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Microbiological and chemical risks in foods: Public perception versus risk ranking☆

Kah Yen Claire Yeak [a], Rallou Thomopoulos [b], Philippe Palmont [c], Gilles Rivière [c], Heidy M.W. den Besten [a], Marcel H. Zwietering [a], Jeanne-Marie Membré [d,*]

[a] Food Microbiology, Wageningen University & Research, Wageningen, the Netherlands
[b] IATE, Univ Montpellier, INRAE, Institut Agro, Montpellier, France
[c] Risk Assessment Department, Environmental and Occupational Health and Safety (ANSES), French Agency for Food, Maisons-Alfort, France
[d] Oniris VetAgroBio, INRAE, Secalim, Nantes, France

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ABSTRACT

Food safety is a critical public health concern, particularly regarding microbiological hazards (MHs) and chemical hazards (CHs) in infant foods. This study examined the risk perceptions of MHs and CHs associated with fruit puree and infant formula within the general public ($n = 3585$) across the European Union with a focus on comparing general public views against outcomes of recently published risk ranking results based on scientific assessment.

In terms of public risk perception, **1)** The general public perceived bacteria causing severe sickness (e.g., *Listeria monocytogenes*) or mild sickness (e.g., *Bacillus cereus)* as the highest concern and viruses or unknown hazards as the lowest; **2)** The general public perceived the greatest and lowest concern for agricultural (e.g., pesticides) and fraudulent (e.g., melamine) contaminants, respectively; **3)** The public exhibited a higher concern for CHs than MHs, likely due to a general distrust of chemicals in foods.

In terms of comparison between public perception and risk ranking, **1)** public perception of hazard severity showed limited alignment with risk rankings ($\rho = 0.67$ for MHs and $\rho = 0.15$ for CHs); **2)** in terms of risk, public perception aligned well with risk rankings for MH risks, with ($\rho = 0.70$ for infant formula and $\rho = 0.97$ for fruit puree). In contrast for CH risks, there was a strong misalignment between public perception and risk rankings showing correlation coefficients of $\rho = -0.70$ for infant formula and $\rho = -0.20$ for fruit puree. The public tended to overestimate risks from agricultural and packaging-related chemicals while underestimating risks associated with environmental and natural contaminants.

These findings highlight the need for targeted communication strategies to bridge the gap between public perception and risk rankings based on scientific assessment, particularly for chemical risks. Clear communication of scientific evidence, addressing misconceptions, and tailoring messages to audience needs could enhance public awareness and trigger appropriate actions.

1. Introduction

Food safety is a crucial public health concern, especially for vulnerable populations, and requires effective management of potential physical, microbiological, and chemical hazards (Engel et al., 2022). Microbiological hazards (MH) such as foodborne bacteria (e.g., *Salmonella*, pathogenic *Escherichia coli*, *Listeria monocytogenes)*, viruses (e.g., Norovirus, Hepatitis A), and parasites (e.g., *Toxoplasma gondii*, *Cyclospora* spp.), can cause a range of mild to severe foodborne illnesses (FAO, 2019; WHO, 2015). The 34 most relevant foodborne MHs have been recently summarized by Yeak, Dank, den Besten and Zwietering (2024). Additionally, chemical hazards (CH) like pesticides and heavy metals (e.g., lead, mercury) pose significant long-term health risks (FAO, 2019; WHO, 2015), with nine chemical families identified as the most relevant in the food chain (Palmont et al., 2023; Yeak et al., 2022). These hazards underscore the importance of food safety management systems

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* Corresponding author at: Oniris VetAgroBio, INRAE, SECALIM, Route de Gachet, CS 40706, 44307 Nantes Cédex 3, France.
E-mail address: jeanne-marie.membre@inrae.fr (J.-M. Membré).

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and regulatory monitoring.

Traditionally, food safety authorities use risk assessments to inform decisions and to develop risk-based communication with the public. However, these assessments often exclude direct input from public risk perceptions. The reality is that food risks are sometimes perceived differently among consumers, food professionals, and policymakers (Kher et al., 2013; Evans et al., 2020; Van der Vossen-Wijmenga, Zwietering, Boer, Velema and den Besten, 2022), as well as for health professions (Kurtz et al., 2021). These perceptions are influenced not only by assessments but also by social, psychological, cultural, and professional factors (Evans et al., 2020; Van der Vossen-Wijmenga, Zwietering, Boer, Velema and den Besten, 2022). For instance, general consumers, swayed by media coverage and discussions, may view the severity and likelihood of food-related hazards differently than food safety experts, often leading to increased anxiety and concern (Sapp & Bird, 2003; Wall & Chen, 2018; Zhu et al., 2021). Conversely, food professionals, equipped with technical knowledge and reliance on scientific evidence, might view these hazards from a different perspective.

