Assessing Thermal Inactivation of *Salmonella* on Cooked Broiler Chicken Carcasses in Trinidad and Tobago

Mark M. Dookeran*,[1], Gail S.H. Baccus-Taylor[1], John O. Akingbala[1], Berhanu Tameru[2] and Anna M. Lammerding[3]

[1]*Food Science & Technology Unit, Department of Chemical Engineering, University of the West Indies, St. Augustine, Trinidad and Tobago*

[2]*Center for Computational Epidemiology, Bioinformatics and Risk Analysis, School of Veterinary Medicine (Animal Health) and the School of Nursing & Allied Health (Human Health). Tuskegee University, Alabama, USA*

[3]*Public Health Agency of Canada, Laboratory for Food-borne Zoonoses, 160 Research Lane, #206, Guelph, Ontario, NIG 2B5, Canada*

Abstract: *Salmonella,* zoonotic bacteria normally present in broiler chicken flocks, are a major cause of food-borne illness of known aetiology in Trinidad and Tobago, and in the wider English speaking Caribbean. Although cooking is regarded as an acceptable method for thermal destruction of these pathogens, consumption of undercooked, and re-contaminated cooked broiler meat remains a common mode of transmission to humans. Since the proportion of undercooked chicken is largely unknown, an assessment of various cooking methods would serve to prioritise intervention strategies that are required to ensure food safety. Cooking time and temperature for fried, boiled, baked, and grilled cooking methods, determined from survey and sampling methods, and D-values from published data were inputs into a modified model. The model was constructed in a Microsoft Excel™ workbook, and simulated using @risk add-in computer software, 100,000 iterations, and Latin Hypercube Sampling. Thermal inactivation of *Salmonella* on broiler chicken meat occurred during boiling (0%) and frying (0%), but *Salmonella* survived baking (0.001%) and grilling (0.012%). Differences in the expected value were due to differences in cooking time, temperature, environment, and size of broiler chicken cuts. Air, the heat transfer medium for both baking and grilling may be the most important factor linked to inadequately cooked broiler chicken carcasses.

Keywords: *Salmonella*, Broiler Chicken, Thermal Inactivation Model, Mark Dookeran.

INTRODUCTION

Salmonella is a leading cause of food-borne illness (FBI) globally, and continues to be of major concern to food safety in the Caribbean region. Approximately 20.2% of FBIs of known aetiology in the English speaking Caribbean are due to *Salmonella*, and even though fewer cases (14%) were reported in Trinidad and Tobago, it remains the most important FBI of known aetiology in the country [1, 2]. Broiler chickens are natural reservoirs for *Salmonella*, and they are widely known to be an important vehicle of transmission to humans, for the pathogens. Thus, it is not unusual that broiler chickens were incriminated in 34% of *Salmonella*-related outbreaks worldwide [3].

The application of heat by cooking increases palatability, and it is the primary method for destruction of pathogens present on raw broiler chicken meat [4]. Broiler chicken meat consumed is, generally, considered as thoroughly cooked, and salmonellosis may be due to re-contamination of cooked meat rather than undercooking [5]. The proportion of cases caused by the consumption of inadequately cooked broiler chicken carcasses compared with re-contaminated cooked broiler carcasses, is largely unknown worldwide. However, inadequate cooking time and temperature are important factors that contribute to FBIs. Cooking time and temperature fluctuates depending on size and shape of the meat, heat transfer medium (water, oil, air), and open or closed environments [6]. Hence, various cooking methods, broadly categorized as boiled (water), fried (oil), grilled (air and open environment), and baked (air and closed environment), may impact differently on thermal inactivation of *Salmonella* [4].

The upper limit for *Salmonella* concentration on processed broiler chicken carcasses is more than 12,000 Most Probable Number (MPN), the most likely concentration is 12 MPN, and the minimum concentration (1 MPN), is the lowest number of *Salmonella* that can exist in a contaminated product [7-9]. *Salmonella* growth may occur during transportation of broiler chicken carcasses to consumers' homes and preparation therein, due to time-temperature abuse [10]. Nevertheless, during cooking, temperature increases substantially with time, reducing *Salmonella* concentration logarithmically. The $\log_{10}$ cycle reductions are estimated from

*Address correspondence to this author at the Food Science & Technology Unit, Department of Chemical Engineering, University of the West Indies, St. Augustine, Trinidad and Tobago; Tel: (868) 682-3289;
Fax: (868) 662-4414; E-mail: Mark.Dookeran@sta.uwi.edu

