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Ranking food products based on estimating and combining their microbiological, chemical and nutritional risks: Method and application to Ready-To-Eat dishes sold in France

Rémi Poissant [a], François Mariotti [b], Daniel Zalko [c], Jeanne-Marie Membré [a,*]

[a] Oniris, INRAE, SECALIM, Nantes, France
[b] Université Paris-Saclay, AgroParisTech, INRAE, UMR PNCA, 91120 Palaiseau, France
[c] Toxalim (Research Centre in Food Toxicology), Université de Toulouse, INRAE, ENVT, INP-Purpan, UPS, 31027 Toulouse, France

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ABSTRACT

Microbiological (M), chemical (C), and nutritional (N) risks associated with food products are usually assessed and managed independently by experts in public services or food companies. This can render difficult the comparison of food products in term of overall risk for the consumer. The objective of this study was to suggest a relatively simple method to (i) classify food products based on their M, C and N risks, and (ii) aggregate these risks and rank the food products accordingly. The method was developed and applied to 17 ready-to-eat (RTE) dishes available on the French market. With regard to food safety, the individual M and C risks were characterized considering likelihood and severity as recommended by the Codex Alimentarius. With regard to nutrition/health, the N risk was estimated based on the tendency of the dish to contribute to nutrient adequacy and to a healthy eating pattern. Finally, the outranking method PROMETHEE was applied to aggregate the three M, C, N risks and rank the food dishes. Food products were ranked relatively to each other, not in absolute terms. When we attributed the same weight to M, C and N risks, the RTE dish "Duck Parmentier" had the highest risk score while "Papillote of chicken, potatoes and small vegetables" and "Vegetarian plate vegetables and quinoa" had the lowest. However, this overall ranking changed according to the weight assigned to individual M, C and N risks, at least for food products whose scores varied according to risk types, such as"sushi discovery" (high M and C risks, low N risk). Since the risk ranking method developed here was built with assumptions and hypotheses related to the specific case study, more applications are needed to assess whether it can be generic. Nevertheless, this method is well grounded, objective, transparent, relatively fast and easy to set up. It might lead to further development of decision tools, particularly for consumers. This study paves the way towards food product multi-risk ranking.

1. Introduction

Food safety and nutritionally healthy diets are inextricably linked with important implications for population health. Food safety addresses food-borne illness, and covers the handling, preparation and storage of food. Nutritionally healthy diets relate to an adequate nutrient intake and overall healthy dietary pattern. Because of their different characteristics, they are managed separately and prioritized differently by policymakers (Nordhagen, Lambertini, DeWaal, McClafferty & Neufeld, 2022; Walls, Baker, Chirwa & Hawkins, 2019). Likewise, microbiological (M), chemical (C), and nutritional (N) risks are assessed separately by expert groups in food safety agencies such as the European Food safety Authority (EFSA) in Europe.

To overcome this issue, several approaches have been developed. Among them, Risk-Benefit Assessment (RBA) is probably the most advanced one (Pires et al., 2019) with several applications such as fish consumption (Thomsen et al., 2021). In RBA, each risk is expressed in number of cases and then aggregated in a common metric such as the disability-adjusted life year (DALY) (Murray & Acharya, 1997).

Although based on a well-documented methodology (Assunção et al., 2019), RBA requires data and time to assess quantitatively the risks, it cannot be considered as an easy and fast method. In the food safety domain, an alternative to RBA is to aggregate the risk using a ranking method (Van der Fels-Klerx et al., 2018) which enables to order hazards,

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

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food or even food establishment in term of risk and to prioritize decisions (Anderson, Jaykus, Beaulieu & Dennis, 2011; Anses, 2022; EFSA, 2015).

A step further to combine food safety and nutritional quality is to use a Multi-Criteria Decision Analysis (MCDA) technique. MCDA enables to overcome issues involving distinct or non-comparable outcomes in many fields and can facilitate the integration of food safety and nutritional quality into a broader food system (Willett et al., 2019). The Food and Agriculture Organization (FAO) has recommended MCDA to rank public health impacts and include factors such as economic losses, food security, consumer perception and socio-cultural concerns (FAO, 2017). Despite these supports, further efforts to aggregate M, C and N risks related to food systems are needed (Nordhagen et al., 2022).

In this context, the objective of this study was to suggest a relatively simple method to i) classify food products based on their M, C and N risks, and ii) aggregate these risks and rank the food products accordingly. Ready-made dishes (RTEs) were chosen as case studies because their diversity gives rise to a wide range of M, C and N risks, allowing an assessment of how the different types of risk are aligned and the extent to which they can be aggregated in a robust way. As RTE dishes are the main dishes of a standard meal, they are not too different in terms of energy intake and weight in the overall usual diet. RTE dishes are also good examples of a product for which the consumer is expected to make a choice at a meal.

2. Material and methods

2.1. Overview of the RTE dishes

Table 1 gives an overview of the 17 RTE dishes included in the study. The code of each RTE dish is used hereafter instead of its full label name. All RTE dishes are meant for 1 person only and eaten at lunch time. No additional food or drink was considered in the assessment. In other words, it was assumed in the study that whatever the person, he/she took only one of the 17 dishes at lunch time and drank nothing else but water. Also, it was assumed that the person was a healthy adult, neither old, pregnant, nor an immune-compromised person.

2.2. Microbiological risk assessment

A list of hazards was established for each RTE dish based on hazards frequently found in food (Poissant & Membré, 2022). We considered that the manufacturers mastered the heating process for cooking RTE dishes, that the operators were healthy and operated according to standard hygiene rules, and that the cold chain was not interrupted until the supermarket (Derens-Bertheau, Osswald, Laguerre & Alvarez, 2015). On the opposite, we considered possible recontamination if it occurred after heat treatment in the factory and also some missuses by consumers after purchase. The final list of hazards associated with each RTE dish is provided in Table 2 while the detailed identification of hazard processed is accessible provided in Poissant and Membré (2022).

Regarding the risk assessment, the method closely followed the FAO general recommendations (FAO, 2020) with the severity on the one hand and the likelihood on the other hand. We assessed the severity of hazards using a severity score provided by the French Agency for Food, Environmental and Occupational Health and Safety (ANSES) from 1 to 4 based on DALYs; 1 was attributed to the lowest severity and 4 to the highest. The likelihood was defined as the probability of exceeding the critical threshold for a hazard (in log CFU/g) considering dish process and formulation (pH, a_w, modified atmosphere, thermal process) and consumers practices (temperature of the refrigerator, time to consumption, etc.), both factors that could allow hazards to survive and grow in RTE dishes.

In more details, the RTE products were divided into 4 categories: sterilized, pasteurized, pasteurized and frozen, or, no submitted to any heat-treatment, as function of their characteristics (packaging, storage recommendation, labelling, etc.). Next, we built a decision tree (Supplement Material, Fig. 1S), which enabled to calculate the overall likelihood of one hazard in a specific RTE dish under all conditions. As all events were disjointed, the overall likelihood was estimated using total probability rule for each hazard identified in a given RTE dish.

Probabilities were attributed to the consumers' practices as they might occur or not, assuming that generally consumers comply with label instructions although they might deviate from the strict application of good hygiene practices at home. Table 3 summarizes the factors associated with consumers' practices and how probabilities were given to each. Putting together all these factors, it was possible to assess for each dish, if the hazards identified initially (Table 2) were unlikely or likely to re-contaminate and/or grow in the product.

