Evaluating the Effectiveness of Pasteurization for Reducing Human Illnesses from *Salmonella* spp. in Egg Products: Results of a Quantitative Risk Assessment

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**Abstract**

As part of the process for developing risk-based performance standards for egg product processing, the United States Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) undertook a quantitative microbial risk assessment for *Salmonella* spp. in pasteurized egg products. The assessment was designed to assist risk managers in evaluating egg handling and pasteurization performance standards for reducing the likelihood of *Salmonella* in pasteurized egg products and the subsequent risk to human health. The following seven pasteurized liquid egg product formulations were included in the risk assessment model, with the value in parentheses indicating the estimated annual number of human illnesses from *Salmonella* from each: egg white (2636), whole egg (1763), egg yolk (708), whole egg with 10% salt (407), whole egg with 10% sugar (0), egg yolk with 10% salt (11), and egg yolk with 10% sugar (0). Increased levels of pasteurization were predicted to be highly effective mitigations for reducing the number of illnesses. For example, if all egg white products were pasteurized for a 6-log10 reduction of *Salmonella*, the estimated annual number of illnesses from these products would be reduced from 2636 to 270. The risk assessment identified several data gaps and research needs, including a quantitative study of cross-contamination during egg product processing and characterization of egg storage times and temperatures (i) on farms and in homes, (ii) for eggs produced off-line, and (iii) for egg products at retail. Pasteurized egg products are a relatively safe food; however, findings from this study suggest increased pasteurization can make them safer.

**Introduction**

The United States Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) regulates egg products under the authority of the Egg Products Inspection Act of 1970. It does so using what is sometimes termed a “command-and-control” approach by specifying to producers the precise minimum times and temperatures at which egg products must be held during the pasteurization process. Industry and consumer groups, however, have called for a move from command-and-control regulations to risk-based performance standards. In the case of *Salmonella* spp. in liquid or dried egg products, performance standards work by specifying the amount of pathogen reduction required during egg product pasteurization, rather than...
specifying minimum times and temperatures at which pasteurization must be performed. As such, performance standards allow processors greater flexibility in developing processes that control Salmonella contamination during egg product manufacture and increase the quality of the finished pasteurized product. Implementation of performance standards for egg product manufacture would complement the recently implemented 1996 Pathogen Reduction/Hazard Analysis and Critical Control Point Systems (PR/HACCP) rule by setting guidelines for industry to ensure the safety of egg products (Food Safety and Inspection Service, 1996).

By synthesizing available information into a framework for predicting changes in the occurrence of foodborne illness based on changes in the way foods are produced, processed, handled by the consumer, and consumed (Lammerding and Paoli, 1997), risk assessment is a valuable tool to assist risk managers during development of performance standards. Accordingly, in response to an increasing number of illnesses traced to Salmonella in eggs, FSIS in collaboration with the Food and Drug Administration (FDA), initiated in 1996 a farm-to-table risk assessment for Salmonella Enteritidis in shell eggs and egg products in an effort to target resources to achieve reductions in egg-related salmonellosis cases (FSIS/FDA, 1998). Results of the assessment provided insight into the factors thought to contribute to public health risks associated with Salmonella Enteritidis in eggs and egg products and suggested multiple interventions in the farm-to-table continuum were necessary to reduce substantially the risk of illness from eggborne Salmonella Enteritidis. These results were the basis for a comprehensive and coordinated federal and state action plan, the Egg Safety Action Plan (FSIS/FDA, 1999), designed to address the safety of shell eggs and egg products along the farm-to-table chain. It was during development of the plan that consumer groups and the egg industry cited the need for national egg safety performance standards to ensure all eggs meet uniform safety standards (FSIS/FDA, 1999).

Since the 1998 release of the risk assessment for Salmonella Enteritidis in eggs and egg products, important new information has become available to design improved risk assessments for Salmonella in eggs and egg products. For example, FSIS completed a national baseline study to quantify Salmonella in pasteurized egg products (Cook et al., 2004), data from which were useful for determining exposure of consumers to Salmonella in egg products. Important data were also generated by a study sponsored by the American Egg Board to determine the lethality kinetics of Salmonella in egg products (Froning et al., 2002). These data allowed us to model the effect of pasteurization in reducing the number of Salmonella in egg products. Also of importance, the Food and Agricultural Organization/World Health Organization (FAO/WHO) convened an expert panel to construct an updated dose-response model for Salmonella (FAO/WHO, 2002), which was important for estimating the probability of illness from consumption of Salmonella-contaminated egg products.

