DTU Library

Risk-benefit analysis in food safety and nutrition

Membré, Jeanne Marie; Santillana Farakos, Sofia; Nauta, Maarten

Published in:
Current Opinion in Food Science

Link to article, DOI:
10.1016/j.cofs.2020.12.009

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Food Science

Risk-benefit analysis in food safety and nutrition☆

Jeanne Marie Membré[1], Sofia Santillana Farakos[2] and Maarten Nauta[3]

Risk-benefit analysis of foods including a formal public health assessment followed by management and communication has been establishing itself as a scientific discipline during the past 15 years. Risk-Benefit Assessments (RBAs), integrating nutrition, toxicology and microbiology, have been increasingly conducted for a variety of foods and food components. Quantitative models in these assessments often use the Disability Adjusted Life Year (DALY) as a common health metric, as it allows for comparison of diverse health effects. Results are typically reported by population group to capture differences in health outcomes and target communication. Strengthening the links between a formal RBA, risk-benefit management decisions and dietary recommendations communicated to the public will improve transparency and potentially public health outcomes. In the coming years, sustainable food production and other factors in addition to public health might result in risk-benefit analysis becoming part of the broader food system analysis.

Addresses
[1] SECALIM, INRAE, Oniris, 44307 Nantes, France
[2] Center for Food Safety and Applied Nutrition, U.S. Food and Drug Administration, College Park, MD, USA
[3] National Food Institute, Technical University of Denmark, 2800 Kongens Lyngby, Denmark

Corresponding author:
Membré, Jeanne Marie (jeanne-marie.membre@oniris-nantes.fr)

Current Opinion in Food Science 2020, **36**:76–82

This review comes from a themed issue on **Food safety**

Edited by **Marcel Zwietering, Heidy den Besten** and **Tjakko Abee**

https://doi.org/10.1016/j.cofs.2020.12.009

Introduction

The analysis of risks and benefits in food including a formal quantitative or semiquantitative public health assessment followed by decision making and communication, although initiated 15 years ago, still needs to gain in visibility. It goes beyond food safety risk analysis, as it includes an analysis of the nutritional risks and benefits of food consumption. Its general framework, based on the three key elements assessment, management and communication, comes from risk analysis [5].

In risk-benefit assessment (RBA) of foods, the risks and benefits associated with a food component, a food product, and a diet are (quantitatively) compared from a public health perspective [7]. Chemical and microbiological hazards are identified, and the resulting health effects characterized together with an assessment of the nutritional health effects. While chemical and microbiological hazards can contribute to food safety risks, nutritional effects of food on human health can contribute to health benefits (e.g. unsaturated fatty acids have been shown to potentially reduce cardiovascular disease risk [8••]) and also health risks (e.g. heme-iron in red meat has been shown to increase the risk of colorectal cancer [9]).

The need for RBA of foods has come forward after separate studies on nutritional health impact and food safety risk assessment for the same food or food component resulted in possible conflicting messages. For example, the consumption of fatty fish might be recommended for pregnant women on the basis of the potential positive effect of fish consumption on the neurological development of a newborn, but discouraged on the basis of negative health effects on the newborn from methylmercury and dioxins [10]. Focusing solely on benefits or risks associated with foods without consideration of other factors in a holistic approach can be confusing when formulating and following dietary recommendations.

In Europe, RBA was formally discussed at an EFSA colloquium in 2006 [11] and taken up by several European Union (EU) projects, such as BRAFO [12]. The RBA methodology was based on the food safety risk assessment approach (including hazard identification, hazard characterization, exposure assessment and risk characterization) [13]. In the BRAFO project, the 'tiered' approach was developed [14] and applied in several case studies[15–17]. More recently, RBA has been taken up by several research groups. Boué *et al.* [18] published a review summarizing the available literature which indicated fish is the most widely studied food in RBA. Nauta *et al.* [19] presented a review of the challenges related to further development of RBA and show these are related to interdisciplinarity, methods, data, health metrics and applications. A workshop held in Denmark 2017 gathered a large international group of experts on RBA, and its conclusions are summarized by Pires *et al.* [20]. Participants of the workshop concluded

☆ This article is part of Food Safety special issue published in the journal Current Opinion in Food Science, Volume 36, 2020.

that while challenges remain in the assessment of risk, communication of uncertainty, and integration of diverse data sources, among others, RBA can extensively support risk-management on decisions with regards to food safety, nutrition and public health. In Nauta *et al.* [7], the available methods for RBA are presented and their dependency with the specific risk-benefit question posed is shown.