For *B. cereus*, *L. monocytogenes*, EHEC, *Salmonella* non typhoida and *S. aureus*, when growth was possible, the online ComBase Predictive Models (Baranyi & Tamplin, 2004; ComBase. Combase Browser Retrieved April 25, 2023) was used to estimate to which extent the growth may reach a hazardous level (set to 5 log, 2 log, 1 log, 1 log, 3 log CFU/g, respectively; Supplement Material Tables 1S and 2S). Combase inputs were pH, atmosphere, a_w and temperature. The pH was calculated following the protocol of the U.S. Food and Drug Administration (FDA, 2022), and we used the device Oxybaby O2/CO2 (Version 6.0, WITT Society, France) to evaluate the inside gas of the package. We assumed

Table 1
List of RTE dishes included in the study.

RTE dishes Name as written on the label in French	RTE dishes name in English	Code of the dish	Preservation	Weight (g)
Saucisses aux lentilles	Sausages with lentils	Meal 1 (M1)	Ambient	420
Plat cuisiné saumon sauce oseille et riz pilaf	Salmon with sorrel sauce and rice pilaf	Meal 2 (M2)	Ambient	300
Papillote de poulet, pommes de terre et petits légumes, jus au persil	Papillote of Chicken, potatoes and small vegetables, parsley juice	Meal 3 (M3)	Frozen	300
Assiette végétarienne légumes et quinoa	Vegetarian plate vegetables and quinoa	Meal 4 (M4)	Ambient	350
Risotto au poulet et aux champignons bio	Risotto with chicken and organic mushrooms	Meal 5 (M5)	Frozen	280
Colin d'Alaska sauce citron riz safrané	Alaskan Pollack with lemon sauce and saffron rice	Meal 6 (M6)	Ambient	300
La moussaka bœuf & aubergines avec une touche de menthe douce	Beef & eggplant moussaka with a touch of sweet mint	Meal 7 (M7)	Refrigerated	300
Choucroute garnie	Sauerkraut	Meal 8 (M8)	Ambient	400
Couscous oriental au poulet	Oriental Couscous with chicken	Meal 9 (M9)	Refrigerated	300
Pâtes farcies Ricotta Epinard, sauce tomate	Pasta stuffed with ricotta and spinach, tomato sauce	Meal 10 (M10)	Ambient	330
Pasta box pâtes fraîches bolognaise	Pasta box fresh pasta bolognese	Meal 11 (M11)	Refrigerated	380
Le parmentier de canard	Duck parmentier	Meal 12 (M12)	Refrigerated	320
Sushi découverte	Sushi discovery	Meal 13 (M13)	Refrigerated	265
Pasta salade œuf thon tomates marinées	Pasta salad egg tuna marinated tomatoes	Meal 14 (M14)	Refrigerated	250
Salade bol poulet avocat	Salad bowl chicken avocado	Meal 15 (M15)	Refrigerated	310
Pizza 3 fromages fondants	Pizza with 3 melting cheeses	Meal 16 (M16)	Refrigerated	200
Poulet au curry et au lait de coco, duo de riz	Chicken curry with coconut milk and rice duo	Meal 17 (M17)	Frozen	300

Table 2
List of hazards included in the microbiological risk assessment for each RTE dish, based on a hazard identification done initially (Poissant & Membré, 2022).

RTE Dish code	RTE dishes	List of microbial hazards
M1	Sausages with lentils	Spore of *Bacillus cereus*
M2	Salmon with sorrel sauce and rice pilaf	Spore of *Bacillus cereus,* Histamine
M3	Papillote of chicken, potatoes and small vegetables, parsley juice	Spore of *B. cereus*, Spore of *C. perfringens*
M4	Vegetarian plate vegetables and quinoa	Spore of *Bacillus cereus*
M5	Risotto with chicken and organic mushrooms	Spore of *B. cereus*. Spore of *Clostridium perfringens*
M6	Alaskan Pollack with lemon sauce and saffron rice	Spore of *Bacillus cereus*. Histamine
M7	Beef & eggplant moussaka with a touch of sweet mint	Spore of *B. cereus*. Spore of *Clostridium perfringens*. Histamine
M8	Sauerkraut	*Spore* of *Bacillus cereus*. Histamine
M9	Oriental Couscous with chicken	Spore of *Bacillus cereus*. Spore of *Clostridium perfringens*. *Listeria monocytogenes*. EHEC. *Campylobacter spp*
M10	Pasta stuffed with ricotta and spinach, tomato sauce	Spore of *Bacillus cereus*
M11	Pasta box fresh pasta bolognese	Spore of *Bacillus cereus*. Spore of *Clostridium perfringens*. *Listeria monocytogenes*.
M12	Duck parmentier	Spore of *Bacillus cereus*. Spore of *Clostridium perfringens*. Histamine
M13	Sushi discovery	*Bacillus cereus*. *Clostridium perfringens*. *Escherichia coli* entérohémorragiques. *Salmonella* non typhique. *Listeria monocytogenes*. *Shigella spp*. *Yersinia* entérocolitica. AEG virus. Hepatitis A/E virus. *Cryptosporidium spp*. *Giardia duodenalis*. *toxoplasma gondii*. *Vibrio*. *Anisakis spp*. *Diphyllobothrium latum*
M14	Pasta salad egg tuna marinated tomatoes	*Bacillus cereus*. *Clostridium perfringens*. EHEC. *Salmonella* non typhique. Shigella *spp*. *Yersinia entérocolitica*. *Staphylococcus aureus*. AEG virus. Hepatitis A/E virus. T*oxoplasma gondii*.
M15	Salad bowl chicken avocado	*Bacillus cereus*. *Clostridium perfringens*. EHEC. *Salmonella* non typhique. Shigella *spp*. *Yersinia entérocolitica*. *Staphylococcus aureus*. AEG virus. Hepatitis A/E virus. *Cryptosporidium spp*. *Giardia duodenalis*. *Toxoplasma gondii*.
M16	Pizza with 3 melting cheeses	Spore of *Bacillus cereus*. *Listeria monocytogenes*. EHEC. *Salmonella spp*
M17	Chicken curry with coconut milk and rice duo	Spore of *Bacillus cereus*. Spore of *Clostridium perfringens*

that the a_w was nearly the same for all RTE dishes (set to 0.998). The temperature was estimated using compiled data from literature (Roccato, Uyttendaele & Membré, 2017). Two remarkable point estimates values were used: 4 °C and 6.9 °C. The 4° value corresponded to the targeted temperature for food stored in chilled conditions. The 6.9 °C value corresponded to the median temperature of domestic refrigerators having a temperature higher than 4 °C value (calculations based on a Normal distribution with a mean temperature of 6.1 °C and a standard deviation of 2.8 °C as given in (Roccato et al., 2017), see also Supplement material Table 3S.

For *C. perfringens*, *Shigella* spp., *Campylobacter* spp., *Yersinia* and non-cholera *Vibrio*, the growth was considered as unlikely whatever the dish (Poissant & Membré, 2022). Conversely, for parasites, virus and histamine production, if kept initially as potential hazards in a dish (Table 2) we considered their presence at a hazardous level as likely (Poissant & Membré, 2022).

