THE DEVELOPMENT OF A RISK ASSESSMENT MODEL FOR USE IN THE POULTRY INDUSTRY

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ABSTRACT

A simulation model that assesses the risk of acquiring salmonellosis from consumption and handling of chicken was created in an Excel™ spreadsheet and was simulated using @Risk™. The model simulated the distribution, preparation, and consumption of 1,000 chickens and was designed to determine the relationship between the level of Salmonella *contamination on chickens at the processing plant exit and the risk of salmonellosis for consumers of the chickens. A scatter plot of the probability of acquiring salmonellosis from consumption of the chickens simulated versus the* Salmonella *load on the chickens at the processing plant exit clearly showed that highly (i.e., > 100* Salmonella*/bird) contaminated chickens at the plant exit did not necessarily pose greater risk of salmonellosis than lightly (i.e., < 10* Salmonella*/bird) contaminated chickens at the plant exit. Rather, greater risk of salmonellosis was realized from lightly contaminated chickens when they were temperature-abused, undercooked, and consumed by someone from the high risk population.*

INTRODUCTION

Risk assessment of microbial hazards in food involves four components: hazard identification, exposure assessment (i.e., dose consumed), dose-response assessment (i.e., infectious dose), and risk characterization (i.e., probability of infection) (Rose *et al.* 1995). Epidemiological studies indicate that *Salmonella spp.* are a primary microbial hazard associated with poultry products (Bryan and Doyle 1995). The risk or probability of acquiring salmonellosis from consump-

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tion of poultry products depends on the *Salmonella* load of the poultry product at consumption, the amount of poultry product consumed, and the infectious dose of *Salmonella*. In turn, the infectious dose of *Salmonella* is a function of the virulence of the *Salmonella* strain, the composition of the food, and the physiological state of the consumer.

With the advent of computer software programs, such as @Risk™, that perform simulations of models created in common spreadsheet programs, such as Excel™, it is now possible to create computer models that predict the risk of salmonellosis from poultry products produced by specified farm-to-table scenarios (Whiting and Buchanan 1997). In the present paper, I describe and demonstrate a simulation model that assesses the risk of acquiring salmonellosis from consumption of chicken. The model simulates the distribution, preparation, and consumption of 1,000 chickens and was designed to determine the relationship between the level of *Salmonella* contamination of chickens leaving the processing plant and the risk of salmonellosis for consumers who ate the chickens.

APPROACH

Model Design

Figure 1 shows the layout of the risk assessment model. The model was constructed in an Excel™ spreadsheet and was simulated using @Risk™ (Palisade Corp., Newfield, NY). The model consisted of nine nodes. The first three nodes in the model were a series of pathogen events that modeled the change in *Salmonella* load of the chickens as they moved from the processing plant exit to consumption. Node four modeled direct consumption of *Salmonella* from cooked chicken, node five modeled indirect consumption of *Salmonella* from handling the raw chicken, node six calculated the total dose of *Salmonella* consumed, node seven modeled the infectious dose of consumers in the normal population, node eight modeled the infectious dose of consumers in the high risk population, and node nine calculated the probability of salmonellosis for each consumption event.

The variability of *Salmonella* load among chickens in the flock and the variability of chicken consumption and infectious dose among consumers were modeled using a combination of probability distributions. A Discrete distribution was used to model the incidence of these nodes, whereas a Pert distribution was used to model the extent of these nodes. A Pert distribution is a continuous distribution that is defined by three values: minimum, most likely, and maximum. The shape of the Pert distribution can vary from normal to log normal depending on the values used to define it.

		Extent			
Node	Incidence	Minimum	Most Likely	Maximum	Output
Raw Chicken	20%	0 log	1.0 log	3.0 log	7
Temperature Abuse	20%	0.1 log	0.5 log	3.0 log	335
Cooking	20%	-2.0 log	-1.5 log	-1 log	0
Consumption, Direct	100%	15%	25%	50%	0
Consumption, Indirect	25%	1%	2%	5%	8.7
Dose Consumed					8.7
Infectious Dose, Normal	80%	500	750	1000	
Infectious Dose, High Risk	20%	50	200	350	142
Probability of Salmonellosis					6.2%

FIG. 1. SIMULATION MODEL FOR ASSESSING THE PROBABILITY OF ACQUIRING SALMONELLOSIS FROM CONSUMPTION OF CHICKEN
Output results are for iteration 844 and are expressed as *Salmonella*/bird.