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the decimal reduction time (D-value), and the cooking time and temperature [11]. D-values for *Salmonella* on chicken at 70 ^{o}C and 67.5 ^{o}C were 0.176 and 0.286 minutes respectively, and the D-value for *S. typhimurium* on chicken skin (neck) macerate at 52 ^{o}C was 61.72 minutes [12, 13]. Thermal inactivation follows first order kinetics, that is, the log number decrease in *Salmonella* at a fixed temperature occurs linearly over time [14]. However, a log linear distribution is best suited for situations involving rapid death. In other circumstances a non-linear curve suggests variability in thermal death kinetics of *Salmonella* [15]. An approach to account for variability and uncertainty is to construct a model in a computer spreadsheet and conduct simulations using @Risk computer software. @Risk performs risk analysis using Monte Carlo simulation to show possible outcomes in the Microsoft Excel^{TM} spreadsheet, and predicts how likely they are to occur. This means one can judge the cooking methods that contribute to undercooked broiler chicken meat, allowing for the best decision making under uncertainty [16].

This research modifies a previously developed thermal inactivation model, to assess the death of *Salmonella* on broiler chicken carcasses after home cooking in Trinidad and Tobago [9]. It presents the first analysis of home cooking time and temperature on *Salmonella* inactivation in the Caribbean region, and offers a structured mechanism to predict the number of undercooked broiler chicken carcasses. Furthermore, the assessment compares the effectiveness of various cooking methods on thermal inactivation of *Salmonella.*

MATERIALS AND METHODS

Data Collection

Enumeration data (MPN) for *Salmonella* on processed broiler chicken carcasses, and D-values for thermal inactivation of *Salmonella* on broiler chicken carcasses were obtained from published data. It was assumed that growth of *Salmonella* on processed broiler chicken carcasses did not occur from processing to retail, since low temperatures were maintained. A survey was conducted to estimate time-temperature changes, not only during cooking, but also during transportation of broiler chicken carcasses to consumers' homes and preparation therein. The survey was conducted in Trinidad, whereby questionnaires were administered to householders during the period July 2006 to February 2007. The respondents were questioned on the most likely transportation time for broiler carcasses from retail outlets to consumers' homes and raw meat preparation time therein. Questions were included in the survey regarding the minimum, most likely, and maximum cooking times for boiled, fried, grilled, and baked chickens cooked at consumers' homes.

Thirty (30) samples (broiler chicken carcasses) were purchased from retail outlets, and the surface temperature for each sample was measured at 10 minute-intervals during transportation to consumers' homes in the early afternoon. Additionally, surface temperature changes for 30 samples (broiler chicken carcasses) were also measured at 10 minute-intervals during preparation of raw broiler chicken carcasses for cooking at consumers' homes. Time-temperature profiles were developed for both data sets. Internal meat temperatures were measured at 15 minute-intervals during cooking and a time-temperature profile for 30 samples (broiler chicken carcasses) were developed for each cooking method (baked, fried, boiled, and grilled).

Concentration of *Salmonella* on Broiler Carcasses Prior to Cooking

A previously developed, but modified growth model was used to estimate the $\log_{10}$ cycle increase in *Salmonella* concentration during transportation to consumers' homes and preparation therein [9, 10]. The responses for transportation times for broiler chicken carcasses to consumers' homes and preparation times therein were entered into a Microsoft Excel^{TM} worksheet, as model inputs (Appendix **A**). Likewise, results of surface temperature increases during transportation of broiler chicken carcasses from retail to consumers' homes, and during preparation of raw meat therein, for cooking, were entered into the Excel worksheet as model inputs. The most likely transportation and preparation times were estimated from Riskdiscrete distributions; whereas, Bestfit distributions were used to define the data set for transportation and preparation temperatures. Logical tests were then used to link transportation and preparation times to the corresponding temperatures in the growth model. The model was run outside the thermal inactivation model using @Risk computer software, 100,000 iterations, and Latin Hypercube Sampling.

Thermal Inactivation Model Description

A previously developed model was modified to examine thermal inactivation of *Salmonella* on broiler carcasses, due to exposure to high temperatures during cooking [9]. The model was constructed on a Microsoft Excel^{TM} worksheet with inputs from the data collected (Appendix **B**). The proportion of responses from the consumer survey, to estimate cooking time (minutes), was described by a RiskDiscrete distribution in the model. @Risk computer software was used to determine the Bestfit distribution from the sample data set for cooking temperatures at specific time intervals. Each cooking time was then linked to the corresponding temperature by logical functions in the thermal inactivation model.