Finally, the likelihood scale was split into four levels as following:

- 0.1: growth very unlikely or very slow and then very far from reaching a hazardous level
- 0.5: hazard has grown but unlikely to have reached a hazardous level
- 0.8: hazard has grown and likely to have reached a hazardous level
- 1: bacterial hazard has grown and exceeded a hazardous level, or, parasites, virus and histamine production were likely to be at a hazardous level

Note that we never considered zero growth (i.e. the lowest score was set to 0.1, not to 0).

At the end of each branch of the decision tree, one of four levels of likelihood was set. Once likelihood and severity were calculated for each hazard in one RTE dish we calculated the risk score using a scalar product between severity and likelihood to have a final score:

$$core_{microbiology} = \begin{pmatrix} Likelihood_{MO_1} \\ \vdots \\ Likelihood_{MO_n} \end{pmatrix} \times \left(Severity_{MO_1} \quad \cdots \quad Severity_{MO_n} \right) \quad (1)$$

Where MO is the microorganism.

2.3. Chemical risk assessment

The principle was the same as described in section 2.2: hazard identification followed by risk assessment based on severity and likelihood.

For each RTE dish, we selected the ingredients for which the percentage was provided on the packaging, in order to identify potential associated hazards. The hazard list was built using both the recommendations of Anses (2020) and the national survey conducted in France "Étude de l'alimentation totale, EAT2″ (Anses, 2011a; 2011b; 2019 Update). These are detailed in Table 3. We assumed that industrial data was genuine, e.g. that no forbidden substance was used and no foodstuff deliberately contaminated. Accordingly, the presence of pollutants was assumed to be linked with their presence and/or persistence in the food-chain. When certain major ingredients were not backed up by contamination data in the EAT2 study, we chose to use "proxies", i.e., the closest ingredients from the same category of substances for which data were available in EAT2.

Regarding the severity of substances, a decision tree proposed by ANSES was used. As explained by (Palmont, Membré, Rivière & Bemrah, 2023), the criterion included in the decision tree were genotoxicity, carcinogenicity, reproductive toxicity, toxicity for a specific target organ, the reversibility of the effect and the accumulation potential of the chemical. While the original decision tree allowed to range substances from A (the most dangerous) to G (the less dangerous), we chose to use numbers instead of letters for further calculations. We arbitrarily selected scores of 25, 12, 10, 9, 8 and 4 respectively for categories A, B, C, D, E, F and G, assuming that category A required to be set much higher than others, in relation to (theoretical) lethal adverse effects. In addition to that, if the substance was an endocrine disruptor chemical (EDC), we added + 2 to the score, or + 1 if the substance was a "suspected" EDC except if the score was already A (e.g. the highest possible score in our study). Supplement Material Table 4S summarizes the scores attributed to each substance.

For each of these substances, we then proceeded to determine their respective toxicological value of reference (TRV), first by prioritizing the TRVs accepted by ANSES, and if these were not available, by the World

Table 3
List of hazards and parameters for RTE dishes used to assess the microbiological risk.

MEAL	DECISION TREE			FACTORS		PROBABILITY TREE			
	Type of heating process[a]	Reconta Mination[b]	Modified atmosphere[c]	pH	Aw	Hazardous storage of RTE [d]	Time to consumption Before Use-by date / After Use-by date [e]	Consumption in multiple times	Hazardous storage of leftovers [d]
MEAL 1	Sterilization (121 °C/3min)	0	Not tested	6	0,998	Irrelevant (ambient air)	Irrelevant (Use-by date too long)	Possible (p = 0,2)	Possible
MEAL 2	Sterilization (121 °C/3min)	0	O2: 0% / CO2: 2%	6.45	0,998	Irrelevant (ambient air)	Irrelevant (Use-by date too long)	Unlikely	
MEAL 3	HTST (74 °C/ 30sec)	0	Ambient air	6.52	0,998	Irrelevant (freezer)	Irrelevant (Use-by date too long)	Unlikely	
MEAL 4	Sterilization (121 °C/3min)	0	O2: 0% / CO2: 2%	6.21	0.998	Irrelevant (ambient air)	Irrelevant (Use-by date too long)	Possible (p = 0.1)	Possible
MEAL 5	HTST (74 °C/ 30sec)	0	Ambient air	6.58	0.998	Irrelevant (freezer)	Irrelevant (Use-by date too long)	Unlikely	
MEAL 6	Sterilization (121 °C/3min)	0	O2: 0% / CO2: 8%	6.64	0.998	Irrelevant (ambient air)	Irrelevant (Use-by date too long)	Unlikely	
MEAL 7	All pasteurized (90 °C/10 min)	0	O2: 0.6% / CO2: 10.8%	5.3	0.998	Possible	5 days / 20 days	Unlikely	
MEAL 8	Sterilization (121 °C/3min)	0	Not tested	4.38	0.998	Irrelevant (ambient air)	Irrelevant (Use-by date too long)	Likely (p = 0.2)	Possible
MEAL 9	All pasteurized (90 °C/10 min)	1 (*Listeria monocytogenes. EHEC. Campylobacter spp*)	O2: 14.4% / CO2: 1.5%	6.12	0.998	Possible	4 days / 19 days	Unlikely	
MEAL 10	Sterilization (121 °C/3min)	0	Not tested	5.51	0.998	Irrelevant (ambient air)	Irrelevant (Use-by date too long)	Likely (p = 0.15)	Possible
MEAL 11	All pasteurized (90 °C/10 min)	1 (*Listeria monocytogenes)*	O2: 1.4% / CO2: 32.9%	5.3	0.998	Possible	5 days / 21 days	Likely (p = 0.05)	Possible
MEAL 12	All pasteurized (90 °C/10 min)	0	O2: 14.9% / CO2: 2.7%	6.12	0.998	Possible	7 days / 29 days	Likely (p = 0.05)	Possible
MEAL 13	Incomplete pasteurization	1 (initial hazards from uncooked food)	Ambient air	4.98	0.998	Possible	1 day / 2 days	Unlikely	
MEAL 14	Incomplete pasteurization	1 (initial hazards from uncooked food)	O2: 0% / CO2: 29%	4.83	0.998	Possible	1 day / 6 days	Unlikely	
MEAL 15	Incomplete pasteurization	1 (initial hazards from uncooked food)	O2: 5.9% / CO2: 13.5%	5.43	0.998	Possible	2 days / 11 days	Likely (p = 0.05)	Possible
MEAL 16	Incomplete pasteurization	1 (initial hazards from uncooked food)	O2: 6.4% / CO2: 42.3%	5.12	0.998	Possible	3 days / 14 days	Unlikely	
MEAL 17	HTST (74 °C/ 30sec)	0	Ambient air	6.08	0.998	Irrelevant (freezer)	Irrelevant (Use-by date too long)	Likely (p = 0.1)	Possible

[a] HTST: High-temperature short-time.
[b] 0: no recontamination / 1: recontamination.
[c] Not tested means that the device could not went through can. We assume that the atmosphere was the same as other sterilized products.
[d] The given probability of a possible hazardous storage is p = 0.77.
[e] The given probability to consume the RTE meal after its use-by-date is p = 0.0183.

Health Organization (WHO), EFSA or other health agencies' data. When no TRV could be found, to anticipate a worst-case scenario, it was decided to use the TRV of a well-studied molecule from the same family. For instance, in the case of perfluorinated substances (PFAS), the TRV of Perfluorooctanoic Acid (PFOA) was used for all PFAS for which no data was available, as PFOA has been extensively studied, particularly in terms of the effects it can induce in the event of chronic exposure scenarios. For Poly-Bromo-Diphenyl-Ethers (PBDE), the TRV of BDE-47 was used for BDE28, BDE183, BDE100 and BDE 154. Table 4S details the TRV values of substances addressed in this study.