The development of systematic decision support system (DSS) tools for hazard identification and risk ranking has become a key initiative, providing objective insights to quantify risks and support informed decision-making (Eygue et al., 2020; Garre et al., 2020; Yeak et al., 2024a). Their adoption ensures a standardized methodology for evaluating food safety hazards, enhancing the reliability of risk assessments (Garre et al., 2020; Talari et al., 2022; Wallace & Oria, 2010). Additionally, integrating user-friendly DSS tools helps bridge gaps in risk perception among food professionals from governmental agencies and industries, ensuring consistent and accessible information delivery (Engel et al., 2022). This integration is essential for fostering mutual understanding of risks, increasing transparency in hazard prioritization, and supporting clearer decision-making among stakeholders in food safety initiatives (van der Vossen-Wijmenga et al., 2022). Combined with transparent, evidence-based communication and strategic DSS use, these tools further strengthen the decision-making process (Yeak et al., 2024a).

In this study, we adopted a consumer science approach to investigate risk perceptions of microbiological and chemical hazards in infant foods (fruit puree and infant formula) among the general public. An EU-wide survey was conducted with 3585 participants to gather feedback on these perceptions, which were then compared with risk rankings based on scientific assessment to identify key differences. This analysis aims to highlight areas for enhancing communication strategies and supporting more effective food safety practices and policy development.

2. Method

2.1. Risk perception of microbiological and chemical risks

2.1.1. Study design and participants

The EU-wide survey was structured into four primary sections to investigate the risk perceptions related to MHs and CHs in infant foods among the general public.

Participants were briefed on the objectives of the survey, and the policies regarding the use and storage of data, and were assured of their anonymity. The process of obtaining informed consent was conducted following the ethical guidelines outlined in the public repository of a survey performed by Thomopoulos et al. (2024) requiring participants to confirm their consent before proceeding. Socio-demographic information was collected from the respondents to determine the eligibility of the participants, with a specific focus on their engagement with infant food products for children up to the age of 3 years. The participant roles spanned parents, childcare providers, and health professionals to ensure a comprehensive perspective on the subject.

The fourth section of the survey assessed participants' views on the safety of infant foods, focusing on risk perceptions of MHs and CHs across various categories. These inquiries specifically measured perceptions of hazard severity, contamination frequency, and general concern levels (this latter assimilated to a risk level). The full survey is accessible in the public repository at https://doi.org/10.57745/8T4VCD (Thomopoulos et al., 2024).

Briefly, the survey was designed to evaluate the general public perceptions of MH and CH hazard categories (Table 1) with three questions:

1. **Hazard severity:** "According to your best guess, how dangerous would you estimate an industrially produced food for infants and young children to be when the following are present?" Participants were asked to respond on a scale from 0 to 3 ranging from "not dangerous" to "very dangerous".
2. **Hazard contamination frequency:** "According to your best guess, how frequent would you estimate the presence of the following in industrially produced food for infants and young children?" Participants were asked to respond on a scale from 0 to 3 ranging from "never present" to "very frequent".
3. **Hazard concern level:** "How often do you wonder if the child's meals contain these contaminants when you choose or prepare them?" Participants were asked to respond with options: "regularly", "occasionally", or "rarely or never". Hereafter the concern perception is assimilated to a risk perception.

2.1.2. Data collection

The survey was originally designed in English and then translated into six additional languages. Data collection took place from July 2022 to March 2023 in seven countries: France, Germany, Greece, Ireland, Italy, the Netherlands, and Spain, using the respective language of each country. 3585 respondents in Europe participated in the survey, but only 1789 answered the questions related to microbiological hazards and

Table 1
Microbiological and chemical hazard grouping used in this study.

Microbiological Hazard Group	Description	Example
Bacteria causing mild sickness	Bacteria that may cause short-term mild sickness, less than 2–3 days	*Bacillus cereus* causing diarrhoea, etc
Bacteria causing severe sickness	Bacteria that may cause long-term sickness, more than 1–2 weeks, or severe symptoms	*Listeria monocytogenes* cause brain swelling, etc.
Bacterial toxins	Preformed bacterial toxins in foods	botulinum toxins, etc.
Viruses	Infectious viruses	Norovirus causing nausea or stomach pain, etc.
Parasites	Infectious parasites	roundworms causing loss of appetite, etc.
Unknown MHs	Unknown microorganisms that may cause illness	
Chemical Hazard Group	**Description**	**Example**
Environment	Contaminants present in the environment	heavy metals, dioxins, etc
Agriculture	Contaminants from agricultural practices	pesticides, mycotoxins, etc.
Processes	Substances generated during industrial processes such as cooking	furan, etc
Packaging	Contaminants present in packaging that could migrate into food	bisphenol A from contact plastics, etc
Additives	Intentionally added substances in food	food additives such as titanium dioxide, etc.
Natural	Substances naturally present in foods	phytoestrogens in soy, etc.
Fraudulent	Fraudulently introduced contaminants	melamine, etc.
Unknown CHs	Unknown chemical substances that may be toxic	

1823 answered the questions related to chemical hazards. From participants who reported being from one of these seven countries (2759/3585), 7.9 % were from France, 16.9 % from Germany, 11.5 % from Greece, 7.9 % from Ireland, 27.7 % from Italy, 11.6 % from the Netherlands and 16.6 % from Spain. Of the 2774 respondents who disclosed their gender, the distribution was: Female (53.93 %), Male (45.24 %), Other (0.83 %).