Published log D-values plotted against its corresponding temperatures, using Microsoft Excel^{TM} computer software, generated a regression line from which the D-value was determined. The equation of the line, Log D-value = $10^{(0.1414.\ Temp)\ +\ 9.0807}$ provided a generalized relationship for D-value, with respect to temperature [17-19]. The equation of the regression line was entered as an input into the model (Appendix **B**). The model was also run in @Risk computer software, using 100,000 iterations and Latin Hypercube Sampling, but a negative value was used to signify a reduction in *Salmonella* on broiler chicken meat due to thermal death [16]. The model calculated the minimum, most likely, and maximum Log_{10} cycle reductions in *Salmonella* (MPN) for each cooking method. Pert distributions were then used to simulate the reduction in *Salmonella* concentration after cooking. The output results were filtered to remove fractions

of *Salmonella* and unfiltered values were reported as undercooked broiler chicken carcasses (Appendix **C**).

RESULTS

Variations in Transportation and Preparation Time

The minimum, most likely, and maximum transportation times for broiler chicken carcasses from retail outlets to consumers' homes were 20 minutes (22.8% respondents), 30 minutes (43.3% respondents), and 60 minutes (23.4% respondents) respectively. The minimum raw meat preparation time (10 minutes) for cooking at consumers' homes was favoured by 5.9% of the respondents; whereas, the most frequent preparation time (30 minutes) was favoured by 43.3% of the respondents. The maximum preparation time for raw broiler chicken meat (60 minutes) was favoured by 23.4% of the respondents (Fig. **I**).

Variations in Transportation and Preparation Temperature

The mean temperatures for 30 broiler chicken carcasses during transportation from retail outlets to consumers' homes ranged from a minimum of 4.9 °C in the display refrigerator to a maximum of 18.8°C after 60 minutes exposure to transportation conditions (Fig. **II**). There was a general increase in broiler chicken carcass temperature during transportation from retail outlets to consumers' homes. The mean temperature for 30 broiler chicken carcasses during the most frequent transportation time (30 minutes) to consumers' homes was 14.4°C. Broiler chicken carcass temperatures also increased during raw meat preparation, from a mean minimum temperature of 14.4 °C (30 minutes) to a mean maximum temperature of 21.7°C (60 minutes). The mean temperature at the most frequent raw meat preparation time (30 minutes) was 18.8°C (Fig. **II**).

Variations in Cooking Time

The minimum, most frequent, and maximum cooking times varied for boiled, baked, fried, and grilled cooking methods (Fig. **III**). The minimum grill-time (9.2% respondents) and bake-time (2.9% respondents) were 15 minutes, whereas the minimum fry-time (21.4% respondents) and boil-time (12.7% respondents) were 30 minutes. Forty-five (45) minutes was the most frequent cooking-time response for fried (57.2% respondents), boiled (53.8% respondents), and grilled (54.9% respondents) broiler chicken meat, and 60 minutes for baked (53.2% respondents). The responses for maximum cooking time (60 minutes) were 21.4% respon-

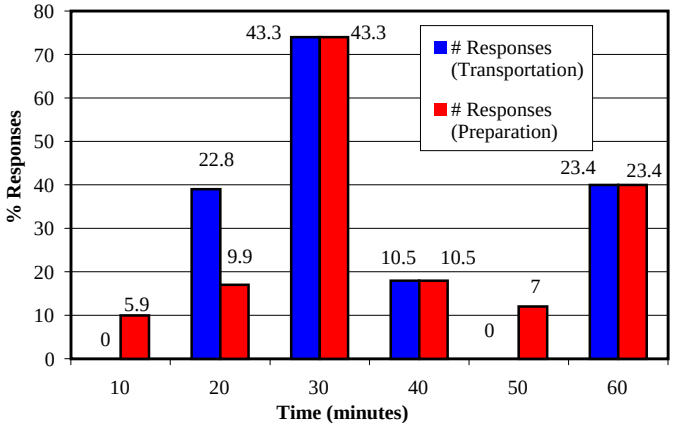

Fig. (I). Transportation time for chilled whole broiler chicken carcasses from retail outlets to the consumers' homes and preparation time therein.

