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Elicitation for food microbial risk assessment: a probabilistic approach extending Risk Ranger proposal

Titre: Elicitation pour l'évaluation des risques microbiologiques dans les aliments : vers une approche probabiliste de l'outil Risk Ranger

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Abstract: Ross and Sumner (2002) proposed a convenient tool, Risk Ranger, for early-stage risk assessment of microbial hazards in food systems. The authors describe the tool as being a simple way of comparing and classifying food-related risks and highlighting main factors that contribute to food safety. The output of the tool is a risk score based on answers to 11 questions. The objective of this work was to extend Risk Ranger towards a probabilistic version, distinguishing uncertainty and variability. For each question, we propose an elicitation procedure where the expert is asked for two quantiles to assess variability. Experts are also asked on their degree of confidence for the given quantiles to incorporate an uncertainty level. The new tool, also an Excel worksheet, allows the expert to check graphically, almost instantly, the uncertainty and variability of the variable of interest from the elicited quantiles and then to interactively modify them according to his/her view.

Résumé : Ross et Sumner (2002) ont proposé un outil sous la forme d'une feuille de calcul Excel, Risk Ranger, pour une évaluation des risques simple et rapide des dangers microbiologiques dans les aliments. Il permet de comparer et classer les risques liés à certains aliments en identifiant les facteurs qui y contribuent le plus. La sortie de l'outil est un score unique calculé à partir de réponses à 11 questions. L'objectif de ce travail est de faire évoluer l'outil Risk Ranger vers une version probabiliste. Nous proposons une procédure d'élicitation de la variabilité à l'aide de deux quantiles de la distribution d'intérêt. De plus, un niveau d'incertitude est spécifié grâce au degré de confiance fourni par les experts sur ces quantiles. Le nouvel outil, également sous forme d'une feuille Excel, permet à l'expert de modifier de vérifier graphiquement presque instantanément les conséquences de ses réponses sur l'incertitude et la variabilité de la quantité d'intérêt pour mieux les ajuster à son expertise.

Keywords: elicitation, risk assessment, variability, uncertainty
Mots-clés : élicitation, appréciation des risques, variabilité, incertitude
AMS 2000 subject classifications: 60-04, 97-Mxx

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1. Introduction

Quantitative microbial risk assessment (QMRA) aims to model the fate of pathogenic micro-organisms through the food production chain and to evaluate the health related risks. Moreover, it allows to estimate the impact of potential interventions measures on public health. QMRA can be complex, time-consuming and expensive according to aims of risk managers (Havelaar et al., 2008). A QMRA can also in principle be simple especially when an order of magnitude estimate is expected (Evers and Chardon, 2010). In such cases, point estimates and simplified model shall be used. In this context Ross and Sumner (2002) proposed a convenient tool, the Risk Ranger. The authors describe the tool as being a simple way of comparing food-related risks and classifying/ranking them and highlighting factors that mainly contribute to food safety risks. Risk ranger uses the principles of risk assessment, i.e. it incorporates the likelihood of exposure to a food-related risk, the prevalence of hazards in a food product when they exist, and the likelihood and severity of the consequences of a particular contamination level and frequency of exposure. The tool requires that the user choose qualitative or quantitative statements concerning the factors that will affect the risk related to a specific food product and a specific hazard for a specific population, from production to consumption. An Excel worksheet translates the qualitative descriptions into numerical values and combines them with the quantitative statements in a series of mathematical and logical steps that use standard spreadsheet functions. Risk Ranger has been used for assessing risk for various pathogen and or food, e.g. by Mataragas et al. (2008) for meat products, by Guillier et al. (2011) for histamine in seafood or by Sosa Mejia et al. (2011) for a steam meal product. As Ross and Sumner (2002) pointed out, the tool can still be improved. They especially identified the possibility ”*to enter a range of values, or distribution of values that would offer some of the benefits of stochastic modelling, but still in a relatively simple tool*”. In this way, Davidson et al. (2006) proposed some modifications to create a fuzzy risk assessment tool (FRAT). In the same way, the objective of this work was to generalize Risk Ranger (RR) in order to obtain a new probabilistic tool for early-stage risk assessment of microbial hazards in food systems taking into account the two major concepts of risk, uncertainty and variability.