2.1.3. Data analysis

Questions (section 2.1.1) dedicated to hazard severity, hazard contamination frequency and hazard concern level were analyzed using the metrics as previously described in Kurtz and Thomopoulos (2021). Briefly, for hazard severity and contamination frequency, mean response values were calculated and normalized to a 0–1 scale, ensuring consistency when comparing with risk rankings of microbiological and chemical severity and contamination frequency.

For hazard concern level, the analysis is based on the following principles: within the responders' answers, which ones can be interpreted as arguments in favor of the effective presence of concern (so-called "pro" arguments), which ones can be interpreted as arguments contradicting the effective presence of concern (so-called "con" arguments). The concepts of pro/con arguments is known as the "bipolar" approach in argumentation, which is part of multi-agent models, formally introduced in Amgoud and Prade (2009). Let us note Npro the total number of such answers. Answers "Rarely or never" are interpreted as arguments contradicting the effective presence of concern; let us note Ncon the total number of such answers. Answers "Occasionally" are considered as non-interpretable, neither as the effective presence of concern, nor contradicting the effective presence of concern, they are not exploitable in bipolar analysis. This approach follows standard social science practices, where midpoints on the Likert scale are often interpreted as indicating an absence of position (Likert, 1932). The "Concern" metrics is then computed as the proportion of pro arguments, within all arguments, i.e. including pro and con arguments. This proportion is thus: Npro / (Npro + Ncon). It is a real value between 0 and 1. It is not to be interpreted statistically, but as a global (not individual, but population descriptor) AI-based metrics. It is straightforward to observe that this proportion is equal to: (Npro x 1 + Ncon x 0) / (Npro + Ncon) which is the value obtained by coding each pro argument with '1' and each con argument with '0', then computing the mean value. The result is a real value between 0 and 1. This is a computation facility, whose interpretation does not refer to statistics but to bipolar argumentation. All the results are rounded to two digits after the decimal points.

2.2. Risk rankings of microbiological and chemical risks

2.2.1. Microbiological risks

The risk ranking of microbiological risks followed the structured methods described by Yeak, Dank, den Besten, & Zwietering (2024), Yeak, Garre, Membré, Zwietering, & den Besten (2024), providing data-driven insights into MH risks. The process began with hazard identification using the Microbiological Hazards Identification (MiID) DSS tool (https://foodmicrobiologywur.shinyapps.io/Microbial_hazards_ID/), which employs a five-step procedure: 1) hazard-food pairing, 2) process inactivation, 3) recontamination, 4) growth opportunity, and 5) MH level selection (Yeak, Dank, den Besten and Zwietering, 2024). This was followed by hazard risk ranking using the Microbiological Hazards Risk Ranking (Mira) DSS tool (https://foodmicrobiologywur.shinyapps.io/Microbial_hazards_RAnking/), prioritizing risks based on seven criteria to identify the top MH risks (Yeak, Garre, Membré, Zwietering and den Besten, 2024).

To facilitate comparison with the survey data, which included six broad MH categories (Table 1), the 34 MHs reported to be the most relevant in the food chain (Yeak, Dank, den Besten and Zwietering, 2024)were grouped into these same categories except for the 'unknown MHs' category as quantitative data could not be linked to an unidentified MH. We included parasites following WHO definition (https://www.who.int/activities/assessing-microbiological-risks-in-food). Within each category, the MH with the highest value was selected to represent that group in severity and risk level comparisons, ensuring consistency with public perception data. For hazard severity, Disability Adjusted Life Year (DALY) per case values calculated for each of the 34 MHs (Yeak, Garre, Membré, Zwietering and den Besten, 2024)were normalized to a 0–1 scale based on min-max scaling ($(N- N_{min})/(N_{max} - N_{min})$) and then compared with public perceptions of severity from the survey. Hazard contamination frequency from the perception survey was not directly compared with risk rankings, as they were based on distinct assessment metrics. Instead, the total risk (similarly normalized to a 0–1 scale), defined as the product of hazard severity and hazard likelihood (hereafter frequency) in the risk ranking (Yeak, Garre, Membré, Zwietering and den Besten, 2024), was compared to survey responses on hazard concern, as both capture the overall risk.

Notably, the risk ranking evaluated and prioritized specific MHs within two infant food types, infant formula and fruit puree, whereas in the survey (Section 2.1.1), the three questions were not subdivided by infant food types.

2.2.2. Chemical risks

The risk rankings of chemical risks used the risk ranking framework described by Palmont et al. (2023), with data drawn from the French infant food dataset and contamination levels reported in the French infant Total Diet study (iTDS) (Sirot et al., 2019). This semi-quantitative method calculated total CH risk based on three criteria: severity, contribution to total exposure, and risk characterization. Hazard severity was assessed through a decision tree developed by ANSES (2020), evaluating health impacts such as genotoxicity, carcinogenicity, reproductive toxicity, organ-specific toxicity, reversibility of effects, and accumulation potential. Contribution to exposure measured the extent to which each food item or category added to overall CH exposure, while risk characterization compared these exposure levels against predefined safety standards, including health-based guidance values or toxicological reference points (Palmont et al., 2023).

