. The capillary tubes were removed from the hypochlorite, rinsed in sterile water and aseptically placed into test tubes containing 5 ml of buffered peptone (BP) with 0.5% yeast extract and 0.5% sodium cholate added for enrichment of heat-injured *Salmonella* (Hong et al., 1995).

These were refrigerated until all heat treatments were finished. The capillary tubes were aseptically crushed in the BP enrichment tubes and serial dilutions were spread plated on Tryptic Soy Agar (TSA) and incubated at 35°C along with the enrichment tubes. After 48 hours of incubation, the TSA plates were enumerated and all countable plates were replicated on Xylose Lysine Tergitol agar (XLT4) using the method of Cassiday et al. (1990).

The colonies were transferred from a TSA plate to a sterile piece of velveteen that had been fastened to a stand that fits perfectly inside a petri dish, then the XLT4 plate was pressed onto the same piece of velveteen to pick up the colonies from the velveteen. The XLT4 plates were incubated for another 48 hours at 35°C to verify that the colonies counted on the non-selective TSA agar were *Salmonella*. The lowest dilution to be plated (i.e., the 10^{-2} consisting of 0.05 ml of liquid egg initially resuspended in 5.0 ml of sterile BP) was spread plated as follows: 1.0 ml of diluted egg evenly distributed on the surface of three TSA plates (i.e., 0.33 ml of diluted egg per plate). After incubation, the number of colonies on all three plates were totaled, verified and reported as CFU/ml at the 10^{-2} dilution. Forty-eight hour BP enrichment tubes were streaked onto XLT4 agar to check for injured cells that were not recovered by plating.

Initial populations in the capillary tubes were verified by recovery and enumeration from sealed, unheated, control tubes of products identical to the heated menstrum with *Salmonella*.

Design of the Experiments. For each product, the experiment was conducted as a split-split plot design with treatment as the whole plot factor in a randomized complete block, temperature as the split-plot factor and time as the split-split plot factor which was nested in temperature. Triplicate samples were averaged for each run x treatment x temperature x time combination. The means of the $\log_{10}$ population levels were used as the response variable.

Statistical Models and Determination of TDT. Survival curves of microorganisms are commonly assumed to follow exponential decay under high temperature conditions. When this assumption holds, the $\log_{10}$ of the population levels, denoted logY(t) at time t, is a linear function of time, i.e., logY = a - bt. Log population levels of all of the egg products, except salted yolk and salted whole eggs, were adequately approximated by a linear function of time. For these products we used a linear mixed model analysis to assess the effects of time, temperature and treatment on logY, to develop a final model and to obtain predictions for the various combinations of the factors. For all products except the salted products, lethality time was used with Stumbo's (1973) formula to calculate the decimal reduction (D) value at each time interval, with surviving organisms, where t = lethality in minutes:

$$D = t/ (\log A - \log B)$$

A = initial microorganism concentration, B = number of surviving microorganisms (assuming one viable organism per tube). The D values were then averaged for the 3 trials at each temperature. A phantom TDT curve (semi-logarithmic plot of D value vs temperature) was drawn by linear regression and the slope of the curve was used to calculate a Z value using the following formula:

$$Z = T_2 - T_1 / (\log D_{T1} - \log D_{T2}).$$

T_2 = highest pasteurization temperature, T_1 = lowest pasteurization temperature.

D_{T1} = D value of lowest pasteurization temperature, D_{T2} = value of highest temperature.

Salted yolk and salted whole eggs had a curvilinear (concave-up) response to time. Consequently, using a model based on logY as a linear function of time would likely under-predict *Salmonella* populations at time values beyond the range of the data. The reason for the non-linearity was not clear but was possibly due to heterogeneity of death rates across cells. To account for this heterogeneity, we used a model based on the assumption that the death of each cell in the population followed a first-order kinetics process where the probability of a cell surviving to time t was $p(t) = e^{-kt}$ where k is the exponential rate of death. Assuming the probability distribution of k over the population of cells has a gamma distribution with parameters a and b where the density is $f(k) = k^{a-1} e^{-k/b}/b^{a}T$ (a), then it can be shown that the model is logY = 9.3 - a In (1 + bt) where 9.3 is the $\log_{10}$ initial population level and In(.) is the natural logarithm (Sharpe and Bektash, 1977). To relate this model to temperature and treatment, we made a and b polynominal functions of temperature and treatment and the resulting model was fit with a non-linear mixed model procedure to account for the split-split plot experimental design. Using this model, we tested the effects of temperature, treatment and time and obtained predictions for the various combinations of these factors. To obtain approximate D values for the salted products, the non-linear mixed model was used to obtain the upper 95% confidence limit of the log population level at time = 0 and the upper confidence limit at the time of a 7 log reduction. The slope of the line between these two points was determined and the D value was obtained as D = -1/slope. SAS was used for all statistical computations (SAS Institute Inc., 1999). Using this D to obtain holding times for 5 and 7 log reductions will give higher holding times than those based on the Figures because the Figures are based on the mean.

Graphs for Time – Temperature Conditions That Gave 5 $\log_{10}$ and 7 $\log_{10}$ Reductions. An important question for egg processors is at what temperature and how long should the product be held to ensure a certain population reduction. For each product and treatment, we used the final statistical model to obtain contour plots that gave the time and temperature combinations that gave approximately a 5 $\log_{10}$ *Salmonella* reduction. Contour graphs for time and temperature combinations were also obtained for 7 $\log_{10}$ reductions. These graphs were obtained for a given product and treatment by setting the dependent variable to either 4 (approximately 5 $\log_{10}$ reduction) or 2 (approximately 7 $\log_{10}$ reduction) and solving for the combination of values of time and temperature that gave these reductions. A separate graph was drawn for each product, treatment and reduction (5 or 7 $\log_{10}$ reduction).

For all products, except salted yolk and whole egg, the contour graph were of the form:

$$time = (red + a_1)/b_1$$

where red is the $\log_{10}$ reduction from the initial population level (5 or 7 $\log_{10}$), a_1 contains all the terms in the model that did not include time and b_1 contains all the model terms that did include time until time factored out. For the salted products, the graphs were of the form:

$$time = (10^{red/a} - 1)/b$$

where a and b are polynomial functions of temperature and treatment in the gamma model as described above and red is defined as before.

Results

Appendix Figures 1 to 16 (pages 31-46) present calculated regression lines with 95% confidence limits for each egg product. Analyses of variance indicated that all products have a highly significant linear response. However, there was a concern with linearity of salted yolk products which also had a significant quadratic response. Salted yolk data was transformed to correct linearity as indicated earlier.

Times and temperatures to provide equivalent pasteurization effectiveness at 5 and 7 log reductions are presented in Appendix Figures 17 to 26 (pages 47-56). These graphic presentations should allow processors to estimate times and temperatures for a selected process. In most cases, these graphic results closely agree with holding times. However, graphs seem to under-predict holding times for salted products.

TABLE 10. D VALUE AVERAGES OF 3 RUNS OF EGG WHITE AT DIFFERENT pH LEVELS

	Temperature °C	D value (minutes)	5D	7D	Z value
pH 7.8					
	54.4	12.51	62.55	87.54	3.30
	55.5	5.82	29.10	40.76	
	56.7	2.47	12.35	17.28	
	57.7	1.25	6.25	8.78	
pH 8.2					
	54.4	9.62	48.10	67.36	3.58
	55.5	4.89	24.45	34.24	
	56.7	2.25	11.25	15.75	
	57.7	1.15	5.75	8.06	
pH 8.8					
	54.4	6.99	34.95	48.92	4.11
	55.5	4.01	20.05	28.07	
	56.7	1.99	9.95	13.91	
	57.7	1.10	5.55	7.68	
pH 9.3					
	54.4	3.05	15.25	21.37	4.19
	55.5	1.74	8.70	12.21	
	56.7	0.85	4.25	5.99	
	57.7	0.50	2.50	3.49	

Egg White. Heat resistance of *Salmonella* was significantly reduced as the pH of egg white was increased. A pH of 9.3 was necessary to obtain substantially lower D values (lower heat resistance). The break point with respect to pH appears to be very narrow and likely lies somewhere between 9.0 to 9.1 (Table 10). However, Table 19 shows that even at a pH of 9.3 the recommended temperature of 56.7°C (134°F) does not obtain a 5 log reduction for the 3.5-minute hold. Cotterill (1968) also reported that pasteurization of egg white at high pH levels permits the use of lower pasteurization temperatures and reduces the chance of survival if the product is recontaminated. If using heat only, a longer holding time of 4.25 minutes will provide a 5 log reduction while 6 minutes at pH 9.3 will give a 7 log reduction which may be considered (Table 10). Higher temperatures such as 57.7°C may adversely affect functional property of leavening. However, process efficiencies and adequate kill could be obtained for egg white with pH 7.8 to 8.8 by heating at 57.7°C and using a holding time of 6.25 minutes (Table 10). By increasing temperature 1°C and increasing hold time, processes could be obtained avoiding the requirement to make pH adjustments and simplifying processing operations. Some, if not all, potential loss in whipping properties may be recovered by use of appropriate whipping aids. Higher temperatures such as 57.7°C would likely adversely affect functional properties. Many processors use the hydrogen peroxide pasteurization method for liquid egg white rather than heat only pasteurization.

The linearity of the results of the TSA study was found to be good and consistent with that reported by Palumbo et al. (1996). Appendix Figures 1 to 4 (pages 31-34) show the calculated regression lines with 95% confidence limits for data on egg white pasteurized at different temperatures and pHs.

TABLE 11. D VALUE AVERAGES OF 3 RUNS OF 10% SALTED YOLK (COMBINED 0- AND 96-HOUR STORAGE) PLATED ON TRYPTIC SOY AGAR OBTAINED FROM THE GAMMA MODEL

Temperature °C	D value (minutes)	5D	7D	Z value
63.3	0.90	4.50	6.30	5.73
65.6	0.41	2.05	2.87	
67.8	0.15	0.73	1.05	
70.0	0.06	0.29	0.42	

Salted Yolk. Table 11 shows the D values for 10% salted yolk as determined from gamma distribution from survival curves and those predicted from secondary regression models (Appendix Figure 5, page 35). Since there were no significant differences in D values when comparing 0- vs 96-hour storage, the two storage times were combined. Several previous workers have reported that the thermal resistance of *Salmonella* is increased by long exposure to salt or sugar exposure before heating (Baird-Parker et al., 1970; Garibaldi et al., 1969; Goepfert et al., 1970; Ng et al., 1979; and Sumner et al., 1991).

Cotterill and Glauert (1971) also found that the heat resistance of *Salmonella* is increased by long exposure in egg yolk containing 10% salt or sugar, with the maximum heat resistance after 4 days storage at 6°C. Palumbo et al. (1995) reported very high D values for salted yolk which again are contrary to our research findings.

The differing results may be partially explained by the use of capillary tubes in our studies. Previous studies have shown that use of capillary tubes provides more accurate results (Schuman et al., 1997; Michalski et al., 1999). Most of the past work has utilized large tubes, which extend the temperature come-up time. Capillary tubes allow for instant come-up times, thereby possibly eliminating or minimizing the effect of viscosity. Since salted yolk has a high viscosity after storage, this may play a role in the increased heat resistance reported by previous investigators using stored salted yolk. Other likely factors influencing differences in larger tubes and capillary tubes are probably related to headspace and flux over the top of the liquid being heated. Table 20 (page 18) shows the log reduction for salted yolk at 63.3°C (146°F) for 3.5 minutes to be 3.89. As shown in Table 11, a holding time of 4.50 minutes is needed to achieve a 5 log reduction and a 6.30-minute holding time to attain a 7 log reduction. The 5 and 7 log time/temperature graphs (Tables 19 and 20, page 18) gave somewhat differing results than that shown in Table 11 (page 16). The reason for this is the Ds for the salted products are based on the 95% confidence limit rather the mean values in Figures 19 and 20.

Sugared Yolk. Tables 12, 13 and 14 show the D values for 10% sugared yolk at 0 and 96 hours. Appendix Figures 8 and 9 (pages 38-39) present the calculated regression lines with 95% confidence limits. Differences in D values between 0- and 96-hours storage were observed to be significant (P<.05). Table 20 (page 18) shows the log reduction at the recommended temperature of 63.3°C (146°F) for sugared yolk at the 0 hours to be 13.46 and 18.42 for the 96-hours storage for the 3.5-minute hold. These results would indicate that holding the sugared yolk 96 hours made *Salmonella* less heat resistant.

TABLE 12. D VALUE AVERAGES OF 4 RUNS OF 10% SUGARED YOLK AT 0 HOUR PLATED ON TRYPTIC SOY AGAR

Temperature °C	D value (minutes)	5D	7D	Z value
61.1	0.84	4.19	5.87	5.33
63.3	0.26	1.27	1.78	
65.6	0.11	0.54	0.75	
67.8	0.05	0.23	0.33	

TABLE 13. D VALUE AVERAGES OF 2 RUNS OF 10% SUGARED YOLK AT 96 HOURS PLATED ON TRYPTIC SOY AGAR

Temperature °C	D value (minutes)	5D	7D	Z value
61.1	0.60	2.98	4.17	5.80
63.3	0.19	0.96	1.33	
65.6	0.09	0.43	0.60	
67.8	0.04	0.21	0.30	

TABLE 14. D VALUE AVERAGES OF 2 RUNS OF 10% SUGARED YOLK AT 96 HOURS PLATED ON TRYPTIC SOY AGAR

Temperature °C	D value (minutes)	5D	7D	Z value
58.9	1.33	6.65	9.32	4.77
61.1	0.51	2.53	3.53	
63.3	0.18	0.88	1.24	
65.6	0.06	0.26	0.37	

Salted and Sugared Whole Egg. Salted whole egg (combined 0 and 96 hours) data are reported in Tables 15 and 16 while sugared whole egg data are shown in Tables 17 and 18 (page 18). Both salted whole egg and sugared whole egg exhibited a significant (P<0.05) storage effect. Salted whole egg at 0-hours storage time required a 5.65-minute holding time to achieve a 5 log reduction. On the other hand, holding salted whole egg 96 hours prior to pasteurization reduced the holding time to 3.05 minutes for a 5 log reduction. Table 21 (page 18) presents log reductions for salted whole egg (0- and 96-hours storage) when using a 3.5-minute holding time. Perhaps there is increased injury of *Salmonella* when holding the salted whole egg or pH changes during storage may be a factor. Again, the 5 and 7 log reduction prediction graphs (Appendix Figures 19 and 20, pages 49-50) gave differing holding times than those observed in Tables 15 and 16. Although the graphic results were fairly accurate for other egg products, their use for predicting holding times for salted whole eggs is not practical. Calculated regression log reductions are also shown in Appendix Figures 6, 7, 10, 11 (pages 36, 37, 40, 41).

TABLE 15. D VALUE AVERAGES OF 3 RUNS OF 10% SALTED WHOLE EGG (0-HOURS STORAGE) PLATED ON TRYPTIC SOY AGAR OBTAINED FROM THE GAMMA MODEL

Temperature °C	D value (minutes)	5D	7D	Z value
61.1	2.13	10.65	14.91	5.19
63.3	1.13	5.65	7.91	
65.6	0.29	1.45	2.03	
67.8	0.11	0.55	0.77	

TABLE 16. D VALUE AVERAGES OF 3 RUNS OF 10% SALTED WHOLE EGG (96-HOURS STORAGE) PLATED ON TRYPTIC SOY AGAR OBTAINED FROM THE GAMMA MODEL

Temperature °C	D value (minutes)	5D	7D	Z value
61.1	1.69	8.45	11.83	5.04
63.3	0.61	3.05	4.27	
65.6	0.22	1.10	1.54	
67.8	0.08	0.40	0.56	

TABLE 17. D VALUE AVERAGES OF 3 RUNS OF 10% SUGARED WHOLE EGG AT 0 HOURS PLATED ON TRYPTIC SOY AGAR

Temperature °C	D value (minutes)	5D	7D	Z value
60.0	0.85	4.27	5.97	4.88
62.2	0.25	1.23	1.73	
64.4	0.08	0.40	0.56	
66.7	0.04	0.18	0.26	

TABLE 18. D VALUE AVERAGES OF 3 RUNS OF 10% SUGARED WHOLE EGG AT 96 HOURS PLATED ON TRYPTIC SOY AGAR

Temperature °C	D value (minutes)	5D	7D	Z value
60.0	0.85	4.27	5.97	4.88
62.2	0.25	1.23	1.73	
64.4	0.08	0.40	0.56	
66.7	0.04	0.18	0.26	

Since the USDA required pasteurization temperature of 61.1°C (142°F) was not a temperature used in the pasteurization study on the sugared whole egg, the D values and log reductions in Table 21 for the 3.5-minute hold were determined from the D-value data attained from the temperature actually used (57.8°C to 66.7°C). The sugared whole egg had approximately an 8 log reduction for the 0 hours while the 96 hours had 11.5 log reduction. This indicates that holding the sugared whole egg made the *Salmonella* less heat resistant, which is similar to that observed with the sugared yolk.

TABLE 19. EFFECT OF pH ON THERMAL RESISTANCE OF *SALMONELLA SPP.* IN EGG WHITE AT 56.7°C, SHOWING D VALUES DETERMINED BY SUBMERGED CAPILLARY TUBE TECHNIQUE AND CALCULATED LOG-UNIT REDUCTION IN 3.5 MINUTES

pH	D value ± SD[a] (minutes)	3.5 minutes reduction (log CFU/g egg white)
7.8	2.47 ± 0.10	1.42
8.2	2.25 ± 0.21	1.56
8.8	1.99 ± 0.12	1.76
9.3	0.85 ± 0.03	4.12

[a]Average of three trials ± standard deviation

TABLE 20. EFFECT OF 10% SALT OR SUGAR ON THERMAL RESISTANCE OF *SALMONELLA SPP.* IN EGG YOLK AT 63.3°C, SHOWING D VALUES DETERMINED BY SUBMERGED CAPILLARY TUBE TECHNIQUE AND CALCULATED LOG-UNIT REDUCTION IN 3.5 MINUTES

Egg Product/Time	D value ± SD[a] (minutes)	3.5 minutes reduction (log CFU/g egg white)
Salted yolk (combined 0- and 96-hours)	0.90	3.89
Sugared yolk 0 hours	0.26 ± 0.04	13.46
Sugared yolk 96 hours	0.19 ± 0.02	18.42

[a]Average of three trials ± standard deviation (sugared yolk was an average of four trails).

TABLE 21. EFFECT OF 10% SALT OR SUGAR ON THERMAL RESISTANCE OF *SALMONELLA SPP.* IN WHOLE EGG AT 63.3°C FOR SALTED AND 61.1°C FOR SUGARED, SHOWING D VALUES DETERMINED BY SUBMERGED CAPILLARY TUBE TECHNIQUE AND CALCULATED LOG-UNIT REDUCTION IN 3.5 MINUTES

Egg Product/Time	D value ± SD[a] (minutes)	3.5 minutes reduction (log CFU/g egg white)
63.3°C		
Salted whole egg (0 hours)	1.13	3.10
Salted whole egg (96 hours)	0.61	5.73
61.1°C[b]		
Sugared Whole egg (0 hours)	0.45	7.78
Sugared Whole egg (96 hours)	0.30	11.51

[a]Average of three trials ± standard deviation.
[b]Extrapolated from D-value data collected at 57.8°C to 66.7°C.

Blended Egg Products. Results for blended egg products are shown in Tables 22 to 26.

D values for the USDA scrambled egg mix #1 are presented in Table 22. These results indicate that a pasteurization temperature of 62.2°C should be adequate. In fact, a 1.7-minute holding time at 62.2°C would provide a 7 log reduction.