Based on this new information, and facilitated by improved modeling techniques, FSIS completed two new risk assessments—one for Salmonella Enteritidis in shell eggs and the other for Salmonella in liquid egg products. Draft versions of these risk assessments were reviewed by five independent scientists and preliminary results presented at an FSIS-sponsored meeting in Washington, DC, in October 2004. At the same time, stakeholder comments were solicited through the Federal Register. The risk assessments were updated based on these comments and full-length reports (including risk assessment models and itemized replies) were released in December 2005. The FSIS risk assessment for Salmonella Enteritidis in shell eggs has been described elsewhere (Schroeder et al., 2006). The purpose of the report presented here is to provide an overview and summary of the FSIS risk assessment for Salmonella in egg products.

Materials and Methods

The risk assessment model was written in Visual Basic for Applications (Microsoft, Redmond, WA), with inputs and outputs stored in Excel Spreadsheets (Microsoft). Monte Carlo simulation—a method of modeling numerical distributions to represent variability (Poschet et al., 2003)—was used to run the model. Scenarios were run for 100,000 iterations with a Pen-
The level of Salmonella in unpasteurized liquid egg product

FSIS conducted a national survey for Salmonella in unpasteurized liquid egg samples using a three-tube, three-dilution most probable number (MPN) procedure. The distribution of colony-forming units (CFUs) Salmonella per milliliter of liquid egg product was estimated for each of three product categories: liquid egg white, liquid whole eggs, and liquid egg yolk. Maximum Likelihood Estimation (MLE) was used to fit a Weibull distribution, with cumulative distribution function, $W(x) = 1 - \exp[-(x/c)^b]$, accounting for the measurement error associated with the MPN procedure. For description of survey design, experimental methods, and analyses of data, see Annex F of the risk assessment report at http://www.fsis.usda.gov/PDF/SE_Risk_Assess_Annex_F_Oct2005.pdf.

The fraction of Salmonella cells surviving pasteurization

The estimate of Salmonella cells surviving pasteurization ($L$) described as $-\log_{10}(p)$, where $p$ is the probability of an individual Salmonella cell surviving pasteurization, was used with information collected from 31 egg processing plants for pasteurization times and temperatures used in processing egg products (see pp. 54–59 in Annex G of the full-length risk assessment report at http://www.fsis.usda.gov/PDF/SE_Risk_Assess_Annex_G_Oct2005.pdf.). Predicted values of $p$ for given temperatures and times were made using lethality models developed by FSIS from data generated by Froning et al. (2002). Because, in practice, pasteurization of liquid egg products is done by passing product through heated pipes, we needed to account for variability in the velocity of individual egg product particles as they moved through the pipe. We assumed a laminar flow of liquid egg products through the pipes. Distribution of particle velocity was then estimated by assuming the amount of pasteurized product proportional to the cross section circumference of the pipe and the particle velocity. In particular, particle velocity was assumed proportional to $1 - x^2$, where $x$ is the relative distance from the center of the pipe ($x = 1$ means that the particle is at the interior edge of the pipe). Because current USDA regulations are specified for fastest particle speeds, for the calculations for net lethalities, the maximum velocity was assumed known (an input variable).
Growth of surviving Salmonella cells in pasteurized egg products