During simulation of the current model (Fig. 1), @Risk randomly sampled the Pert distribution for each node as a function of their incidence and used the random numbers selected to calculate the outputs of the model. The model was simulated once using Latin hypercube sampling and 1,000 iterations. The following outputs were calculated by the model: (1) the *Salmonella* load of raw chicken at the processing plant exit; (2) the *Salmonella* load of raw chicken after temperature abuse during distribution and meal preparation; (3) the *Salmonella* load of cooked chicken; (4) the dose of *Salmonella* consumed directly from cooked chicken; (5) the dose of *Salmonella* consumed indirectly from handling of raw chickens; (6) the total dose of *Salmonella* consumed; (7) the infectious dose of *Salmonella*; and (8) the probability of acquiring salmonellosis from consumption of chicken. The results of iteration 844 from the simulation are shown in Fig. 1 as an example of the output generated by the model.

RESULTS AND DISCUSSION

Salmonella Load of Raw Chicken at the Processing Plant Exit

The model (Fig. 1) was defined such that 20% or 200 of the 1,000 chickens simulated were contaminated with *Salmonella* at the plant exit. The extent of contamination of the 200 *Salmonella*-positive chickens was modeled by a Pert distribution defined by a minimum value of 0 log or 1 *Salmonella*, a most likely value of 1 log or 10 *Salmonella*, and a maximum value of 3 log or 1,000 *Salmonella*. During simulation of the model, @Risk randomly sampled the Pert distribution to determine the level of contamination of each of the 200 *Salmonella*-positive chickens. The level of contamination ranged from 1 to 953 *Salmonella* per bird (Fig. 2) which is in agreement with published data (Surkiewicz *et al.* 1969).

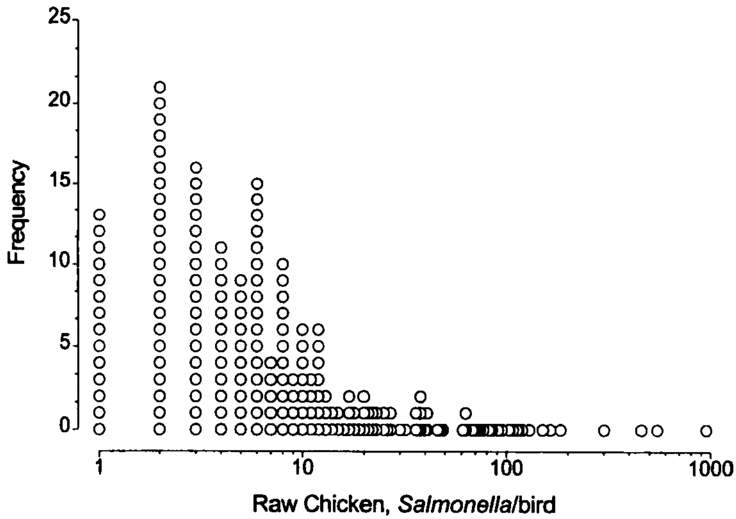

FIG. 2. FREQUENCY DISTRIBUTION OF THE *SALMONELLA* LOAD OF 200 *SALMONELLA*-POSITIVE CHICKENS AS THEY LEFT THE PROCESSING PLANT

Salmonella Load of Raw Chicken after Temperature Abuse

The second node in the model (Fig. 1) simulated temperature abuse that resulted in growth of *Salmonella* on the chickens during distribution and meal preparation. Similar to contamination of the raw chickens, temperature abuse was modeled by considering its incidence and extent. Although a consumer survey by Worsfold and Griffith (1997) indicated that 45% of consumers temperature abuse their food during transport, the incidence of temperature abuse during distribution and meal preparation was set at 20% in the current model and the variation of the extent of *Salmonella* growth on the chickens during temperature abuse was defined by a Pert distribution with a minimum value of a 0.1 log cycle increase, a most likely value of a 0.5-log cycle increase, and a maximum value of a 3.0 log cycle increase. Results of the simulation indicated that of the 200 *Salmonella*-positive chickens at the plant exit only 33 underwent temperature abuse (i.e., those circular symbols in Fig. 3 above the circular symbols that form a straight line) during distribution and meal preparation. The level of contamination of the 200 *Salmonella*-positive chickens after temperature abuse ranged from 1 to 11,814 *Salmonella* per bird (Fig. 3).