2. The Risk Ranger Chain

RR can be interpreted as a Directed Acyclic Graph with deterministic relationships (Figure 1). Our attempt can be seen as introducing randomness in the root (input) nodes.

2.1. Description of the input nodes

The calculation of the outputs of RR is based on inputs obtained from answers to 11 questions. The answer to the question number n, noted x_n, will be associated to the variable X_n. The first question concerns the severity of the hazard considered. The hazard severity was in the first RR version arbitrarily weighted by factors of 10 for increasing levels of severity. In the current available version, it is assumed that a ”severe hazard” has a weighting factor of 1. Other hazards: ”moderate”, ”mild” and ”minor” have lower weighting factors respectively 0.01, 0.001 and 0.0001.

Then, four questions concern the exposed population. Question 2 precises the population of interest. The expert has to select it among four proposed categories ($X_{2,2}$), based on their susceptibility to illness ($X_{2,1}$). The weighting of relative susceptibility of these categories of consumers, with known predisposing conditions, was based on the relative risk of listeriosis. Question 3 deals with the frequency of consumption. The expert has five possible choices. He/she can choose within the following frequencies: daily, weekly, monthly, a few times per year or "other". For the first four choices, the number of days of consumption per year is 365, 52, 12 and 3 respectively. When "other" is selected, the expert has to indicate the number of days between two servings. The frequency of consumption per year is then calculated by dividing 365 by x_3. Question 4 deals with the proportion of population consuming the product. The expert has four possible following choices: 100%, 75%, 25% and 5%. Question 5 concerns the size of the general population of interest. The expert can select "Australia" or one the various Australian regions, or enter a specific population size.

The last six questions deal with the fate of the hazard in the food chain. Question 6 is about the proportion of raw product contaminated. The expert can either choose within five linguistic values: rare (1 product contaminated out of 1000), infrequent (1%), sometimes (10%), common (50%), all (100%) or give its own estimate. Question 7 deals with the effect of processing on the hazard. Here again the expert can either choose within seven linguistic values that represent the ability of the processing step to reduce or to increase the level of the considered hazard. The following qualitative statements are proposed: reliably eliminates (100% reduction), usually eliminates (99% of reduction), slightly reduces (50% of reduction), has no effect, increases (multiplication by 10), greatly increases (multiplication by 1000). For question 8 the expert has to evaluate the frequency of recontamination after processing within the following statements: no (0%), minor (1%), major (50%) and other (% to assess). Question 9 considers the potential increase of the hazard during storage, distribution and retailing. Question 10 is about the ratio between the level of hazard in the product at consumption and the level thought to cause an illness in a consumer (with a susceptibility corresponding to the general population). Question 11 deals with the effect of meal preparation. For this question, the expert can choose between statements that are almost identical to those proposed in question 7.

2.2. *Description of the output nodes*

Four outputs are produced by RR. Let us denote them by Y_1, Y_2,Y_3 and Y_4. Y_1 is the probability that a serving contains a dose of pathogen that would lead to illness. It is calculated as $Y_1 = min(1, max(X_6X_7, X_8) \cdot X_9X_{10}X_{11})$. Y_2 is defined as the "probability of illness per consumer per day" and is calculated as $Y_2 = min(1, Y_1X_{2,1}X_3)$. Y_3 is the "total predicted illnesses/annum in population of interest" given by $Y_3 = 365 \cdot Y_2X_{2,2}X_4X_5$. Ross and Sumner also introduced another output defined as "comparative risk", CR, as a measure of risk that is adjusted by the proportion of the population consuming but is independent of population size, $CR = Y_2X_{2,2}X_4X_1$. CR output is not proposed to RR end-user but it is helpful to calculate the global risk score, Y_4. Y_4 is scaled logarithmically between 0 and 100, where 0 represents the risk probability of illness for a mild hazard of less than one case per 10 billion people per 100 years. CR in this situation corresponds to $2.75 \cdot 10^{-17}$ (i.e. -17.56 for $\log_{10}(CR)$). Y_4 is calculated as follows $Y_4 = 100 \cdot (1+\log_{10}(CR)/17.56)$.