RBA can support science-based decision making when establishing dietary guidelines and recommending foods to a population or a population group. This latter consideration is of crucial importance as research indicates tailoring materials to specific population groups might more effectively promote healthier behaviours that would be missed with messages targeting the general population [21]. Nevertheless, decision making is complicated since different outcomes in different magnitude and timescales are involved, leading to difficult weighting between outcomes. Moreover, there may be uncertainty associated with the results of the assessment. For example, when ranking the health impacts of two different food intake scenarios based on a limited amount of data or knowledge, the risk-benefit balance may not lean clearly in favour of one of the two scenarios. Additionally, RBAs require a large collection of data and expertise as they could cover chemical, microbiological and nutritional aspects of a food. The time required to perform a comprehensive quantitative or semiquantitative RBA is not always compatible with the decision agenda.

Consumers, at least unconsciously, make risk-benefit decisions when purchasing food products and preparing meals. As such, consumers frequently need to make trade-offs between the known risks and benefits associated with consumption of food products. Additionally, issues such as availability, costs, personal preferences, food quality, sustainability, and so on, can play a role. A survey in several EU countries in 2019 showed that food safety is as important as other factors such as food origin, cost and taste in consumer purchasing decision-making [22].

Communication about food safety risks and benefits is important to allow consumers making a balanced, objective food choice. However, communicating risk and benefit information about foods is challenging. The presentation order of benefits and risks in the message can affect both behavioural intention and consumer perception, with the first message component being generally the most influential [3]. Even more challenging is when the wording of a benefit can bring negative associations. For example, consumers might perceive 'fatty', in general, as negative and then associate 'fatty fish' with being unhealthy, which may be the opposite of the intended message [23]. To involve the public in the decision making process of developing appropriate communication strategies, citizen science approaches such as the use of consumer focus groups can be useful [24]. The development of the internet and emergence of social media provide additional opportunities to involve and empower consumers in food risk and benefit communication processes [23,25].

In this review, the three interconnected elements of risk-benefit analysis (assessment, management and communication), as illustrated in Figure 1, are covered. The first step in risk-benefit analysis is agreeing on the question. Next, a RBA includes health effect identification (adverse and beneficial), exposure assessment, dose-response relationship and risk-benefit characterisation. The results of the RBA can then be used in risk-benefit management to inform food safety, dietary recommendations and setting of legal standards. Finally, the communication of risks and benefits can aid in understanding of the RBA and dietary recommendations made (Figure 1). This general approach linking assessment, management and communication, advocated by EFSA [11], has been illustrated here with fish. We anticipate that other applications will emerge, which illustrate how RBA can be used to make informed decisions, followed by dietary recommendations communicated to the public.

Risk-benefit assessments focusing on human health

Weighing risks and benefits related to the various health effects requires a comparison of estimated incidences of diseases/health effects with different severity and duration, as well as mortality. A common health metric is required. The health metric that is used most often in RBAs is the Disability Adjusted Life Year (DALY). The DALY is also applied as the metric to quantify the burden of disease/health effects. One DALY can be thought of as one year of healthy life lost [27]. A recent example of weighing risks and estimating the impact of a food substitution using DALYs as the common health metric includes a case study which explored exposure to inorganic arsenic (iAs) and aflatoxins through consumption of infant cereals in the U.S. and the risk of developing lung, bladder and liver cancer over a lifetime [28•]. Estimated additional DALYs in the U.S. population from exposure to iAs and aflatoxin during the first year of age based on contamination and consumption patterns of infant rice and oat cereal in the study (the baseline) was 4900 DALYs (CI 90% 400; 8800) or 1.5 DALYs per 100 000 people per year. If all consumers shifted (maintaining equivalent serving size and frequency) to only infant rice or only infant oat cereal, the model predicted DALYs would increase 1.4 times or decreased 0.4 times relative to the baseline, respectively.