High solids scrambled egg mix #2 D values indicate that either 60°C or 62.2°C would provide an adequate kill of *Salmonella* (Table 23). A 3.5-minute holding time at 60°C would provide a 7.31 log reduction, and 62.2°C at a holding time of 3.5 minutes gives a 24.72 log reduction.

D values for the fortified whole egg "Tex" egg product #4 are shown in Table 24. The 62.2°C again appears to be appropriate since a 3.5-minute holding time will give a 16 log reduction.

The fortified egg yolk "Tex" egg product #6 was a product with a higher solids content which affected D values (Table 25). A 63.3°C temperature with a 3.5-minute holding time gave a 5.04 log reduction, while 65.6°C with a 3.5-minute holding time provided an 18.81 log reduction.

When considering an imitation egg product, pasteurization temperatures are limited somewhat by the high amount of egg white (Table 26). D value at 56.7°C was 0.92, which would give only a 3.81 log reduction when utilizing a 3.5-minute holding time. If the pasteurization temperature is raised to 58.9°C, the log reduction with a 3.5-minute holding time is 14.98.

TABLE 22. AVERAGES OF USDA SCRAMBLED EGG MIX #1

Temperature °C	D value (minutes)	5D	7D	Z value
60.0	0.77	3.87	5.41	6.48
62.2	0.24	1.22	1.71	
64.4	0.11	0.58	0.74	
66.7	0.07	0.36	0.50	

TABLE 23. AVERAGES OF HIGH SOLIDS SCRAMBLED EGG MIX #2

Temperature °C	D value (minutes)	5D	7D	Z value
57.8	2.11	10.56	14.79	4.09
60.0	0.48	2.39	3.35	
62.2	0.14	0.71	0.99	
64.4	0.05	0.26	0.36	

TABLE 24. AVERAGES OF FORTIFIED WHOLE EGG "TEX" PRODUCT #4

Temperature °C	D value (minutes)	5D	7D	Z value
60.0	0.71	3.57	4.99	5.24
62.2	0.22	1.09	1.53	
64.4	0.08	0.39	0.54	
66.7	0.04	0.19	0.26	

TABLE 25. AVERAGES OF FORTIFIED EGG YOLK "TEX" PRODUCT #6

Temperature °C	D value (minutes)	5D	7D	Z value
61.1	2.22	11.12	15.56	4.48
63.3	0.69	3.47	4.86	
65.6	0.19	0.93	1.30	
67.8	0.07	0.35	0.49	

TABLE 26. AVERAGES OF IMITATION EGG PRODUCT

Temperature °C	D value (minutes)	5D	7D	Z value
54.4	2.09	10.46	14.64	4.99
56.7	0.92	4.59	6.43	
58.9	0.23	1.17	1.64	
61.1	0.09	0.47	0.66	

It should be noted that the egg white used in the imitation formulation was at pH 8.8. As indicated in the egg white studies, a higher pH at 9.3 provided a better kill of *Salmonella*. However, the other ingredients, including non-fat dry milk, soybean oil, modified food starch and xanthan gum, likely may allow a higher pasteurization temperature without harming functional properties.

PASTEURIZATION USING HEAT PLUS HYDROGEN PEROXIDE

Objective

To determine thermal death kinetics of *Salmonella* during pasteurization of liquid egg white.

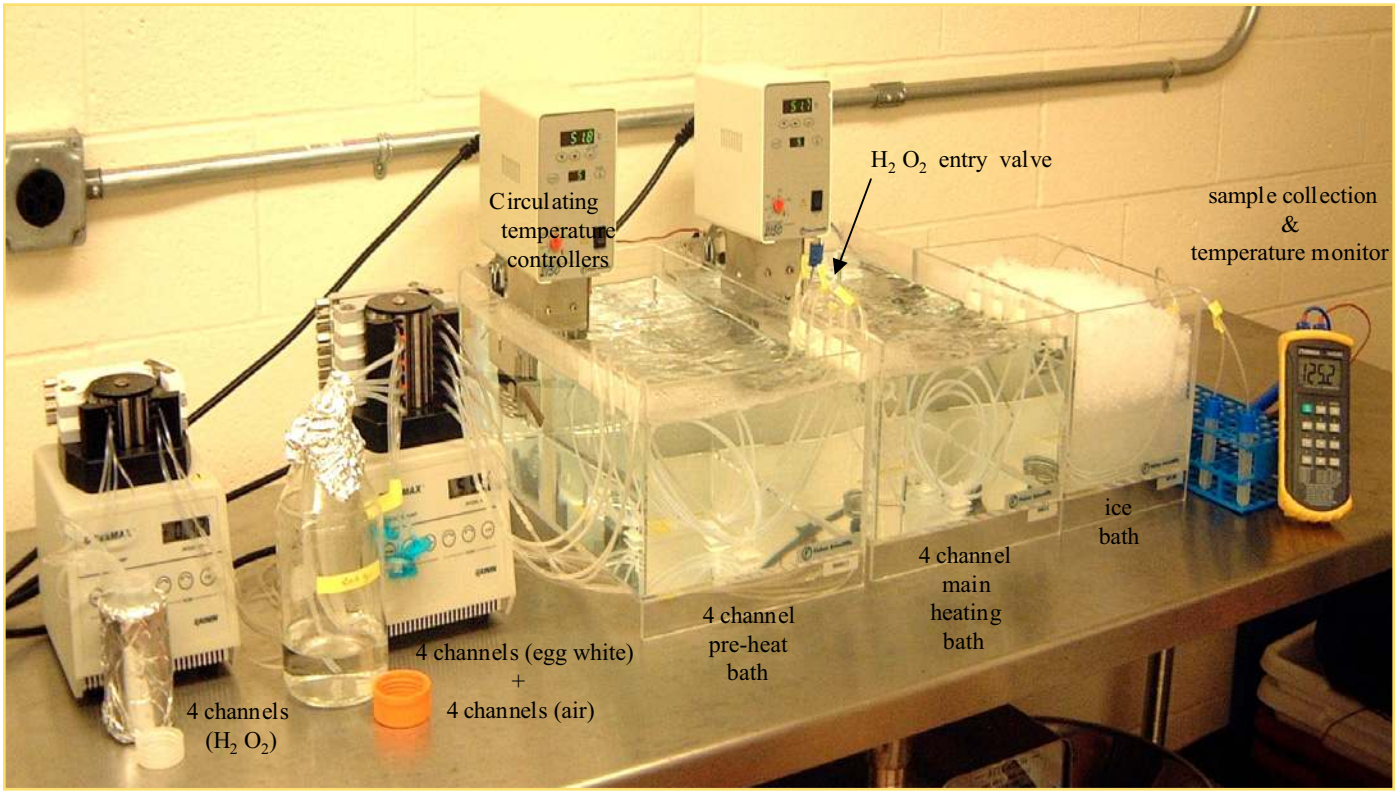
- Time-temperature combinations using bench-top pasteurizer with metered addition of H_20_2 were utilized.
- Both the Standard Brands and the Armour processes were tested.
- Five *Salmonella* strains were used: *S. enteritidis* (phage types 4 and 13), *S. heidelberg, S. typhimurium* and *S. blockley*.
- Tests were performed with egg white at pH 8.2, 8.8 and 9.0.
- Data were obtained by triplicate replications.

Background

During the time that data were collected for the first USDA Egg Pasteurization Manual (1969), a large proportion of egg pasteurization was done "offline" whereby eggs were collected from a producer, stored and subsequently processed at an egg processing facility. Because of the delay in processing, the pH of egg white increased from pH 7.8 at laying to pH 9.0 or higher at the time of processing. Consequently, pH 9.0 was considered the "natural pH" of egg white. In recent times, a greater proportion of eggs are processed "inline" whereby they are laid by hens and carried by conveyor to another building for processing. The result of using freshly processed egg whites is that the pH can be much lower than with offline eggs, as low as pH 7.8 to 8.2 at the time of processing. Therefore, it is important for today's egg white processors to have a pasteurization system that is as effective at pH 8.2 as it is at 9.0. The Egg Pasteurization Manual has evaluated various egg pasteurization systems, including a comparison of the Standard Brands and Armour pasteurization methods for egg white, two popular commercially-used processes that utilize hydrogen peroxide.

In order to properly compare these methods using laboratory conditions, a simulated continuous-flow bench-top pasteurization process was devised that replicated the commercial process: a) separate pre-heat and main-heat water baths were used to mimic heat-exchange and holding-tube conditions, b) hydrogen peroxide was metered into the holding tube after the initial pre-heat but before the main-heating regimen and c) multiple residence times were obtained with the same inoculated egg white preparation by devising multiple channels, each with a different length holding tube in the main-heating bath (i.e., different residence time [Figure 2]).

FIGURE 2.



Bench-top pasteurization unit composed of 4- and 8-channel peristaltic pumps, pre-heat and primary-heat water baths, and ice bath. Four (4) lines of different residence time (i.e., length) were run simultaneously.

Methods

Fresh egg white (pH 8.2, 8.6, and 9.0) was inoculated with a 5-strain cocktail of *Salmonella* and subjected to the Standard Brands and the Armour processes. Samples were obtained at various processing times and evaluated for microbial reduction efficiencies.

Strain Culturing, Handling, Identification

Freshly cultured strains were used the day of each run. Cultures were grown in Brain Heart Infusion broth (BHI) for 20 to 24 hours at 35°C and centrifuged/washed several times with 3x-strength peptone water (adjusted to pH of the particular egg white pH to be used) to remove media components and to concentrate the cells for inoculation of egg white. Inoculation of egg white in this manner provided CFU levels at 10^7-10^8 CFU/ml egg white depending on the degree of concentration or volume of egg white inoculated. (The goal was to obtain a minimum of 10^8 CFU/ml or higher with minimum dilution of egg white.)

Because of likely injury from the egg white processing conditions, samples were plated on Tryptic Soy agar (TSA) and some representatives from countable plates were replicated via patch plating onto XLT4 agar to verify that colonies counted on the non-selective TSA agar were indeed *Salmonella*.

Also, a filter-sterilized catalase solution was added immediately to collected samples to eliminate any residual H_2O_2 that may be present to render additional lethality in the interim before plating. Conversely, since samples are likely to be diluted and plated immediately upon recovery from the automated continuous flow system, the first dilution tube may contain the catalase. The amount of catalase to be used was determined upon the source/purity of the catalase and sufficient to neutralize tenfold higher levels than used in either process.

Processing of Egg White

Dr. Joe Berry (poultry extension specialist, Department of Animal Science, Oklahoma State University) provided fresh local eggs obtained from Oklahoma State University poultry facilities. Fresh egg white was recovered by sanitizing the outside of eggs with either 70% EtOH or 200 ppm of chlorine. Eggs were hand broken and egg whites recovered using a simple kitchen yolk-white separator utensil. Several dozen eggs were sufficient to provide enough egg white to run one replicate of tests at a given temperature. Pooled egg white was gently mixed with an electric mixer at low speed in an ice bath with care taken not to introduce air which could cause shearing of albumen. In order to evaluate pasteurization of whipping-aid egg white, citric acid (0.15% w/v) and triethylcitrate (0.03% w/v) were added by a subsequent mixing. Initial egg white pH was modified naturally by holding eggs in refrigerated storage. The egg white pH was adjusted using 1N HCL or 1N NaOH after gentle mixing. (An equal volume of water was added to other batches of egg white in order to provide the same dilution effect. However, the combined dilution by pH adjustment and inoculum addition was less than 5% to 6%). The final preparation was filtered through sterile cheesecloth as per the UNL procedure.

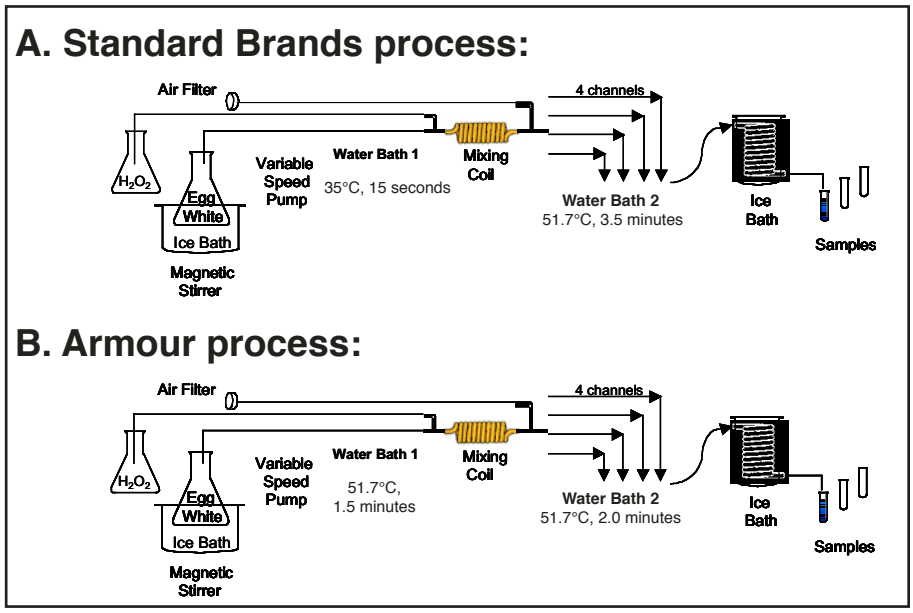
Bench-top Pasteurizer

A laboratory bench-top pasteurizer was previously developed at Oklahoma State University for pasteurization studies on both liquid whole egg (Muriana et al., 1996) and egg white (Muriana, 1997).

The bench-top pasteurizer (Figure 2) was set up to mimic the Standard Brands process and the Armour process (Figure 3) in which the pre-heating temperature was 51.7°C (125°F) for both processes. They differed mostly by the holding time in which the egg white was held before and after addition of hydrogen peroxide. It was felt that this pre-heating helped inactivate natural catalase which, in turn, inactivated some of the hydrogen peroxide. Holding time was changed by either adjusting the pump rate or the length of holding tube. Since the project involved a primary-heating regimen, it was preferred to change the final residence time by changing the holding tube length, which eliminated the need to change the configuration involving the initial heating of egg white as required by both processes.

Hydrogen peroxide levels used (final concentrations) were minimum levels of 0.0875% (w/v) for the Standard Brands process and 0.05% (w/v) for the Armour process. Distilled de-ionized water was used to make any dilutions of the H_2O_2 stock solution. The final concentration of H_2O_2 was obtained after mixing via mixing coils (i.e., residence time in the mixing coil was calibrated as part of the residence time for the process). The proper pre-blend concentration was determined empirically from manual calibration of pumped volume dispensed from different sized pumping tubes for egg white and H_2O_2 such that the egg white was diluted less than 5% by addition of hydrogen peroxide.

FIGURE 3. DIAGRAM OF THE STANDARD BRANDS AND ARMOUR METHODS FOR PASTEURIZATION OF EGG WHITE USING HYDROGEN PEROXIDE



Sample Treatments and Replications

Heat treatments were accommodated using a circulating water bath with a precision temperature control. Circulation insured consistent temperature around the product during heat treatments. Two independent circulating water baths provided heating for the two temperature requirements in each of the two processes (Standard Brands and Armour) to be tested. Temperatures were obtained for various points in the process to give a "temperature profile" of each process.

Flow rates (i.e., mls/minutes) were accurately calculated based on accumulated final volume over time (obtained at the final sampling port). The system included the use of filtered air to form segmented liquid flow such that the residence time could be easily calculated through the glass capillary tubes. It was important that the residence time be accurately assessed to be able to make accurate D and Z value determinations.

D VALUE DETERMINATIONS. D values for Standard and Armour processes were determined by running arrays of pasteurization assays at a given temperature where the processing time has been changed. In the case of the Standard Brands process, the holding tube temperature was changed since it is higher than the initial heating temperature; for the Armour process, both pre-heating and post-hydrogen peroxide heating times were changed because, in this process, both are held at the same temperature.

Results

Data indicated that the Standard Brands method gave better $\log_{10}$ reductions at comparable processing conditions as compared to the Armour method (Figure 4). D and Z_D values were calculated at pH 8.2, 8.6 and 9.0 from survivor curves obtained at different temperatures using the bench-top process described earlier (Tables 27 and 28, page 23). The effect of pH can be appreciated when plotting the data for the minimum allowable processing time and temperature conditions against pH (Figure 4). The data show a variable microbial reduction depending on the pH. However, the Standard Brands process showed the most consistent results at all three pH levels tested. At 54.4°C and 55.8°C, the Standard Brands process gave similar log reductions at all pHs. The Standard Brands process provided an approximate 9 log reduction at 55.8°C at all pHs. When using the Armour process, 55.8°C gave about a 9 log reduction at pH 8.6 or 9.0.

Based on these results, the Standard Brands method is clearly superior to the Armour method. This is particularly true at higher temperatures. The advantage of the higher temperatures (54.4°C or 55.8°C) for the Standard Brands process is that the processor would not need to adjust egg white pH to 9.0 prior to pasteurization to achieve an acceptable log reduction.