To facilitate comparison with the survey data, which included eight broad CH categories (Table 1), the nine chemical families comprising 101 CHs (Yeak et al., 2022) in the assessment were grouped into these same categories, excluding unknown and fraudulent CHs, as they were not covered by the iTDS (Sirot et al., 2019). Only additives authorized by French regulations were considered. Among the 14 prioritized additives in the iTDS, including sodium acetate (E262), ascorbyl palmitate (E304), tocopherols (E306–E309), tartaric acid (E334), sodium tartrate (E335), potassium tartrate (E336), calcium tartrate (E354), phosphoric acid (E338), sodium phosphates (E339), calcium phosphates (E341), and diphosphates (E450) (Hulin et al., 2014), none were detected in infant formula or fruit puree (Sirot et al., 2019). Consequently, these additives were excluded from the chemical assessment and from comparisons with consumer risk perceptions, as their approved use at regulated levels suggests no concern.

CH severity values were normalized to a 0–1 scale and compared to perceived hazard severity in the survey. Total risk, defined as the product of severity, contribution to exposure, and risk characterization, was also normalized and compared to survey responses on hazards concern. Similarly to microbiological hazards, CH with the largest value within each category was used as the representative for that CH group.

Note that as "contribution to exposure" (terminology associated with chemical assessment) does not match exactly "likelihood" (microbiological assessment) and "frequency" (perception survey), it was decided to limit the comparison between perception and assessment to severity and risk.

2.3. Spearman correlation analysis

To assess correlations between the different variables of interest, the non-parametric Spearman's correlation, based on ranks, was used (Spearman, 1904). Spearman's coefficient was calculated using the function cor() of R (version 4.4.1) with the stats package (R Core Team, 2024). In the event of a tie, the average rank was computed by the algorithm of the cor function, reason why we decided to report hereafter the average rank in case of a tie. A value of +1, 0, and − 1 implies a perfect positive correlation, no correlation and a strong negative correlation between the variables, respectively.

3. Result and discussion

3.1. Perception of general public

In Table 2, the scores, and their associated ranks, given by the general public on microbiological and chemical hazards are provided.

Related to microbiological hazards, the general public perceived bacteria that may cause severe sickness (e.g., *L. monocytogenes*) or mild sickness (e.g., *B. cereus*) as the most and least severe, respectively. Regarding the frequency, the ranking was almost the opposite: the general public perceived the bacteria causing mild sickness as highly frequent (6th) but not the bacteria causing severe sickness (2nd). Nevertheless, regarding the concern, these two bacteria groups obtained high ranks (6th and 5th) far ahead viruses (2nd) and unknown hazards (1st).

Related to chemical hazards, the general public perceived unknown, agricultural and environmental CHs as among the most severe, ranking them equally high (7th, higher number = higher rank).Public perceptions could be shaped by immediate effect, media exposure, or limited information, leading to distinct severity rankings (Kher et al., 2013; McCluskey & Swinnen, 2011; Zhu et al., 2021). Regarding hazard contamination frequency, the general public perceived natural chemical contaminants and those from agricultural as highly frequent but not environmental, unknown or fraudulent contaminants. Regarding the general concern, the general public ranked agricultural chemicals highest (8th), followed by additives (7th) and packaging (6th).

Table 2
Perceptions of the general public. Details per hazard group are given in Table 1. S – hazard severity; F – hazard contamination frequency; C- Hazard concern level, i.e., risk perception. Highest score number = highest rank (i.e. highest rank is given as the highest number).

Microbiological hazard groups	General Public Perception score			General public Perception rank		
	S	F	C	S	F	C
Bacteria causing mild sickness	0.59	0.46	0.43	1	6	6
Bacteria causing severe sickness	0.80	0.33	0.31	6	2	5
Bacterial toxins	0.73	0.36	0.27	5	3	4
Viruses	0.68	0.37	0.21	2	5	2
Parasites	0.70	0.33	0.23	3	2	3
Unknown MHs	0.71	0.37	0.19	4	5	1
Chemical hazard groups	General Public Perception score			General public Perception rank		
	S	F	C	S	F	C
Environment	0.76	0.44	0.38	7	2.5	5
Agriculture	0.76	0.52	0.51	7	7	8
Processes	0.67	0.48	0.32	3	4	3
Packaging	0.71	0.51	0.43	4	6	6
Additives	0.63	0.50	0.48	2	5	7
Natural	0.44	0.60	0.34	1	8	4
Fraudulent	0.72	0.37	0.25	5	1	1
Unknown CHs	0.76	0.44	0.30	7	2.5	2

Footnotes: Environment = contaminants present in the environments (heavy metals, dioxins, etc.); Agriculture – contaminants from agricultural practices (pesticides, etc.); Processes = substances generated during industrial processes such as cooking (furan, etc.); Packaging = contaminants present in packaging that could migrate into food (bisphenol A from contact plastics); Natural = substances naturally present in foods (e.g., phytoestrogens in soy); Fraudulent = fraudulently introduced contaminants (e.g., melamine).

Fraudulent contaminants were perceived as low concern (1st), which is quite surprising as fraudulent contaminants, such as melamine are widely recognized by experts as a significant risk due to their potential health impacts (Gossner et al., 2009; Wen et al., 2016).