To model growth of Salmonella in liquid egg yolk or liquid whole egg product, we assumed that Salmonella cells surviving pasteurization in egg white products would not grow. This assumption was made because egg yolk, a rich nutrient source, is needed for bacterial growth. To model growth of Salmonella in liquid egg yolk or liquid whole egg product during the exponential phase of growth, a logistic growth curve

\[
\frac{dx(t)}{dt} = \mu x(t) \left[ 1 - \frac{x(t)}{M} \right]
\]

was used, where \(x(t)\) is the level of Salmonella (CFU/mL) at time \(t\); \(\mu\) is the maximum exponential growth rate; and \(M\) (10.59 log\(_{10}\) CFU/mL) is the maximum population level. The parameter \(\mu\) was modeled as a function of the temperature using a Ratkowsky equation

\[
\mu^{1/2} = (a + bT) \left\{ 1 - \exp\left[ c(T - T_{max}) \right] \right\}
\]

where \(T\) is temperature at time \(t\); \(T_{max}\) (45.6°C) the maximum temperature at which growth occurs; and \(a\), \(b\), and \(c\) are parameters estimated from data of observed generation times or exponential growth rates in egg yolk product (Fehlhaber and Kruger, 1998; Bradshaw et al., 1990; Schoeni et al., 1995; Gast and Holt, 2000, 2001; Saeed and Koons, 1993; Humphrey et al., 1991). For determining a complete growth curve that included a lag phase to account for time needed for the surviving Salmonella cells to recover and become acclimated to their environment, Equation 1 was embedded into a Baranyi growth curve (Baranyi and Roberts, 1994). Following an often-used assumption, the ratio of the duration of the lag phase to that of the exponential growth phase was assumed constant (= 5) for all temperatures. Growth was calculated by integrating over temperature as a function of time following standard procedures (Baranyi and Roberts, 1994). This procedure provides what can be termed a deterministic growth model. The model was extended to allow for stochastic (random) growth of Salmonella cells in the model (Marks and Coleman, 2005). The basic assumption for this was that the times for which cells were in lag phase or exponential growth phase were distributed exponentially.

The fraction of Salmonella cells surviving cooking

Pasteurized liquid egg products are typically cooked prior to consumption. Thus, as a final step to estimating levels of Salmonella in servings of pasteurized liquid egg products, the effect of cooking was modeled using data for cooking time and temperature and subsequent reduction of Salmonella in eggs (Humphrey et al., 1989; FSIS/FDA, 1998). It was assumed that all egg products consumed as a main meal were served either scrambled or as omelets. It was estimated that 49% of egg products served as main meals are cooked to a 4.9 log\(_{10}\) lethality of Salmonella, 49% are cooked to a 6.1 log\(_{10}\) lethality of Salmonella, and 2% are uncooked (no lethality). It was estimated that all egg products served as ingredients in mixtures (such as cakes) are cooked to a 12-log\(_{10}\) lethality of Salmonella. Finally, it was assumed that all egg products served in beverages (such as eggnog) are uncooked (i.e., no reduction of Salmonella).

The amount of liquid egg products consumed annually

The amount of liquid egg products consumed each year in the United States was estimated using data from the Continuing Survey of Food Intakes by Individuals (CSFII). The CSFII was conducted by telephone by the USDA in 1994–1996 and 1998 using a 2-day recall of survey respondents (respondents were asked to document food items they had eaten in the 2 days prior to the survey). It is a national probability survey of consumers (see http://www.barc.usda.gov/bhnrc/foodsurvey/home.htm).

Production weights of egg product formulations

Relative frequencies of seven egg product formulations—egg white, egg yolk, whole egg, egg yolk with 10% sugar, egg yolk with 10% salt, whole egg with 10% sugar, and whole egg with 10% salt—were obtained from data from the National Agricultural Statistics Service (National Agricultural Statistics Service, 1998).
The dose–response relationship for Salmonella infection in humans

The risk assessment model used a beta-Poisson dose–response relationship developed by the Food and Agricultural Organization/World Health Organization (2002). The relationship is described by

\[ I_s = 1 - \left(1 + \frac{S^2}{\beta}\right)^{-\alpha} \]  

(3)

where \( I_s \) is probability of illness per serving; \( S \) is the number of Salmonella cells at the point of consumption; \( \alpha = 0.1324 \); and \( \beta = 51.45 \). Based on this relationship, consuming one Salmonella cell gives an approximate 0.25% probability of illness. Because the relationship is a concave function, with a positive but steadily decreasing derivative, the rate of increase in the probability of illness per cell decreases with an increase in the number of cells. The dose–response relationship was developed from 20 outbreaks worldwide and included information for the following Salmonella serotypes: Enteritidis (12 strains), Typhimurium (3 strains), and Oranienburg, Newport, Infantis, Cubana, and Heidelberg (one strain each).