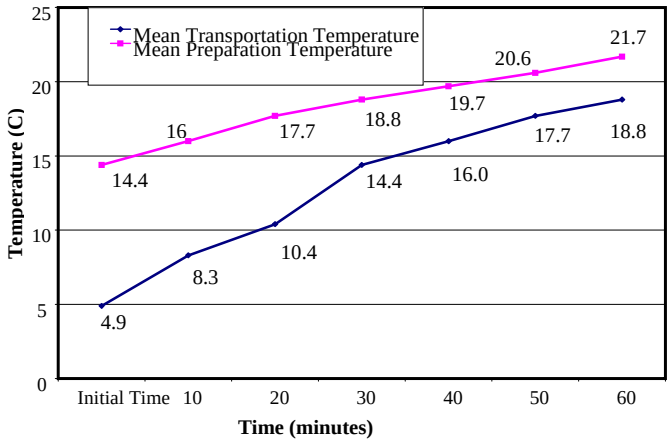

Fig. (II). Time-temperature variations for transportation of chilled whole broiler chicken carcasses from retail outlets to consumers' homes and preparation time therein.

dents (fry-time), 53.2% respondents (bake-time), 33.5% respondents (boil-time), and 22% respondents (grill-time) (Fig. **III**).

Variations in Cooking Temperature

The minimum, most frequent, and maximum home cooking temperatures for 30 broiler chicken carcasses varied with the cooking times and cooking methods (Fig. **IV**). The cooking temperatures (mean values) at the minimum cooking time (15 minutes) for grilled and baked broiler meat were 33.3°C and 37.8°C respectively. The minimum cooking time (30 minutes) and the respective cooking temperatures for fried (45.2°C) and boiled (71.4°C) broiler meat were higher than grilled and baked. The mean temperatures for boiled, fried, and grilled chicken at the most frequent cooking time (45 minutes) were 94.4°C, 73.8°C and 64.8°C respectively; whereas, the mean temperature for baked chicken at its most frequent cooking time (60 minutes) was 79.0°C . The mean cooking temperatures, at the maximum cooking time (60 minutes), for boiled, fried, grilled, and baked were 98.2°C, 81.8°C, 72.5°C, and 79.0°C respectively. The temperature at the most frequent baking time was equivalent to the temperature at the maximum baking time (60 minutes). The highest mean temperature at the most frequent cooking time was attained during boiling, followed by baking, frying, and grilling. The boiling temperature was higher than the baking temperature even though the cooking time for the latter process was greater by 15 minutes (Fig. **IV**).

Model Results

The growth model predicted that *Salmonella* concentration neither increased during transportation to consumers' homes nor during preparation therein. Thus, the extent of *Salmonella* contamination on broiler carcasses prior to cooking was equivalent to *Salmonella* concentration after processing – minimum, most likely, and maximum values of 1 MPN, 12 MPN, and 12,000 MPN respectively. The results of the thermal inactivation model predicted a reduction in *Salmonella* concentration (MPN) during cooking due to elevated temperatures. Fried-chicken method destroyed all *Salmonella* on the 100,000 broiler chicken carcasses simulated in the model, represented by 0 in cell B12, shown in Table **I**. Consequently, since *Salmonella* were destroyed, any single iteration would return a value less than 1, indicated as filtered (Error!). This method of cooking ensured that the meat was thoroughly cooked. Boiling also destroyed 100% *Sal-*

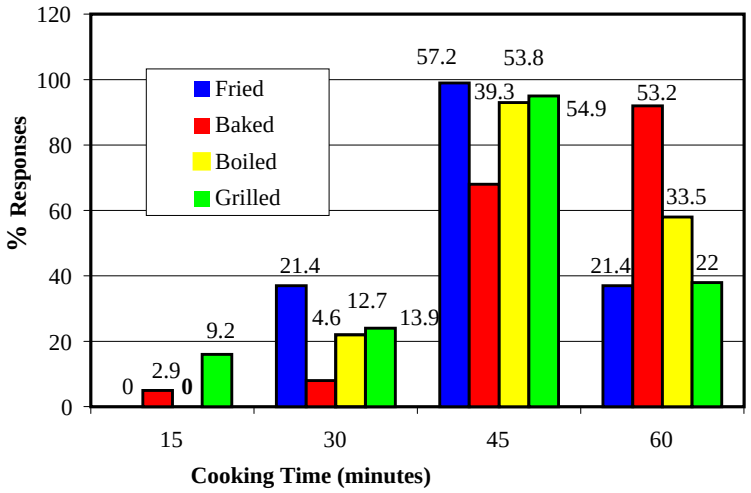

Fig. (III). Responses for fry-time, bake-time, boil-time, and grill-time for home cooked chicken.