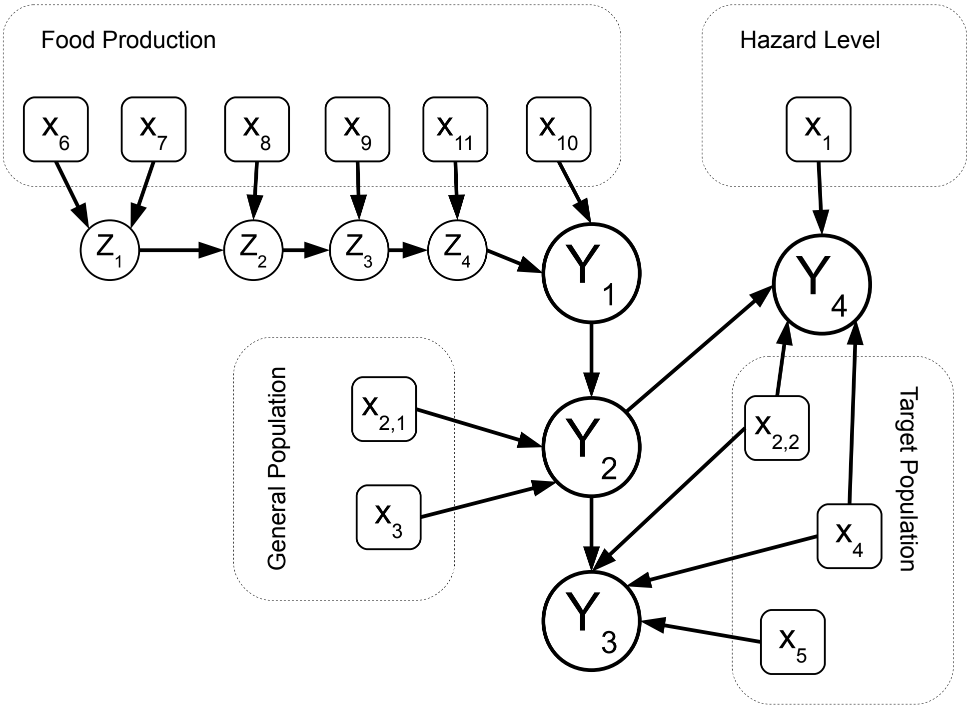


FIGURE 1. *Structure of the DAG associated to RR calculations*

2.3. Limitations of RR

As described above the outputs are not simple multiplication of probability. Several inputs like X_1, $X_{2,2}$, X_7 or X_{10} are weighting factors that modulate final ouputs. As Davidson et al. and authors themselves pointed out, RR "*was created via a reactive process based on testing with epidemiological data. When the model failed, it was modified to make it consistent with the epidemiological data*". The weighting factors for severity (X_1) and susceptibility ($X_{2,2}$) are the more questionable. For severity, weighting factors could be proposed based on relative clinical severity scores such as those proposed by Fosse et al. (2008) that take into account hospitalization and lethality rates. For particular hazards that weighting might be inappropriate as there is no or little difference of susceptibility between subgroups of population. This is the case for foodborne pathogen that produce toxin in foods such as *Staphylococcus aureus*, *Bacillus cereus* or *Clostridium perfringens*. Another issue of RR is elicitation of X_{10}, the expert has to establish which "*increase in the post-processing contamination level would cause infection or intoxication*". It appeared that it is not straightforward for the expert to provide an estimate to this question, as he/she has to take into account several quantities such as the initial level of the contamination and the illness dose. An improvement would be to ask the expert several questions. All these changes would help elicitation procedure but we decided to keep RR questions and calculations as they were initially proposed in RR to concentrate on introduction of elicitation of variability and uncertainty.