We used the Hazard Quotient (HQ) (EFSA Scientific Committee et al., 2021) as an estimation of the likelihood required to create a score risk. We did not consider values under 1 as a "no risk" situation, but rather, in such case, we considered that the ingredient/substance contributed to the overall exposure.

- Mass of the ingredient: information available on the package.
- Average concentration of the substance in the ingredient: average concentration found in EAT 2.
- TRV: Toxicological value of reference (Table 4S)
- Weight of consumer: set as 63.5 which is the mean of body weight for people (men and women) aged 18 to 69.

Aware of the theoretical aspect of this approach, we also added a "strength of the link" factor that was built from RASFF Portal (European Commission, No date). A score of 1 was set if the number of notifications were below 100, 1.5 between 100 and 1000, and 2 above 1000 (Supplement material, Table 4S).

Finally, the formula used for calculating the likelihood for each substance in one ingredient was:

$$Hazardquotient = \frac{Masstheingredient(kg) \times averageconcentrationofthesubstanceintheingredient\left(mg.kg^{-1}\right)}{TRVofsubstance\left(mg.kgbw^{-1}.d^{-1}\right) \times Weightofconsumer(kgbw)} \quad (2)$$

Table 4
List of substances taken into account as chemical hazards of RTE dishes.

Family	Substances
–	Acrylamide
PAH	BcFL; DbahP; DbahP; DbaiP; DbaeP; DbalP; IP; BkF; BjF; BbF; CPP; BaA; PY; PHE; FA; AN; CHR; MCH; BaP; DBahA; BghiP
Dioxins and PCBs	PCDD, PCDF, PCB
Perfluorinated compound	PFOS; PFDoA; PFTeDA; PFTrDA; PFDA; PFPA; PFHpS; PFUnA; PFHxS; PFHxA; PFHpA; PFBS; PFDS; PFOA
Organobromine compound	HBCD alpha; HBCD beta; HBCD gamma; BDE28; BDE153; BDE183; BDE99; BDE209; BDE47; BDE100; BDE154
Inorganic compound and metals	Al; V; Cr; Ni; Co; Cu; Ga; Ge; As; Se; Sr; Ag; Cd; Sn; Sb; Te; Ba; Pb
Phytotoxins	Genistein
Mycotoxins	AFB1; AFB2; AFG1; AFG2; AFM1; OTA; Pat; T2; HT2; Niv; DON; 3-Ac-DON; 15-Ac-DON; ZEA; alpha-ZOL; beta-ZOL; FB1; FB2
Food additive	Sulfites (E220, E221, E222, E223, E224, E226, E227, E228); Nitrites (E249-250); Rocou(E160b)
Pesticide residue	Bifenthrin; Carbendazim; Dimethoate; Dithiocarbamates; Folpet; Imazalil; Methomyl; Oxamyl; Thiabendazole; Bitertanol; Carbaryl; Methamidophos; Methidathion; Prochloraz
Food contact materials	BPA

For each RTE dish, we used the excel sheet from EAT2 Anses (2019 Update) to identify which of these substances were found in ingredients.

$$\boldsymbol{Likelihood} = \boldsymbol{strength of the link} \times \boldsymbol{HQ} \tag{3}$$

As explained in section 2.2, we calculated the risk score as a scalar product between severity and likelihood for each substance in each ingredient:

$$Score_{chemical} = \begin{pmatrix} Likelihood_{substance_{1,1}} \\ Likelihood_{substance\ 1,2} \\ \vdots \\ Likelihood_{substance\ n,k} \end{pmatrix} \times \left(Severity_{substance_1} \quad Severity_{substance_1} \quad \cdots \quad Severity_n \right) \tag{4}$$

n: substance index

k: ingredient index.

n, k: substance n of ingredient k.

2.4. Nutritional risk assessment

We assumed that the RTE dish was consumed during lunch. In France, lunch covers 36% of the daily energy intake (Anses, 2017; Dubuisson et al., 2019). We retained the value of 30% because the RTE may not fully represent a regular lunch which would include a first course or a dessert or a drink containing energy. We built 4 criteria to assess a nutritional score risk.

The first one, called C1, was the RTE dish total energy, as displayed on the package. We considered that the lower the criterion was, the lower the risk was.

The second one, called C2, intended to assess the potential contribution of the RTE dish to adequate levels of vitamins and minerals in the diet, based on its ingredients. First, we used a table of 45 food groups showing their relative richness for 21 vitamins and minerals, based on data from the INCA 3 study and CIQUAL food composition database as previously described (Dussiot et al., 2022). A micronutrient score was then assigned to each food category based on their standardized richness for each of the vitamins and minerals, taking into account the prevalence of their inadequacy in the general adult population (Anses, 2015) and their related severity (Salomé et al., 2021); the values were finally standardized. When possible, each ingredient was assigned to one of these food groups, and C2 was calculated for each RTE dish by taking into account the micronutrient score for each ingredient weighted by the relative quantity of the ingredient in the dish, as follows:

$$\boldsymbol{C}_2 = \frac{\sum_1^n \boldsymbol{Score\_g_k} \times M_k}{\boldsymbol{E}} \tag{5}$$

Score_g$_k$: micronutrient score of the food group to which the ingredient k present in the RTE dish was assigned to (Supplement Material, Table 5S).

$$M_k = \frac{\text{mass of the ingredient k in the RTE dish (g)}}{100(\text{g})}$$

E: RTE dish total energy (kcal).

By construction, the nutritional risk increased as the C2 value decreased.

The third criteria (C3) considered the content of nutrients whose reference values refer to the risk of chronic disease: saturated fatty acids, salt and sugar as "negative" nutrients, i.e. nutrients with upper level value, and fibers as positive nutrient, i.e. a nutrient with a lower level value. Considering the French Recommended Dietary Intake (RDI) and still assuming that the RTE dish covered 30% daily energy intake, we used the following upper and lower values:

- 2.2 g of salt at most ($Amax_{salt}$)
- 30 g of sugar at most ($Amax_{sugar}$)
- 9.4 g of saturated fatty acids at most (AS_{fatty})
- 9 g of fiber at least (AS_{fiber})

We used the quantity (in gram) of each nutrient (Q_{salt}, Q_{sugar}, Q_{fatty}, Q_{fiber}) as shown on the package of each RTE dish, to calculate C3 as follows:

$$\boldsymbol{C}_3 = \left(\frac{\boldsymbol{Q_{salt}}}{\boldsymbol{Amax_{salt}}} + \frac{\boldsymbol{Q_{sugar}}}{\boldsymbol{Amax_{sugar}}} + \frac{\boldsymbol{Q_{fatty}}}{\boldsymbol{Amax_{fatty}}} \right) + (1 - \frac{\boldsymbol{Q_{fiber}}}{\boldsymbol{AS_{fiber}}}) \tag{6}$$

The nutritional risk increased as C3 value increased.

