Predictive Modeling for Risk Assessment of Microbial Hazards

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Risk assessment models of meat animal production and processing systems have great potential for assisting meat animal producers, meat animal processors, and regulatory agencies in making critical food safety decisions that impact public health. With the advent of computer software programs, such as @Risk (Palisade Corporation, Newfield, NY), that perform simulations of models created in common spreadsheet programs, such as MicroSoft Excel, it is now possible to create computer models that predict the risk of foodborne disease from meat products produced by specified farm to table scenarios.

An important concept is that the design of a risk assessment model depends on its intended use. In other words, it is not possible to create a generic model that applies to all pathogens, animal systems, and meat products. Instead, basic modeling approaches can be developed and then adapted to meet specific modeling needs. In the current paper, I describe and demonstrate a computer model that assesses the impact of broiler production and processing on the risk of foodborne disease from cooked chicken. The model was designed to simulate the behavior of *Salmonella* on chicken. It is hoped that this model will prove useful for those interested in designing similar models for application with other pathogens, meat animal systems, and meat products.

Model Design and Assumptions

The risk of foodborne disease from consumption of cooked chicken is a function of the dose of pathogen consumed and the infectious dose. In turn, the dose of pathogen consumed is a function of the pathogen load of the chicken and the amount of chicken consumed, whereas the infectious dose is a function of pathogen virulence and host resistance.

Figure 1 shows the layout of the risk assessment model for cooked chicken. The model was constructed in an Excel spreadsheet and is simulated using @Risk. The top section of the model estimates pathogen load, whereas the bottom section of the model calculates the probability of foodborne disease in the human population.

Estimation of Pathogen Load

The top section of the model is divided into 28 nodes (Figure 1). Each node represents a pathogen event in the farm to table continuum. Three types of pathogen events—contamination (C), reduction (R), and growth (G) occur in the model. Each pathogen event is defined by an incidence (column C) and an extent (columns D to F). The extent of each pathogen event is defined by a triangular distribution consisting of a minimum, most likely, and maximum value. The @Risk command that determines the incidence at which each triangular distribution is sampled is in column I. A zero in column I means the distribution is sampled, whereas a one means that it is not.

Cells in column G calculate the change in pathogen load (i.e., delta) at each node, whereas cells in column H sum the pathogen load at each node. Pathogen load is expressed in colony forming units (cfu) per bird. The model estimates for pathogens that have potential for being carried along until consumption. Thus, pathogens on structures (i.e., hocks, feathers, heads, etc.) which are removed during processing are not considered.

Each simulation of the model involves a single defined farm-to-table scenario and 1,000 iterations. During each iteration, @Risk randomly samples each triangular distribution based on its defined incidence and calculates the probability of foodborne disease. Thus, at the end of a simulation, @Risk has accumulated data on 1,000 iterations or chickens.

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FIGURE 1.

	A	B	C	D	E	F	G	H	I
1		Estimation of Pathogen Load							
2	Node		Incidence	Minimum	Most Likely	Maximum	Delta	Output	Rare Event
3			%	log			cfu/bird		
4	1	Hatch (I)	5	0	0.7	1.5	0	0	1
5	2	Hatchery Operations (C)	5	0	0.7	1.5	0	0	1
6	3	Chick Transport (C)	5	0	0.7	1.5	0	0	1
7	4	Early Grow-out (C)	5	0	0.7	1.5	0	0	1
8	5	Late Grow-out (R)	90	-9	-8	-7	0	0	0
9	6	Broiler Transport (C)	5	0	0.7	1.5	0	0	1
10	7	Bleed-out (C)	0	0	0.7	1.5	0	0	1
11	8	Scalding (R)	100	-0.2	-0.1	0	0	0	0
12	9	Scalding (C)	5	0	0.7	1.5	0	0	1
13	10	Defeathering (C)	5	1	2	4	0	0	1
14	11	Evisceration (C)	5	1	2	4	0	0	1
15	12	Prechill wash (R)	100	-1.1	-1	-0.1	0	0	0
16	13	Chilling (R)	100	-1.1	-1	-0.1	0	0	0
17	14	Chilling (C)	5	0	0.7	1.5	0	0	1
18	15	Cut-up (C)	5	0	0.7	1.5	0	0	1
19	16	Packaging (C)	5	0	0.7	1.5	0	0	1
20	17	Irradiation (R)	0	-3.1	-3	-1	0	0	1
21	18	Retail Product Transport (G)	20	0.1	0.3	1.0	0	0	1
22	19	Retail Display (G)	20	0.1	0.3	1.0	0	0	1
23	20	Consumer Product Transport (G)	20	0.1	0.3	1.0	0	0	1
24	21	Raw Food, Cold Storage (G)	20	0.1	0.6	1.0	0	0	1
25	22	Raw Food Handling (C)	5	0	0.7	1	0	0	1
26	23	Meal Preparation (G)	20	0.1	0.3	1.0	0	0	1
27	24	Cooking (R)	20	-2	-1.5	-1	0	0	1
28	25	Cooling (G)	20	0.1	0.6	1.0	0	0	1
29	26	Cooked Food Handling (C)	5	0	0.7	1	0	0	1
30	27	Cooked Food, Cold Storage (G)	20	0.1	0.3	1.0	0	0	1
31	28	Reheating (R)	50	-2	-1.5	-0.1	0	0	0
32		Probability of Disease Calculation							
33		Food Consumption, %	100	15	25	50	30		0
34		Dose Consumed, cfu	25					0	1
35		Infectious Dose, cfu	80	80	100	120		100	0
36		Probability of Disease, %						0	