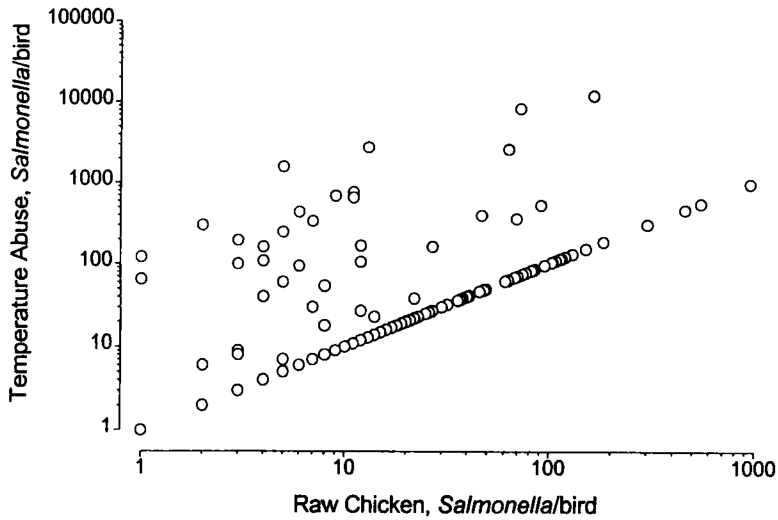

FIG. 3. SCATTER PLOT OF THE *SALMONELLA* LOAD OF RAW CHICKENS AFTER TEMPERATURE ABUSE DURING DISTRIBUTION AND MEAL PREPARATION VERSUS THEIR *SALMONELLA* LOAD AT THE PROCESSING PLANT EXIT

Salmonella Load of Cooked Chicken

The third node in the model (Fig. 1) simulated the impact of cooking on the number of *Salmonella* consumed. Results of a survey by Worsfold and Griffith (1997) indicated that 15% of consumers undercook their food. In the current model, cooking was defined such that 20% of the chickens were undercooked resulting in 1 to 10% survival of the contaminating *Salmonella*. It was assumed that the other 80% of the chickens were properly cooked resulting in no survival of *Salmonella*. Results of the simulation indicated that of the 200 chickens contaminated with *Salmonella* at the plant exit only nine were undercooked resulting in survival of between 1 and 445 *Salmonella* per bird (Fig. 4).

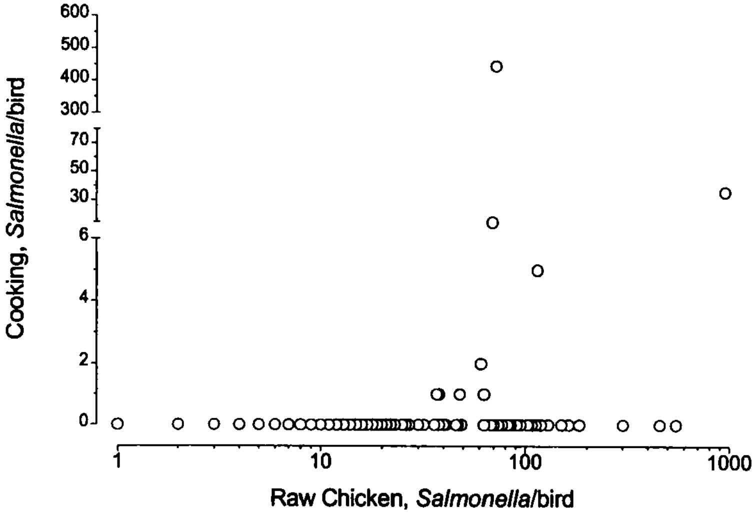

FIG. 4. SCATTER PLOT OF THE *SALMONELLA* LOAD OF COOKED CHICKENS VERSUS THEIR *SALMONELLA* LOAD AT THE PROCESSING PLANT EXIT