3.2. Perception of general public on microbiological versus chemical hazards

The comparison of MH versus CH risk perceptions by the general public (Fig. 1) revealed similar perceptions on hazard severity but showed generally higher perception of hazard contamination frequency and higher level of concern for CHs. This trend may be attributed to the fact that CHs are often associated with long-term effects and a perceived lack of personal control, whereas MH risks are frequently underestimated or not as readily recognized by the public (Kher et al., 2013). Thus, the results of the survey emphasized the need for tailored risk communication strategies that address the nuances of MHs and CHs in foods, which consider consumer perspectives on these hazards as their perceptions are not necessarily inaccurate, but may rather reflecting individual experiences, cultural contexts, and education differences. Moreover, the general public receives information on foodstuffs from a wide variety of sources, most of which contains inaccurate information. To enhance food safety understanding, it is crucial to balance perceptions of CH and MH risks and communication should address the complexity of food risks and accommodate the variability in risk perception across demographic groups (Hallman, 2007; Kher et al., 2013).

Comparatively, the Eurobarometer survey conducted earlier by the European Food Safety Authority (EFSA) explored perceptions of Europeans on food safety, covering various aspects from interest in food safety to responses to foodborne illnesses (EFSA, 2022). While not directly comparable to this study, similarities in CH risk perceptions were noted. The Eurobarometer highlighted widespread concern over chemical food safety issues, especially regarding pesticide, antibiotic residues, and additives, with both surveys underscoring concerns about agricultural contaminants. However, the Eurobarometer also showed a generally strong interest in food safety, without distinctly separating MH and CH risks in concern levels.

3.3. Risk perception versus risk rankings in foods

Subsequently, the risk perception of the general public on MHs and CHs was compared to the risk ranking results to examine the extent to which public concerns align with the risk rankings of these hazard groups. As described in Sections 2.1 and 2.2, first public responses on hazard severity were compared to the severity results obtained in the risk ranking studies; and second, public responses on hazard concern level were compared to the risk results.

3.3.1. Hazard severity: Perception versus risk ranking

The comparison of MH severity between public perception and risk ranking showed moderate agreement, with a $\rho = 0.67$ (Fig. 2A, Supplementary Table S1). Both public perception and ranking classified bacteria causing mild sickness as lowest in severity (e.g., *Yersinia enterocolitica* with the highest DALY/case within this group). However, the general public ranked bacteria causing severe sickness, bacterial toxins, parasites and viruses, as 5, 4, 3, and 2, respectively (higher number = higher rank = higher perceived severity), while ranking ranked these as 4, 3, 5, and 1.5, respectively (Fig. 2A, Supplementary Table S1). These differences in rankings may stem from low public familiarity with certain MHs (e.g., parasites), leading to underestimation of their potential severity (Kher et al., 2013; Verbeke et al., 2007).

For CHs, notable discrepancies were observed between public perception and ranking. The public classified equally the severity of hazards from environmental and agricultural in front of packaging, processing and natural sources, with values of 4.5, 4.5, 3, 2 and 1,

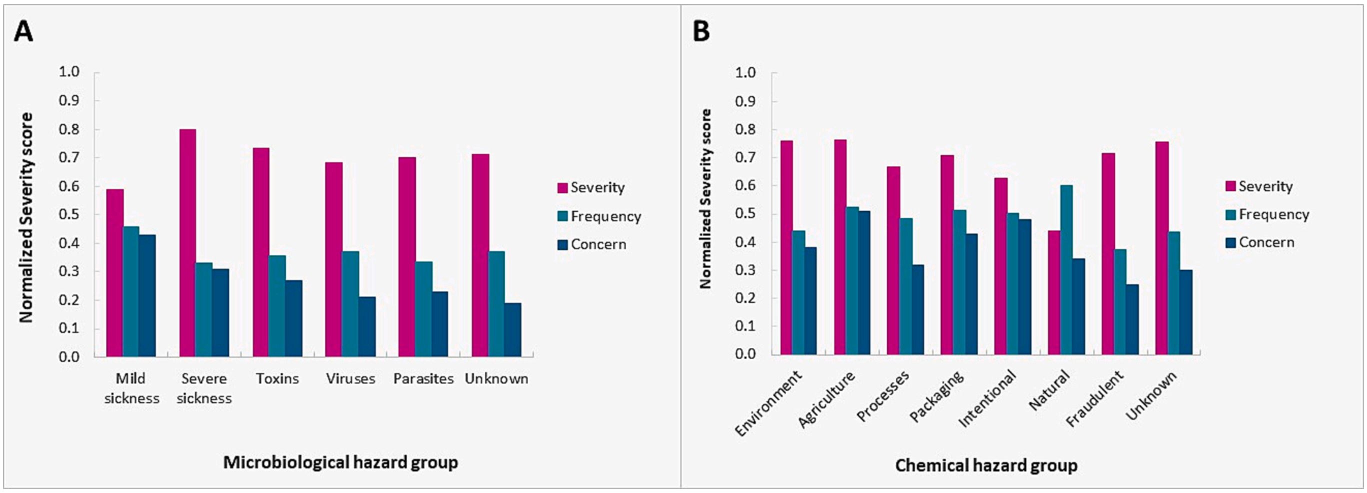
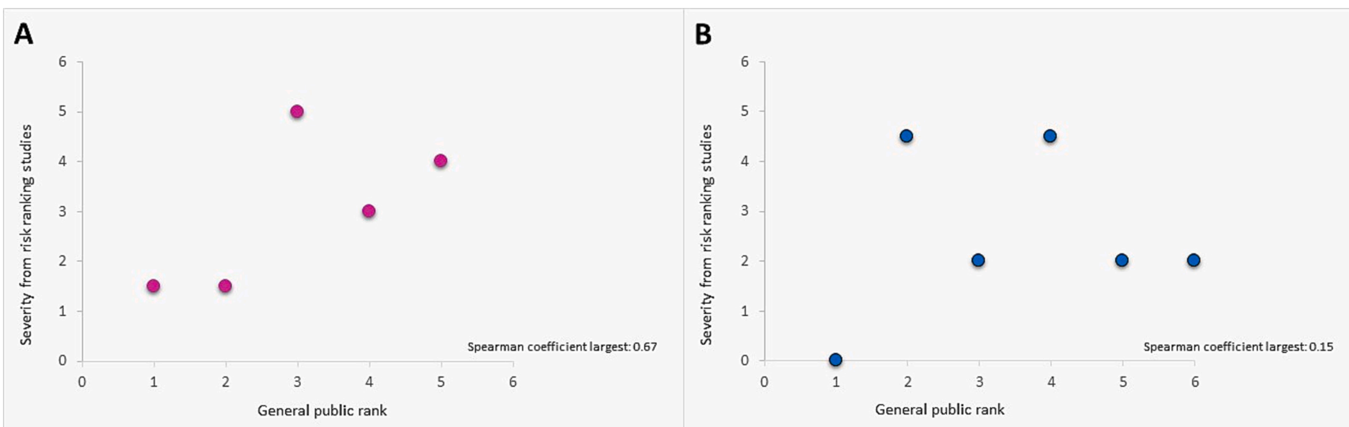