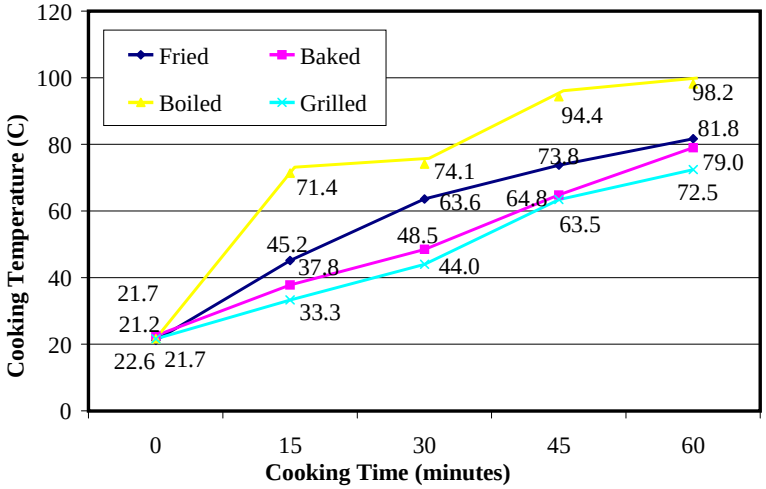

Fig. (IV). Comparison of mean temperatures for fried, baked, boiled, and grilled broiler chicken carcasses.

Table I. Output Results for Thermal Inactivation of *Salmonella* on Cooked Broiler Meat

1	A	B	C	D	E
1	Description	Output Fried	Output Baked	Output Boiled	Output Grilled
2	Minimum	Error!	2	Error!	1
3	Maximum	Error!	2	Error!	23
4	Mean	Error!	2	Error!	5.833333
5	Std Deviation	Error!	Error!	Error!	6.422027
6	Variance	Error!	Error!	Error!	41.24242
7	Mode	Error!	2	2	1
8	Filter Minimum	1	1	1	1
9	Filter Maximum	-	-	-	-
10	Type (1 or 2)	1	1	1	1
11	# Values Filtered	100000	99999	100000	99988
12	Unfiltered	0	1	0	12
13	Undercooked (%)	0.00%	0.001%	0.00%	0.012%

monella present on broiler chicken carcasses. However, *Salmonella* survived cooking on 12 (0.012%) of the 100,000 broiler chicken carcasses simulated for grilled broiler chicken and on 1 (0.001%) baked carcass. The pert distribution assigned a *Salmonella* load for each contaminated broiler chicken after cooking. The minimum, maximum, and mean *Salmonella* loads on the grilled undercooked broiler chicken carcasses were 1 MPN, 23 MPN, and 5.83 MPN respectively (cells E2, E3 and E4 respectively, in Table **I**). However, the minimum, maximum, and mean values for undercooked baked chicken were the same (2 MPN) since only 1 broiler chicken carcass was undercooked.

DISCUSSION

Bacterial thermal death due to cooking was simulated using a computer model to estimate the number of undercooked broiler chicken carcasses, and to describe the factors that contributed to inadequate cooking. Computer software was used to produce a Monte Carlo simulation as the complexity of algebraic models made it difficult to check for errors, conduct simulations, and change parameters when new information becomes available. In addition, computer simulations are more readily accepted by persons involved in risk analysis. A probability approach was used to predict the number of *Salmonella* contaminated broiler carcasses after cooking. This approach carried forward fractions of *Salmonella*, which was filtered at the end of the simulation, indicating the number of undercooked broiler chicken carcasses.