A farm to table risk assessment model for cooked chicken. The settings are for the control simulation.

Contamination Events

As chickens move through the farm to table continuum, they contact surfaces (i.e., equipment, litter, hands etc.) and vehicles (i.e., water, feces etc.) that may contain pathogens and thus result in cross-contamination. In this model, it is assumed that fecal material is the most concentrated source of pathogen and that feathers protect birds from cross-contamination. Thus, the extent of fecal/feather-off contamination events (i.e., defeathering and evisceration, nodes 13 and 14) is set higher than other contamination events.

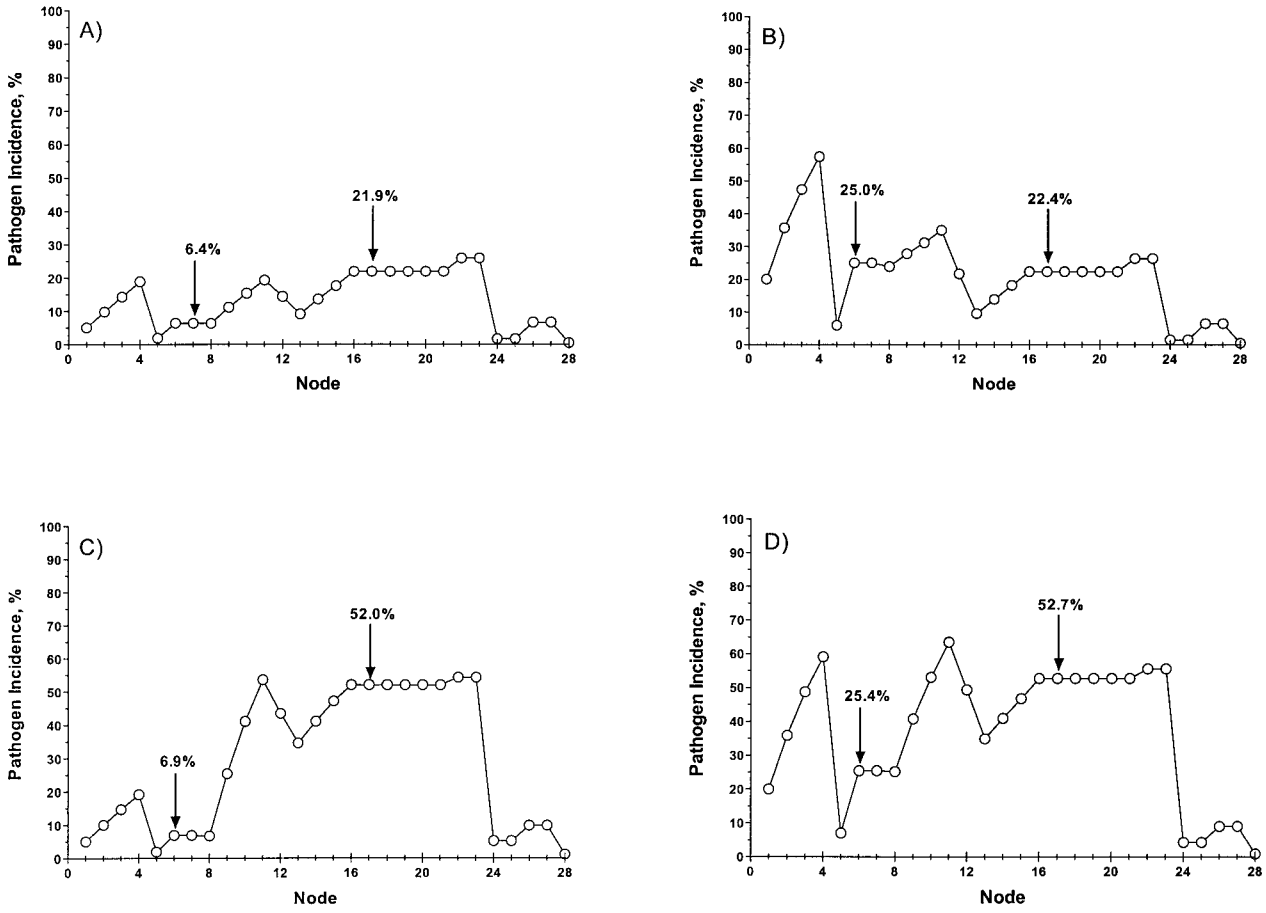
Reduction Events

Pathogen reduction events occur during production, processing, and consumption. The first pathogen reduction event is during late grow-out. Here, an assumption is made that as broilers age, their immune system and gut microflora develop, resulting in elimination of pathogens from their gut and skin. Node 5 is defined such that 90% of the chickens become pathogen-free during late grow-out.

The next four pathogen reduction events occur during processing and include scalding (node 8), prechill washing (node 12), chilling (node 13), and irradiation (node 17). These pathogen reduction events consider physical removal by washing as well as inactivation by heat, chlorine, and radiation. Note that the incidence of the irradiation node is 0%, which means that this node is not active. A salient feature of the model design is that nodes can be inactivated; this allows flexibility in model design and usage.

Perhaps the most critical pathogen reduction events in the model are cooking (node 24) and reheating (node 28) by consumers. Cooking and reheating are defined such that the

FIGURE 2.



Pathogen incidence results for the A) control, B) production, C) processing, and D) production/processing simulations.

incidence refers to the percentage of chickens that are not properly heated, resulting in pathogen survival. The model assumes that properly-cooked and reheated chickens are sterile.

Growth Events

All pathogen growth events occur after packaging. The model assumes that processing operations are too rapid to provide an opportunity for pathogen growth. Rather, increases in pathogen numbers during production and processing are accounted for by contamination events. In contrast, during distribution and consumption, there are several opportunities for pathogen growth. Temperature abuse may occur during product transport (nodes 18 and 20), retail display (node 19), refrigerated storage (nodes 21 and 27), and food handling (nodes 23 and 25).