Estimating annual illnesses from Salmonella in pasteurized liquid egg products

The number of annual illnesses from Salmonella in pasteurized egg products was calculated by multiplying the probability of illness per liquid egg product serving by the number of egg product servings consumed per year.

Anchoring results from the risk assessment model

“Anchoring,” as used here, means that results from the risk assessment were adjusted to account for information from epidemiologic surveillance data. In the FSIS risk assessment for Salmonella Enteritidis in shell eggs, an adjustment factor, \( w \), was used to anchor final estimates to surveillance data. In brief, the unanchored model estimate for annual illnesses from Salmonella Enteritidis in shell eggs was about 350,000, whereas the estimate of annual illnesses from surveillance data was about 130,000 (for details see Schroeder et al., 2006). The value of \( w \) is the ratio of the latter estimate to the former one, or about 0.37. Therefore, all outputs of the risk assessment model obtained for any assumed scenarios were multiplied by 0.37. The same adjustment factor was used in the risk assessment for liquid egg products, described in this paper. The rationale for doing so was the belief that because outbreak investigations are done in a similar manner regardless of food vehicle (shell eggs or egg products), the same discrepancy between model predictions and outbreak-based estimates of illness from Salmonella in shell eggs would also exist for illness from Salmonella in egg products. Another common factor for both risk assessments was the dose–response curve (Equation 3). These two factors have great influence on the results of the risk assessments and thus without any other discriminating information available, a common anchoring adjustment factor \( w \), was used for both.

Sensitivity analysis

Nominal range sensitivity analysis was conducted to identify influential model parameters and data gaps in the risk assessment. All model inputs were set to their most likely values (baseline scenario) and the model was run for 100,000 iterations. Upper and lower bounds were then selected for each model input. For fixed inputs, bounds were selected by multiplying the input by a set factor. For distributional inputs, the distribution parameters such as the mean or standard deviation were adjusted. Some inputs were thought to be correlated with other inputs. If the correlation was below –0.5 or above 0.5 then the inputs were changed and evaluated separately. After selecting lower and upper bounds for each input or set of inputs, the model was run for 100,000 iterations for each lower and upper bound modeled. After each input was evaluated at its lower and upper bound, the input was changed to its most likely value and the next input was evaluated.

Results

Figure 2 shows the estimated cumulative distribution of the number of Salmonella cells in...
unpasteurized liquid egg products, represented as the number of cells per serving. The number is reflective of (i) the *Salmonella* concentration per milliliter of liquid egg product and (ii) the variability in serving sizes. Thus, larger serving sizes result in exposure to more bacteria, on average. The mean level for *Salmonella* in liquid egg white before pasteurization was 83 CFU/mL; within liquid whole eggs, 160 CFU/mL; and within liquid egg yolk, 287 CFU/mL.

Figure 3 shows the fraction of *Salmonella* predicted to survive pasteurization. Note that liquid egg white product would be expected to have a relatively large fraction of bacteria surviving pasteurization compared to the other products. In contrast, there was a predicted virtually zero probability of bacteria surviving pasteurization in whole egg product with 10% added sugar. These observations are related to the predicted log$_{10}$ reductions for the time and temperature values listed in Table 1. These time and temperature values are the present regulatory required minimum times and temperatures. Note that temperature is an extremely sensitive input to the calculation for the pasteurization factor for liquid egg white. Increasing the temperature from 56.7°C to 57.0°C (while keeping the pasteurization time constant) decreases the pasteurization factor from $5.6 \times 10^{-3}$ to about $1 \times 10^{-4}$; further increasing the temperature to 58.0°C decreases the pasteurization factor to about $1 \times 10^{-8}$, or an 8-log$_{10}$ reduction due to pasteurization. From information collected in the aforementioned FSIS survey of 31 processing plants, many plants that process egg whites use higher temperatures and longer times than those required by FSIS. However, there are plants that stated that they use the minimum required temperatures and times, thus causing the relatively high survival probability of *Salmonella* in the egg white product.