FIGURE 4. EFFECT OF pH AND TEMPERATURE ON EGG WHITE PASTEURIZATION ACCORDING TO THE ARMOUR AND STANDARD BRANDS METHODS AT THE MINIMUM ALLOWABLE TIME AND TEMPERATURE CONDITIONS

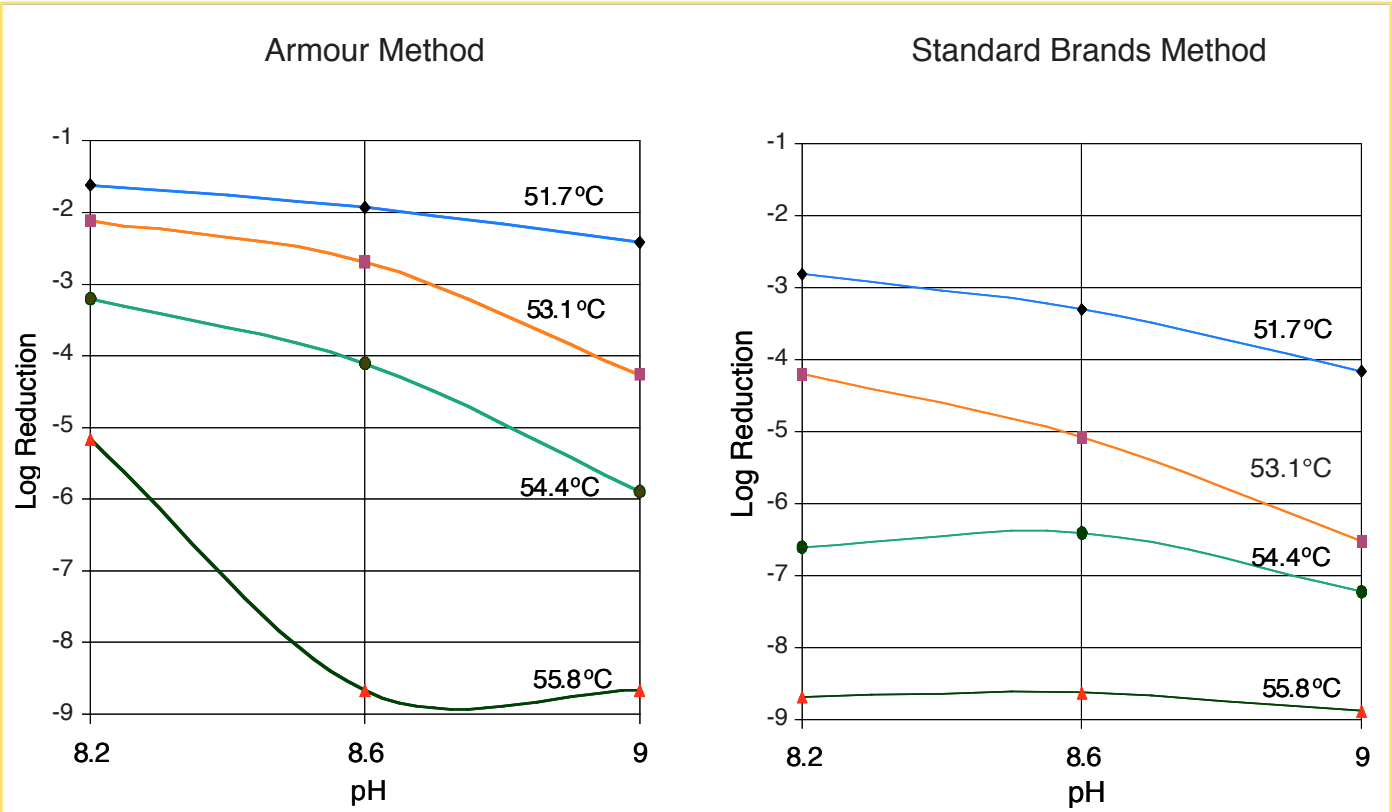


TABLE 27. D VALUES (MINUTES) AND Z VALUES (°C) OBTAINED WITH THE ARMOUR METHOD FOR EGG WHITE AT pH 8.2, 8.6 AND 9.0, PROCESSED AT 51.7°C, 53.1°C, 54.4°C AND 56.8°C (VALUES ARE AVERAGES OF TRIPLICATE REPLICATIONS AND 2 SAMPLES PER REPLICATION)

pH	$D_{51.7°C}$	$D_{53.1°C}$	$D_{54.4°C}$	$D_{56.8°C}$	Z_D
8.2	1.33	1.03	0.78	0.38	4.48
8.6	0.91	0.69	0.37	0.24	5.96
9.0	0.63	0.50	0.35	0.23	10.29

TABLE 28. D VALUES (MINUTES) AND Z VALUES (°C) OBTAINED WITH THE STANDARD BRANDS METHOD FOR EGG WHITE AT pH 8.2, 8.6 AND 9.0, PROCESSED AT 51.7°C, 53.1°C, 54.4°C AND 56.8°C (VALUES ARE AVERAGES OF TRIPLICATE REPLICATIONS AND 2 SAMPLES PER REPLICATION)

pH	$D_{51.7°C}$	$D_{53.1°C}$	$D_{54.4°C}$	$D_{56.8°C}$	Z_D
8.2	1.19	0.75	0.52	0.305	4.73
8.6	1.03	0.66	0.52	0.298	5.85
9.0	0.81	0.54	0.47	0.286	8.16

Conclusions

On the basis of these studies, times and temperatures to provide equivalent pasteurization effectiveness at 5 and 7 log reductions are presented in Appendix Figures 17 to 26 (pages 47-56). These graphic presentations should allow processors to estimate times and temperatures for a selected process. Research presented in this manual did not include all egg products. Some egg products, such as those containing higher salt or sugar contents, would likely require the processor to validate the proper pasteurization process. As noted previously in this manual, researchers have indicated that egg products containing as high as 20% salt, or combinations of salt and sugar, may not have adequate log reductions using current pasteurization methods (Palumbo et al., 1995; Michalski et al., 1999). Perhaps egg products with higher levels of salt or combinations with sugar may need to be pasteurized prior to addition of salt and sugar. This approach would require careful monitoring to avoid recontamination.

Table 29 shows new pasteurization guidelines for egg products. With these processes, some changes are indicated. Adjustment of pH of albumen would be required if the 56.7°C pasteurization temperature was used. However, this may not be practical for many processors. Therefore, it is recommended that a pasteurization temperature of 57.7°C also be considered. In many cases, the hydrogen peroxide method should not require any pH adjustment.

With respect to salted yolk, it is recommended that the holding time be increased to 63.3°C. Salted whole egg would continue to have a process of 63.3°C for 3.5 minutes if held 96 hours after salt addition. Many processors may find holding time to be impractical and prefer to increase the holding time for salted whole egg. These changes for salted egg products should have minimum influence on functional properties.

Times and temperatures for various blended products are shown. These guidelines, of course, are presented for specific formulations. If processors have formulations different from these, they would have to obtain approval from USDA.

This study did not include plain yolk or plain whole egg. Presently, it would appear that the old pasteurization requirements should be adequate for these egg products, as indicated by recent studies by other microbiologists (Palumbo et al., 1995; Michalski et al., 1999).

Sanitary standards for equipment are important and should meet 3-A sanitary standards. The 3-A sanitary standards are published by the International Association for Food Protection, 6200 Aurora Avenue, Suite 200W, Des Moines, IA 50322-2863.

TABLE 29. NEW PASTEURIZATION GUIDELINES

Liquid Egg Product	Minimum Temperature °C (°F)	Minimum Holding Time Minutes[1]
Egg white with pH adjusted	56.7 (134)	4.3
Egg white without pH adjusted	57.7 (136)	6.3
Egg white pH 8.6 with hydrogen peroxide (Standard Brands process)	54.4 (130)	3.5
USDA scrambled egg mix (30% solids)	62.2 (144)	2.0
Scrambled egg mix (22% solids)	60.0 (140)	2.4
Fortified whole egg "Tex" product (32% solids)	62.2 (144)	2.0
Fortified egg yolk "Tex" product (49% solids)	63.3 (146)	3.5
Imitation egg product	56.7 (134)	4.6
Salted yolk (10%)	63.3 (146)	4.5
Salted whole egg (10%) without storage	63.3 (146)	5.7
Salted whole egg (10%) with 96-hours storage	63.3 (146)	3.5
Sugared yolk (10%)	63.3 (146)	3.5
Sugared whole egg (10%)	61.1 (142)	3.5
Plain yolk	61.1 (142) 60.0 (140)	3.5 6.2
Plain whole egg	60.0 (140)	3.5

[1]Based on a 5 log reduction

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APPENDIX A: FIGURES

FIGURE 1. REDUCTION OF *SALMONELLA* IN LIQUID EGG WHITE AT pH 7.8 AT VARIOUS TEMPERATURES, SHOWING LINEAR REGRESSION WIH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

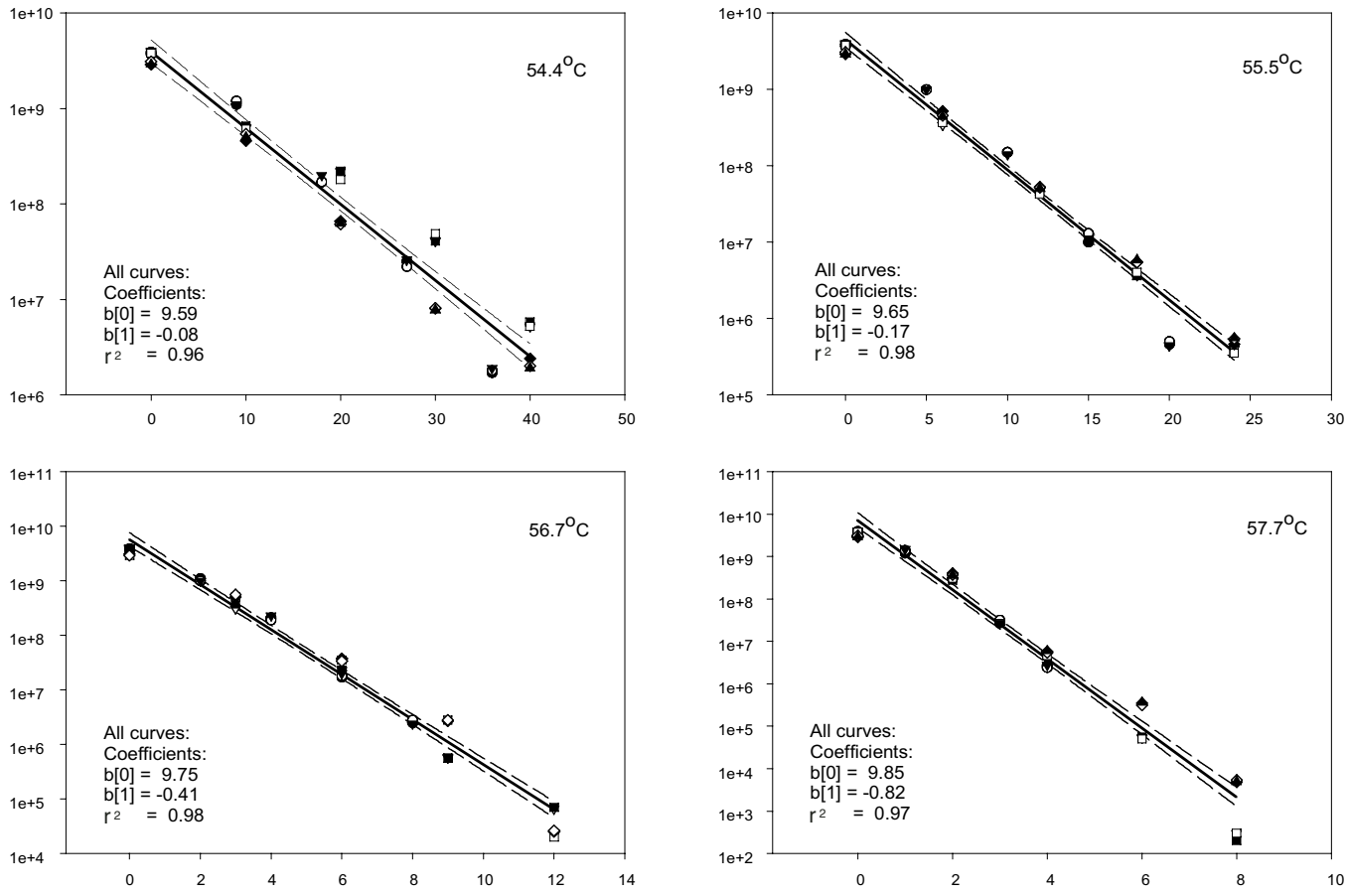


FIGURE 2. REDUCTION OF *SALMONELLA* IN LIQUID EGG WHITE AT pH 8.3 AT VARIOUS TEMPERATURES, SHOWING LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

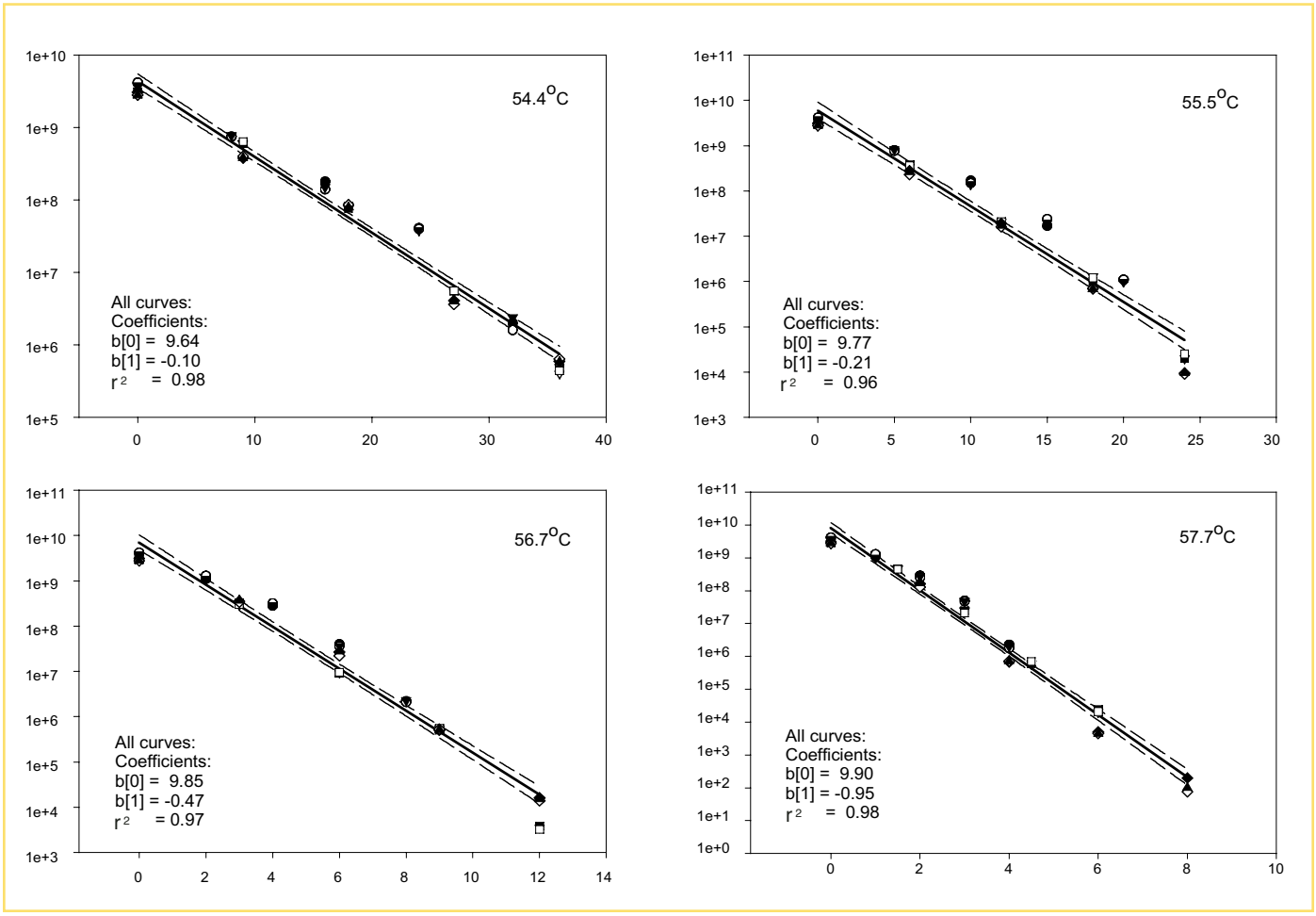


FIGURE 3. REDUCTION OF *SALMONELLA* IN LIQUID EGG WHITE AT pH 8.8 AT VARIOUS TEMPERATURES, SHOWING LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

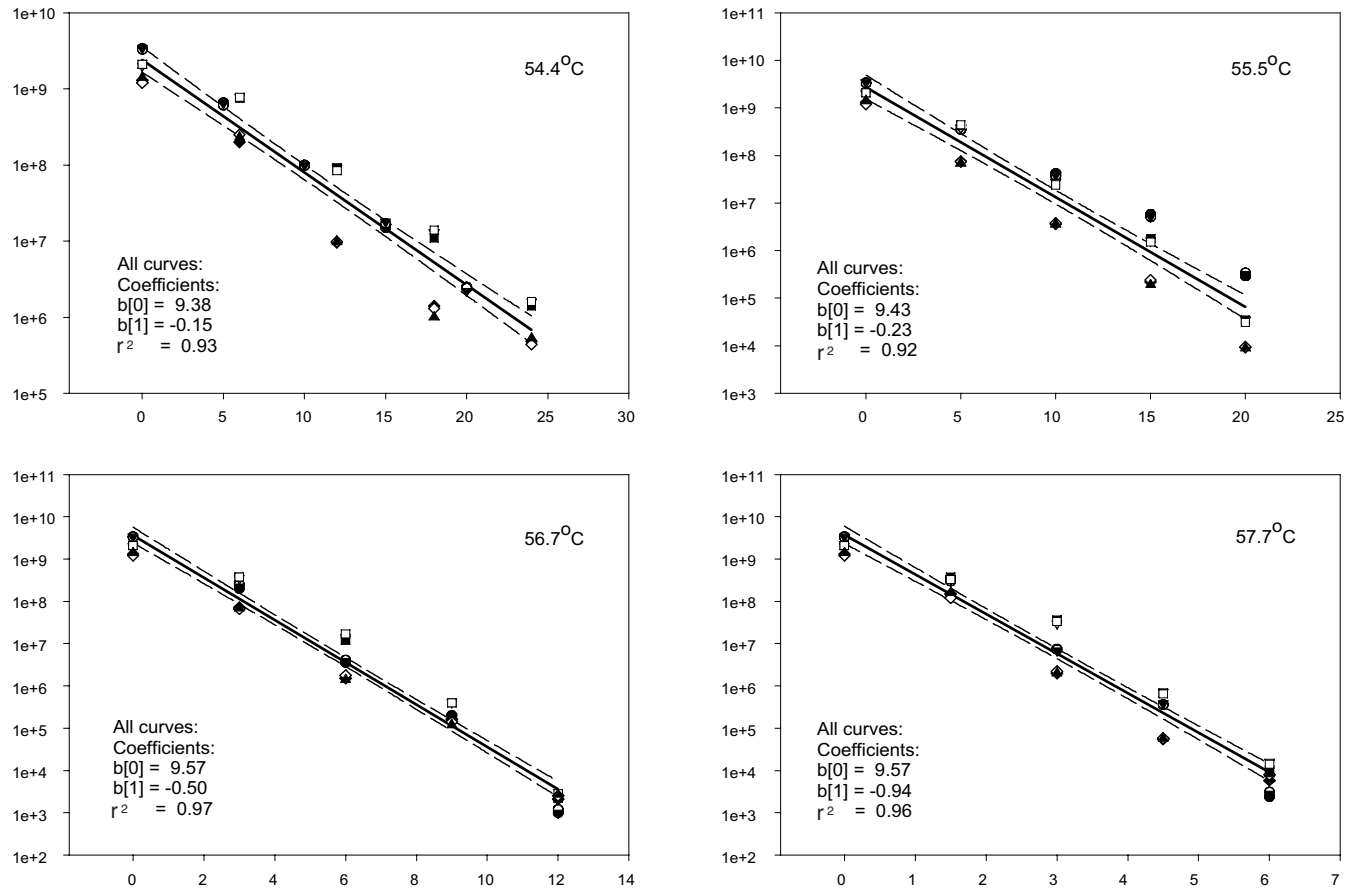


FIGURE 4. REDUCTION OF *SALMONELLA* IN LIQUID EGG WHITE AT pH 9.3 AT VARIOUS TEMPERATURES, SHOWING LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