Probability of Foodborne Disease Calculation

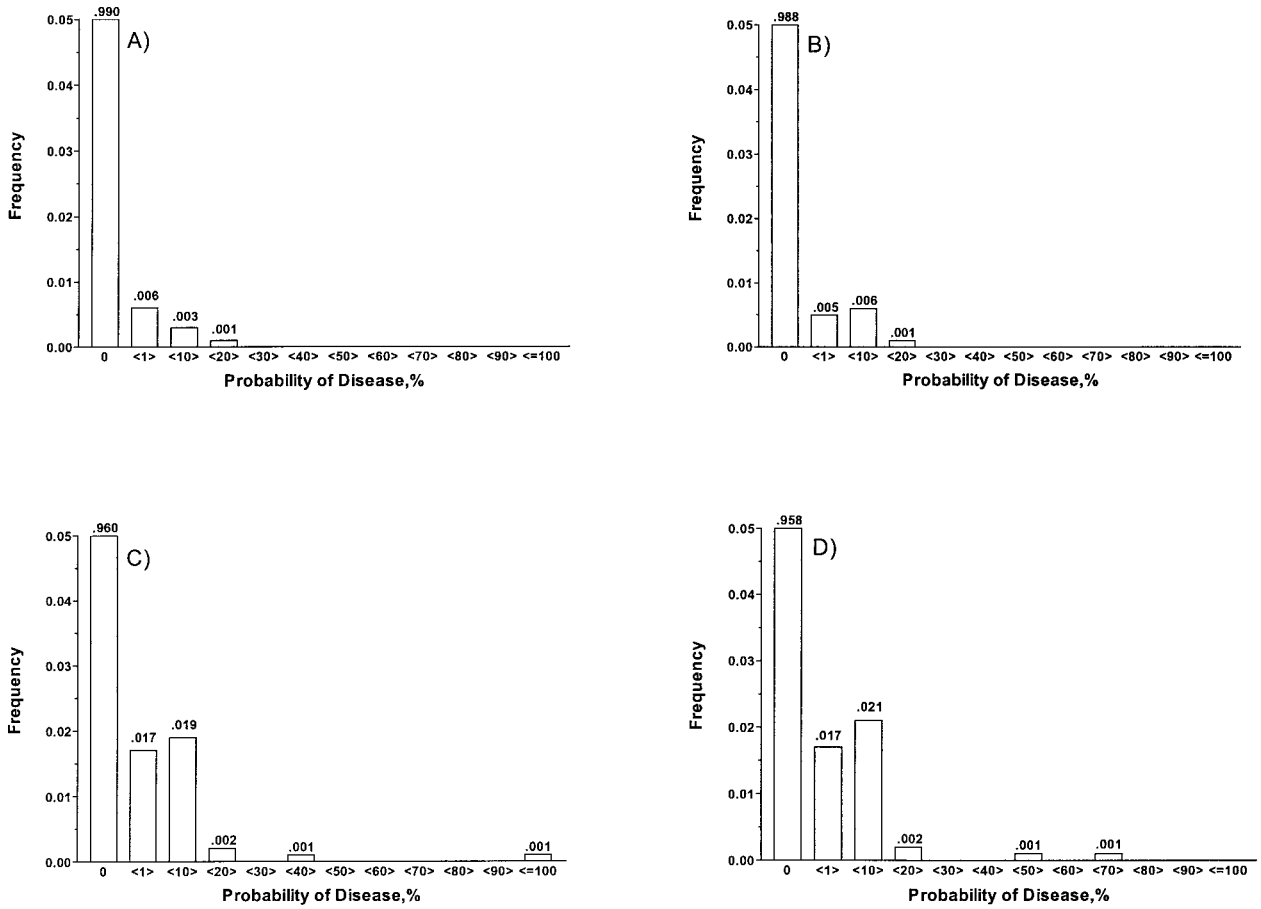
The bottom section of the model estimates food consumption and infectious dose and calculates dose consumed and probability of foodborne disease. Food consumption is defined such that consumers eat from 15 to 50% of a chicken, with the most likely amount consumed being 25%. Dose consumed is calculated by multiplying pathogen load after cooking (cell H24) or reheating (cell H28) by food consumption. Cell C34 defines the incidence of consumption events that occur after reheating.

Infectious dose is defined such that 80% of consumers are from the normal population and 20% are from the high risk (i.e., immunocompromised) population. The triangular distribution for infectious dose in cells D35 to F35 is for the normal population, whereas the infectious dose for the high-risk population is set at 20 cfu. Finally, the probability of foodborne disease (*P*), a value from 0 to 100%, is calculated using the following equation:

$$P = IF(D/I > I, ID/I)* 100$$

where *D* is the dose of pathogen consumed in cfu, *I* is the infectious dose in cfu, and the statement reads that IF the ratio of *D* to *I* is greater than one, then *P* is one, otherwise *P* is the ratio of *D* to *I*. This calculation assumes that one cell of the pathogen is capable of causing disease.

FIGURE 3.



Probability of foodborne disease results for the A) control, B) production, C) processing, and D) production/processing simulations.

Simulation Results

To use this model to make food safety decisions, one would run multiple simulations and then compare the results. In this section, I present the results from four simulations designed to assess the impact of broiler production and processing on the microbiological safety of cooked chicken.

Figure 1 shows the settings for the control simulation. The other three simulations involved increasing the incidence of contamination events during production, processing, or both. Triangular distributions for extent of pathogen events were held constant throughout all four simulations. Each simulation was run with @Risk settings of 1,000 iterations and Latin Hypercube sampling. Results of each simulation were exported to an Excel spreadsheet for calculation of pathogen incidence at each node and for determination of the frequency distribution for probability of foodborne disease in the human population. These data, as well as pathogen numbers by node for individual iterations, were exported to and graphed in GraphPad PRIZM™ (GraphPad Software, San Diego, CA).