Fig. 1. Comparison of hazard severity (magenta), hazard contamination frequency (teal) and general concern level (blue) perceived by the general public regarding microbiological hazard groups **(A)** and chemical hazard group **(B)**. Details of each hazard group are listed in Table 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



	Hazard (Largest)	Perception rank (severity)	Quantitative ranking (severity)
Microbiological risks		**General public**	
Bacteria that may cause mild sickness	*Yersinia enterolitica*	1	1.5
Bacteria that may cause severe sickness	*Listeria monocytogenes*	5	4
Bacterial toxins	*Clostridium botulinum*	4	3
Viruses	Hepatitis E	2	1.5
Parasites	*Echinococcus multilocularis*	3	5

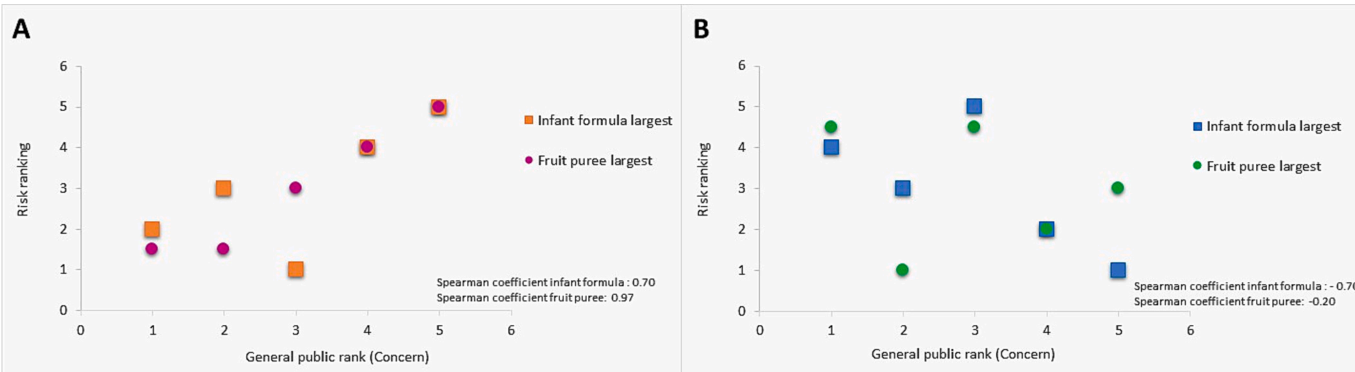
	Hazard (Largest)	Perception rank (severity)	Quantitative ranking (severity)
Chemical risks		**General public**	
Environment	Inorganic arsenic, Chromium VI	4.5	4.5
		4.5	2
Agriculture	Carbendazim		
Processes	Furan, acrylamide	2	4.5
Packaging	4-NP	3	2
Natural	Genistein	1	2

Fig. 2. Perceived severity versus risk ranking studies on microbiological (A) and chemical (B) hazards. The microbiological hazard with the highest severity value in each group was chosen as the representative severity measure (for actual DALY/case value, refer to Supplementary Table S2). For chemical hazards, all hazards within a group that shared the same highest severity value were collectively used as the representative measure for that group (refer to Supplementary Table S3). See section 2.2 for details.

respectively (with higher numbers indicating greater perceived severity). In contrast, the ranking assigned severity as 4.5, 2, 2, 4.5 and 2, respectively (Fig. 2B, Supplementary Table S1). This low correlation (ρ = 0.15) may be due in part to the presence of multiple ties in both public perception and ranking. For instance, the public assigned equal severity scores to CHs from environmental and agricultural sources (Supplementary Table S1), whereas in ranking, both inorganic arsenic and Chromium VI, heavy metals known for their genotoxic properties, are placed in the highest severity category (Supplementary Table S3). Additionally, public perceptions of CHs may also be influenced by their “unnatural” or “synthetic” origins. Chemicals associated with environmental and agricultural sources are often perceived by the public as more severe, with the lack of personal control over exposure heightening their perceived risks, even when health impacts could be relatively low (Verbeke et al., 2007).

