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Virginie Desvignes, Tasja Buschhardt, Laurent Guillier, Moez Sanaa. Quantitative microbial risk assessment for Salmonella in eggs. Food Modelling Journal, Pensoft, 2019, 1, pp.e39643. 10.3897/fmj.1.39643 . anses-02434116

HAL Id: anses-02434116

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Food Modelling Journal 1: e39643
doi: 10.3897/fmj.1.39643

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FSKX (Food Safety Knowledge)

Quantitative microbial risk assessment for *Salmonella* in eggs

Virginie Desvignes[‡], Tasja Buschhardt[§], Laurent Guillier[‡], Moez Sanaa[‡]

‡ ANSES - French Agency for Food, Environmental and Occupational Health and Safety, Maisons-Alfort, France
§ BfR- Federal Institute for Risk Assessment, Berlin, Germany

Corresponding author: Virginie Desvignes (virginie.desvignes@anses.fr)

Academic editor: Lyubomir Penev

Received: 02 Sep 2019 | Accepted: 25 Nov 2019 | Published: 23 Dec 2019

Citation: Desvignes V, Buschhardt T, Guillier L, Sanaa M (2019) Quantitative microbial risk assessment for *Salmonella* in eggs. Food Modelling Journal 1: e39643. https://doi.org/10.3897/fmj.1.39643

Abstract

The scope of this quantitative risk assessment model is to estimate the number of salmonellosis cases per million servings of table egg, as well as the probability of illness when ingesting a random serving of table egg. The model describes the potential egg contamination by *Salmonella* Enteritidis from farm to fork according to time/temperature storage conditions, as well as consumption practices.

Keywords

QMRA model, eggs, *Salmonella* Enteritidis, R programming language

Introduction

There were 91,662 human salmonellosis cases reported in Europe in 2017 (19.7 cases per 100,000 population) by the European Food Safety Authority and European Centre for Disease Prevention and Control (EFSA and ECDC 2018). The more prevalent serovar in human cases acquired in the EU during 2017 is *Salmonella* Enteritidis. The food and animal monitoring data showed that *S.* Enteritidis was mainly associated with laying hens and next with broiler meat. In Europe, amongst 269 *Salmonella* food-borne outbreaks

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reported with strong-evidence on the implicated food vehicle, 99 (37%) were associated with eggs and egg products. *S.* Enteritidis has been causing large outbreaks associated with international trade in table eggs (Dallman et al. 2016). The number of cases of human salmonellosis in the European Union has been increasing since 2014 (EFSA Panel on Biological Hazards et al. 2019). One of the reasons given could be the increase in the prevalence of *Salmonella* Enteritidis in laying hens (De Cesare 2018).

This work provides a generic model for assessing the risk of salmonellosis associated with the consumption of table eggs. It estimates the expected number of salmonellosis cases based on the prevalence of egg contamination and the temperature profiles of egg storage. The exposure assessment model comprises six process steps of the egg food chain from lay to consumption: on farm before collection, during grading step, during transport to wholesale, during storage at wholesale, at retail and at household. The model was adapted from “Scientific Opinion on the public health risks of table eggs due to deterioration and development of pathogens” (EFSA BIOHAZ Panel (EFSA Panel on Biological Hazards) 2014). Model parameters used to describe the growth, the rupture of the yolk membrane or for the dose response were taken from the EFSA opinion. The prevalence and the condition storage of the eggs were set to new values for illustrating the output of the model. The consumer phase model considers three cooking scenarios: uncooked, lightly and well-cooked. A beta-Poisson dose response model (Thomas et al. 2006) is then used to estimate the probability of illness per *S.* Enteritidis-contaminated serving of egg for each of the egg-cooking scenarios. This model is avalaible in Food Safety Knowledge Markup Language (FSK-ML) format to facilitate its reuse. This open information exchange format is based on harmonised terms, metadata and controlled vocabulary to harmonise annotations of risk assessment models (Haberbeck et al. 2018). This format also contained model script, visualisation script and simulation settings (de Alba Aparicio et al. 2018).