The last criteria (C4) was the composition of the ingredients of the RTE dish with respect to their potential impact on the long-term risk of chronic disease. We used the dietary risk identified by the Global Burden of Disease (GBD 2019 Risk Factors Collaborators, 2020), and the estimate Disability Adjusted Like Years (DALYs) related to the over- or under-consumption of the food group. We considered that RTE dishes contributed to these dietary risks when their ingredients, assigned to food groups, contributed to the Theoretical Minimum Risk Exposure Level (TMREL, gram per day) for food groups consumed in excess or to the TMREL failure for food groups insufficiently consumed. Supplement Material Table 6S shows the dietary risks included in this study, as well as their related burden of disease (as DALYs) and TMREL. First, for each RTE dish, each ingredient was assigned, when possible, to one of these dietary risks. Then, we calculated criterion C4 as the sum of the total mass for each ingredient, weighted by the TMREL of their related food group, corrected by the assumption that the RTE dish represent 30% energy, and multiplied by their DALYs.

$$\boldsymbol{C}_4 = \sum_1^n \boldsymbol{a_k} \times \boldsymbol{q_k} \times \boldsymbol{DALYs_k} \tag{7}$$

a_k: direction of the dietary risk k (=+1 for food groups to be limited; = −1 for food groups insufficiently consumed).

q_k: contribution of ingredient to the TMREL of the food group k

$$q_k = \frac{Totalmassofingredient}{TMRELoffoodgroupkx30\%}$$

Table 5
Parameters used to run PROMETHEE II on R. software.

Parameters	Microbiological risk	Chemical risk	Nutritional risk	Justification
Indifference	0.2	3.3	0.08	The indifference threshold is the median of the smallest distances between 2 relative risk scores
Preference	0.9	9.8	0.17	The preference threshold is the 3rd quartile of the smallest distances between 2 relative risk score
Type of preference	"V-shape"	"V-shape"	"V-shape"	"V-shape" to generate proportional preference
Weight	1/3	1/3	1/3	We assume at first* that the 3 risks had the same weight on human health

* In the second scenario, we put gradually more weight on the nutritional risk than on the safety risks.

$DALYs_k$: DALYs for the group k.

The nutritional risk increased as C4 value increased.

The final nutritional risk was obtained by summing the four nutritional criteria which were each standardized and weighted as 0.3, −0.1, 0.3 and 0.3 for C1, C2, C3 and C4, respectively.

2.5. Aggregation of microbiological, chemical and nutritional risks.

From M, C and N risk assessment, three scores were calculated, namely $Score_{microbiology}$, $Score_{chemical}$ and $Score_{nutritional}$. First of all, to assess whether the three risks were correlated, a Spearman correlation coefficient was calculated using Xlstats software (version 2021.5). Next, to aggregate it and provide a single score per RTE dish, the outranking PROMETHEE II was carried out using the package Promethee in R software (Version R 4.1.2). This method was considered suitable for our case-study according the classification suggested by Wątróbski, Jankowski, Ziemba, Karczmarczyk, and Zioło (2019), moreover has been used by the FAO to rank chemical and microbiological hazards (FAO, 2017). Table 4 provides the values of the parameters required to run the algorithm. (Table 5).

The initial weight attributed to M, C and N risks was 1/3 for each. However, as in Western European countries it is generally admitted that the nutritional risk is higher than the microbiological and chemical risks (van Kreijl, Knaap & van Raaij, 2006), we gradually increased the weight of the nutritional risk up to 0.90 (by 0.05 steps) to be potentially more representative of the observations done in Western Europe. In parallel, the weights of M and C risks were decreased (whilst remaining equal to each other) to maintain a sum of weights equal to 1.

Finally, a qualitative uncertainty analysis, reflecting how we dealt with some major lack of knowledge, was carried out to examine how uncertainty impacted the results. The aim was to further investigate how the results might have been affected if we had dealt with uncertainty differently.

3. Results

3.1. Microbiological risk

The results of the microbiological risk scoring are shown in Fig. 1. The RTE dish with the higher risk was "Sushi discovery", M13, for which there was no modified atmosphere, whose ingredients were not fully cooked, and recontamination risks high. It was followed by RTE salad dishes ("Salad bowl chicken avocado", M15, and "Pasta salad egg tuna marinated tomatoes", M14) whose ingredients were not fully cooked and where recontamination risks were also high. Next, RTE dishes for which recontamination risks were possible ("Oriental Couscous with chicken", M9, "Pasta box fresh pasta Bolognese", M11, and "Pizza with 3 melting cheeses", M16) obtained an intermediate risk scores. All the other RTE dishes obtained a similar and low score. The small differences between them can be explained with the potential presence of histamine, which is heat resistant ("Sauerkraut", M8, "Alaskan Pollack with lemon sauce and saffron rice", M6, "Salmon with sorrel sauce and rice pilaf", M2, "Duck Parmentier", M12, and"Beef & eggplant moussaka with a touch of sweet mint", M7). In general, frozen and sterilized products were estimated less risky than fresh products (Fig. 1).

3.2. Chemical risk

Results of chemical risk scoring are presented in Fig. 2. Schematically, there were three classes of equivalent risks: (1) "Sushi discovery", M13 and "Salmon with sorrel sauce and rice pilaf", M2; (2) "Alaskan Pollack with lemon sauce saffron rice", M6 and "Pasta salad egg tuna marinated tomatoes", M14; and (3) all other dishes.

The high score for M13, M2, M6 and M14 was partly explained by the proportion of substances known to be frequently found in seafood, namely Polychlorinated biphenyls (PCB) and Arsenic (As), which were attributed high severity scores (14 and 25, respectively).

Nevertheless, it is important to keep in mind that only 72% ± 12% of

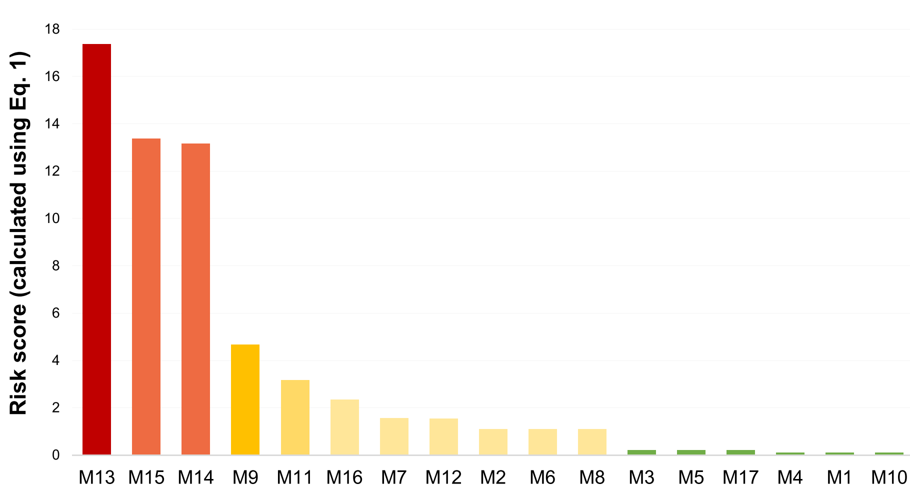

Fig. 1. Microbiological risk score of the RTE dishes. Red: high risk score / green: low risk score.