An example of estimating risks as well as quantifying the benefits assuming a diet shift using the DALY metric includes a recent study by De Oliveira Mota *et al.*

Figure 1

Step 1. Risk-Benefit Question

A risk-benefit question is agreed upon between risk-benefit assessor and risk-benefit manager

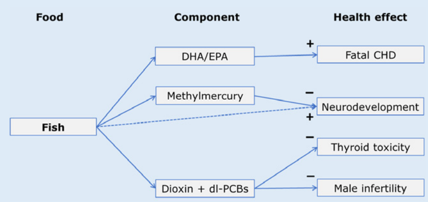
For example: What will the overall health impact be, in DALYs, of increasing the current fish consumption in a population to a recommended level? Next to the reference intake scenario (current intake), different fish intake scenarios can be defined with combinations of fish species.

Step 2. Risk-Benefit Assessment (RBA)

As many RBAs have been performed for fish, the elements of this step are illustrated by an example based on the study of Thomsen et al. [1].

2.1 Health Effect Identification: Adverse and beneficial health effects are identified based on scientific evidence, along with the food component (nutritional, chemical or microbial) linked to the health effect. The health effect might also be directly linked to the food. Identification of health effects, components and foods is preferably done on the basis of predefined selection criteria, and includes considerations on potential substitution scenarios.

An example for fish, adopted from [1, 7] is shown below. It does not necessarily include all relevant health effects related to fish intake.



The food and its components are found to be associated with both beneficial (+) and adverse (-) health effects, making a RBA relevant. CHD: Coronary Heart Disease, DHA: Docosahexaenoic Acid, EPA: Eicosapentaenoic Acid and dl-PCB: Dioxin-Like Polychlorinated Biphenyls.

2.2 Exposure Assessment: The intake of the food and the relevant components are described as a distribution expressing the variability of mean daily intakes per consumer.

Exposure to each component can be assessed by integrating the individual mean daily fish consumption, based on dietary survey data, with the concentration of the individual components.

2.3 Dose-Response: Dose-response relations for the food and/or its components are obtained from scientific publications.

Dose response relations can be of different nature. In [6], the dose response relations for neurodevelopment and male infertility are for maternal intake. The dose response relations for dioxins are based on animal experiments [6].

2.4 Risk-Benefit Characterisation: Exposure assessment and dose response relations are combined and expressed as changes in disease incidence and mortality. By using a common health metric (i.e. DALY), severity and duration of a disease can be considered and quantitative health impact estimates can be combined and integrated.

In [1], an overall health gain was estimated when increasing the fish consumption in the Danish

Step 3. Risk-Benefit Management

Results of a RBA can inform food safety, dietary recommendations and setting of legal standards.

In the Thomsen et al. fish example [1], the RBA confirmed the current dietary recommendation on fish consumption in Denmark provides a health benefit to the Danish population.

Examples of dietary advice on eating fish based on risk-benefit assessments include those published in France [2] and Norway [4].

DALY estimates are not only used in RBA to support risk management. DALYs can be used to support or disqualify advice or recommendations in public health, and help when weighing the recommendation based on estimated public health impacts against other factors such as sustainability, the economy and societal impact.

Step 4. Risk-Benefit Communication

Communication of risks, benefits and the overall health impact can facilitate understanding of the RBA and the dietary recommendations made. The perception of risks versus benefits remains an important challenge *[3]*.

In the ANSES [2] and VKM [4] advice on fish consumption, a summary of the benefits and specific risks is presented together with a recommendation which targets a sensitive population group (i.e. women who are or might become pregnant, breastfeeding mothers, and young children).

Current Opinion in Food Science

Overview of the steps in risk-benefit analysis, with an example for risk-benefit analyses of fish [4].