Model metadata

General metadata

Source: RISK ASSESSMENTS: Risk assessments models

Identifier: QMRA_Salmonella_egg

Rights: Creative Commons Attribution-NonCommercial 4.0

Software: R

Product/matrix

Product Name: Eggs Chicken

Product Unit: Piece

Hazard

Hazard Name: *Salmonella*

Hazard Description: *Salmonella* Enteritidis

Data background

Study Title: QMRA for *Salmonella* Enteritidis in eggs

Study Description: This QMRA assesses the risk to consumers posed by *Salmonella* Enteritidis associated with the consumption of table eggs. The model estimates (a) the number of illnesses per million servings of egg (uncooked, lightly or well-cooked) and (b) the probability of illness when ingesting a random serving of egg.

Material and methods

Fig. 1 describes the global method of risk assessment of salmonellosis due to *S.* Enteritidis related to egg consumption. This model includes an exposure model, that considers six steps along the farm to household and a dose-reponse model for risk characterisation.

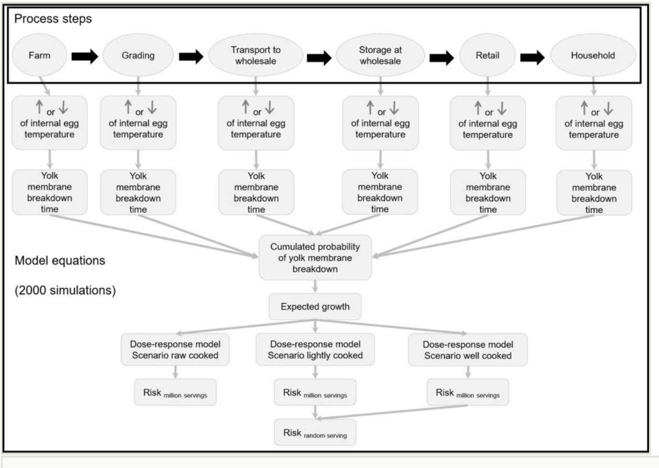

Figure 1. doi

Global method of risk assessment.

Exposure model

The exposure assessment model is composed of six steps. The evolution of the contamination along theses steps is assessed with the model equations described below. It takes into account the time and temperature conditions described in default simulation settings. Three scenarios of egg cooking are defined to assess the probability of illness: uncooked, lightly and well-cooked. The reduction of concentrations is applied to the initial concentration of *S.* Enteritidis in egg. Risk is evaluated when a random serving is ingested (i.e. either lightly or well-cooked egg).

Hazard characterisation

The beta-Poisson dose response model was used to characterise the relationship between the ingested dose and the probability of salmonellosis. In this model, the variability in host-pathogen interaction is assumed to be beta distributed. The parameterisation of Thomas et al. (2006) was chosen.

Risk characterisation

Risk was estimated through different metrics (risk per serving or number of illnesses per millions of serving) for the different cooking modes of the eggs. The default number of simulations to explore variability was set to 2,000.

Model equations

At each step, the yolk membrane breakdown time and the expected growth of *S.* Enteritidis following the membrane breakdown are estimated. These two parameters depend on the internal temperature of egg which varies at each step of the process. At the end of the six steps, the number of ingested bacteria is calculated and the dose-response model estimates the probability of illness. After that, risk is evaluated.

The yolk membrane breakdown time

In this model, we only considered the internal contamination of egg with *S.* Enteritidis. Growth models of *S.* Enteritidis are different in egg yolk and albumen. While the yolk membrane does not break down, we consider the growth of *S.* Enteritidis albumen as insignificant. However, the resistance of the yolk membrane can decrease, for example, with the vibrations during the transport phase. At the storage phase, the resistance of the membrane depends on the time and temperature. At ambient temperature, the yolk membrane is rapidly damaged, leading to the yolk diffusion in egg albumen and contamination with *S.* Enteritidis. After the breakdown of the yolk membrane, the distribution of *S.* Enteritidis is considered to be uniform in the egg.

$(log_{10}TRMV=a+b\times T)$

where $TRMV$ is the time of the yolk membrane breakdown (day), a is the intercept of the equation (a = 2.0872 hours) (Thomas et al. 2006), b is the slope of the equation (b = -0.042579 hours/°C) (Thomas et al. 2006) and T is the temperature (°C).