3.3.2. *Microbiological hazards: Perceived concern versus risk ranking*

The perceived concern for microbiological risks from the public was compared with the risk rankings, which involved identifying relevant MHs and ranking them in infant formula and fruit puree, as outlined in section 2.2.1. In these rankings, higher numbers indicate higher ranking. Public responses showed relatively strong alignment with risk ranking, with Spearman correlations of ρ = 0.70 for infant formula and ρ = 0.97 for fruit puree (Fig. 3A, Supplementary Table S4). The public ranked bacteria causing mild sickness, severe sickness, bacterial toxins, viruses, and parasites in the order of 5, 4, 3, 1, and 2, respectively, indicating highest concern for bacteria causing mild sickness, and lowest concern for viruses and parasites. The risk ranking classified these hazards slightly differently for infant formula (5, 4, 1, 2, 3) and for fruit puree (5, 4, 3, 1.5 and 1.5). However, it is important to keep in mind that the risk ranking provided nuanced and detailed pieces of information (see



Microbiological Hazard Group	Hazard Infant formula	Hazard Fruit Puree	Perception Rank (concern) General public	Quantitative ranking Infant Formula	Quantitative ranking Fruit Puree
Bacteria causing mild sickness	*Salmonella* non-Typhi	*Salmonella* non-Typhi	5	5	5
Bacteria causing severe sickness	**Cronobacter* spp.	*Listeria monocytogenes*	4	4	4
Bacterial toxins	none	*Staphylococcus aureus*	3	1	3
Viruses	Norovirus	none	1	2	1.5
Parasites	*Cryptosporidium* spp.	none	2	3	1.5

Chemical Hazard Group	Hazard Infant formula	Hazard Food puree	Perception Rank (concern) General public	Quantitative ranking Infant Formula	Quantitative ranking Fruit Puree
Environment	PCDD/F	Inorganic arsenic	3	5	4.5
Agriculture	-	Carbendazim	5	1	3
Processes	Furan	Furan	1	4	4.5
Packaging	4-NP	4-NP	4	2	2
Natural	Genistein	Patulin	2	3	1

Fig. 3. Comparison of public perception and risk ranking studies on microbiological hazards (A) and chemical hazards (B) in infant formula and fruit puree. The highest risk value within each microbiological hazard (MH) and chemical hazard (CH) group was used as the representative in the risk ranking studies. See Section 2.2 for details on the methods used to rank MH and CH groups. A full list of MHs and CHs grouped by category, as shown in Table 1, is available in Supplementary Tables S5 and S7, and hazard with the largest total risk values was used as a representative for each hazard group. Symbols: Orange square – microbiological risks in infant formula; Magenta circle – microbiological risks in fruit puree; Blue square – chemical risks in infant formula; Green circle – chemical risks in fruit puree. * - *Cronobacter* spp. is only considered a bacterium that causing severe illness in infant foods because it causes severe illness to infant <6 months. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Supplementary Table S5) that the perception survey could not bring. For instance, bacteria causing mild sickness (e.g., *Salmonella non-Typhi*) were ranked as the highest risk, followed by bacteria causing severe sickness (e.g., *Cronobacter* spp. in infants), with a tenfold lower risk in infant formula. Bacterial toxins, such as those produced by *Clostridium botulinum*, were not identified as relevant in infant formula, since toxin production is not possible in dry infant formula (see selection criteria detailed in Supplementary Table S5). However, it was classified 3rd by the public. This discrepancy may stem from general concerns about foodborne toxins, or a lack of awareness regarding the specific conditions required for toxin formation in specific food types. Similarly, viruses and parasites were also not identified as relevant hazards in fruit puree, indicating that these MHs can be excluded as relevant MH risks for this food type. The public also classified viruses and parasites as the lowest risks, which aligns with the risk rankings in fruit puree. Nonetheless, this alignment may also reflect limited public familiarity with these organisms. For instance, pathogens like *Cryptosporidium* (a parasite) and Norovirus (a virus) are less widely recognized compared to bacterial pathogens like *Listeria* or *Salmonella*. The public may not fully understand under what conditions these organisms would or would not be relevant in certain foods, such as the fruit puree in this study.

These findings demonstrate a relatively strong overall alignment between public perception and risk ranking for MH risks in infant foods. However, targeted public education remains important to improve understanding of MH relevance in specific food products. Bridging gaps in public awareness can ensure informed risk prioritization and appropriate precautionary measures.