Growth of *Salmonella* that survive pasteurization is minimal because of the quick cooling and low storage temperatures at which the pasteurized liquid egg products are expected to be held. The model outputs reflect this. No

### Table 1. Current Time–Temperature Requirements and Expected *Salmonella* log$_{10}$ Reductions for Pasteurized Liquid Egg Products

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Liquid egg product</th>
<th>Time (minutes)</th>
<th>Temp (°C)</th>
<th>log$_{10}$ reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td></td>
<td>3.5</td>
<td>56.67</td>
<td>−3.3</td>
</tr>
<tr>
<td>Whole</td>
<td></td>
<td>3.5</td>
<td>60.00</td>
<td>−5.9</td>
</tr>
<tr>
<td>Yolk</td>
<td></td>
<td>3.5</td>
<td>61.11</td>
<td>−5.5</td>
</tr>
<tr>
<td>Whole 10% salt</td>
<td></td>
<td>3.5</td>
<td>62.22</td>
<td>−6.0</td>
</tr>
<tr>
<td>Whole 10% sugar</td>
<td></td>
<td>3.5</td>
<td>62.22</td>
<td>−42.0</td>
</tr>
<tr>
<td>Yolk 10% salt</td>
<td></td>
<td>3.5</td>
<td>63.33</td>
<td>−7.2</td>
</tr>
<tr>
<td>Yolk 10% sugar</td>
<td></td>
<td>3.5</td>
<td>63.33</td>
<td>−12.4</td>
</tr>
</tbody>
</table>

**FIG. 2.** Fitted cumulative frequency of log$_{10}$ *Salmonella* per serving of egg white, yolk, and whole egg product before pasteurization.

**FIG. 3.** Fraction of *Salmonella* surviving pasteurization in each of seven liquid egg product formulations.

**FIG. 4.** Growth of *Salmonella* in pasteurized liquid egg products.
contaminated servings had more than $2\log_{10}$ Salmonella growth; the maximum Salmonella growth predicted in pasteurized liquid egg white was less than $0.5\log_{10}$ (Fig. 4).

Data from the CSFII are shown in Table 2. Because the CSFII was a 2-day recall survey, the number of egg product servings reported through the survey was multiplied by 182.5 ($365/2$) to estimate the annual number of egg product servings—approximately 47 billion. The fraction of egg product servings represented by each egg product type is shown in Figure 5. Based on this information, the predicted illnesses per serving were computed (Table 3). Pasteurized liquid egg white was associated with the highest probability of illness per serving. Liquid egg products with added ingredients tended to be associated with lower probabilities of illness. Estimating the total illnesses from Salmonella in liquid egg products for a given year in the United States was accomplished by multiplying the probability of illness per serving by the total number of servings consumed. The number of predicted annual illnesses from Salmonella in pasteurized liquid egg products is shown in Table 4 in the row marked “baseline” (current practices). The remaining rows of the table show the predicted effect of various pasteurization scenarios on the number of annual illnesses.

Sensitivity analysis showed that the effect of changing upper and lower bounds of model parameters was similar for each of the seven egg product types. The most influential model parameters were those related to (i) cooking of egg products during preparation and (ii) Salmonella contamination of unpasteurized egg products.

**Discussion**

Though epidemiologic data have implicated shell eggs as important vehicles of illness in foodborne outbreaks of salmonellosis (Patrick et al., 2004), pasteurized liquid or dried egg products appear to be very safe. Indeed, to the best of our knowledge, no outbreak of illness with Salmonella has been linked to consumption of pasteurized egg products since passage of egg product pasteurization regulations in 1970. The first issue to address, therefore, is the apparent discrepancy between the epidemiologic data and the results of the risk assessment described in this report.

It is possible that each year, no one becomes ill from consumption of Salmonella in pasteurized egg products. We hypothesize, however, that consumption of pasteurized egg products does cause cases of illness with Salmonella, albeit relatively few. Our hypothesis is based on two lines of reasoning.