Direct Dose of *Salmonella* Consumed from Cooked Chicken

The dose of *Salmonella* consumed directly from cooked chicken was calculated by multiplying the amount of chicken consumed by the *Salmonella* load of the chicken after cooking. The variation in the amount of a chicken consumed was modeled by a Pert distribution with a minimum value of 15%, a most likely value of 25%, and a maximum value of 50%. Of the 200 *Salmonella*-positive chickens at the plant exit only nine were still contaminated after cooking and thus, resulted in direct consumption of *Salmonella* by consumers. The direct dose of *Salmonella* consumed from these nine chickens ranged from 0.3 to 102.7 *Salmonella*/bird (Fig. 5). The direct dose of *Salmonella* consumed was expressed as a fraction because it was a probability that was calculated by assuming that the contaminating *Salmonella* were uniformly distributed on the chicken.

Indirect Dose of *Salmonella* Consumed from Handling of Raw Chicken

The average amount of chicken consumed by consumers was 25%. Thus, each chicken was consumed on average by four consumers. It was assumed that one of these four consumers was the food handler who prepared the chicken for consumption. Thus, the incidence of indirect consumption of *Salmonella* by consumers was 25% (Fig. 1). The extent of indirect consumption of *Salmonella* by food handlers was defined by a Pert distribution with a minimum value of 1%, a most likely value of 2%, and a maximum value of 5%. Results of the simulation indicated that of the 200 *Salmonella*-positive chickens at the plant exit, 61 resulted in ingestion of *Salmonella* by food handlers. The dose of *Salmonella* ingested by food handlers ranged from 0.015 to 310 *Salmonella* (Fig. 6) and was calculated by multiplying the *Salmonella* load after temperature abuse by the percentage of *Salmonella* ingested by food handlers.

FIG. 5. SCATTER PLOT OF THE DOSE OF *SALMONELLA* CONSUMED FROM COOKED CHICKENS VERSUS THEIR *SALMONELLA* LOAD AT THE PROCESSING PLANT EXIT

Total Dose of *Salmonella* Consumed

The total dose of *Salmonella* consumed was obtained by adding the dose of *Salmonella* consumed directly from the cooked chicken to the dose of *Salmonella* consumed from handling the raw chicken. Of the 200 *Salmonella*-positive chickens at the plant exit, none of the nine chickens still contaminated after cooking were consumed by food handlers. Thus, the total number of chickens that resulted in a dose of *Salmonella* consumed was 70. The total dose consumed from these 70 chickens ranged from 0.015 to 310 *Salmonella* (Fig. 7).

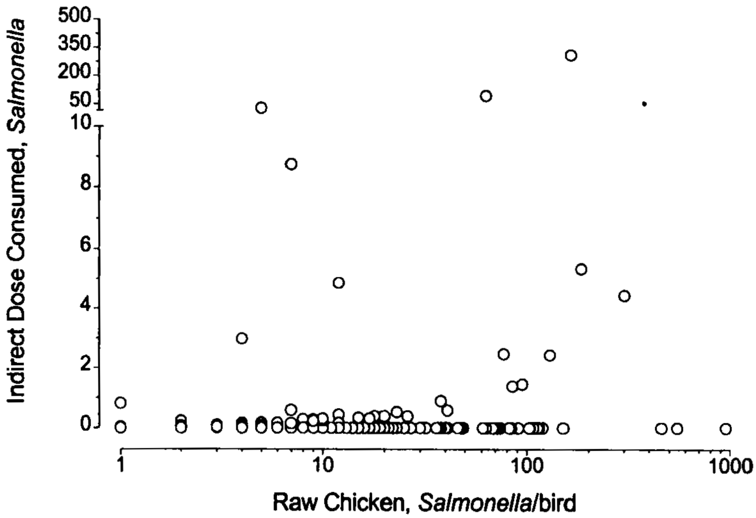

FIG. 6. SCATTER PLOT OF THE DOSE OF *SALMONELLA* CONSUMED FROM HANDLING RAW CHICKENS VERSUS THEIR *SALMONELLA* LOAD AT THE PROCESSING PLANT EXIT