The estimation of the time required for the yolk membrane breakdown becomes more complicated because the temperature is no longer constant and changes over time. The calculation of the breakdown time is, therefore, done step by step at each temperature change. In order to determine whether or not there is a rupture, the *TRMV* is calculated hourly as a function of temperature and the cumulative sum of the inverse of the different previous *TRMVs*. If the sum of the inverses of the *TRMVs* is less than 1, then the membrane is considered still intact, otherwise (cumulative sum greater than or equal to 1), the yolk membrane is no longer intact and *Salmonella* growth then becomes possible.

Expected growth of *S.* Enteritidis following membrane breakdown

Using the Rosso growth rate equation (Delignette-Muller and Rosso 2000, Rosso et al. 1993, Rosso et al. 1995, Whiting et al. 2000), in particular μ_{opt} also called kopt in the model script:

$(\mu_{max} = \mu_{opt} \times \gamma(T))$

with

$$\gamma(T) = \begin{cases} 0 & T < T_{min} \\ \frac{(T-T_{max})(T-T_{min})^2}{(T_{opt}-T_{min})[(T_{opt}-T_{min})(T-T_{opt})-(T_{opt}-T_{max})(T_{opt}+T_{min}-2T)]} & T_{min} \leq T \leq T_{max} \\ 0 & T > T_{max} \end{cases}$$

where μ_{max} is the growth rate (log_{10}CFU/g per hour) at temperature T (°C), μ_{opt} is the optimal growth rate (1.6) and $\gamma(T)$ is the growth mitigation factor, T_{min} is the minimal growth temperature (6.29°C), T_{opt} is the optimum growth temperature (40.11°C) and T_{max} is the maximum growth temperature (43.46°C) (EFSA BIOHAZ Panel (EFSA Panel on Biological Hazards) 2014).

The decrease of internal egg temperature

The temperature of a laid egg is 41.2°C (Thomas et al. 2006) and then this temperature decreases progressively, according to the environmental conditions of the different process steps like production, transport and storage. The formula of the temperature decrease (EFSA BIOHAZ Panel (EFSA Panel on Biological Hazards) 2014) is:

$T=T_s+(T_i-T_s)\ exp(-kr_s t_s)$

where T is th egg temperature (°C), T_s is the storage temperature in stage s, T_i is the internal temperature at the start of the time interval, kr_s is the cooling rate constant in stage s and t_s is the time spent in stage s. T_s follows a Pert distribution with *minT*, *modeT* and *maxT* as parameters, which vary at each step of the process (Tables 1, 3). The rapidity of internal tempearture decreasing depends on the storage place, in particular, on the ventilation systems and air humidity. Pert distributions were used to describe this variability of the cooling rate due to the conditions of storage. The values of Pert distributions differ according to the process step (Table 2). t_s follows a Pert distribtuion with *minD*, *modeD* and *maxD* as parmeters, which vary at each process step (Tables 1, 3)

Table 1.

Parameters used to describe the variability of times and temperatures for the steps from farm to consumer kitchen.

Process step	Minimum time period	Mode time period	Maximum time period	Minimum temperature	Mode temperature	Maximum temperature
On farm, before collection	MinD1	ModeD1	MaxD1	MinT1	ModeT1	MaxT1
Grading	MinD4	ModeD4	MaxD4	MinT4	ModeT4	MaxT4
Transport to wholesale	MinD5	ModeD5	MaxD5	MinT5	ModeT5	MaxT5
Storage at wholesale	MinD6	ModeD6	MaxD6	MinT6	ModeT6	MaxT6
Retail	MinD8	ModeD8	MaxD8	MinT8	ModeT8	MaxT8
Household	MinD10	ModeD10	MaxD10	MinT10	ModeT10	MaxT10

Table 2.

Parameter values of the Pert distribution describing the cooling rate, according to the process step (Thomas et al. 2006)

Process step	**Minimum value**	**Mode value**	**Maximum value**
On farm before collection	0.8	0.9	1
Grading	0.0528	0.08	0.1072
Transport to wholesale, Storage at wholesale, Retail, Household	0.066	0.1	0.134

Table 3.