First, Salmonella have been recovered from raw and, more tellingly, pasteurized egg products (White et al., 2007). Over a 16-month period in 2002–2003 in which 375 raw whole egg, 340 raw egg whites, and 319 raw egg yolk product samples were analyzed for Salmonella, 80%, 74%, and 67%, respectively, were found positive for Salmonella, including Salmonella Heidelberg (49% of the positive samples) and Salmonella Enteritidis (41% of the positive samples) (Cook et al., 2004). In an FSIS survey of pasteurized egg products from federally inspected establishments for the years 1995 through 2003, Salmonella were recovered from 79 (0.01%) of 14,606 products sampled (FSIS, 2005). Though it is unclear whether the presence of Salmonella in

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**Table 2. Number of Liquid Egg Product Servings for Two Days in the United States Determined from the Continuing Survey of Food Intake by Individuals (CSFII), 1994–1996, 1998**

<table>
<thead>
<tr>
<th>Meal type</th>
<th>Main meal</th>
<th>Beverage</th>
<th>Ingredient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption average (g/p/d)</td>
<td>77.8</td>
<td>182.5</td>
<td>36.0</td>
</tr>
<tr>
<td>Std Dev (g)</td>
<td>49.0</td>
<td>75.1</td>
<td>71.0</td>
</tr>
<tr>
<td>Eating occasions</td>
<td>32,345,212</td>
<td>286,428</td>
<td>226,268,156</td>
</tr>
</tbody>
</table>

**FIG. 5.** Fraction of market and production in pounds of seven formulations of pasteurized liquid egg products.
pasteurized egg products is the result of incomplete pasteurization or postpasteurization contamination, or both, it is reasonable to assume that people become exposed to *Salmonella* by consuming pasteurized egg products, notwithstanding that egg products are often reheated prior to consumption.

Second, surveillance for foodborne illness does not always delineate illnesses from *Salmonella* in shell eggs versus those from *Salmonella* in egg products. The Centers for Disease Control and Prevention (CDC) conducts surveillance for illnesses from *Salmonella* through two programs: the Foodborne Diseases Active Surveillance Network (FoodNet) and the National *Salmonella* Surveillance System of the Public Health Laboratory Information System (PHLIS). When a suspected outbreak of foodborne salmonellosis is investigated, it is not always possible to identify the food vehicle. Further, if a vehicle is identified, it may be difficult to identify the precise nature of the ingredients in the vehicle. Hollandaise sauce, for example, may be implicated in an outbreak of illness, but whether the sauce was made with shell eggs or egg products may be unknown (CDC, 2005).

Assuming, therefore, that consumption of pasteurized egg products causes illness, the risk assessment model described here can provide an informative tool, both for evaluating mitigations for reducing foodborne salmonellosis and for identifying data gaps and research needs. The key mitigation examined in this risk assessment was that of changes in the level of pasteurization of liquid egg products. Predictions from the model suggest that by increasing pasteurization levels, the number of illnesses from *Salmonella* in liquid egg products can be reduced.

There are, of course, limitations to these types of straightforward calculations. First, we do not know whether the baseline values used in the risk assessment are reflective of all liquid egg

### Table 3. Frequency of Illness per Serving from *Salmonella* in Pasteurized Egg Products

<table>
<thead>
<tr>
<th>Liquid egg product type</th>
<th>White</th>
<th>Whole</th>
<th>Yolk</th>
<th>Whole + 10% salt</th>
<th>Whole + 10% sugar</th>
<th>Yolk + 10% salt</th>
<th>Yolk + 10% sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of illness per serving</td>
<td>$3.3 \times 10^{-7}$</td>
<td>$8.2 \times 10^{-8}$</td>
<td>$3.5 \times 10^{-7}$</td>
<td>$6.8 \times 10^{-8}$</td>
<td>$&lt;10^{-12}$</td>
<td>$7.6 \times 10^{-9}$</td>
<td>$&lt;10^{-12}$</td>
</tr>
</tbody>
</table>

### Table 4. Predicted Effect of log$_{10}$ Reduction of *Salmonella* from Pasteurization of Egg Products on Annual Number of Illnesses