Salmonella enumeration tests are not conducted in Trinidad and Tobago as microbiological criterion is not specified in law for raw meat, and the presence of *Salmonella* on cooked food is sufficient scientific evidence to deem a food unfit for human consumption. Furthermore, analysis of samples to determine the numbers of *Salmonella* present on food, are labor-intensive and expensive. Therefore, in this model, concentration of *Salmonella* data was substituted with surrogate data from international sources. As *Salmonella* concentration varied amongst countries due to differences in *Salmonella* load prior to processing, cross contamination during processing, and sensitivity and specificity of different isolation methods, both processors and regulators need to address the issue of obtaining country-specific quantitative data to improve models. Thus, standardized systems must be designed to collect and analyze data to improve current and future models. In so doing, improvements in sampling and analysis methodologies may be required to isolate *Salmonella* at lower detection limits. Probabilistic distributions were used to bridge data gaps or represent levels of variability, determined as random effects of chance, and uncertainty (lack of knowledge); however, separation of these parameters is very complex and was not considered in this research [20].

The differences in expected value for *Salmonella* prevalence on broiler chicken meat cooked by boiling (0%), frying (0%), baking (0.001 %), and grilling (0.012%) could be due to differences in cooking size, temperature, time, and cooking environment. The cooking duration and amount of heat reaching the meat both internally and surface varied with the type of cooking, resulting in differences in thermal destruction of *Salmonella* on the broiler chicken meat [6]. In this study, the cooking size was different for the various cooking methods; whole broiler chicken carcasses were baked, broiler chicken carcasses were halved for grilling, portioned broiler chicken carcasses for frying and small pieces for boiling. The cooking environment, which was enclosed (oven) for baking, or open (such as grilled), and the different heating medium - air (baked and grilled), water (boiled), and oil (fried) - also contributed to the rate at which temperature increased during cooking [4]. The combination of large cooking size (halves) and cooking in an open environment, with air as the heat transfer medium, may be the major con-

tributory factor for undercooked carcasses during grilling (0.012%). A reduced number of undercooked carcasses (0.001%) were predicted for cooking with air in a closed environment (baking), compared with an open environment (grilling).

It is common knowledge that adequate cooking and good hygienic practices after cooking reduces the pathogens on broiler chicken meat. The application of control measures at these stages may be better suited to reduce the occurrence of salmonellosis, as management of the factors that contribute to the incidence of *Salmonella* on broiler chickens and carcasses at production and processing are highly variable and unsuccessful [4]. Since testing of cooked foods on a regular basis is not practical due to the high costs of labour and material, the model provided an alternative method to establish the presence of the pathogen in cooked food. Thus, a basis was established for prioritization of intervention strategies to maximize benefits, as these measures incurred substantial cost. In this regard, intervention is required to ensure baked and grilled meats are thoroughly cooked by increasing the cooking time and temperature or instituting a pre-cooking (steaming) stage. As a result, government is encouraged to introduce compulsory intervention strategies, in the form of regulations and improve health education measures to better protect the national community. As the cooking process may be affected by the socio-economic aspects of the population, lack of legislation, and an unapprised population, together with a perceived growing preference for undercooked meat, it is not a guaranteed method of control.

Sensitivity analysis (several assumptions) may be used to compare and analyse possible scenarios based on assumptions, and to compare the cost-benefit to changes in the system from intervention strategies. Sensitive factors that contributed to health risks may be incorporated in regulations. For example, based on this thermal inactivation assessment, regulations may be stipulated to inactivate *Salmonella* during baking and grilling. Although the amount of infected broilers after cooking was relatively low, it must be appreciated that the total absence of the pathogen after cooking would reduce the potential for FBIs. Regulations should set minimum acceptable limits for the sensitive factors based on priority as determined by the assessment.

CONCLUSIONS AND RECOMMENDATIONS

This model examined thermal inactivation (during cooking) of *Salmonella* on broiler chickens in a scientific and systematic method; thus, providing insights to mitigation measures. The model also identified major data gaps and allows users to substitute values as information becomes available, while underscoring the need for country specific data. Thus, it provided a useful tool to strengthen capacity in this area and to develop future models for similar pathogen food associations. The assessment demonstrated that baked (0.001%) and grilled (0.012%) chicken were inadequately cooked and provided a scientific basis for intervention strategies. The data collected and the model can be incorporated in risk analysis tripartite for *Salmonella* on broiler chicken carcasses in Trinidad and Tobago and the wider Caribbean region.

CONFLICT OF INTEREST

The author(s) confirm that this article content has no conflicts of interest.

ACKNOWLEDGEMENT

None declared.