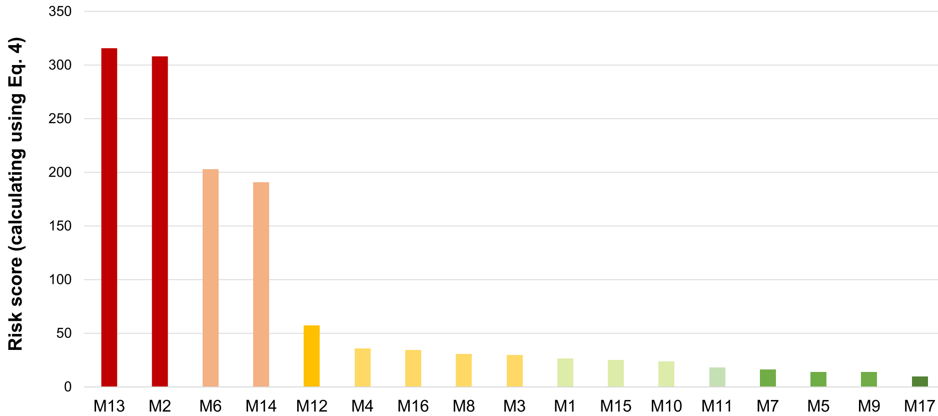

Fig. 2. Chemical risk score of the RTE dishes. Red: high risk score / green: low risk score. The percentage given above each bar represents the percentage of mass (deduced from the pack label).

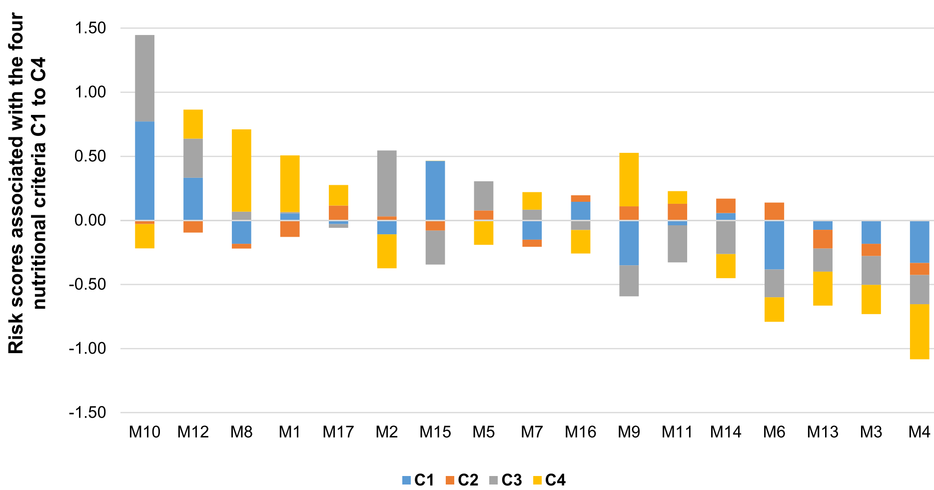

Fig. 3. Nutritional risk score after standardization and weighting.

the mass of the RTE dishes could be taken into account in the assessment, which generated some uncertainty in the final assessment; this is further discussed in section 4.

3.3. Nutritional risk

Fig. 3 presents the nutritional risk score obtained for the 17 dishes. “Vegetarian plate vegetables and quinoa” (M4) appeared to bear the lower risk score, with the lowest C4 value among all the RTE dishes, and also relatively low C1 and C3 values. On the opposite, “Pasta stuffed with ricotta and spinach, tomato sauce” (M10) had the highest risk score among the 17 RTE dishes considered in this study. This could be explained by the highest C1 and C3 values, which were related to high energy content and excess/lack of nutrients associated with a higher/lower risk of chronic disease (being here high in saturated fatty acids, and to a lesser extent in salt, and low in fiber).

The six dishes M15, M5, M7, M16, M9 and M11 did not have a final high nutritional risk score but interestingly, this group could be split into two sub-groups. On one hand, M5, M7, M16 and M11 had low scores for the four nutritional criteria, C1 to C4, which explained why the sum was small. On the other hand, M15 and M9 had divergent criteria: M15 (“Salad bowl chicken avocado”) had high positive C1 and low C3, M9 (“Oriental Couscous with chicken” had high C4 values and low C1 and C3 values.

Table 6
Spearman correlation value between the three types of risks.

	Chemical risk	Nutritional risk	Microbiological risk
Chemical risk	1	−0.284	0.193
Nutritional risk	−0.284	1	−0.278
Microbiological risk	0.193	−0.278	1

3.4. Comparison and aggregation of MCN risks

Overall, we did not find strong correlations between risks (Table 6). Indeed, microbiological risk was weakly correlated with chemical risk (Spearman coefficient = 0.19) and weakly negatively correlated with nutritional risk (Spearman coefficient = -0.28). Similarly, nutritional risk was weakly negatively correlated with chemical risk (Spearman coefficient = -0.28). It was therefore difficult to see at a glance which dishes had the higher (the lower) food safety and health risks. Nevertheless, in Fig. 4, nutritional risk scores are plotted versus chemical risk scores, while microbiological scores are illustrated with the color of the symbol. From this 3D-visualization (Fig. 4), it seemed that “Vegetarian plate vegetables and quinoa”, M4 and “Papillote of chicken, potatoes and small vegetables, parsley juice”, M3 were the least risky dishes. To confirm this finding, a further analysis was performed.

To aggregate results, an outranking multi-criteria methodology was applied. First, we put the same weight to the M, C and N risks. Results are presented in Fig. 5. The phi value, which is higher when the risk is

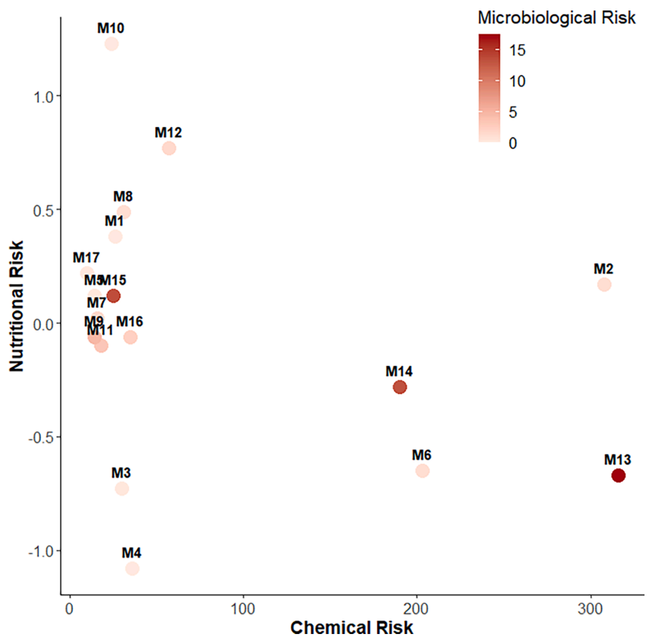

Fig. 4. MCN risk in 3D. Each risk domain represents an axis of the figure. RTE dishes that are placed in the lower part of the x-axis, close to the y-axis and represented by a circle of pale color (e.g. "papillote of chickenl" M3 and "Vegetarian plate vegetables and quinoa" M4) have little risk compared to the others.

higher, ranged from −0.16 to + 0.16, for a theoretical range scale from −1 to + 1. That is in line with the low correlation observed: there was no dish which over-rank or under-rank all the other ones in the three M, C, N dimensions at the same time. Consequently, for some dishes, deducing the final rank from the three individual risk scores was not straightforward. For instance, "Duck Parmentier", M12, was found to be the dish with the highest risk out of the 17 RTE dishes while it had medium–high risk scores in each domain. In other words, the M12 dish outranked many dishes without dominating them systematically (phi positive + 0.239, phi negative −0.076, which makes + 0.163).