Description of the model parameters of the quantitative microbial risk assessment for *Salmonella* Enteritidis in eggs, according to metadata schema of FSK-ML

minD1	
parameterID	minD1
parameterClassification	input
parameterName	minD1
parameterDescription	minimum time period at farm (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer

parameterValue	2
modeD1	
parameterID	modeD1
parameterClassification	input
parameterName	modeD1
parameterDescription	mode time period at farm (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	6
maxD1	
parameterID	maxD1
parameterClassification	input
parameterName	maxD1
parameterDescription	maximum time period at farm (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	13
minD4	
parameterID	minD4
parameterClassification	input
parameterName	minD4
parameterDescription	minimum time period at grading (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	1
modeD4	
parameterID	modeD4
parameterClassification	input

parameterName	modeD4
parameterDescription	mode time period at grading (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	2
maxD4	
parameterID	maxD4
parameterClassification	input
parameterName	maxD4
parameterDescription	maximum time period at grading (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	4
minD5	
parameterID	minD5
parameterClassification	input
parameterName	minD5
parameterDescription	minimum time period at transport (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	7
modeD5	
parameterID	modeD5
parameterClassification	input
parameterName	modeD5
parameterDescription	mode time period at transport (hours)
parameterUnit	h
parameterUnitCategory	time

parameterDataType	integer
parameterValue	48
maxD5	
parameterID	maxD5
parameterClassification	input
parameterName	maxD5
parameterDescription	maximum time period at transport (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	72
minD6	
parameterID	minD6
parameterClassification	input
parameterName	minD6
parameterDescription	minimum time period at storage/wholesale (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	1
modeD6	
parameterID	modeD6
parameterClassification	input
parameterName	modeD6
parameterDescription	mode time period at storage/wholesale (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	5
maxD6	
parameterID	maxD6

parameterClassification	input
parameterName	maxD6
parameterDescription	maximum time period at storage/wholesale (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	24
minD8	
parameterID	minD8
parameterClassification	input
parameterName	minD8
parameterDescription	minimum time period at retail (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	1
modeD8	
parameterID	modeD8
parameterClassification	input
parameterName	modeD8
parameterDescription	mode time period at retail (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	24
maxD8	
parameterID	maxD8
parameterClassification	input
parameterName	maxD8
parameterDescription	maximum time period at retail (hours)
parameterUnit	h

parameterUnitCategory	time
parameterDataType	integer
parameterValue	72
minD10	
parameterID	minD10
parameterClassification	input
parameterName	minD10
parameterDescription	minimum time period at household (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	1
modeD10	
parameterID	modeD10
parameterClassification	input
parameterName	modeD10
parameterDescription	mode time period at household (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	24
maxD10	
parameterID	maxD10
parameterClassification	input
parameterName	maxD10
parameterDescription	maximum time period at household (hours)
parameterUnit	h
parameterUnitCategory	time
parameterDataType	integer
parameterValue	336
minT1	

parameterID	minT1
parameterClassification	input
parameterName	minT1
parameterDescription	minimum temperature at farm
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	29
modeT1	
parameterID	modeT1
parameterClassification	input
parameterName	modeT1
parameterDescription	mode temperature at farm
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	30
maxT1	
parameterID	maxT1
parameterClassification	input
parameterName	maxT1
parameterDescription	maximum temperature at farm
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	35
minT4	
parameterID	minT4
parameterClassification	input
parameterName	minT4
parameterDescription	minimum temperature at grading

parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	25
modeT4	
parameterID	modeT4
parameterClassification	input
parameterName	modeT4
parameterDescription	mode temperature at grading
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	27
maxT4	
parameterID	maxT4
parameterClassification	input
parameterName	maxT4
parameterDescription	maximum temperature at grading
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	30
minT5	
parameterID	minT5
parameterClassification	input
parameterName	minT5
parameterDescription	minimum temperature at transport
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	28