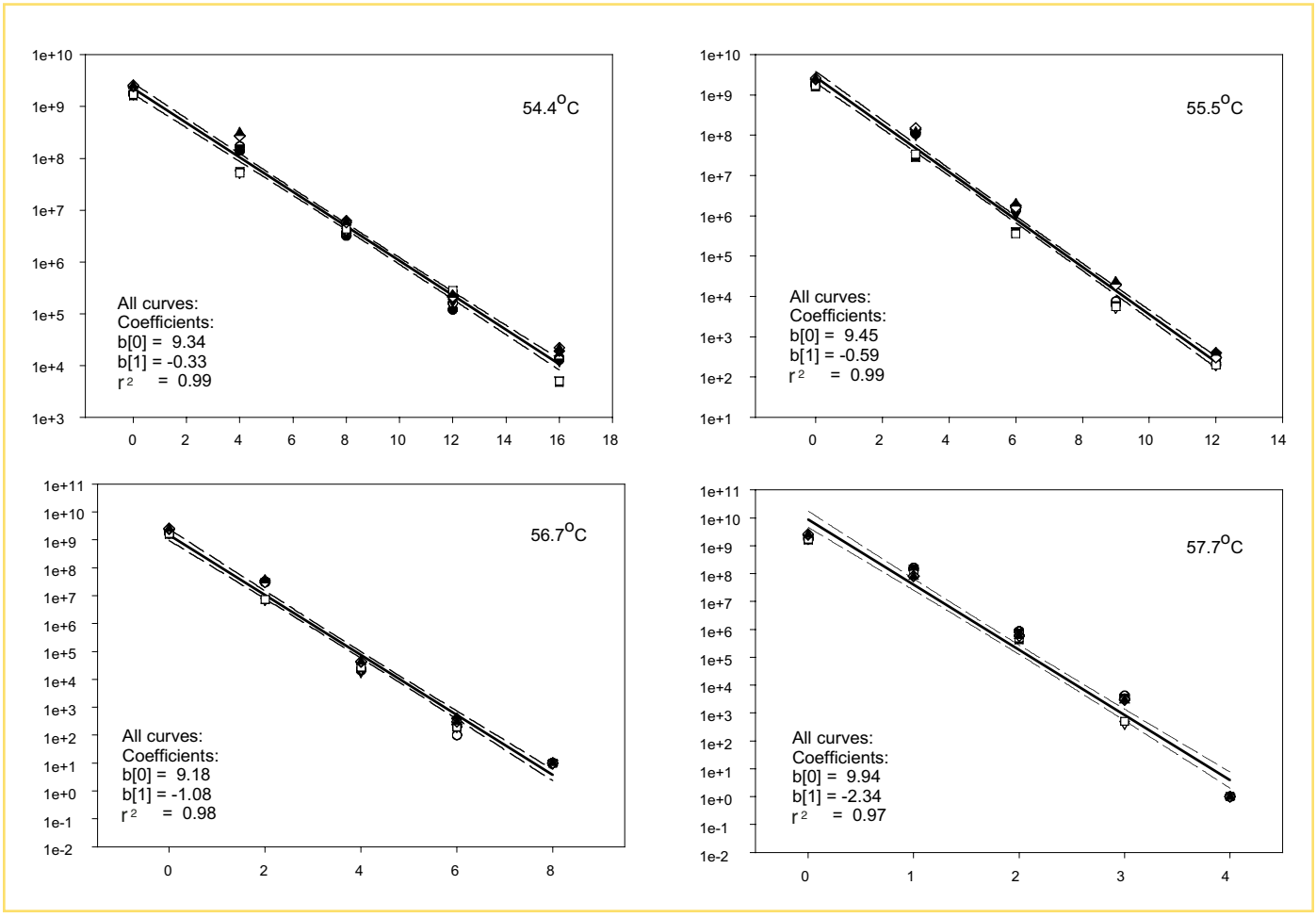


FIGURE 5. REDUCTION OF *SALMONELLA* IN LIQUID 10% SALTED EGG YOLK AT VARIOUS TEMPERATURES FOR 0- AND 96-HOUR TREATMENTS, SHOWING A PREDICTION LINE CALCULATED FROM GAMMA DISTRIBUTION SURVIVAL CURES WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

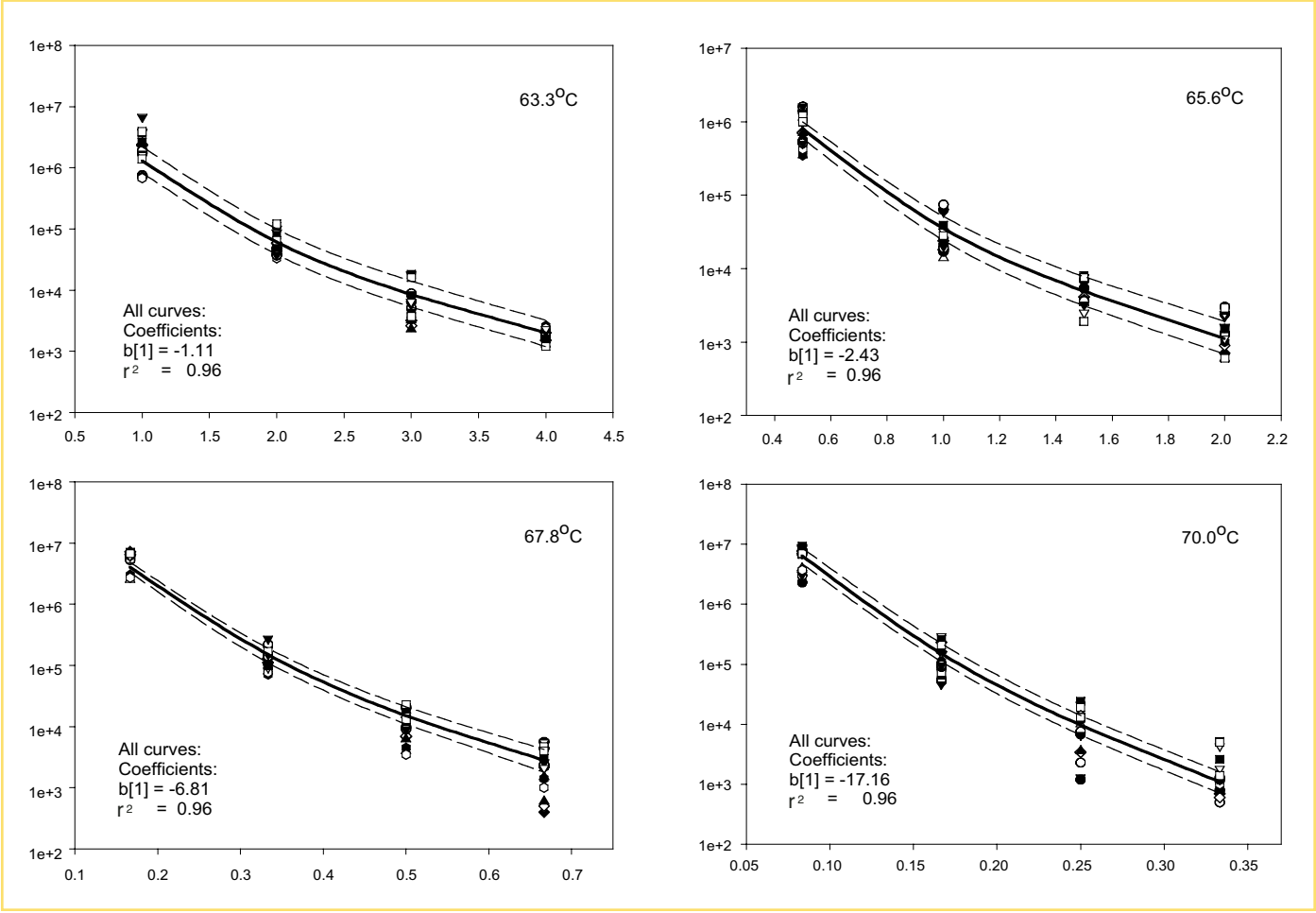


FIGURE 6. REDUCTION OF *SALMONELLA* IN LIQUID 10% SALTED WHOLE EGG AT VARIOUS TEMPERATURES FOR 0 HOURS, SHOWING A PREDICTION LINE CALCULATED FROM GAMMA DISTRIBUTION SURVIVAL CURES WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

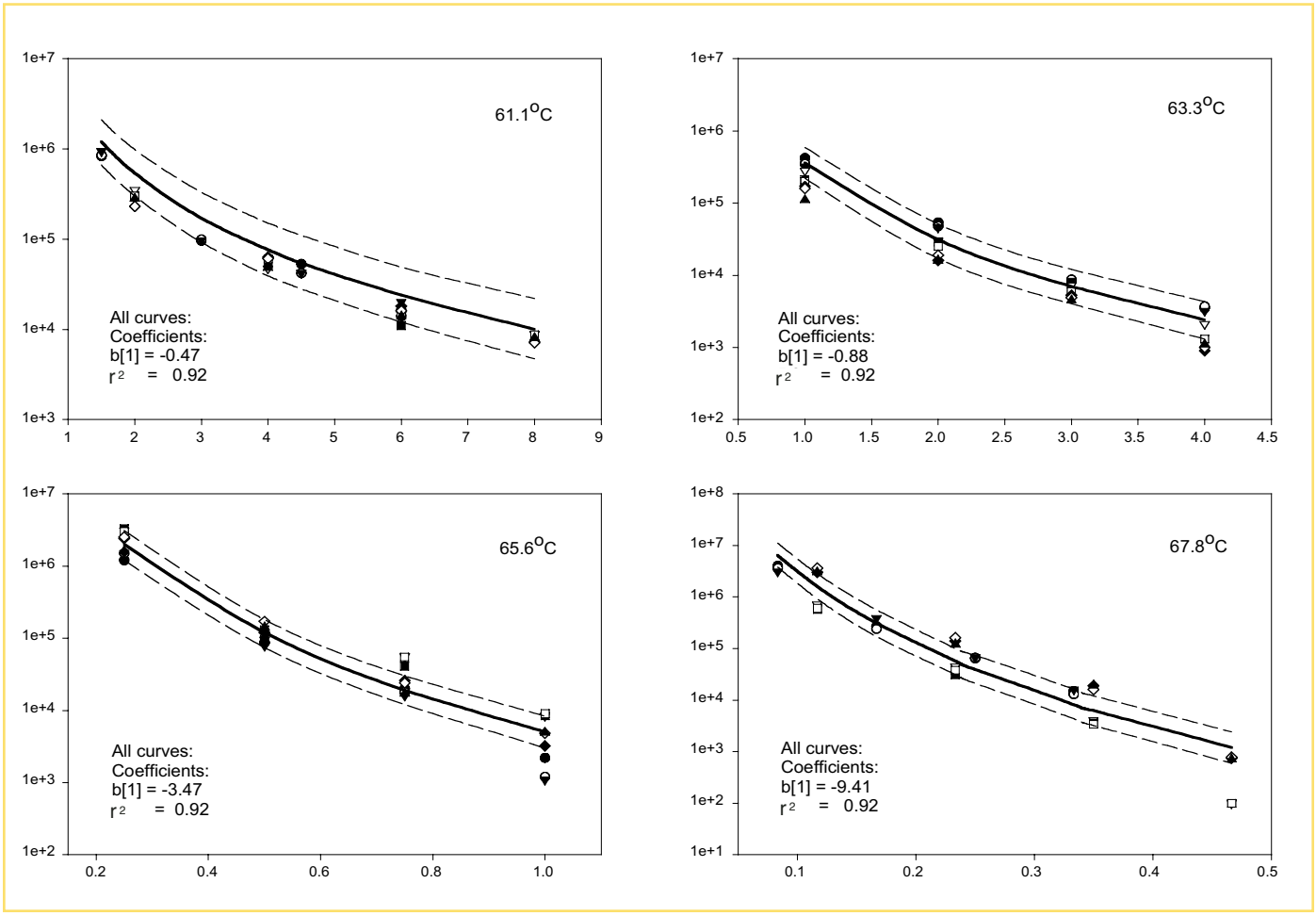


FIGURE 7. REDUCTION OF *SALMONELLA* IN LIQUID 10% SALTED WHOLE EGG AT VARIOUS TEMPERATURES FOR 96 HOURS, SHOWING A PREDICTION LINE CALCULATED FROM GAMMA DISTRIBUTION SURVIVAL CURES WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

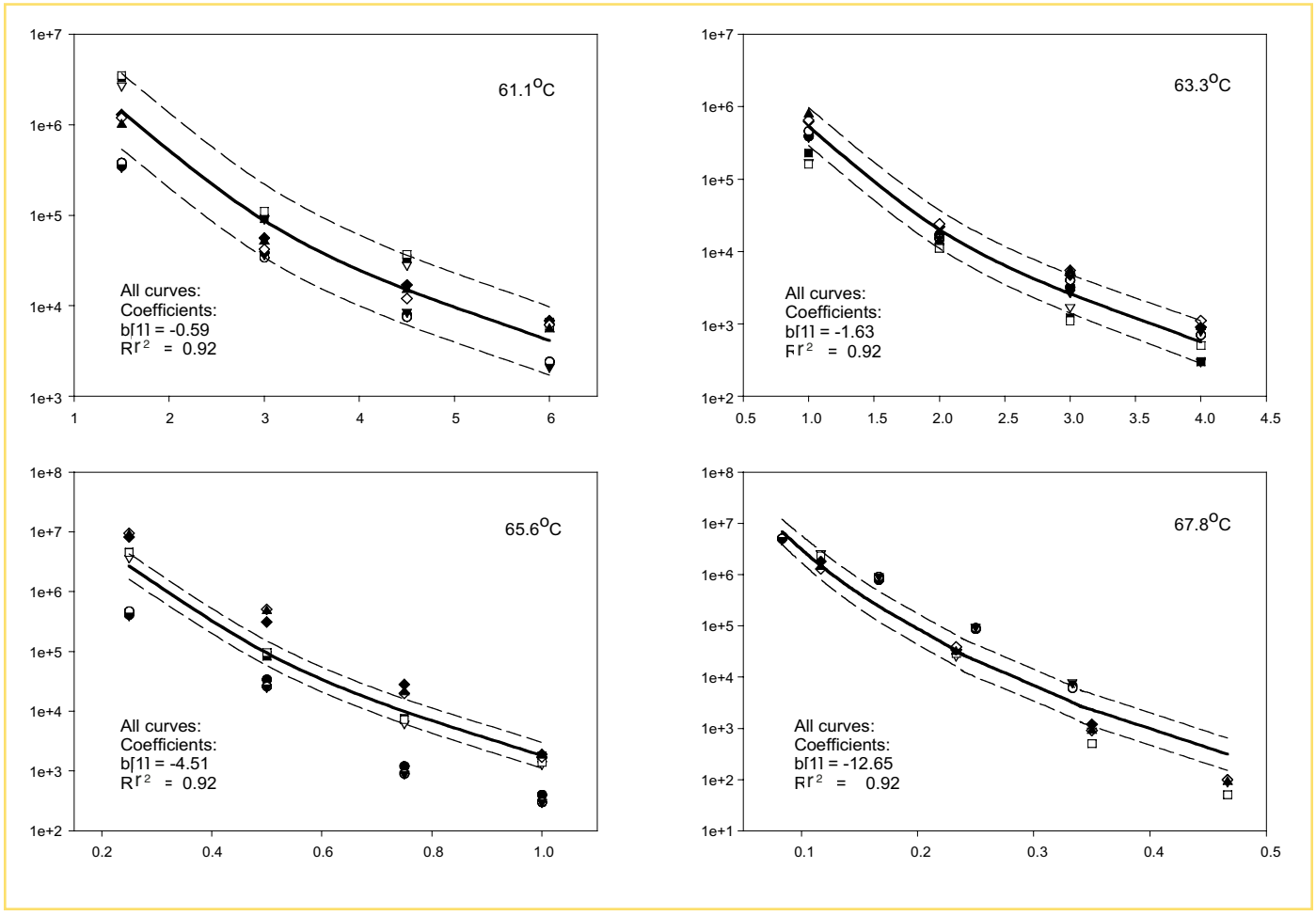


FIGURE 8. REDUCTION OF *SALMONELLA* IN LIQUID 10% SUGARED EGG YOLK AT VARIOUS TEMPERATURES FOR 0 HOURS, SHOWING A LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

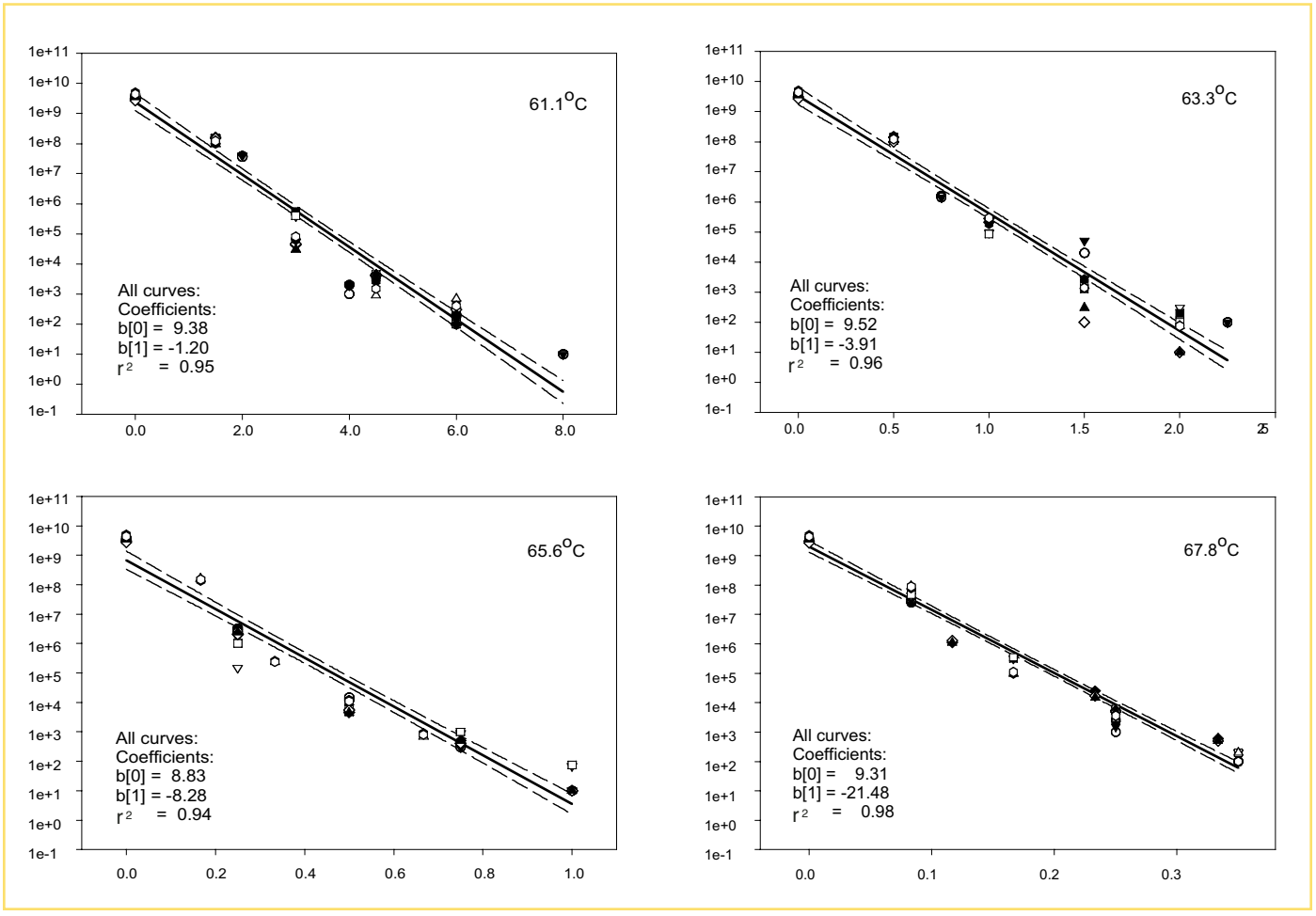


FIGURE 9. REDUCTION OF *SALMONELLA* IN LIQUID 10% SUGARED EGG YOLK AT VARIOUS TEMPERATURES FOR 96 HOURS, SHOWING A LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