[9,29,30] using red meat consumption in France as the example. Per 100 000 people per year, red meat consumption was estimated to account for a mean of 19 DALY from colorectal cancer (CRC), 21 DALY from cardiovascular disease [9] and 6.6 DALY from foodborne pathogen infections [29]. Evaluation of consumption of iron in the diet led to a mean estimate of 16 DALY/100 000 due to iron-deficiency anaemia (IDA) [30]. These 16 DALY could be reduced if the IDA-suffering population changed their diet to consume more iron-rich foods. An interesting finding in this set of studies is that the population group at risk from CRC is different from the one suffering from IDA showing there might be a possibility to mitigate overall risks by developing a communication plan which is population group specific. For example, one in which, based on the findings [9,29,30], the male adult population would be encouraged to reduce their red meat consumption while the young female adult population would be encouraged to increase consumption of iron-rich foods.

When estimating the health impact of food intake, and specifically nutrients, a special challenge arises from the fact that the impact of an increase or decrease from one food or one nutrient in isolation does not consider the substitution food and/or nutrient which will generally impact the overall health outcomes [2]. It also does not consider the synergy, interaction and potentially cumulative relationships that occur in total diet exposures from all dietary components which may not equally contribute to the associated health outcome [31]. Thomsen *et al.* [1••,32] specifically studied the substitution of red and processed meat with fish, following the Danish food-based dietary guidelines. The RBA performed included health effects associated with an increase of fish consumption, as well as those associated with a decrease in red and processed meat intake. In addition to the health effects associated with fish consumption (Figure 1), including the substitution of red and processed meat introduced additional health effects from the diet shift such as reduction in colorectal cancer and non-cardia stomach cancer and increases in iron-deficiency anaemia. Model results predicted that substituting red and processed meat with fish further increased the benefit compared to considering fish consumption alone, by an additional 20 DALYs averted/100 000 per year [7]. This example illustrates the importance of considering substitutions when conducting RBAs.

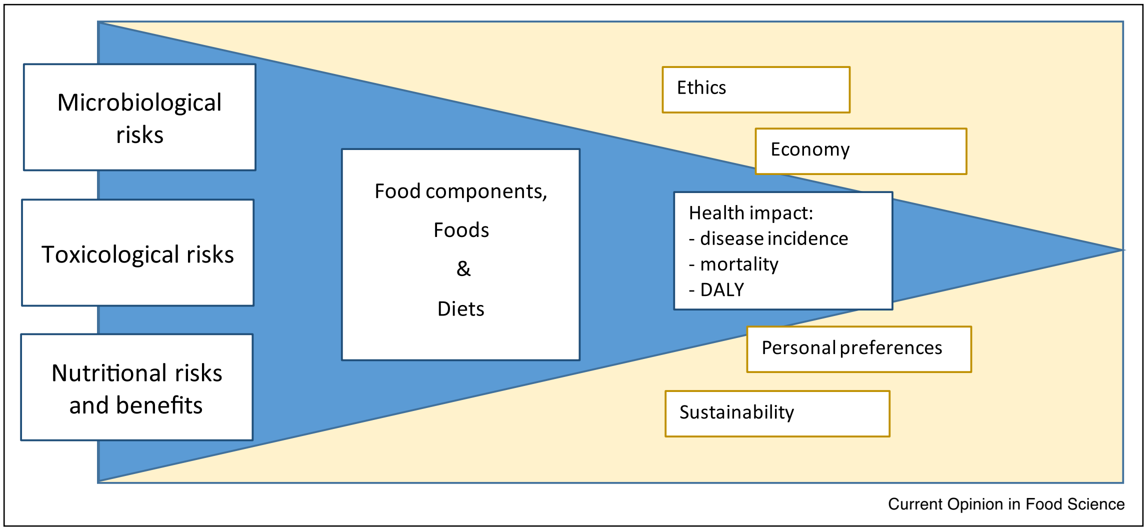
Risk-benefit analysis in a broader perspective

Although the DALY is a common health metric often used in RBAs, there are cases where, even for quantifying public health issues, it is difficult to apply this metric. In the domains of toxicology and nutrition it is not always possible to accurately quantify diseases/health effects per capita (number of cases, number of fatalities) resulting in the inability to obtain a DALY measure [33]. In those cases, risk ranking techniques based on multi-criteria decision analysis (MCDA) can help by bringing the flexibility of including in the assessment ordered values (e.g. low, medium, high) beside quantitative data [35]. This MCDA approach has been illustrated by a ranking microbial and chemical risks associated with emerging dietary practices in France [34•].