TABLE 1. *Description of possible answers for question 3 and associated deterministic values for RR or intervals for FRAT and the PRR.*

Descriptors proposed	RR (deterministic value)	FRAT 4-tuple $< a, b, c, d >$	PRR $[X_{min}, X_{max}]$
”Daily”	365	$< 250, 300, 400, 450 >$	[250,450]
"Weekly"	52	$< 35, 45, 55, 65 >$	[35,65]
"Monthly"	12	$< 8, 10, 14, 16 >$	[8,16]
"A few times per year"	3	$< 1, 2, 3, 5 >$	[1,5]
"Other" Enter the number of days between two servings (N)	365/N	not possible	[1,450]

3. The Probabilistic Risk Ranger (PRR)

The widespread use of Risk Ranger can be explained by its implementation in Excel. Indeed experts, who are generally food microbiologists, are more likely to use a tool developed in an already known friendly environment. To keep this advantage we decided to develop the Probabilistic Risk Ranger in VBA Excel. As experts can be reluctant to give a quantitative value, RR lets the expert choosing between descriptors (like ”Meal Preparation SLIGHTLY REDUCES (50%) hazards”) or the opportunity to enter its own value. PRR keeps this idea of the use of descriptors. In PRR, whatever the descriptor chosen, the expert selects an interval of possible values, $[X_{min}, X_{max}]$, instead of a deterministic value in RR. Some intervals were inspired by those proposed by Davidson et al. (2006) for the fuzzy version of RR that they developed (FRAT). Indeed, FRAT represents most inputs as fuzzy values, represented by a 4-tuple <a,b,c,d>. $[X_{min}, X_{max}]$ intervals were directly inspired by a and d values of Davidson et al. (2006). Other intervals in PRR were built in order to frame the different x values associated to the descriptors of RR questions. Table 1 illustrates the x values in RR and the intervals associated to FRAT and PRR.

3.1. From a unique value to a distribution of values for input nodes

In Risk Ranger, for a given question, the user is asked to propose a characteristic value, noted x. We propose now that the user gives four values to derive the probability distribution of the random variable X. These four quantities are q_l, q_u the elicited quantities for standard quantiles of X associated to known probability levels (α_l and α_u); and d_l, d_u the elicited associated degrees of confidence of the expert in her/his assessment about the quantiles. We assume that these degress can range from 1 (poor confidence) to 10 (perfect confidence).

Figure 2 displays the graph associated to the modeling of each question. For now, all X are supposed to follow a Beta distribution defined on the support X_{min}, X_{max} and depending on two parameters (θ) which can be retrieved from two quantiles Q_l and Q_u (in practice, we propose to use $\alpha_l = 0.25$ and $\alpha_u = 0.75$ probabilities, but any couple of values can be used). The numerical procedure developed by Van Dorp and Mazzuchi (2000) was used to obtain the two parameters of the Beta distribution from the two quantiles.