<table>
<thead>
<tr>
<th>Log$_{10}$ reduction</th>
<th>White</th>
<th>Whole</th>
<th>Yolk</th>
<th>Whole + 10% salt</th>
<th>Whole + 10% sugar</th>
<th>Yolk + 10% salt</th>
<th>Yolk + 10% sugar</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline*</td>
<td>2,636</td>
<td>1,763</td>
<td>708</td>
<td>407</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>5,526</td>
</tr>
<tr>
<td>−3.0</td>
<td>140,551</td>
<td>545,757</td>
<td>59,613</td>
<td>159,632</td>
<td>166,766</td>
<td>41,550</td>
<td>63,462</td>
<td>1,177,331</td>
</tr>
<tr>
<td>−3.5</td>
<td>59,541</td>
<td>251,449</td>
<td>29,191</td>
<td>71,735</td>
<td>76,118</td>
<td>20,812</td>
<td>31,227</td>
<td>540,073</td>
</tr>
<tr>
<td>−4.0</td>
<td>22,656</td>
<td>103,794</td>
<td>13,138</td>
<td>28,781</td>
<td>31,005</td>
<td>9,388</td>
<td>13,901</td>
<td>222,663</td>
</tr>
<tr>
<td>−4.5</td>
<td>7,893</td>
<td>38,673</td>
<td>5,379</td>
<td>10,801</td>
<td>11,715</td>
<td>3,884</td>
<td>5,718</td>
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<td>−5.0</td>
<td>2,636</td>
<td>13,229</td>
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<td>708</td>
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<td>−6.0</td>
<td>270</td>
<td>1,407</td>
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<td>407</td>
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<td>−6.5</td>
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<td>447</td>
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<td>131</td>
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<td>81</td>
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<td>−7.0</td>
<td>27</td>
<td>140</td>
<td>25</td>
<td>41</td>
<td>43</td>
<td>17</td>
<td>26</td>
<td>319</td>
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<tr>
<td>−7.5</td>
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<td>8</td>
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<td>14</td>
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<td>−9.5</td>
<td>0</td>
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*"Baseline" refers to current practices. *Salmonella* log$_{10}$ reductions for the baseline scenario were determined from current time-temperature regulations for pasteurization of liquid egg products (see Table 1).
product processors. If, for instance, most liquid egg products are pasteurized at higher temperatures and/or for longer times than those specified by current regulations, then the predicted effectiveness of the increased pasteurization scenarios described in this report would be off-scale. Second, a consideration not addressed in this risk assessment is the effect of increased pasteurization on egg product quality. For example, it is possible that pasteurizing egg products to achieve a 7-log$_{10}$ reduction of *Salmonella* would result in a final product with altered consistency. As a result, the real world feasibility of increased pasteurization should be scrutinized.

One of the strengths of risk assessment modeling is that it offers a formalized approach for collating and analyzing existing data. Because they are iterative in nature, risk assessment models can be built with incomplete data and assumptions, and updated as new data become available. As such, an important component of risk assessment is the use of sensitivity analyses to identify the most influential parameters of the risk assessment model. The results of sensitivity analyses indicated that for the risk assessment model described here, the initial levels of *Salmonella* in unpasteurized egg products and the way in which those products are prepared for consumption had the greatest impact on human health.

In addition to identifying influential model parameters, sensitivity analyses are also useful for identifying data gaps and, consequently, helping to prioritize research needs. Sensitivity analyses of the risk assessment model for *Salmonella* in egg products indicated at least two important research needs should be addressed prior to future risk assessment models for *Salmonella* in egg products: (i) a quantitative study of cross-contamination during liquid egg product processing; and (ii) characterization of egg storage times and temperatures on farms and in homes, for eggs produced off-line, and for egg products at retail.

**Conclusions**

This report summarizes the FSIS risk assessment for *Salmonella* in egg products. The risk assessment model, which is equipped with a user-friendly interface so that users can change model inputs and rerun the model to examine the impact on predicted human illnesses, is available at http://www.fsis.usda.gov/Science/Risk_Assessments/index.asp. We encourage interested parties to download the model and use it.

**Acknowledgments**

We thank Alice Thaler and Joshua Gurtler for helpful comments during preparation of the manuscript.

**References**


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