The PROMETHEE method made it possible to aggregate risks which, if taken alone, would have led to a contradictory ranking. This is the case with dish M13. It was classified as "high risk" in terms of safety, from both microbiological and chemical risks (Figs. 1 and 2) but "low risk" in terms of nutritional risk (Fig. 3). When equal weight was given to all three criteria, it was classified as high risk overall (2nd most risky of the 17 dishes) (Fig. 5). However, when gradually the weight given to safety risks was reduced in favor of nutritional risk, the classification changed as explained in section 3.5″. The dish M2 had also conflicting scores given by the MCN criteria. It was "high risk" in term of chemical risk, "medium–high risk" in term of nutritional risk but "low risk" in term of microbial risk (Fig. 4). Put together that leads to a high risk (Fig. 5). Still conflicting scores but on the other way around leading to an overall low score, there were "Risotto with chicken and organic mushrooms" (M5, phi value −0.13) and "Chicken curry with coconut milk and rice duo" (M17, phi value −0.13) which had medium nutritional score (Fig. 3) but low food safety risk scores (Figs. 1 and 2).

Nevertheless, for some dishes, it was a clear cut, as already observed in Fig. 4. "Vegetarian plate vegetables and quinoa", M4, and "Papillote of chicken, potatoes and small vegetables, parsley juice", M3, were found to be overall the least risky dishes (phi value of −0.16), which was not surprising as they had low scores in M, C and N risks.

3.5. *Impact of criteria weighting and uncertainties*

In an aggregation method, using MCDA Promethee or another outranking algorithm, definitively, the weight given to the criteria plays a role on the final ranking. First, we decided to assign the same weight to the three risks. Next, we decided to increase gradually the nutritional risk and therefore to reduce the microbiological and chemical risks. Fig. 6 depicts how each ranking varied according to the weight of nutritional risk. "Duck Parmentier" (M12) was very stable and remained one of the riskiest RTE dish whatever the weighting scheme. Likewise, "Papillote of chicken, potatoes and small vegetables, parsley juice" (M3) and "Vegetarian plate vegetables and quinoa" (M4) remained also among with low risk ranks whatever the weighting scheme. On the opposite, for some dishes, the ranking differed according to the weighting scheme. For example, "Sushi discovery" (M13), which was one of the riskiest RTE dish, became one of the least risky as the weight applied to the nutritional risk increased. Conversely, the M5 and M17 dishes, which were classified overall as "low risk" when the weight on the criteria was the same, moved up the ranking with the importance given to the nutrition criterion: when the weight on this criterion reached 0.9, they were classified as 8th and 6th most risky of 17 dishes, respectively. This illustrates the importance of weight in the face of conflicting criteria.

Beside the weight given to the nutrition/health criteria and consequently to the chemical/microbiological safety criteria (as sum of

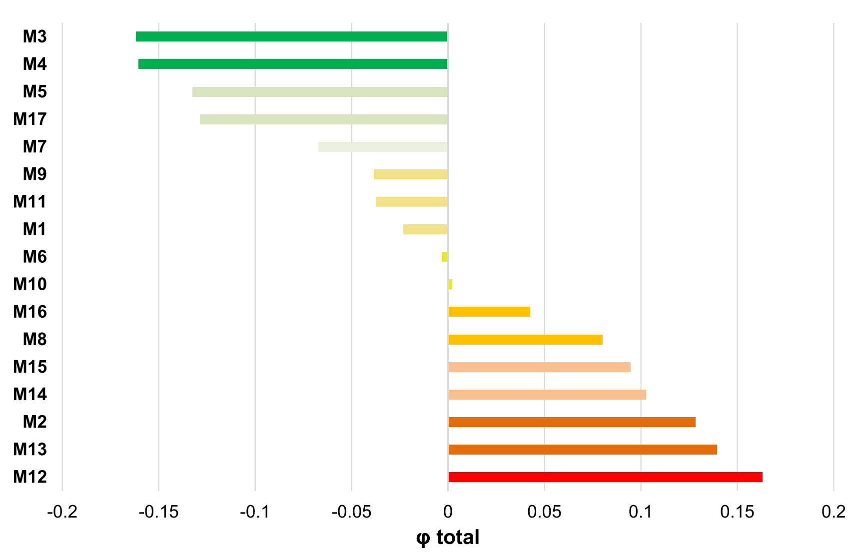

Fig. 5. Results of an equal weighting outranking using PROMETHEE II. Negative φ value corresponds to the less risky and positive φ value to the more risky ready-to-eat dishes.

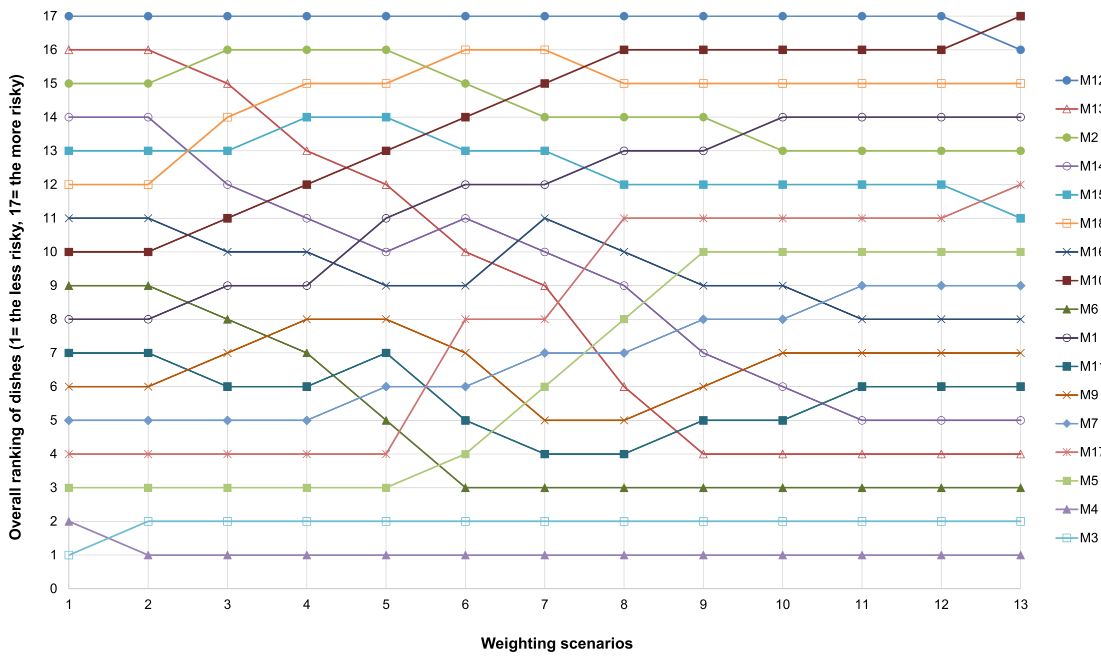

Fig. 6. Effect of various weightings between microbial, chemical and nutritional risks on final ranking of the RTE dishes. The x-coordinates from 1 to 13 correspond to different weighting scenarios. **X-coordinate 1**: equal weighting scenario. **X-coordinate 2**: nutrition weight equals 0.35; two other weights equal to $\frac{1-0.35}{2}$ each. **X-coordinate 3**: nutrition weight equals to 0.4; two other weights equal to $\frac{1-0.4}{2}$ each. **X-coordinate 13**: nutrition weight equals to 0.9; two other weights equal to $\frac{1-0.9}{2}$ each.