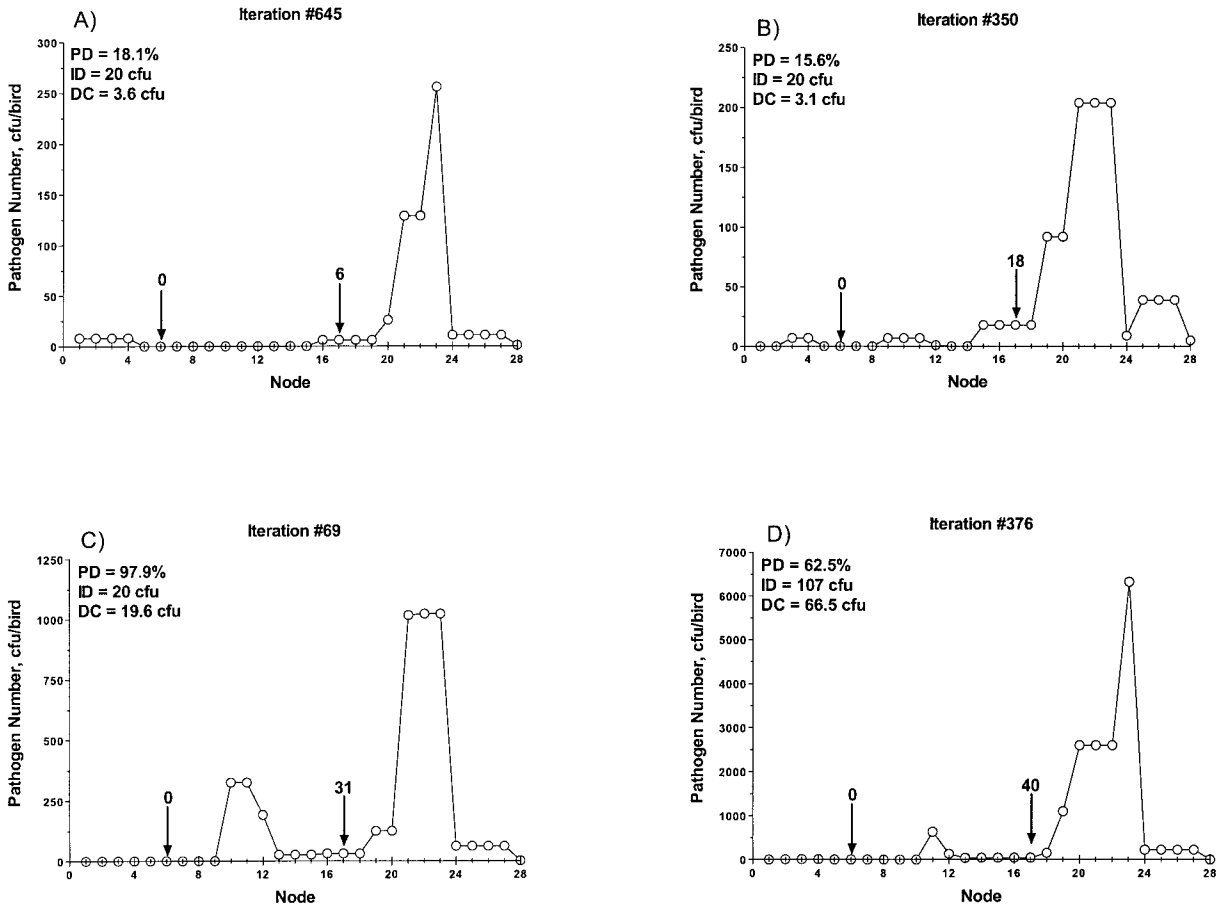
Control Simulation

For this simulation, the incidence of contamination events was set at 5% during production and processing (Figure 1). Figure 2A shows pathogen incidence at each node in the model. Pathogen incidence was 6.4% at the processing plant entrance and 21.9% at the plant exit. Of the 1,000 chickens simulated, only 10 posed a risk of foodborne illness (Figure 3A). This simulation indicated that the defined farm-to-table scenario resulted in a low probability of foodborne disease.

Production Simulation

A second simulation was conducted in which the incidence of contamination events during broiler production (nodes 1 to 4 and 6) was increased from 5 to 20%. All other settings in the model were left unaltered from the control simulation (Figure 1). Increasing the incidence of production contamination events in this manner resulted in an increase in pathogen incidence at the plant entrance from 6.4 to 25.0% (Figure 2B). However, pathogen incidence at the

FIGURE 4.