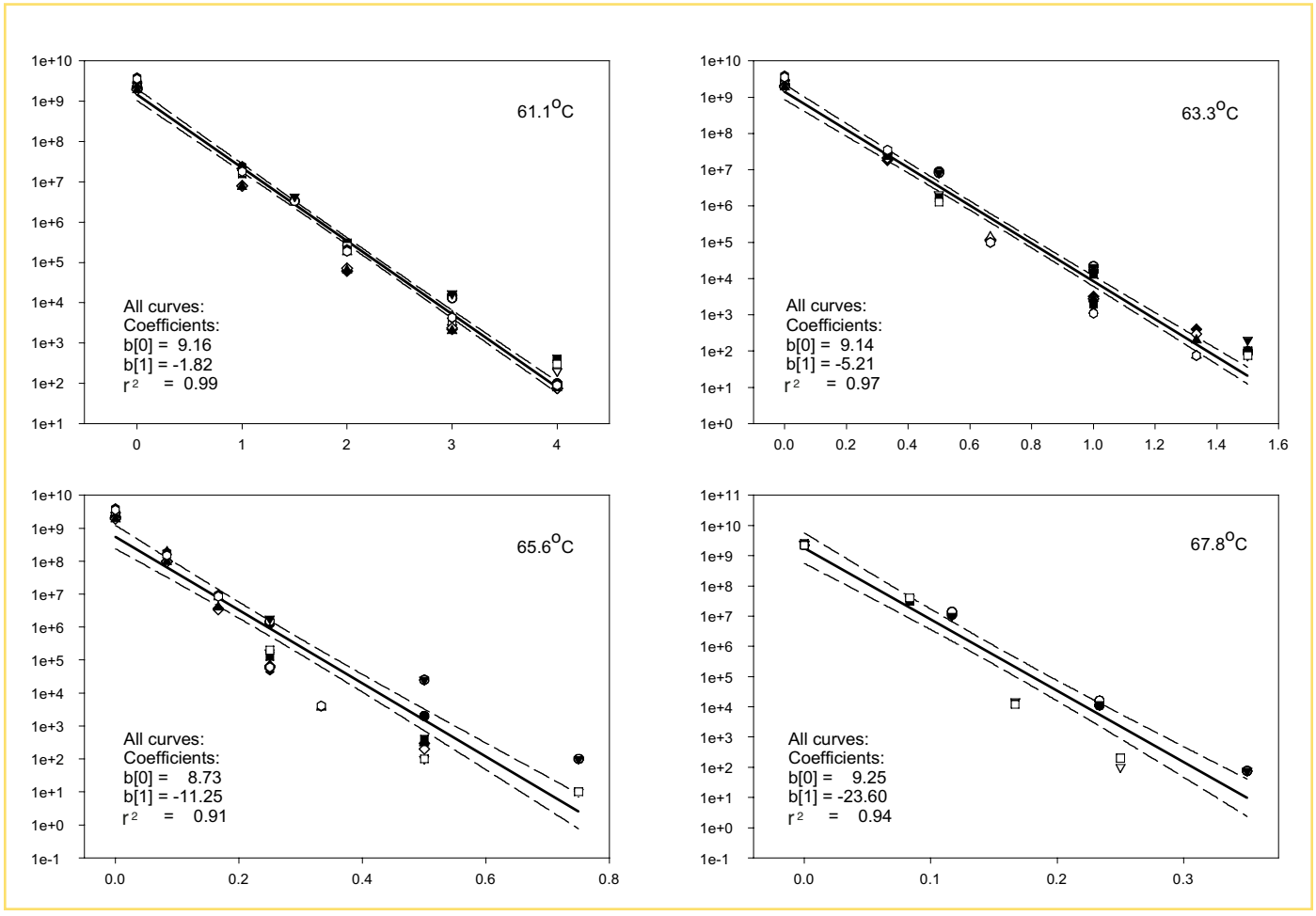


FIGURE 10. REDUCTION OF *SALMONELLA* IN LIQUID 10% SUGARED WHOLE EGG AT VARIOUS TEMPERATURES FOR 0 HOURS, SHOWING A LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

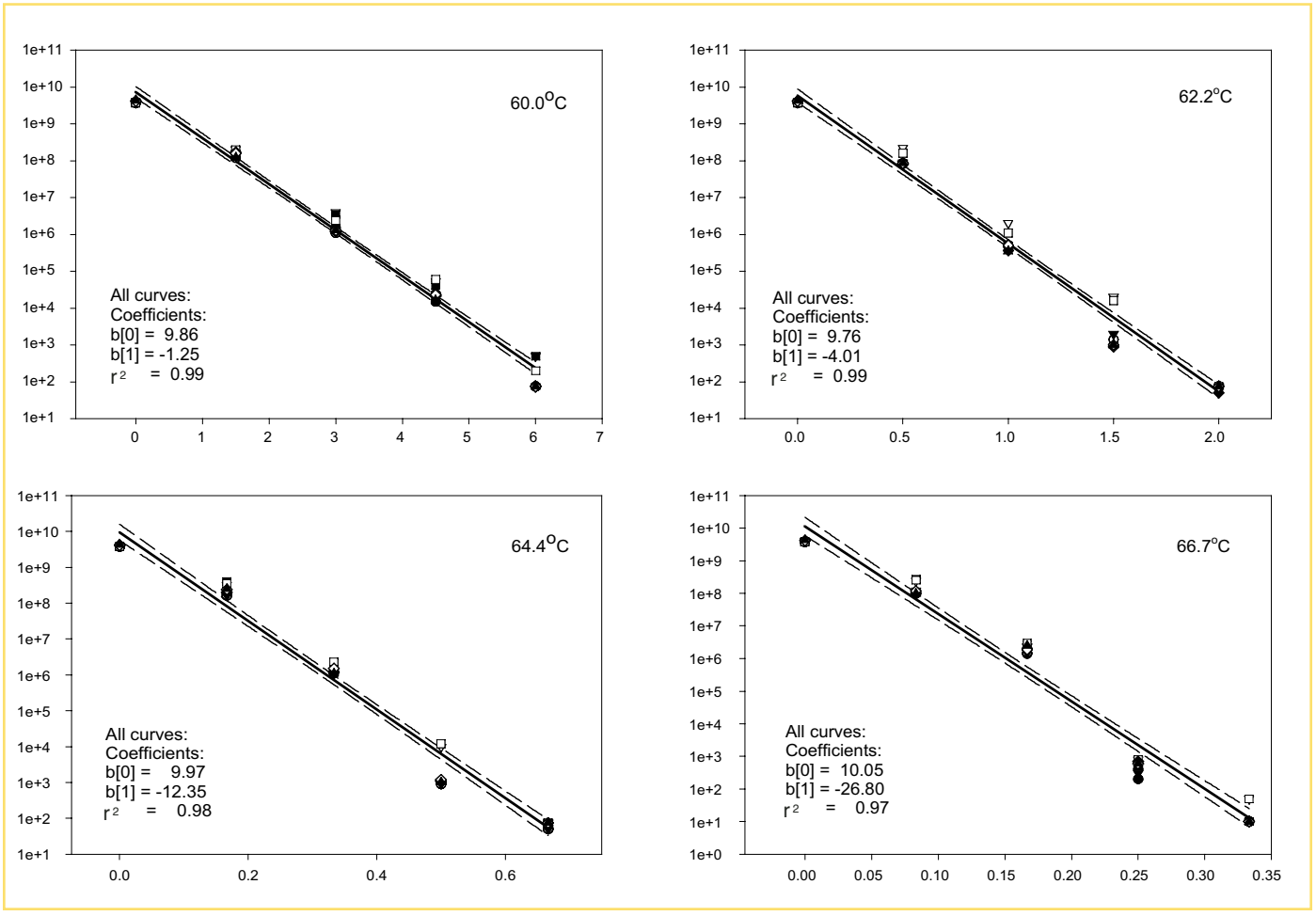


FIGURE 11. REDUCTION OF *SALMONELLA* IN LIQUID 10% SUGARED WHOLE EGG AT VARIOUS TEMPERATURES FOR 96 HOURS, SHOWING A LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

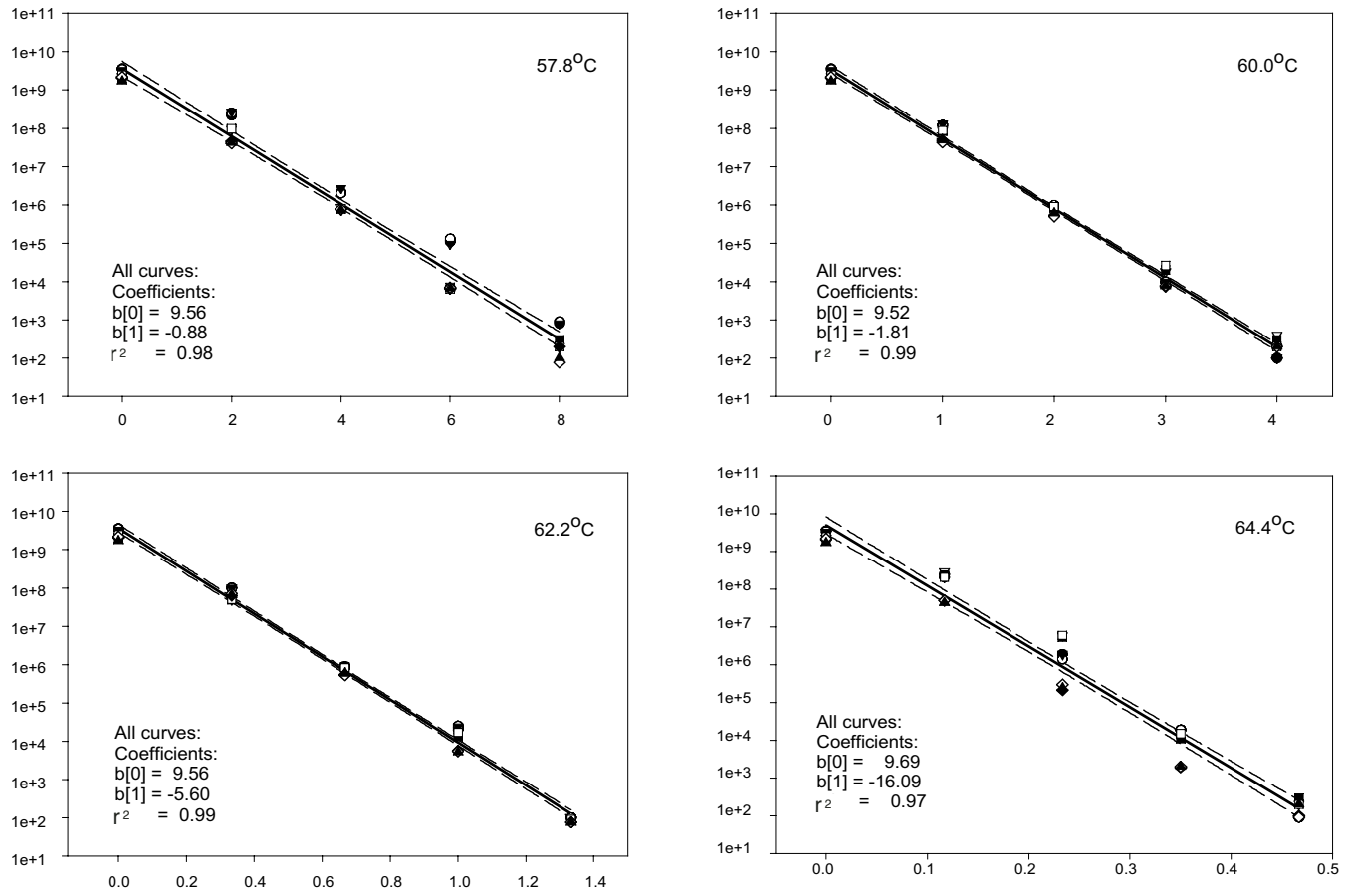


FIGURE 12. REDUCTION OF *SALMONELLA* IN LIQUID USDA SCRAMBLED EGG MIX (#1) AT VARIOUS TEMPERATURES, SHOWING A LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

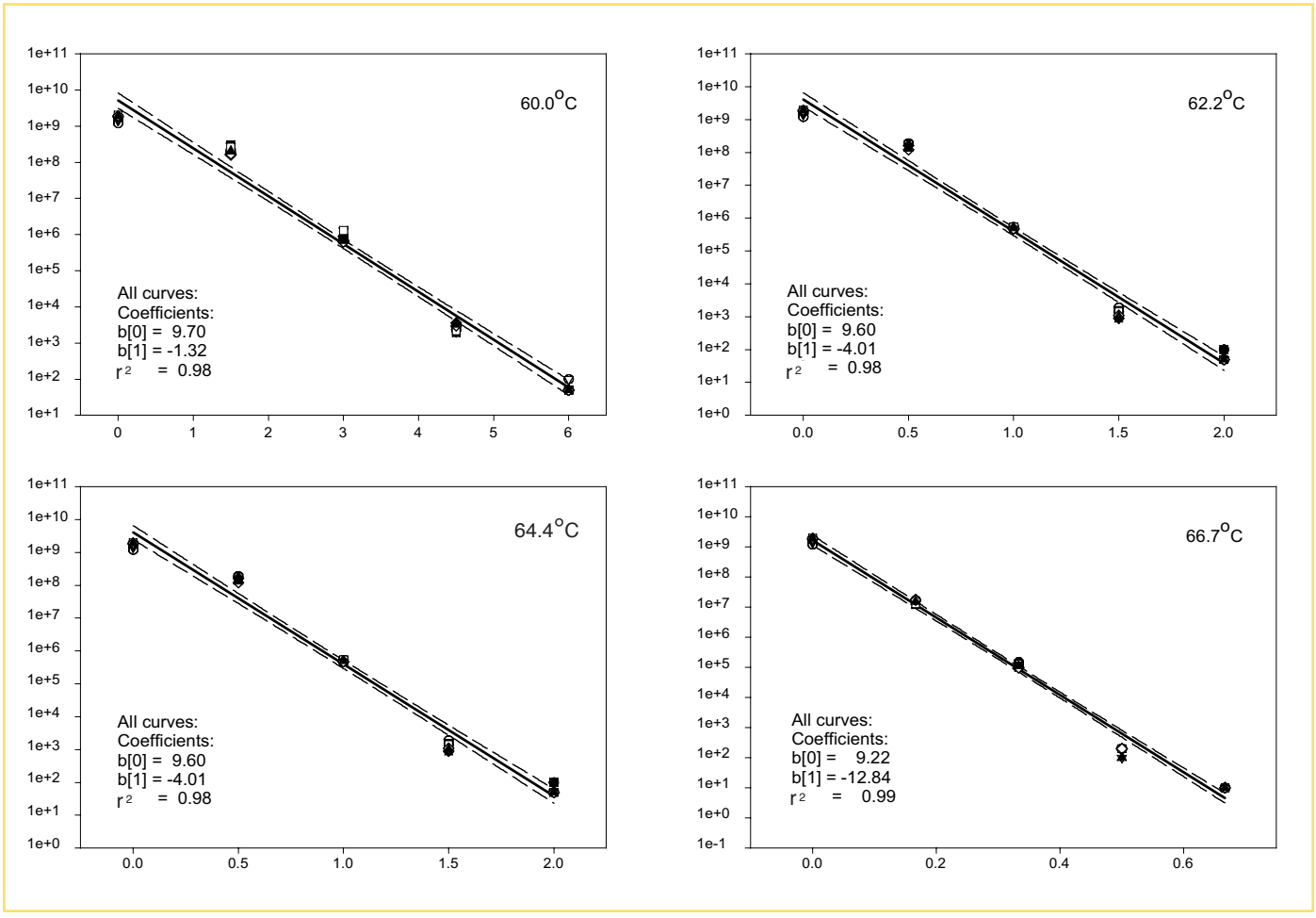


FIGURE 13. REDUCTION OF *SALMONELLA* IN LIQUID SCRAMBLED EGG MIX-HIGH SOLIDS (#2) AT VARIOUS TEMPERATURES, SHOWING A LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

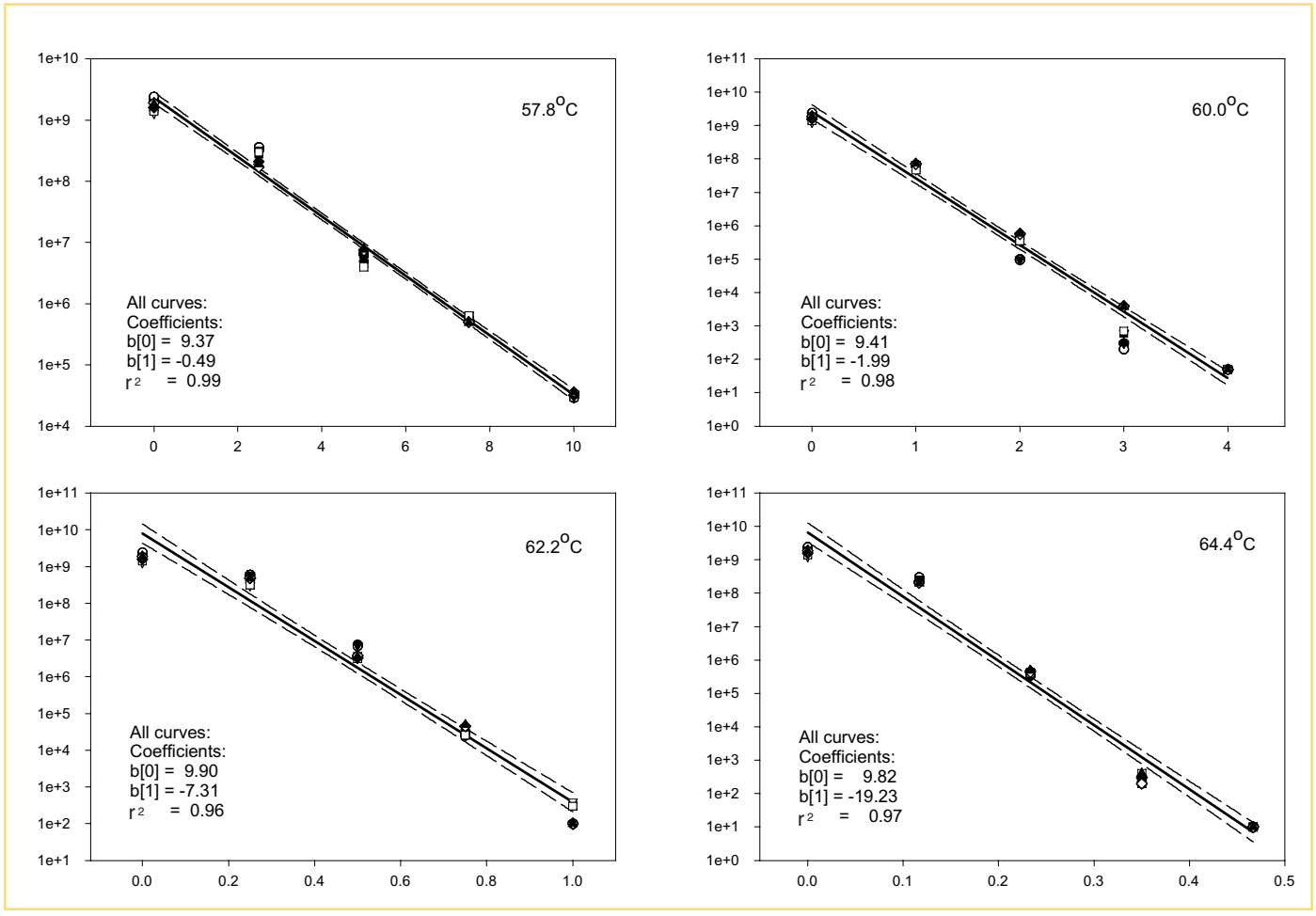


FIGURE 14. REDUCTION OF *SALMONELLA* IN LIQUID FORTIFIED WHOLE EGG – "TEX" PRODUCT (#4) AT VARIOUS TEMPERATURES, SHOWING A LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