modeT5	
parameterID	modeT5
parameterClassification	input
parameterName	modeT5
parameterDescription	mode temperature at transport
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	30
maxT5	
parameterID	maxT5
parameterClassification	input
parameterName	maxT5
parameterDescription	maximum temperature at transport
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	33
minT6	
parameterID	minT6
parameterClassification	input
parameterName	minT6
parameterDescription	minimum temperature at storage/wholesale
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	25
modeT6	
parameterID	modeT6
parameterClassification	input
parameterName	modeT6

parameterDescription	mode temperature at storage/wholesale
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	27
maxT6	
parameterID	maxT6
parameterClassification	input
parameterName	maxT6
parameterDescription	maximum temperature at storage/wholesale
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	30
minT8	
parameterID	minT8
parameterClassification	input
parameterName	minT8
parameterDescription	minimum temperature at retail
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	20
modeT8	
parameterID	modeT8
parameterClassification	input
parameterName	modeT8
parameterDescription	mode temperature at retail
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer

parameterValue	25
maxT8	
parameterID	maxT8
parameterClassification	input
parameterName	maxT8
parameterDescription	maximum temperature at retail
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	30
minT10	
parameterID	minT10
parameterClassification	input
parameterName	minT10
parameterDescription	minimum temperature at household
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	6
modeT10	
parameterID	modeT10
parameterClassification	input
parameterName	modeT10
parameterDescription	mode temperature at household
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	15
maxT10	
parameterID	maxT10
parameterClassification	input

parameterName	maxT10
parameterDescription	maximum temperature at household
parameterUnit	°C
parameterUnitCategory	temperature
parameterDataType	integer
parameterValue	30
sim	
parameterID	sim
parameterClassification	input
parameterName	sim
parameterDescription	simulation parameter: iteration number
parameterUnit	others
parameterUnitCategory	other
parameterDataType	integer
parameterValue	2000
parameterValueMin	1000.0
parameterValueMax	10000.0
prevalence	
parameterID	prevalence
parameterClassification	input
parameterName	prevalence
parameterDescription	simulation parameter: prevalence of egg contamination
parameterUnit	others
parameterUnitCategory	other
parameterDataType	double
parameterValue	0.1
parameterValueMin	0.0
parameterValueMax	1.0
freqcuisson	
parameterID	freqcuisson
parameterClassification	input

parameterName	freqcuisson
parameterDescription	simulation parameter: frequency of well-cooked eggs
parameterUnit	others
parameterUnitCategory	other
parameterDataType	double
parameterValue	0.9
parameterValueMin	0.0
parameterValueMax	1.0
Rlcuit	
parameterID	Rlcuit
parameterClassification	output
parameterName	Rlcuit
parameterDescription	number of illnesses per million servings of lightly-cooked egg
parameterUnit	others
parameterUnitCategory	other
parameterDataType	integer
Rbcuit	
parameterID	Rbcuit
parameterClassification	output
parameterName	Rbcuit
parameterDescription	number of illnesses per million servings of well-cooked egg
parameterUnit	others
parameterUnitCategory	other
parameterDataType	integer
Rlcuit_1	
parameterID	Rlcuit_1
parameterClassification	output
parameterName	Rlcuit_1
parameterDescription	probability of illness when ingesting a serving of lightly-cooked egg
parameterUnit	%
parameterUnitCategory	arbitrary Fraction

parameterDataType	double
Rbcuit_1	
parameterID	Rbcuit_1
parameterClassification	output
parameterName	Rbcuit_1
parameterDescription	probability of illness when ingesting a serving of well-cooked egg
parameterUnit	%
parameterUnitCategory	arbitrary Fraction
parameterDataType	double
Risque	
parameterID	Risque
parameterClassification	output
parameterName	risque
parameterDescription	probability of illness when ingesting a random serving of egg
parameterUnit	%
parameterUnitCategory	arbitrary Fraction
parameterDataType	double

Estimated number of *Salmonella* in one egg (CFU)

From the moment that growth becomes possible, the growth rate is re-assessed hourly according to the γ model already presented. The growth rates calculated hourly until the end of egg storage are then cumulated. At the end, a number of ten-fold increase (NCD) is obtained for each egg. In order to determine the concentration before the egg's preparation, data on the initial concentration, i.e. at the time of laying, must be available.