weights = 1), we tried to list as exhaustively as possible the uncertainties associated with our study. That includes approximation in values (e.g. "likelihood scale for microbiological risk is arbitrary set"), assumption in scenarios (e.g. "if a recontamination was possible, we assumed that it happened every time) and more generally lack of knowledge (e.g. "proxys have been set up in case no data were found for some food"). Results are provided in Supplementary Material Table 7S. For many uncertainties, it was not possible to quantify their impact, reason why the synthesis of the uncertainty analysis was reported with a semi-quantitative scale: +: important impact / ±: moderate impact / -: minor impact. Comments were also added when a conclusion regarding the direction (over- or under-estimation of the risk) due to the uncertainty could be drawn. For instance, as we did not make laboratory measures to evaluate the water activity, we took the same value (0.998) for each RTE dishes. That could lead to a slight over-estimation of microbiological risk for some dishes.

Due to the impact of risk weighting and various sources of uncertainties, we would like to emphasize that the risk score values presented in this study cannot be interpreted in an absolute manner. The three MCN risks were assessed to make relative comparison among the dishes per type of risk (i.e. in each Microbiology, Chemistry and Nutrition domain) and finally to rank the dishes relatively to each other from the riskiest one to the less risky one.

4. Discussion

The first objective of this study was to suggest a relatively simple method to classify food products based on their microbial, chemical, and nutritional risks. This is already a challenge in itself, as quantitative evaluation in each domain is already long and tedious.

Regarding the risk assessment of chemical and microbial hazards, the method closely followed the FAO general recommendations (FAO, 2020) with the severity on the one hand and the likelihood on the other hand. Next, likelihood and severity were combined in a scalar product following in essence the schematic definition of food safety risk (risk = Severity × Probability). This approach is in line with what has been suggested in the FAO guidance document (FAO, 2020), which presents hazards in a 2-D plot with likelihood on one axis and severity on the other axis, even if our method goes beyond. Indeed, plotting enables to visualise a rectangular surface using x- and y-axes, but the visualisation does not provide an explicit ranking output. Here, we calculated a scalar product, which corresponds to a sum of rectangle surfaces (calculating a rectangle surface means multiplying x- and y-axes values). Besides, our M and C risk assessment method presents some novelties, which are worth mentioning. To estimate quantitatively the severity of chemical hazards, we adopted the recent approach developed by Anses (2020), further refined by Palmont et al. (2023). In this latter study, chemical hazard ranking was applied on follow-on formulae for the 7–12 months French infant population. To estimate quantitatively the likelihood of each microbial hazard, we combined a decision trees to describe how the consumer handles each dish with a growth prediction (ComBase tool) to evaluate whether a hazardous level could be reached or not. This approach provides a quantitative output while being simpler and faster than building a full quantitative probabilistic exposure assessment (Nauta, 2022).

The method developed here for nutritional risk combines in an interesting way the two dimensions of nutrition, namely the nutrient and the dietary dimensions. This differs from most approaches to addressing the nutritional value of a food based solely on the energy and nutrient content (which is the mandatory information on the package), or by simply considering the nutritional value of a food to be that of the food category to which it corresponds in terms of recommendations for long-term disease risk. In Western countries, when assessing nutrients, it is important to place more emphasis on energy and nutrients that are related to long-term health and contribute to the burden of disease (e.g. sodium, fiber) than on nutrients that are not of concern, being consumed in sufficient quantities by virtually all adults (e.g. protein). Here, based on four criteria, the nutritional risk assessment was relatively comprehensive and wide, quantitative and fast to perform as based on the regulatory information provided on the RTE dish pack.

Nevertheless, it is important to keep in mind that since the scoring of each risk was carried out with approximations, assumptions and hypothesis, the food dishes could be compared to each other (as ranks) but their scores could in no way be interpreted in an absolute manner. For transparency, we performed an uncertainty analysis were we pointed out the effect of lack of knowledge and assumptions on risk score as recommended by food safety authorities (EFSA Scientific Committee, 2018; FAO/WHO, 2020).

Suggesting a methodology to aggregate M, C, N risks was the second challenge in our study. The DALY metric (Murray & Acharya, 1997) could not be used as numbers of cases were not estimated. That would have been far too long but also likely impossible for some dishes, particularly in chemical risk assessment due to absence of dose–response for some hazards (Camel, Rivière & Le Bizec, 2018; Van der Fels-Klerx et al., 2018). Furthermore, using the DALY metric is appropriate for a comparison of the current situation with alternative scenarios regarding the food consumption or the diet of a population. Our study was limited to the risk per dish portion; we did not characterize the population diet associated with the 17 dishes.

Deducting the rank of dishes from the individual M, C, N risk scores was not straightforward, as there was no high positive correlation between the risks. Indeed, the absence of correlation meant that a dish (for instance "Sushi discovery") could have a low score in nutrition/health and at the same time a high score in safety (both chemical and microbial dimensions). It could not be immediately concluded whether "sushi discovery" was overall risky or not, considering health and safety criteria. An aggregation technique was needed. We adopted an outranking MCDA method. PROMETHEE algorithm was chosen as it has been advocated by Wątróbski et al. (2019) and Van der Fels-Klerx et al. (2018) when dealing with semi-quantitative, ordered criteria. PROMETHEE algorithm has also the advantage of being relatively easily, and freely, carried out using its dedicated package in R. Several examples of its use in the food safety domain have been made available in literature (Eygue, Richard-Forget, Cappelier, Pinson-Gadais & Membré, 2020; FAO, 2017; Fazil, Rajic, Sanchez & McEwen, 2008).

The absence of correlation may also lead to confusing messages towards consumer, reinforced by a general lack of understanding of the nature of the risks (Slovic, 1987). Risk communication campaigns are likely to reach only those who are already more aware of risks, and have virtually no effect on others (Verbeke, Frewer, Scholderer & De Brabander, 2007). An alternative to communication campaigns may be the development of on-pack information using food scoring systems or mobile apps. In France, the "Nutriscore" has been developed to make it easier for consumers to understand nutritional information and thus to help them make informed choices; it appears as a logo on the front of packaging with letters from A to E (Santé publique, 2023). The next step might be to add the safety dimension to the nutritional dimension into an on-pack food scoring logo by regulation, or to give the general public access to this information e.g. using mobile apps showing aggregated M, C, N risks.

Nevertheless, the risk-ranking method developed here is still in an infancy stage and it needs to be tested furthermore and in other contexts to assess its genericity. Once consolidated, such a method would be highly relevant for consumers but also policy makers and food company managers willing to move forward transparent and evidence-informed decisions. In this respect, this study paves the way towards food product multi-risk ranking.

CRediT authorship contribution statement

Rémi Poissant: Conceptualization, Formal analysis, Investigation, Writing – original draft. **François Mariotti:** Methodology, Writing – review & editing. **Daniel Zalko:** Methodology, Writing – review & editing. **Jeanne-Marie Membré:** Conceptualization, Methodology, Investigation, Supervision, Writing – review & editing.

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.

Data availability

All data used in this article are aither available (sources in ref list) or availble on demand

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodres.2023.112939.

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