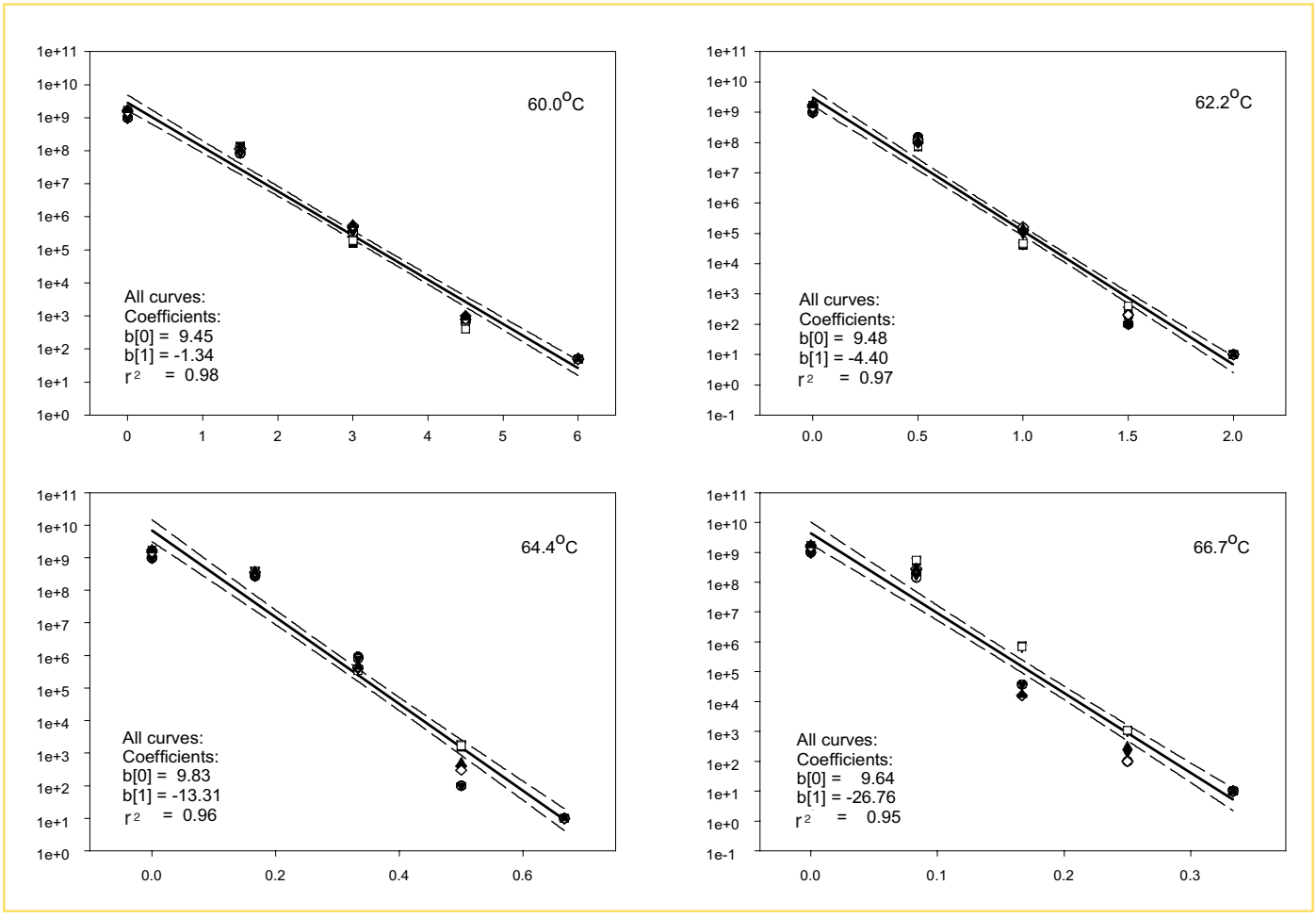


FIGURE 15. REDUCTION OF *SALMONELLA* IN LIQUID FORTIFIED EGG YOLK – "TEX" PRODUCT (#6) AT VARIOUS TEMPERATURES, SHOWING A LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

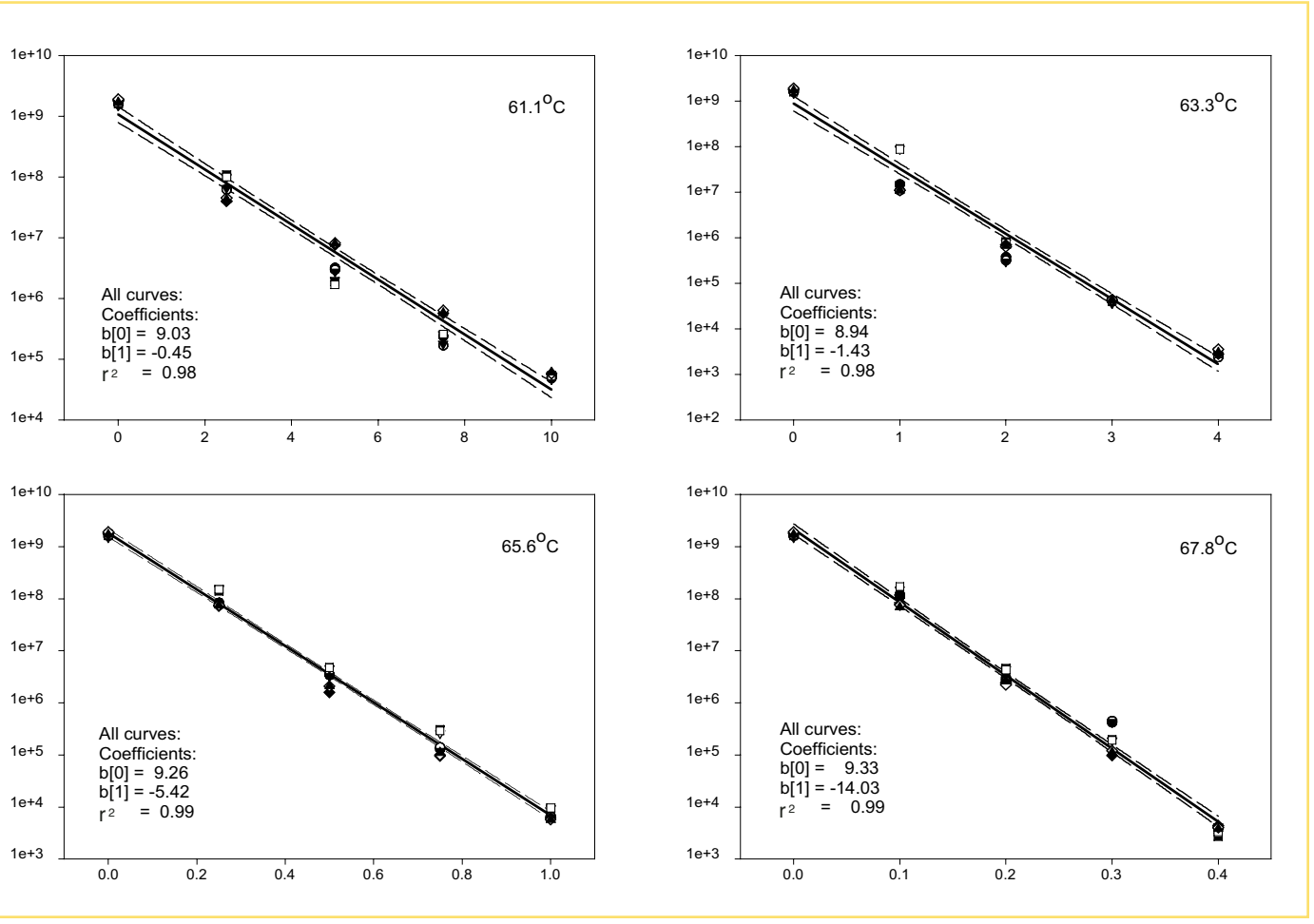


FIGURE 16. REDUCTION OF *SALMONELLA* IN LIQUID IMITATION EGG PRODUCT AT VARIOUS TEMPERATURES, SHOWING A LINEAR REGRESSION WITH 95% CONFIDENCE INTERVALS (3 REPS/GRAPH, Y = MICROBIAL LOAD, X = TIME IN MINUTES)

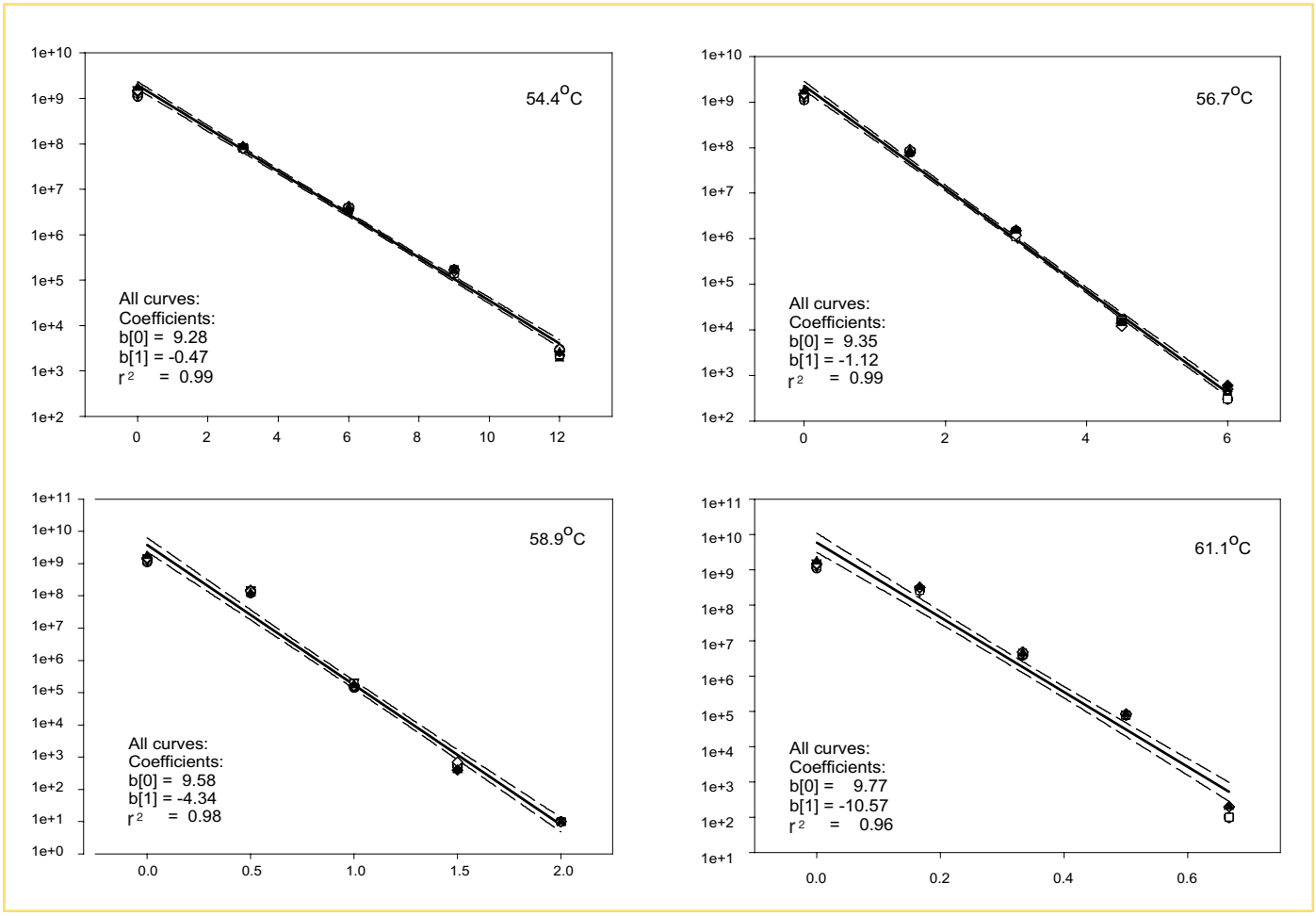


FIGURE 17. TIMES AND TEMPERATURES REQUIRED TO ACHIEVE A 5 LOG_{10} REDUCTION OF *SALMONELLA* POPULATIONS FROM AN INITIAL POPULATION OF APPROXIMATELY 9.3 LOG_{10} FOR LIQUID EGG WHITE AT VARIOUS pHs AND LIQUID IMITATION EGG PRODUCT

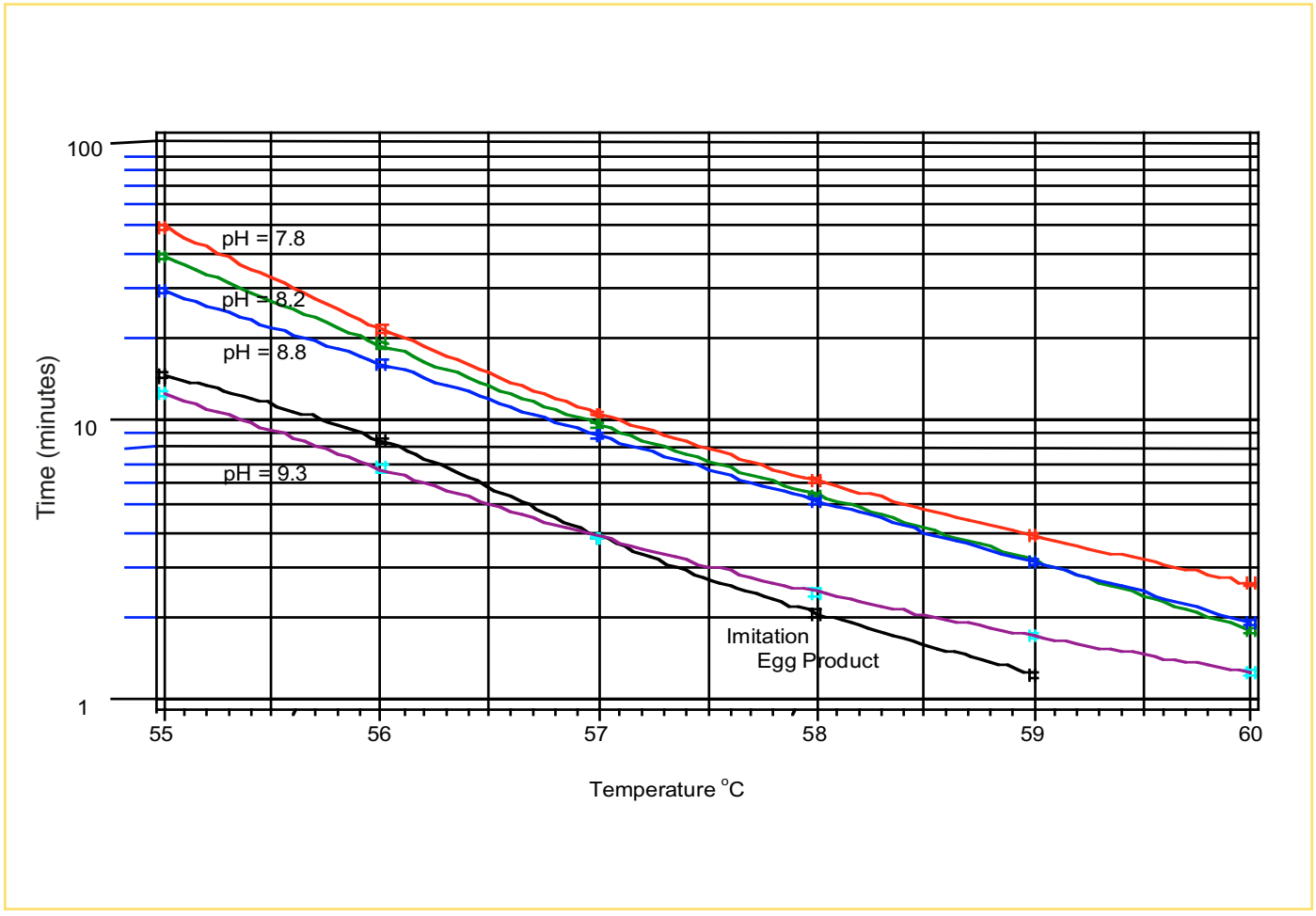


FIGURE 18. TIMES AND TEMPERATURES REQUIRED TO ACHIEVE A 7 LOG_{10} REDUCTION OF *SALMONELLA* POPULATIONS FROM AN INITIAL POPULATION OF APPROXIMATELY 9.3 LOG_{10} FOR LIQUID EGG WHITES AT VARIOUS pHs AND LIQUID IMITATION EGG PRODUCT

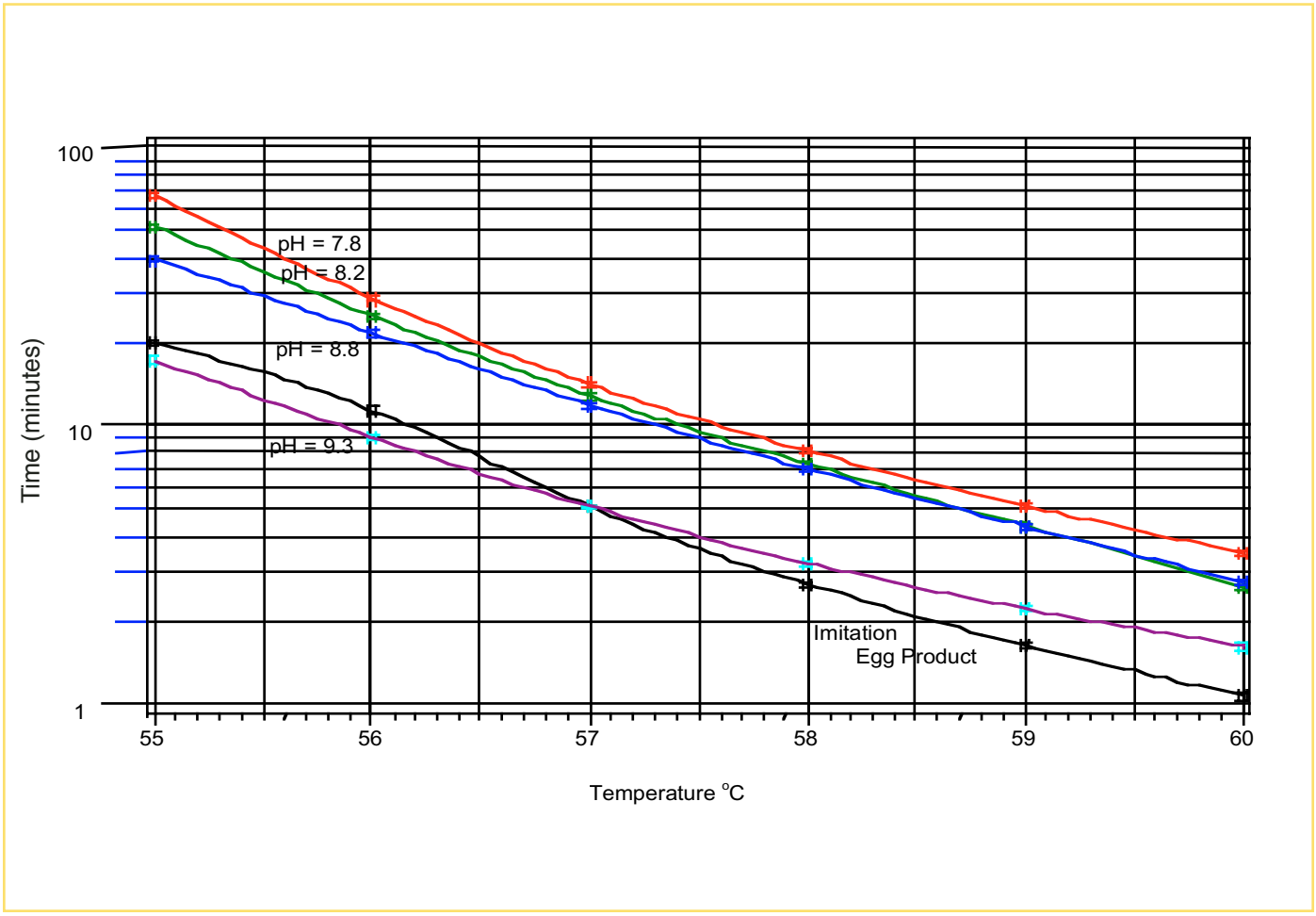


FIGURE 19. TIMES AND TEMPERATURES REQUIRED TO ACHIEVE A 5 LOG_{10} REDUCTION OF *SALMONELLA* POPULATIONS FROM AN INITIAL POPULATION OF APPROXIMATELY 9.3 LOG_{10} FOR LIQUID SALTED YOLK AND LIQUID SALTED WHOLE EGG AT HOLDING TIMES OF 0 AND 96 HOURS