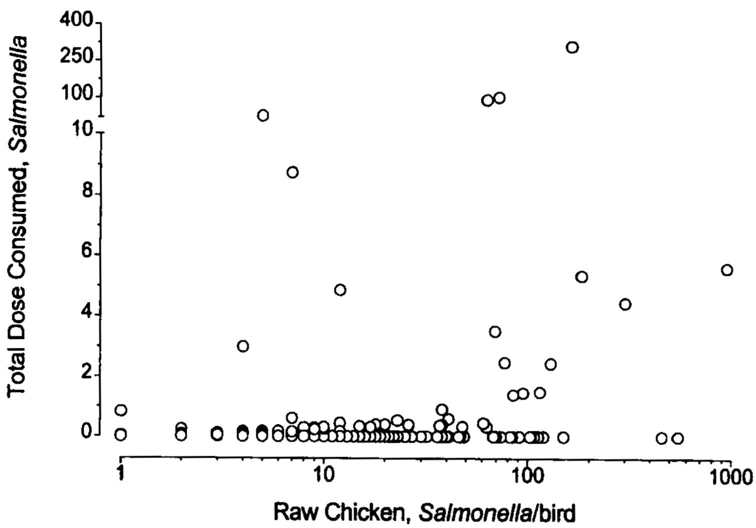

FIG. 7. SCATTER PLOT OF THE TOTAL DOSE OF *SALMONELLA* CONSUMED FROM CONSUMPTION AND HANDLING OF CHICKENS VERSUS THEIR *SALMONELLA* LOAD AT THE PROCESSING PLANT EXIT

Infectious Dose

Infectious dose was defined such that 80% of consumers were from the normal population and 20% were from the high risk (i.e., immunocompromised) population. The Pert distribution for infectious dose of individuals in the normal population was defined by a minimum value of 500 *Salmonella*, a most likely value of 750 *Salmonella*, and a maximum value of 1,000 *Salmonella* (Fig. 1). The Pert distribution for infectious dose of individuals in the high risk population was defined by a minimum value of 50 *Salmonella*, a most likely value of 200 *Salmonella*, and a maximum value of 350 *Salmonella* (Fig. 1). The values used to define infectious dose in the model are consistent with those reported for *Salmonella* which range from 10^1 to 10^9 depending on the strain of *Salmonella* and food vehicle (Blaser and Newman 1982). For the 200 *Salmonella*-positive chickens at the plant exit, Fig. 8 shows the random selection of infectious dose for each of the consumers who ate those chickens.

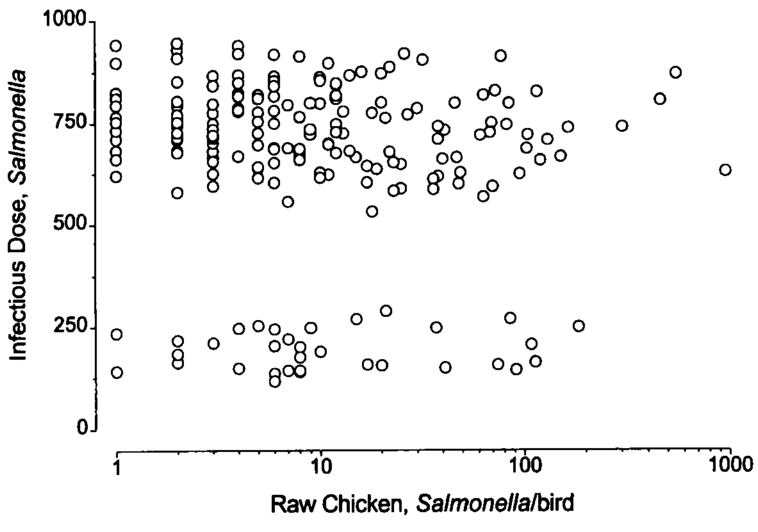

FIG. 8. SCATTER PLOT OF THE INFECTIOUS DOSE OF *SALMONELLA* FOR CONSUMERS IN THE NORMAL (UPPER CLUSTER) AND HIGH RISK (LOWER CLUSTER) POPULATIONS VERSUS THE *SALMONELLA* LOAD OF THE CHICKENS AT THE PROCESSING PLANT EXIT