We also add uncertainty using the degrees of confidence given by the expert. The uncertainty on the two variability quantiles, Q_l and Q_u is modeled with a uniform distribution, $U(q_{l1}, q_{l2})$ and $U(q_{u1}, q_{u2})$ respectively. The bounds for both uniform distributions are calculated as follow:

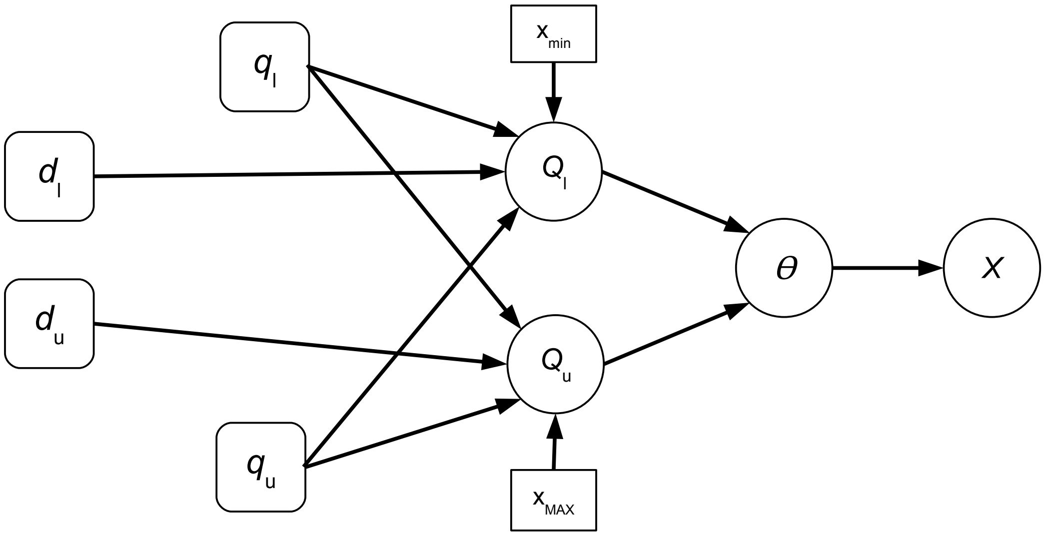


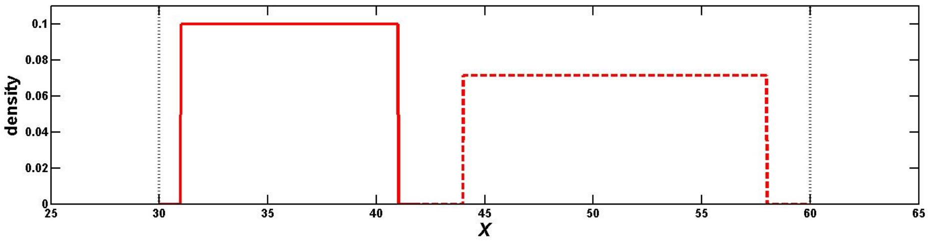
FIGURE 2. *Graphical model illustrating the conditional dependencies between the four values given by the expert q_l, q_u, d_l, d_u and the random variables, Q_l, Q_u and X. d stand for degree of confidence, q for assessed quantiles. θ is the vector of parameters associated to the prefixed distribution of X. X_{min} and X_{max} define the range of X.*

$q_{l1} = q_l - (1 - \frac{d_l}{10}) \cdot (q_l - X_{min})$ and $q_{l2} = q_l + (1 - \frac{d_l}{10}) \cdot (q_0 - q_l)$
$q_{u1} = q_u - (1 - \frac{d_u}{10}) \cdot (q_u - q_o)$ and $q_{u2} = q_u + (1 - \frac{d_u}{10}) \cdot (X_{max} - q_u)$
with $q_0 = \frac{q_u + q_l}{2}$. It must be underlined that when the expert chooses $q_l = q_u$ and $d_l = d_u = 10$ then X is fixed and corresponds to x of the former version of Risk Ranger. When $q_l < q_u$ and $d_l = d_u = 10$ then X represents only variability. When $q_l < q_u$ and d_l or $d_u < 10$ then X represents expert uncertainty and variability. When $q_l = q_u$ and $d_l = d_u < 10$, X represents uncertainty and follows a uniform distribution of bounds $\mathrm{U}(q_{l1}, q_{u2})$. An illustration of the expert variability and uncertainty construction is shown on Figure 3.