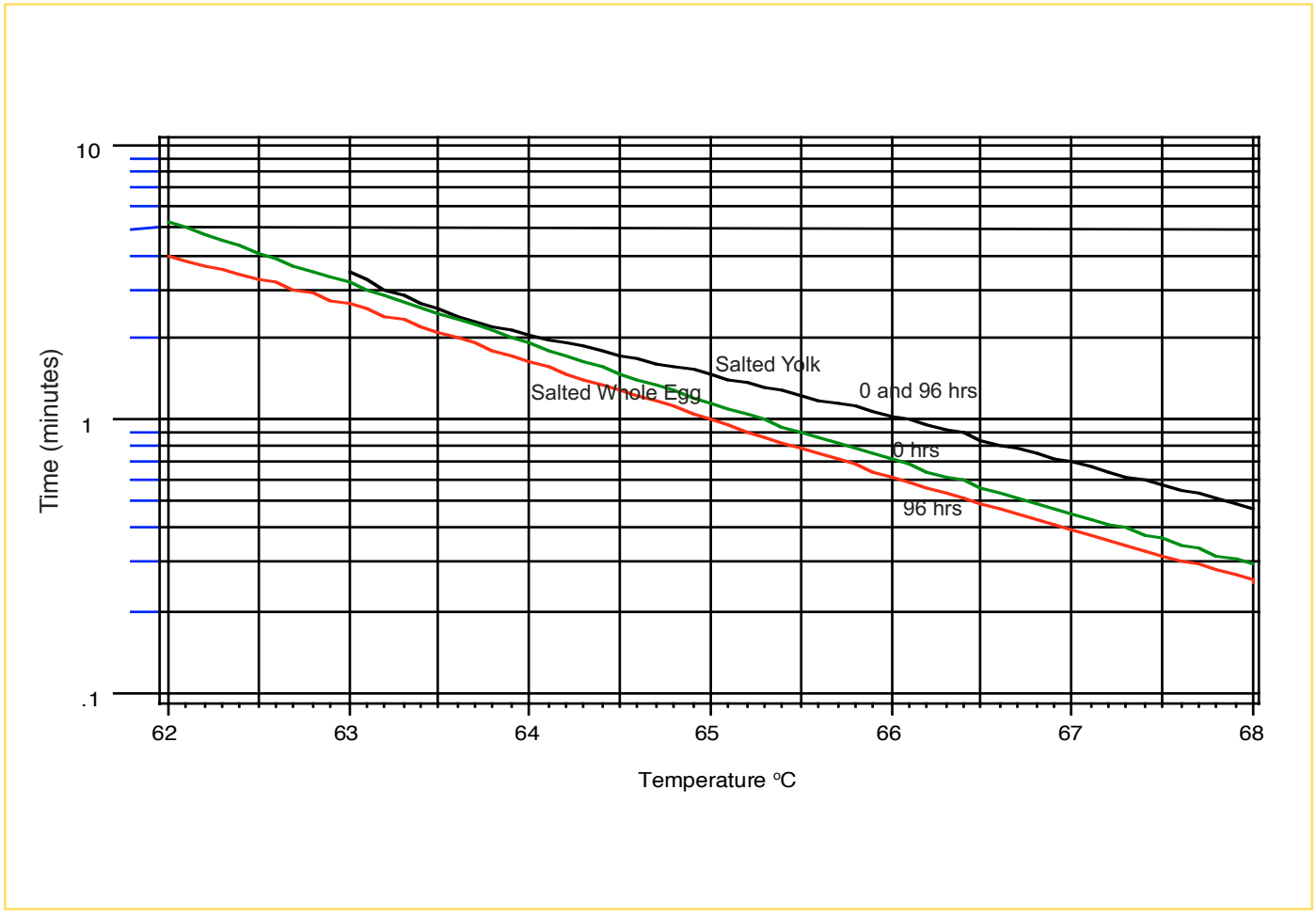
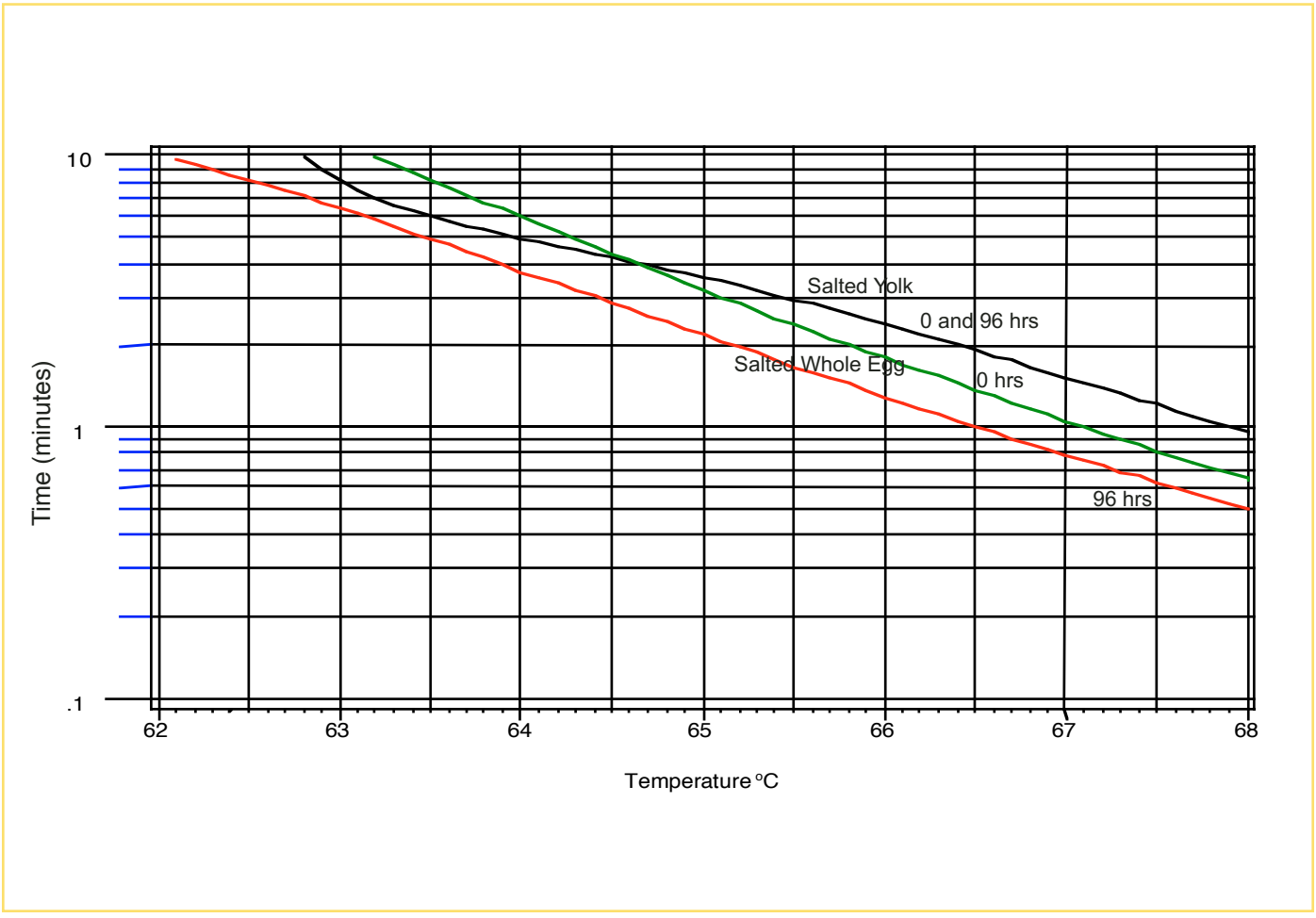


FIGURE 20. TIMES AND TEMPERATURES REQUIRED TO ACHIEVE A 7 LOG_{10} REDUCTION OF *SALMONELLA* POPULATIONS FROM AN INITIAL POPULATION OF APPROXIMATELY 9.3 LOG_{10} FOR LIQUID SALTED EGG YOLK AND LIQUID SALTED WHOLE EGG AT HOLDING TIMES OF 0 AND 96 HOURS



0 and 96 Hours Liquid Salted Egg Yolk
0 Hours Liquid Salted Whole Eggs
96 Hours Liquid Salted Whole Eggs

FIGURE 21. TIMES AND TEMPERATURES REQUIRED TO ACHIEVE A 5 LOG_{10} REDUCTION OF *SALMONELLA* POPULATIONS FROM AN INITIAL POPULATION OF APPROXIMATELY 9.3 LOG_{10} FOR LIQUID SUGARED EGG YOLK AND LIQUID SUGARED WHOLE EGG AT THE 0-HOURS HOLDING TIME

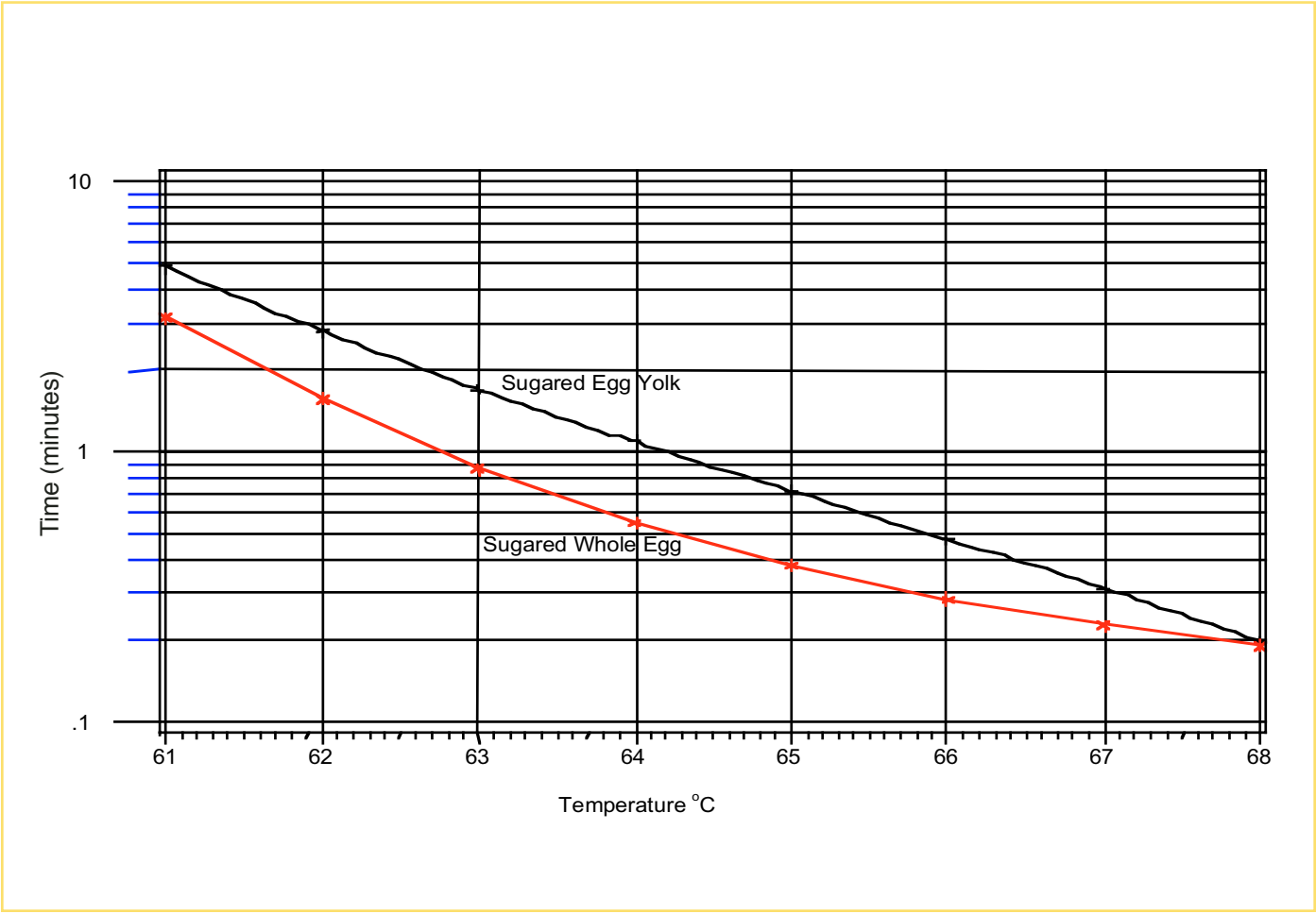


FIGURE 22. TIMES AND TEMPERATURES REQUIRED TO ACHIEVE A 5 LOG_{10} REDUCTION OF *SALMONELLA* POPULATIONS FROM AN INITIAL POPULATION OF APPROXIMATELY 9.3 LOG_{10} FOR LIQUID SUGARED EGG YOLK AND LIQUID SUGARED WHOLE EGG AT 96-HOURS HOLDING TIME

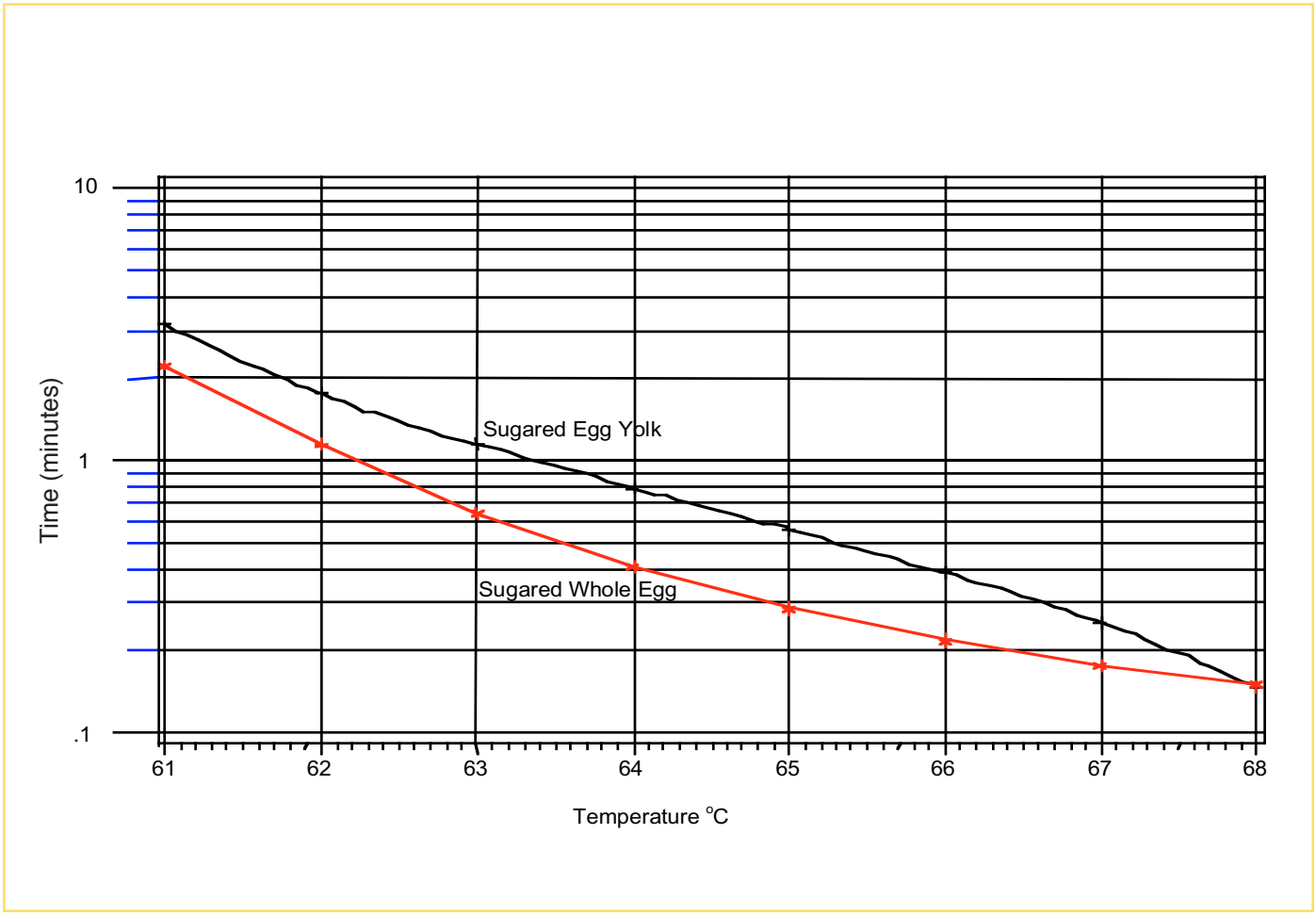


FIGURE 23. TIMES AND TEMPERATURES REQUIRED TO ACHIEVE A 7 LOG_{10} REDUCTION OF *SALMONELLA* POPULATIONS FROM AN INITIAL POPULATION OF APPROXIMATELY 9.3 LOG_{10} LIQUID SUGARED EGG YOLK AND LIQUID SUGARED WHOLE EGG AT 0-HOURS HOLDING TIME

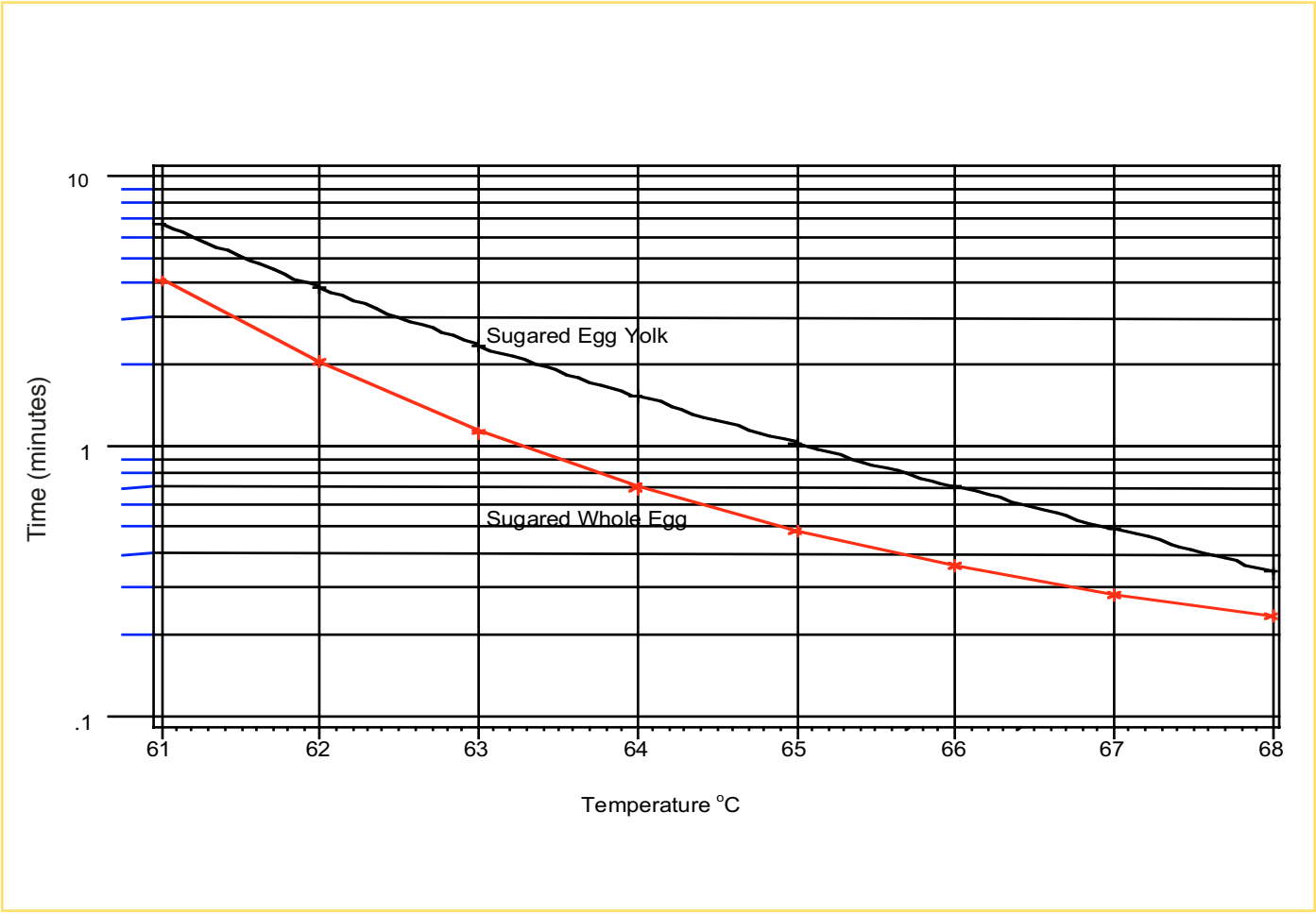


FIGURE 24. TIMES AND TEMPERATURES REQUIRED TO ACHIEVE A 7 LOG_{10} REDUCTION OF *SALMONELLA* POPULATIONS FROM AN INITIAL POPULATION OF APPROXIMATELY 9.3 LOG_{10} FOR LIQUID SUGARED EGG YOLK AND LIQUID WHOLE EGG AT 96-HOURS HOLDING TIME