APPENDICES

Appendix A

Growth Model for *Salmonella* on Broiler Carcasses during Transportation (T) to Consumers' Homes and Preparation (P) of Raw Meat therein

	A	B	C	D	E	F	G
1	**Unit Operation**	**[1]Proportion of Responses at 10 minutes intervals (p)**					
2	Time (x) (h)	**0.167**	**0.333**	**0.5**	**0.667**	**0.833**	**1**
3	T Time	0.058	0.110	0.428	0.104	0.069	0.231
4	P Time	0.00	0.225	0.428	0.116	0.00	0.231
5	[2]T Temp. (TT)	9.64	9.42	16.00	18.40	15.30	19.68
6	[3]P Temp. (PT)	18.05	17.78	19.82	18.36	19.01	20.09
7		**Distribution**	**T**	**P**			
8	Time (h)	[4]t	0.167	0.5			
9	Temperature (°C)	θ	[5]9.64	[6]19.8			
10	Lag time (h)	[7]λ	54.7	4.4			
11	Specific growth rate (log_{10}/h)	[8]μ	87.1	0.189			
12	Potential growth (log_{10}) (μ(t-λ), if t≤λ, 0)	RiskOutput()+IF (B8<B10,0, B11*(B8-B10))	0.00	0.00			

[1]p = frequency/total respondents.
[2]Bestfit Distributions from sample data: B5=RiskLoglogistic(4.78,3.1,3.08), C5=RiskBetaGeneral(0.43, 0.53,8.1,13.2), D5=RiskUniform(12.44,17.26), E5=RiskExpon(1.78)+14.14, F5=RiskBetaGeneral(0.35, 0.5,15.3,20.8), G5=RiskBetaGeneral (0.52,0.6,16,22.3).
[3]Bestfit Distributions from sample data: B6=RiskExpon(1.78)+14.14, C6=RiskBetaGeneral(0.35,0.5, 15.3,20.8), D6=RiskBetaGeneral(0.52,0.6,16,22.3), E6=RiskPearson5(4.08,10.98)+16.25, F6=Risk Expon(1.9)+18.64, G6=RiskPareto(11.44,19.8).
[4]t= Riskdiscrete (x1,x2, x3, x4, x5, x6, p1, p2, p3, p4,p5,p6).
[5]C9=IF(B8=B2,B5,IF(B8=C2,C5,IF(B8=D2,D5,IF(B8=E2,E5,IF(B8=F2,F5,IF(B8=G2,G5))))))).
[6]D9=IF(B8=B2,B6,IF(B8=C2,C6,IF(B8=D2,D6,IF(B8=E2,E6,IF(B8=F2,F6,IF(B8=G2,G6))))))).
[7]Model Parameters (Oscar 2002): λ =[p/(B9-q)]^m where p=RiskPert (34.95,40.67,46.39), rate of change of lag time as a function of temperature; q=RiskPert(4.601,5.251,5.9), temperature at which lag time is infinite; m=RiskPert(1.228,1.415,1.6), an exponent.
[8]Model Parameters (Oscar 2002): μ= μopt*(D/E), where μopt=RiskPert(0.7143,0.732,0.75), specific growth rate at Topt;; D=(T-Tmax)(T-Tmin); E=(Topt-Tmin)[(Topt-Tmin)(T-Topt)-(Topt-Tmax) (Topt+Tmin-2T); Tmin=RiskPert (4.09,5.699,7.31), minimum temperature for growth; Tmax= RiskPert (48.89,49.26,49.64), maximum temperature for growth; and Topt=RiskPert(39.51,40.01,40.51), optimum temperature for growth.

Appendix B

Thermal Inactivation Model for *Salmonella* on Cooked Broiler Meat.

	A	B	C	D	E	F	G
1	**Unit Operation**	**Proportion of Responses for Cooking Times at 15 minutes intervals (p)**					**[1]Distribution**
2		**0**	**15**	**30**	**45**	**60**	
3	Fried	-	0.000	0.214	0.572	0.214	45
4	Baked	-	0.030	0.046	0.393	0.532	60
5	Boiled	-	0.000	0.127	0.538	0.335	60
6	Grilled	-	0.092	0.139	0.549	0.220	60
7	**Unit Operation**	**[2]Bestfit Distributions for Temperature at 15 minutes intervals**					**[7]Cooking Temperature**
		0	**15**	**30**	**45**	**60**	
8	[3]Fried	22.8	46.5	68.7	75.6	83.4	75.6
9	[4]Baked	9.5	39.8	44.8	63.4	80.5	80.5
10	[5]Boiled	21.3	71.5	74.4	94.9	98.1	98.1
11	[6]Grilled	2.7	32.6	44.0	63.8	70.9	70.9
12	**[8]Unit Operation**	**[9]Formula**	**Outputs**				-
			Fried	**Baked**	**Boiled**	**Grilled**	-
13	θ	G8	75.6	80.5	98.1	70.9	-
14	D	POWER(10, (-0.1414*G8) +9.0807)	0.002	0.003	1.64E-05	0.115	-
15	T	G3	45	60	60	60	-
16	R	RiskOutput() + -B15/B14	-2.3+04	-1.2+04	-3.7+07	-2.9+01	-