Like FRAT, PRR expresses also uncertainty, but with a different method, fuzzy logic and probability respectively. While the two methods can be used to represent subjective belief, fuzzy logic uses the concepts of fuzzy set membership (what is the degree to which the variable is thought to be in the set). Fuzzy logic is thus rather a possibility measure rather than a probability measure. Hence both methods are not directly comparable.

3.2. The Excel worksheet of PRR: an interactive tool

The elicitation process is not a one-blind step process (Albert et al., 2012). It is good to provide the expert some feedback and to let him/her the possibility to revise his/her judgment. For now, the new tool allows the expert to check graphically, almost instantly, the uncertainty and variability of the variable of interest at each question and then to interactively modify it according to the consistency between his/her opinion and that he/she sees on the graph. Figure 4 presents a screen



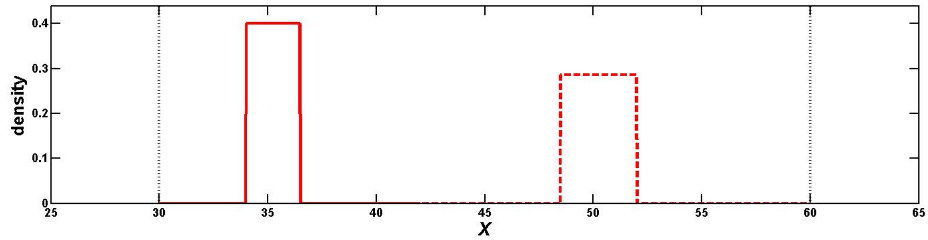


FIGURE 3. *Example of uncertainty construction on Q_l (solid line) and Q_u (dashed line). Expert given quantiles are $q_l = 35$ $q_u = 50$. $X_{min} = 30$ and $X_{max} = 60$ (dotted lines). Upper graph $d_l = d_u = 2$, bottom graph $d_l = d_u = 8$.*

shot of question 3 when using PRR. In RR, all the questions are grouped in a single worksheet. This has for consequence that the expert can measure immediately the change of the outputs when modifying one input. He/she can in this way appreciate instantly the weight of that input on the outputs. With PRR, this opportunity is lost as there are as many spreadsheets as questions. If the expert can interact between the elicited values and the variability and uncertainty of inputs, he/she can't easily measure the impact of one input on the final outputs. For future improvements of the assessment, it would be important to indicate to the user which inputs are the most influential. For that, sensitivity analysis could be added to the tool.

3.3. An application of PRR and comparison with RR

In PRR, uncertainty and variability are automatically transferred to the outputs of the model using standard arithmetic operations that define the RR chain (the deterministic links between the nodes). We applied PRR on a same hazard/food pair that Guillier et al. (2011) treated with RR. Guillier et al. (2011) assessed risk of histamine poisoning in different categories of seafoods. Histamine poisoning is the leading cause of food poisoning related to the consumption of fishery products in France. Histamine results essentially from the decarboxylation of free L-histidine, an amino acid that is contained in high concentration in muscle of some fish, by enzymes produced during the growth of various bacterial species. With RR (unique values for inputs), the interpretation of the score is ambiguous as it is difficult to know if the expert has given a median estimate or an extreme one (worst-case scenario) for the different inputs. Guillier et al. (2011) tried to overcome this ambiguity by returning two values for inputs, corresponding to ”lower” or ”upper” estimates. Two estimates of outputs were then obtained by combining what the experts thought to be low estimates or high estimates of inputs.