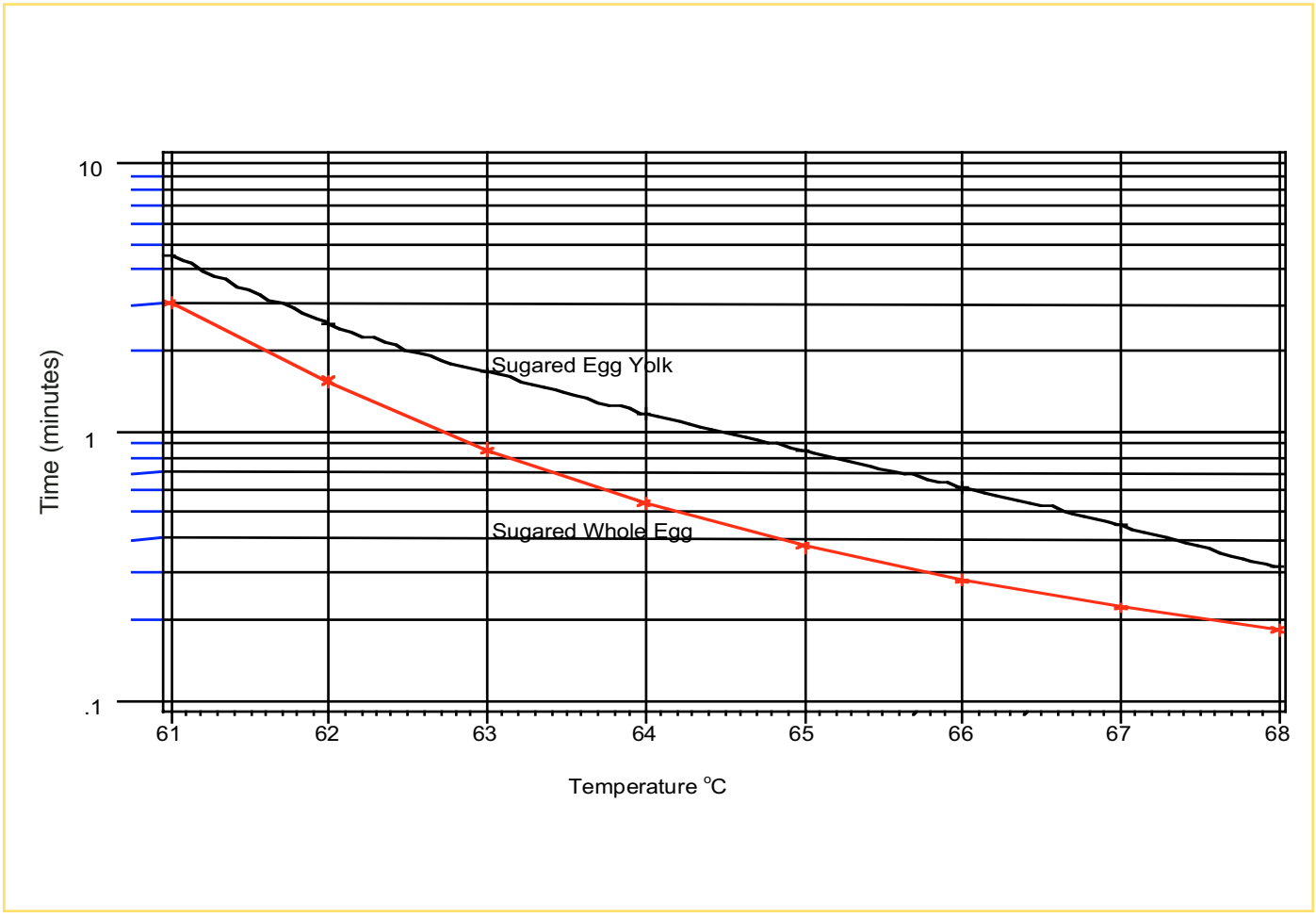
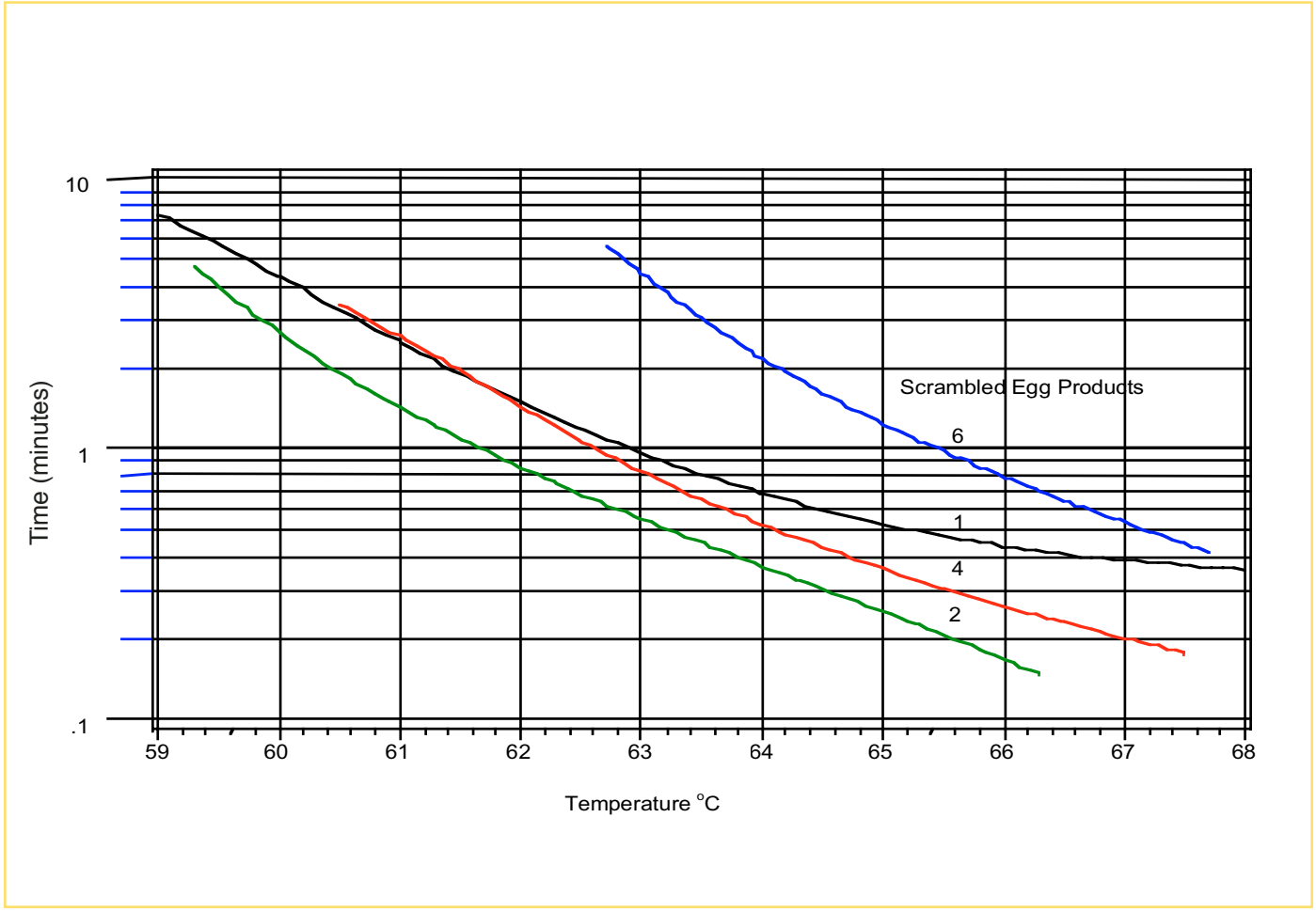
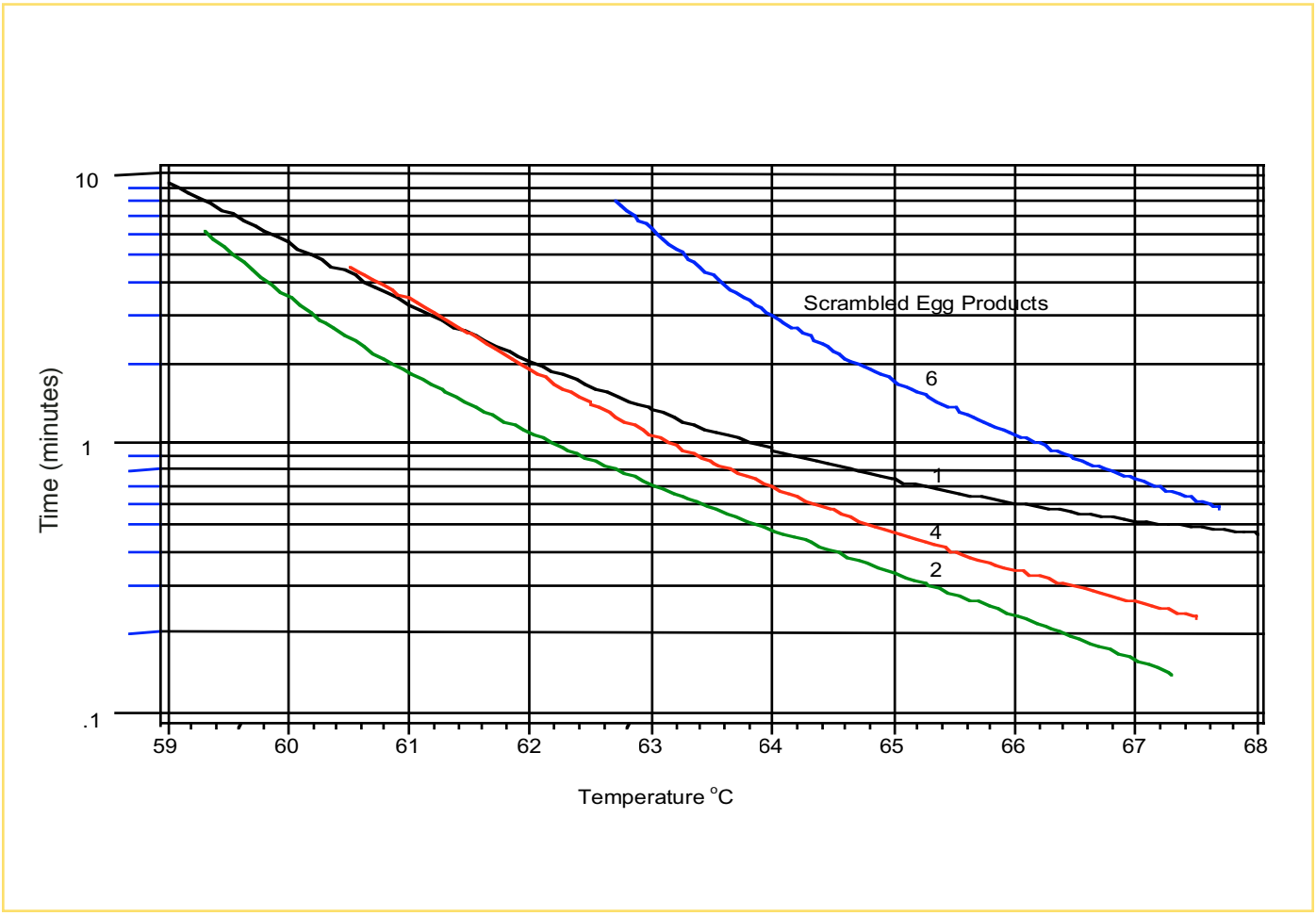


FIGURE 25. TIMES AND TEMPERATURES REQUIRED TO ACHIEVE A 5 LOG_{10} REDUCTION OF *SALMONELLA* POPULATIONS FROM AN INITIAL POPULATION OF APPROXIMATELY 9.3 LOG_{10} FOR SCRAMBLED EGG PRODUCTS 1, 2, 4 AND 6



- Liquid Fortified Egg Yolk – "Tex" Product (#6)
- Liquid Scrambled Egg Mix – USDA (#1)
- Liquid Fortified Whole Egg – "Tex" Product (#4)
- Liquid Scrambled Egg Mix – High Solids (#2)

FIGURE 26. TIMES AND TEMPERATURES REQUIRED TO ACHIEVE A 7 LOG_{10} REDUCTION OF *SALMONELLA* POPULATIONS FROM AN INITIAL POPULATION OF APPROXIMATELY 9.3 LOG_{10} FOR LIQUID SCRAMBLED EGG PRODUCTS 1, 2, 4 AND 6



- Liquid Fortified Egg Yolk – "Tex" Product (#6)
- Liquid Scrambled Egg Mix – USDA (#1)
- Liquid Fortified Whole Egg – "Tex" Product (#4)
- Liquid Scrambled Egg Mix – High Solids (#2)

Appendix B: Letters

USDA

United States Department of Agriculture

Office of the Secretary
Washington, D.C. 20250

Mr. Al Pope, President
United Egg Association
Suite 200, 1303 Hightower Trail
Atlanta, Georgia 30350

Dear Mr. Pope:

The United States Department of Agriculture (USDA) has a goal to provide safe and wholesome food to all consumers. No part of the Department plays a more critical role in public health than our food safety mission area.

The Office of Food Safety believes in science as the basis for enhancing food safety, and encourages collaborative efforts by industry and the scientific community to achieve this. The Egg Pasteurization Guidelines developed by scientists at the University of Nebraska and Oklahoma State University, through work supported by the egg products industry, are a good example of how such cooperation can work to the benefit of consumers.

USDA commends the United Egg Association's work on pasteurization guidelines and hopes that their application will enhance the safety of egg products.

Sincerely,

Dr. Elisa A. Murano
Under Secretary
Food Safety

United States Department of Agriculture
Food Safety Inspection Service
Washington, D.C. 20250

Mr. Al Pope, President
United Egg Producers
One Massachusetts Avenue, N.W. Suite 800
Washington, D.C. 20001

Dear Mr. Pope:

In 1996, the United Egg Producers (UEP) presented to the Food Safety Inspection Service (FSIS) a protocol for studying lethality kinetics of *Salmonella spp.* in liquid egg products. The study results were to be used in the development of industry guidelines for pasteurization treatment of liquid egg products. In a written letter to the UEP, FSIS agreed with the design of the study as spelled out in the protocol. The study was to be conducted under the direction of Dr. Glenn Froning of the University of Nebraska.

In the past year, data from the study were provided to FSIS for review and a series of meetings between FSIS and UEP representatives took place wherein issues concerning the data, statistical analysis and the application of the developed models were discussed.

FSIS believes the data from the University of Nebraska study provide a reliable source of information for use in developing models for predicting the lethality of *Salmonella spp.* for pasteurization treatments and thus can be considered in developing guidelines.

FSIS does not intend to in any way prescribe statistical procedures that can be used for developing models and derivative guidelines for pasteurization of liquid egg products. As with HACCP, FSIS expects that plants justify their pasteurization procedures on scientifically-based considerations.

Sincerely,

William J. Hudnall
Acting Administrator

United States Department of Agriculture
Food Safety Inspection Service

FSIS STATEMENT

Ken Klippen, Vice President
United Egg Producers
One Massachusetts Ave., N.W., Suite 800
Washington, D.C. 20001

Dear Ken:

In 1996, the United Egg Producers (UEP) presented to the Food Safety Inspection Service (FSIS) a protocol for studying lethality kinetics of *Salmonella spp.* in liquid egg products. The study results were to be used in the development of industry guidelines for pasteurization treatment of liquid egg products. In a written letter to the UEP, FSIS agreed with the design of the study as spelled out in the protocol. The study was to be conducted under the direction of Dr. Glenn Froning of the University of Nebraska.

In the past year, data from the study were provided to FSIS for review and a series of meetings between FSIS and UEP representatives took place wherein issues concerning the data, statistical analysis and the application of the developed models were discussed. The purpose of this letter is to express FSIS's opinion on the above issues.

FSIS believes that this study is the most extensive of its kind on liquid egg products with respect to the number of types of products covered, and thus, the results will be an important contribution to the scientific literature. The contribution is further enhanced because of the good repeatability of the results that were obtained from three independent replications performed for each product type studied. Thus, FSIS believes that these data could and should be used in considering time-temperature guidelines for pasteurization of liquid egg products.

FSIS does not intend to in any way prescribe statistical procedures that can be used for developing models and derivative guidelines for pasteurization of liquid egg products; as with HACCP, FSIS expects that plants justify their pasteurization procedures on scientifically-based considerations. FSIS believes the data from the University of Nebraska study provide a reliable source of information for use in developing models for predicting lethality of *Salmonella spp.* for pasteurization treatments, and thus, should be considered in developing guidelines.

The agency is willing to assist you in developing scientifically-based models and would be glad to comment on technical papers that you are developing for this purpose. My staff and I would be glad to further discuss with you matters raised in this letter.

Sincerely,

Judith W. Riggins
Associate Deputy Administrator
Office of Policy, Program Development
and Evaluation

United Egg Association

Al Pope*
President

Gene Gregory*
Sr. Vice President

Ken Klippen**
V.P. Government Relations

Michael McLeod**
Washington Counsel

Randy Green**
Sr. Government Relations Rep.

July 22, 2002

All Stakeholders:

On behalf of the United Egg Association's Further Processors Board of Directors, we want to acknowledge all the financial contributors, cooperation from the US Department of Agriculture, and certainly the authors, and UEA Technical Committee.

The pasteurization manual will provide the stakeholders a valuable resource in their current and future research and marketing activities.

Elliot Gibber, Chairman

Albert Pope, President

EG,AP/ck

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**One Massachusetts Ave., N.W., Suite 800 • Washington, D.C. 20001 • (202) 842-2345 • Fax (202) 682-0775 or (202) 408-7763

Mr. Al Pope, President
United Egg Producers
One Massachusetts Avenue, N.W. Suite 800
Washington, D.C. 20001

Dear Mr. Pope:

As Chairman of the International Egg Commission and a member of the European Egg Processors Association (EEPA), I am pleased to have been involved with this study.

This important work has updated our knowledge of effective pasteurisation and will be of great value to the egg products industry worldwide, as we all seek to achieve the highest standards of food safety.

Sincerely,

Clive Frampton
President
Framptons Ltd.
Somerset, England