Probability of Acquiring Salmonellosis from Consumption of Chicken

Finally, the model calculated the probability of acquiring salmonellosis for each of the 1,000 chickens simulated using the following equation:

$$P = \text{IF (D/I} > 1, 1, \text{D/I}) * 100$$

where P was the probability of acquiring salmonellosis in %, D was the total dose of *Salmonella* consumed, I was the infectious dose of *Salmonella*, and the statement read that IF the ratio of D to I was greater than one then P was one otherwise P was the ratio of D to I. This calculation assumed that one *Salmonella* was capable of causing an infection and that infectious dose was the dose of *Salmonella* consumed that resulted in a 100% probability of salmonellosis. This calculation of the probability of salmonellosis for each consumption event was very similar to the exponential dose-response model used by others (Haas 1983; Rose *et al.* 1995) except that it was assumed that the probability of salmonellosis increased linearly rather than exponentially as a function of dose consumed and infectious dose.

Of the 1,000 chickens simulated only 70 or 7% posed a risk of salmonellosis. The probability of salmonellosis from these 70 chickens ranged from 0.0018 to 42.1% (Fig. 9). In addition, results in Fig. 9 showed that highly (i.e., > 100 *Salmonella*/bird) contaminated chickens at the plant exit did not necessarily pose greater risk of salmonellosis than lightly (i.e., < 10 *Salmonella*/bird) contaminated chickens. Rather, greater risk of salmonellosis from lightly contaminated chickens was realized when they were temperature abused, undercooked, and consumed by someone from the high risk population.

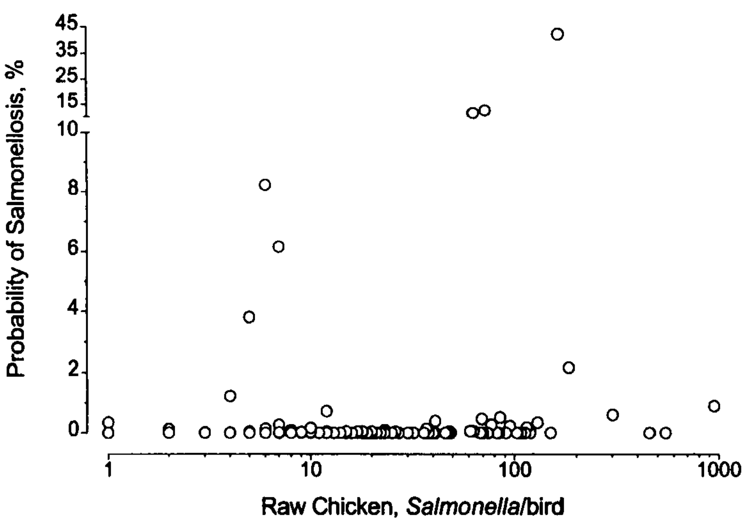

FIG. 9. SCATTER PLOT OF THE PROBABILITY OF ACQUIRING SALMONELLOSIS VERSUS THE *SALMONELLA* LOAD OF THE CHICKENS AS THEY LEFT THE PROCESSING PLANT

CONCLUSION

A simulation model was designed to determine the relationship between the level of *Salmonella* contamination of chickens at the processing plant exit and the risk of salmonellosis in consumers. Results of the model simulation indicated that greater risk of salmonellosis can be realized from lightly (i.e., < 10 *Salmonella*/bird) than heavily (i.e., > 100 *Salmonella*/bird) contaminated chickens. Thus, current attempts by the poultry industry to lower the incidence of *Salmonella* contamination of raw poultry are justified.

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