3.3.3. Chemical hazards: Perceived concerns versus risk rankings

Similarly, the perceived concern for chemical hazards from the public was compared with the risk rankings in infant formula and fruit puree as described in Section 2.2.2. As depicted in Fig. 3B, there was a negative agreement between perception and risk ranking regarding chemical risk, with Spearman's coefficient of $\rho = -0.70$ for infant formula and $\rho = -0.20$ for fruit puree (Supplementary Table S6). This negative correlation indicated a major divergence between public perception and the risk ranking, highlighting substantial differences in how CHs were viewed.

The general public classified agricultural CHs (e.g., pesticides) as the highest concern, followed by chemical contaminants from packaging, environment, natural sources, and processing (refer to Table 1 for details), with rankings of 5, 4, 3, 2, and 1, respectively (higher number = higher rank). In contrast, the risk ranking in infant formula ranked these CHs differently: environmental contaminants were given the highest risk (ranked 5), followed by CHs from processes (4), natural substances (3), packaging (2), and agricultural contaminants as the lowest risk (1). For fruit puree, environmental contaminants were again ranked the highest (4.5) equaled with processes contaminants, followed by agriculture (3), packaging (2) and natural substances (1) as the lowest risk (Fig. 3B, Supplementary Table S6).

The public's greater concern for agricultural and packaging-related CHs may stem from a fear of deliberately added chemical substances (e.g., pesticides) and a belief that all "man-made" substances are inherently dangerous, while natural substances are perceived as safe (Jansen et al., 2020). This dichotomy can lead to a misunderstanding of the actual risks, where naturally occurring CHs are underestimated, and human-made hazards are overemphasized. For instance, environmental contaminants, such as heavy metals and dioxins, pose significant risks due to their persistence in the environment and potential for bioaccumulation, which can lead to serious health effects over time (Dhiman, 2024; González & Domingo, 2021; Jeno et al., 2021; Palmont et al., 2023). Natural substances, while often perceived as less harmful by the public due to the "natural" label, can include potent toxins and allergens that are not well recognized or understood by the general public. This underestimation of natural contaminants by the public may lead to insufficient precautionary measures, potentially increasing the likelihood of exposure to harmful substances (refer to Supplementary Table S7). Improving public understanding of chemical risks requires clear, evidence-based communication. By highlighting the risks triggered by natural substances and environmental contaminants (Supplementary Table S7), which are often underestimated, public perception can be better aligned with scientific assessments.

This study has certain limitations, notably because the two sets of data, public perception and risk ranking, are different in nature, which limits the direct comparison of results, but still makes possible to compare their hazard classification. Another limitation is on the datasets: on the perception side, the hazards were grouped by sub-categories, whereas for the risk ranking, each hazard was scored. It was therefore necessary to summarize the results of the risk ranking into a single value per category. We chose the worst-case values within each hazard category, which may have introduced bias. Nevertheless, our results are overall in agreement with the literature. Discrepancies between public perceptions and risk rankings of food hazards have been reported in earlier studies, indicating a general tendency for misalignment (Bruhn, 1999; Hoefkens et al., 2009; Kher et al., 2013; Poulain, 2019; Zhu et al., 2021; Van der Vossen-Wijmenga, Zwietering, Boer, Velema and den Besten, 2022; Haentjens et al., 2023). Research suggests that public food risk perceptions are often influenced by cognitive biases and external factors, such as media coverage and personal beliefs (McCluskey & Swinnen, 2011). Consequently, risk management decisions based solely on risk rankings may be misunderstood or even rejected by the public if their perceptions are not aligned. Although the findings in this study are specific to infant foods, they highlight the importance of public perceptions to develop effective food safety standards and consumer education programs. As pointed out by Siegrist and Árvai (2020), understanding consumer risk perception and behavior remains an ongoing challenge, and thus it is essential to examine how risk perceptions impact acceptance of risk management measures. This underscores the interconnected roles of assessment, management, and communication in food safety and confirms the critical role of consumer science in bridging these areas.

4. Conclusion

This study compared the perceptions of the general public regarding microbiological and chemical risks in infant foods, as well as the alignment of these perceptions with risk ranking studies. The general public expressed slightly higher concern for CHs compared to MHs, consistent with previous studies. However, the way these hazards were grouped for easier public understanding may have influenced these perceptions. There was a relatively good alignment between public perception and risk ranking of microbiological hazards, with a Spearman coefficient of 0.70 in infant formula and 0.97 in fruit puree. However, for chemical hazards, the correlation was negative ($\rho = -0.70$ for infant formula and $-$ 0.20 for fruit puree), indicating a significant misalignment. Overall, these results highlight the importance of aligning public perceptions and scientific assessment such as risk rankings of hazards as closely as possible in order to promote effective public health strategies in the area of food safety.

CRediT authorship contribution statement

Kah Yen Claire Yeak: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Rallou Thomopoulos:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Philippe Palmont:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Gilles Rivière:** Writing – review & editing, Methodology, Conceptualization. **Heidy M.W. den Besten:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Marcel H. Zwietering:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Jeanne-Marie Membré:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodres.2025.117586.

Data availability

The data are shared through Supplmeentaru Tables or though database on internet (links provided)

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