Pathogen number results for the highest risk iteration from the A) control, B) production, C) processing, and D) production/processing simulations. PD = probability of disease; ID = infectious dose; and DC = dose consumed.

plant exit only increased from 21.9 to 22.4%. Likewise, only a small increase in the probability of foodborne disease, from 10 to 12 "risky" chickens, was noted (Figure 3B). These results indicated that a moderate increase in pathogen incidence of birds entering the plant caused only a small increase in the risk of foodborne disease.

Processing Simulation

A third simulation was conducted in which the incidence of production contamination events was set at 5%, the incidence of prechill processing contamination events was increased from 5 to 20%, and the incidence of postchill contamination events was increased from 5 to 10%. In this scenario, pathogen incidence was 6.9% at the plant entrance and 52.0% at the plant exit (Figure 2C). The number of "risky" chickens was 40 (Figure 3C), which was three-fold higher than the control and production simulations. These results indicated that a moderate increase in the incidence of contamination events during processing resulted in a significant increase in the risk of foodborne disease.

Production and Processing Simulation

A fourth simulation was conducted in which the incidence of contamination events was set at 20% for production, 20% for prechill processing, and 10% for postchill processing. Pathogen incidence for this simulation was 25.4% at the plant entrance and 52.7% at the plant exit (Figure 2D). The number of chickens that posed a risk of foodborne disease was 42 (Figure 3D) as compared to 40 for the processing simulation. Thus, an increase in pathogen incidence of birds entering the plant caused only a small increase in the risk of foodborne disease.

Individual Simulations

Additional insight about the farm-to-table scenarios can be gained by examining the pathogen load profiles for individual iterations from the simulations. The following pathogen load profiles represent the iteration from each simulation that resulted in the highest risk of foodborne disease.

The pathogen load profile for iteration #645 (Figure 4A)

of the control simulation showed that chicken #645 was pathogen-free at the plant entrance, became contaminated during packaging, contained six pathogens at the plant exit, was temperature-abused three times before cooking, was undercooked, and was consumed by a person from the high-risk population. The dose consumed was 3.6 cfu, the infectious dose was 20 cfu, and the probability of foodborne disease was 18.1%.

The pathogen load profile for iteration #350 (Figure 4B) of the production simulation showed that chicken #350 was pathogen-free at the plant entrance, became contaminated during cut-up, contained 18 pathogens at the plant exit, underwent temperature abuse twice before cooking, was undercooked, and was consumed by someone from the high-risk population. The dose consumed was 3.1 cfu, the infectious dose was 20 cfu, and the probability of foodborne disease was 15.6%.

The pathogen load profile for iteration #69 (Figure 4C) of the processing simulation showed that chicken #69 was pathogen-free at the plant entrance, became contaminated during defeathering, contained 31 pathogens at the plant exit, underwent temperature abuse twice before cooking, was undercooked, and was consumed by someone from the high-risk population. The dose consumed was 19.6 cfu, the infectious dose was 20 cfu, and the probability of foodborne disease was 97.9%.

The pathogen load profile for iteration #376 (Figure 4D) of the production and processing simulation showed that chicken #376 was pathogen-free at the plant entrance, became contaminated during evisceration, contained 40 pathogens at the plant exit, underwent temperature abuse three times before cooking, was undercooked, and was consumed by someone from the normal population. The dose consumed was 66.5 cfu, the infectious dose was 107 cfu, and the probability of foodborne disease was 62.5%.

All four chickens in these iterations were pathogen-free at the plant entrance, became contaminated during processing, carried a pathogen load into distribution, were temperature abused more than once before cooking, were undercooked, and three of four were consumed by someone from the high-risk population. These simulations suggest that in addition to consumer education, pathogen reduction efforts are needed in the processing plant but not on the farm.

Summary

A model for assessing the impact of broiler production and processing on the microbiological safety of cooked chicken was presented. The model simulates the production, processing, and consumption of 1,000 chickens. It provides predictions of pathogen incidence and pathogen load as chickens move through the farm-to-table continuum. In addition, it considers consumer behavior and demographics (i.e., the high risk population) in its assessment of the risk of foodborne disease from consumption of cooked chicken. The model was designed to simulate the behavior of *Salmonella* on chicken. Users can customize the model by using their own data and by adding or removing nodes to more accurately simulate their poultry operation. The model is an ideal tool for identifying critical control points in the farm to table continuum where intervention methods can be applied to improve the microbiological safety of cooked chicken. In addition, the model can be used to evaluate the impact of intervention methods on the microbiological safety of cooked chicken.

References

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