The number of bacteria at the end of the storage is estimated by:

$NSS = C_0 \times 10^{NCD}$,

where NSS is the number of *Salmonella* per egg (CFU), C_0 is the initial concentration which follows a Poisson law with a mean value at 7 and a minimum value at 1 cell per egg and NCD is the number of ten-fold increase; after that, the different process steps ($\log_{10}$ CFU/h). NCD are estimated by:

$$NCD = \sum_{s=1}^{6} \mu_{max,s} \cdot t_{TRMV}$$

where t_{TRMV} is the duration of the step after the complete deterioration of the yolk membrane is observed (*TRMV*).

The number of bacteria ingested is calculated as follows:

$NSC = NSS \times 10^{-NRD}$

where NSC is the number of *Salmonella* per egg after cooking and NRD is the number of $\log_{10}$ reductions, according to the conditions of cooking. NRD follows a normal distribution with a mean value at 2 and a standard deviation at 0.5 when eggs are lightly-cooked and a normal distribution with a mean value at 12 and a standard deviation at 1 when eggs are well-cooked (Thomas et al. 2006).

Dose-response model

The beta-Poisson dose-response model from (FAO/WHO 2002) was used:

$$P_{ill|contserving} = 1 - (1 + \frac{NSC}{\beta})^{-\alpha}$$

$P_{ill|cont\ serving|w}$ and $P_{ill|cont\ serving|l}$ are the probability of illness per *S.* Enteritidis-contaminated serving for well or lightly cooked eggs, respectively. The coefficients of the dose-response model are α (0.1345) and β (53.33) which were taken from (Thomas et al. 2006).

Risk estimation

The potential risk for humans of becoming infected via egg consumption is estimated by:

$R_{lightly-cooked} = (1 - fq_{cooking}) \times prevalence \times P_{ill\ |\ cont\ serving\ |\ l} \times 10^6$

$R_{well\text{-}cooked} = fq_{cooking} \times prevalence \times P_{ill\ |\ cont\ serving\ |\ w} \times 10^6$

where $R_{lightly-cooked}$ is the number of illnesses per million servings of cooked egg, $fq_{cooking}$ is the percentage of people who well cook eggs (set to 0.9), $prevalence$ is the prevalence (set to 10% for illustration purposes) and $P_{ill\ |\ cont\ serving}$, the probability of illness per *S.* Enteritidis-contaminated serving of egg.

Simulations

All model parameters are presented in Table 3. The default simulation values of these parameters take account of the conditions of production, transport and storage of eggs and they are summarised in the supplementary material (Suppl. material 2).

Results

Fig. 2 is generated thanks to the visualisation script and shows the number of salmonellosis cases per million eggs consumed dependent on the cooking method. According to the parameters entered for the time-temperature conditions and for 10% prevalence , the number of cases would reach at 186 salmonellosis per million serving of lightly-cooked eggs. The risk levels of well-cooked eggs are 1690 lower than lightly-cooked eggs. The risk associated raw egg cunsumption is two times more important than for lighly-cooked eggs.

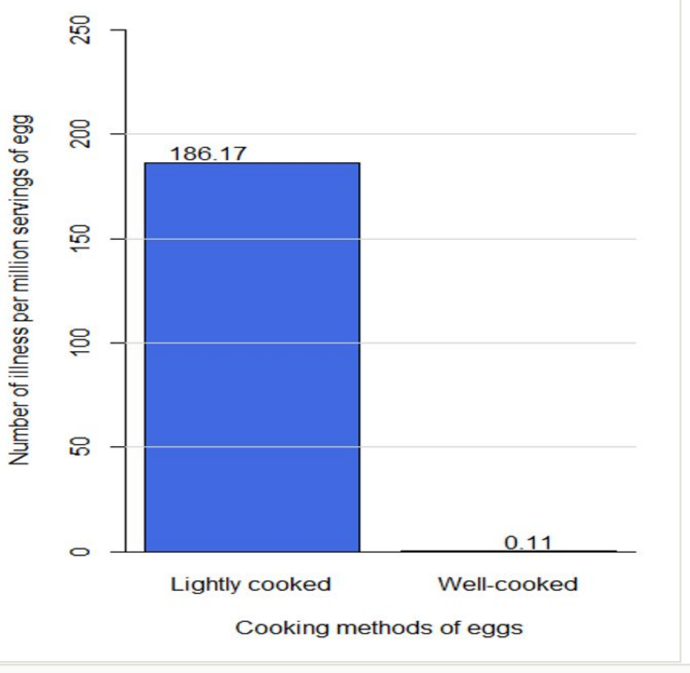

Figure 2. doi

Predicted number of salmonellosis per million servings of eggs, according to the cooking method.