TABLE 2. *Elicitated values for risk assesment of histamine poisoning with fresh fish with high histidine content with Risk Ranger (RR) and Probabilistic Risk Ranger (PRR).*

Questions	RR				PRR				
	Descriptors		Associated values		Elicitated values				type of X [a]
	Lower	Upper	Lower	Upper	q_l	q_u	d_l	d_u	
1: Hazard severity	Mild		0.001		0.001		8		U
2: Susceptibility of the population	General population		1		1.25	2	9	9	UV
3: Product consumption frequency	Once a month		12		5	20	7	9	UV
4: Proportion of population consuming the product (%)	Some		0.25		25		7		U
5: Size of consuming population	Other		63.10^6		63.10^6		10		Fixed
6: Probability that a serving of raw product is contaminated	"Infrequent"	"Sometimes"	0.01	0.1	0.01	0.1	6	9	UV
7: Effect of processing	"No effect"		1		1	2	8	8	UV
8: Potential for recontamination	"No"	"Other"	0	0.1	0.005	0.01	4	4	UV
9: Effectiveness of the postprocessing control system	"Not controlled"		10		10	20	6	6	UV
10: Increase in the postprocessing contamination level needed to cause illness	"Other"	"Other"	10^7	10^8	10^7	10^8	9	9	UV
11: Effect of meal preparation	"No effect"		1		0.75	1	10	10	V

[a] U=uncertain, V=variable, UV=variable and uncertain

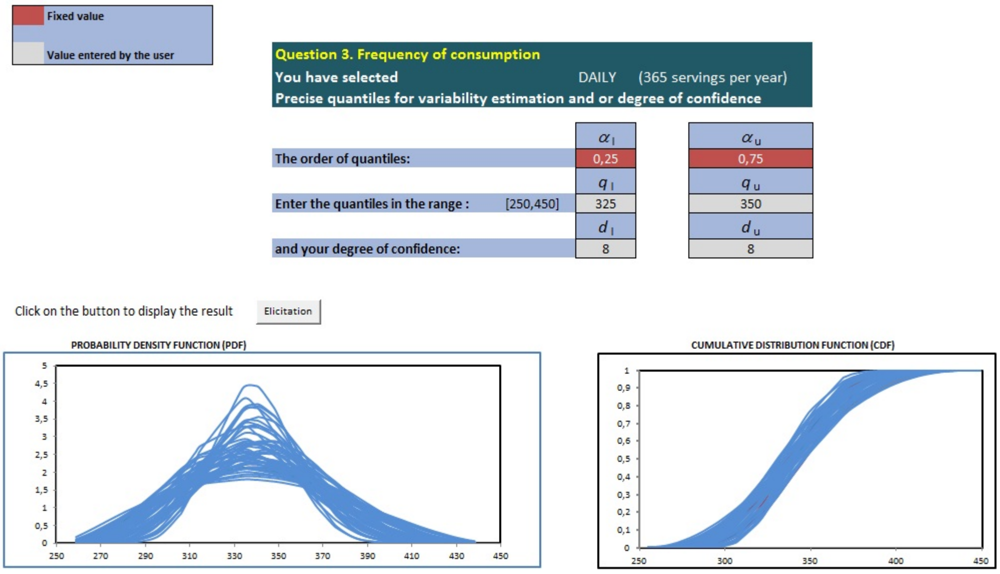


FIGURE 4. *Screen shot of question 3 worksheet of PRR. In the two graphs, following the 2D simulation practice, the probability distributions are associated to variability conditionnally to uncertainty values.*

The expert that informed RR in Guillier et al. paper, proposed values in PRR for the fresh fish with high histidine content category. Elicitated values for both RR and PRR are given in Table 2. Figure 5 shows the risk scores (Y_4 output), obtained with both tools. On this Figure, we observed that risk score variabilities of PRR include lower and upper outputs obtained by Guillier et al. (2011) . These two values, 25 and 37, are close to medians of risk scores obtained by PRR, indicating that inputs values given in 2011 were thought as estimates of median.