[1]Distributions = Riskdiscrete (x1,x2,x3, x4,x5,x6,p1,p2,p3,p4,p5,p6) where x1=15, x2=30, x3=45, x4=60 and p = corresponding proportion of responses.
[2]Bestfit Distributions from sample data.
[3]Fried; B8=RiskExtvalue(20.78,0.8); C8=RiskExtvalue(44.81,0.62); D8=RiskLogistic(63.82,1.62); E8=RiskTriang(65.79,76.4,79.7); F8= RiskTriang(72.8,84.1,87.86).
[4]Baked; B9=RiskExpon(2.06+19.53), C9=RiskTriang (31.72,33.8,34.28), D9=RiskLogistic(44.13,0.42), E9=RiskLogistic (63.51,0.53), F9=RiskTriang(69.06,74.3,74.3).
[5]Boiled; B10=RiskExtvalue (21.06,1.01), C10=RiskExtvalue(71.2,0.37), D10=RiskLogistic(74.03,0.64), E10=RiskTriang (92.43,94.8,95.44), F10=RiskLogistic (98.25,0.31).
[6]Grilled; B11=RiskExpon(2.06+19.53), C11=RiskTriang (31.72,33.8,34.28), D11=RiskLogistic(44.13,0.42), E11=RiskLogistic (63.51,0.53), F11=RiskTriang(69.06,74.3,74.3).
[7]Logical Functions Linking Cooking Time to Temperature for fried, baked, boiled and grilled chicken;
IF(Cooking!G3=15,C8, IF(Cooking!G3=30,D8,IF(Cooking!G3=45,E8, IF(Cooking!G3=60,F8))))
IF(Cooking!G4=15,C9, IF(Cooking!G4=30,D9,IF(Cooking!G4=45,E9, IF(Cooking!G4=60,F9))))
IF(Cooking!G5=15,C10, IF(Cooking!G5=30,D10,IF(Cooking!G5=45,E10, IF(Cooking!G5=60,F10))))
IF(Cooking!G6=15,C11, IF(Cooking!G6=30,D11,IF(Cooking!G6=45,E11, IF(Cooking!G6=60,F11)))).
[8] θ =Final Temperature (°C); D= D-value (mins); T= Cooking Time (mins); R= Log Cycle Reduction.
[9]Formula for Fried chicken; Baked G8=G9, G3=G4; Boiled G8=G10, G3=G5; Grilled G8=G11, G3=G6.

Appendix C

Reduction of *Salmonella* Load on Cooked Broiler Meat.

	A	B	C	D	E	F
14	[1]Unit Operation	Log_{10} MPN				[3]Output (MPN)
		Min	ML	Max	[2]Distribution	
15	**Input Concentration**	0	1.08	4.08	1.40	25
16	**Fried**	-127605	-6621.5	-0.69629	-28236.1	0
17	**Baked**	-252769.8	-5298.07	-5.60E-04	-36106.77	0
18	**Boiled**	-9204198	-1760273	-189.7753	-2.15E+06	0
19	**Grilled**	-1597.55	-233.36	-3.9E-04	-2.24E+02	0

[1]A16, A17, A18, A19 = *Salmonella* Reduction in fried, baked, boiled and grilled broiler carcasses

[2]Distribution = RiskPert (B#,C#,D#), where # = row number.

[3]Output; F15 = ROUNDDOWN(POWER(10,E15,0); F16 = RiskOutput()+ROUNDDOWN(POWER(10,E16)*F15,0); F17 RiskOutput()+ROUNDDOWN (POWER(10,E17)*F15,0); F18 RiskOutput()+ROUNDDOWN(POWER(10,E18)*F15,0); F19 RiskOutput()+ROUNDDOWN(POWER(10,E19)*F15,0)

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