The output shown in Fig. 3 is also generated by the visualisation script. It illustrates the evolution of the risk of salmonellosis per egg consumed as a function of the age of the egg at consumption. The probability of illness becomes high, especially after 9 days of storage.

Fig. 4 displays the cumulative distribution of the $\log_{10}$ of the probability of illness when ingesting a random contaminated serving of egg. It takes into account the proportion of lightly and well-cooked consumption practice.

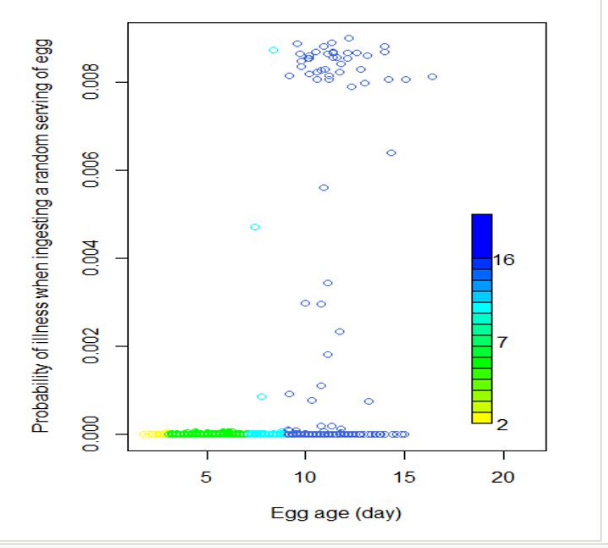

Figure 3. doi

Probability of illness according to storage duration.

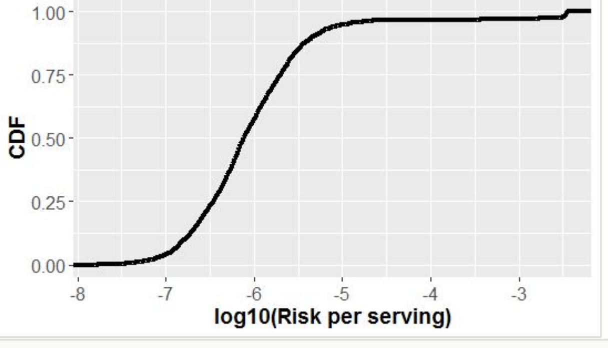

Figure 4. doi

Probability of salmonellosis for a random serving of egg.

Conclusion

This quantitative risk assessment model allows the estimation of the number of salmonellosis cases per million servings of table egg, as well as the probability of illness when ingesting a random serving of table egg. The model can be adapted to different situations in setting the parameters values especially time/temperature storage conditions (Suppl. materials 1, 2). Prevalence, set at 10% in the simulation settings, could also be adapted to more realistic values (EFSA BIOHAZ Panel (EFSA Panel on Biological Hazards) 2014). In the same way, the frequency of consumption of well-cooked eggs could be adapted to consumer practices, based on national consumption survey (Dubuisson et al. 2019).

Author contributions

Moez Sanaa developed the model code in a R Shiny application at first (https://qram.shinyapps.io/Eggs/). This model was recoded and prepared by Virginie Desvignes who drafted the manuscript. Laurent Guillier and Moez Sanaa reviewed the manuscript. Tasja Buschhardt filled in the metadata sheet of the model and the final FSK file was compiled by Virginie Desvignes.

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Supplementary materials

Suppl. material 1: QMRA_Salmonella_egg_Virginie.fskx doi

Authors: Virginie Desvignes
Data type: fskx model
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Suppl. material 2: Parameter settings doi

Authors: Virginie Desvignes
Data type: Model parameters
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