According to the level of the risk score (Y_4), Sumner and Ross (2002) defined threshold values that help to define the importance of a food/hazard pair. For risk scores below 32, the food/hazard pair is considered as not significant. For scores above 48, the food/hazard pair is thought to present a major concern for public health as they found that hazard/product pairs which had risk scores above 48 have caused outbreaks of food poisoning in Australia. With PRR, the risk scores are variable and/or uncertain, if the expert introduces them in at least one of the eleven inputs. Here, considering histamine in fresh fish with high content of histidine, the median of risk scores per serving that are above the score of 48 is 3.1% with a credibility interval at 95% of $[0.4-8.6\%]$. The spread in the distribution can indicate whether uncertainty or variability is dominating the model. In the present case, we can advance that variability is the dominant force.

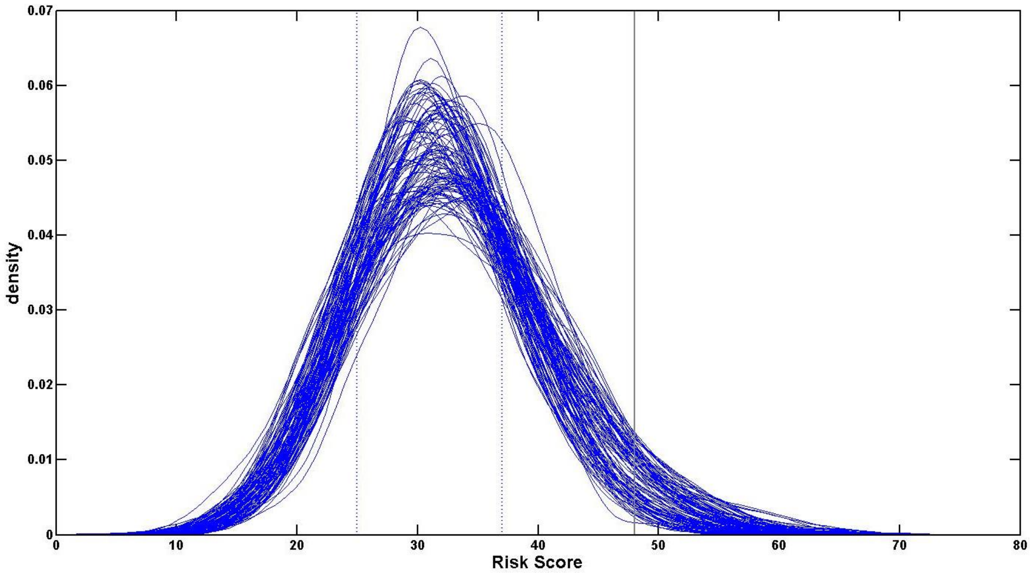


FIGURE 5. *Variability density distribution plots of the risk scores (Y_4) obtained with PRR for histamine in fresh fish with high content on histidine. Upper and lower scores obtained with RR by Guillier et al. (2011) (Dotted line). Limit defining a food/hazard pair of major concern (Continuous line). Y_4 scores were obtained here with 101 iterations in uncertainty dimension and 1001 iterations in the variability dimension.*

4. Conclusion

Although RR considers all stages of the food chain (processing, transport, recontamination, preparation and consumption among consumers), it presents some weaknesses identified by the authors themselves (Sumner et al., 2005) and by Davidson et al. (2006). They concern e.g. the question wording or the absence of an explicit dose-response relationship. A new version where the limitations of the tool would be corrected is desirable. Whatever these weaknesses, we decided to keep the questions and the RR chain as it had been proposed in order to let the opportunity to past and current users to compare both approaches. PRR results are in the same scale as RR and it will facilitate the transition from one tool to the other. PRR can be requested by email to the first author.

The separated estimation of uncertainty and variability is a classical recommendation in risk assessment estimation (Pouillot and Delignette-Muller, 2010) because each has a different implication for risk management. Two dimensional (or second-order) Monte-Carlo simulations allow calculating outputs that are variable and uncertain. With the Probabilistic Risk Ranger, the elicitation procedure allows to take into account both variability and expert uncertainty for the different inputs used to calculate risk scores.

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