Moreover, while RBA typically focusses on health impact assessment, making recommendations or decisions on dietary choices can include other factors such as costs, personal preferences, sustainability, and ethics (Figure 2). The EU Agenda for 'Food 2030' considered food safety to be part of a food system driven mainly by nutrition, climate, circularity (resource efficiency) and innovation (empowering communities) [36]. In the EU, there are societal expectations with regards to sustainable food production, particularly concerning food safety and food quality as well as environmental and animal welfare standards [37]. Initiatives to integrate Life Cycle Assessment (LCA) into the risk-based decision process have emerged recently [38,39]. Using a multi-faceted framework presented by Zijp *et al.* [40], which integrates elements of risk assessment, governance, adaptive management and sustainability assessment, Hollander *et al.* [8••] compared several foods rich in fatty acids. The analysis introduced public health criteria to quantify nutritional benefits and food safety risks, as well as sustainability criteria such as land and water use, chemical pollution and disruption of local ecosystems (both qualitative and quantitative). The study showed the impact of policy when based on a single metric versus inclusion of other dimensions such as food safety and the environment and emphasized the use of integrative assessments when designing recommendations [8••].

To integrate multi-dimensional and not easily comparable variables with differing impacts into the decision-making process, again, MCDA is a helpful technique. FAO has recommended to apply MCDA in order to rank public health impacts and include factors such as economic losses, food security, consumer perception and socio-cultural concerns [41]. Similarly, Ruzante *et al.* [42] has prioritized six 'pathogen bacteria – food matrix' pairs considering public health but also market impact, consumer perception and social sensitivity. A challenge in using MCDA is to assign weights to criteria. This can be done, for example, at the assessment stage based on uncertainties and/or at the management stage according to stakeholder priorities and the question being posed. Among MCDA methods, mathematical optimisation techniques are useful to understand the trade-offs between variables like food safety, nutritional health impact, sustainability and costs [43]. This technique was recently applied to evaluate the trade-off between health impact, cost and personal preference when looking at fish consumption [44] and to integrate environmental,

Figure 2



Traditionally, risk-benefit assessment (RBA) of foods is applied to assess the combined health impact of microbiological, toxicological and nutritional risks and benefits, preferably into a single metric. As consumption and food policies are not only guided by health, the scope of RBA is increasingly broadened up to include aspects that are important for decision making in relation to dietary choices, but not related to the impact on health.

health, economic, and cultural dimensions of diet sustainability in the food supply for school meals [45].

In the near future, risk-benefit analysis on food and health could be merged into a broader food system analysis [26•,36]. In this broader perspective, one can use MCDA, mathematical optimisation or other modelling frameworks to assess, manage and communicate the complex factors and ranking outcomes. Criteria are difficult to characterize and compare, as in the EAT-Lancet Report [26•] where health and environmentally sustainable factors like greenhouse-gas emissions, land and freshwater use as well as biodiversity loss are indicators. The challenge can be greater if economic, social and ethical considerations are taken into account. Broad multidisciplinary interaction and collaboration will likely be required [46] and the examples above show that this is possible.

Concluding remarks

Risk-benefit analysis in food safety and nutrition has established itself in the last 15 years with key research projects in assessment [6,12] and communication [23] in addition to academic studies covering methodological developments and/or applications. Strengthening the links between a formal RBA, management decisions and dietary recommendations communicated to the public can improve transparency. This approach can potentially also improve public health outcomes by ensuring the best science informed management decisions, and that communications are accurate and developed with enhanced knowledge of the decision-making process. Even though significant progress has been made, challenges remain [19]. RBA faces specific challenges in traditional risk assessments like availability of data, variability between groups of consumers and individuals, the strength of the evidence and the uncertainty in the dose-response and in defining how uncertainty is communicated. The integration of diverse data sources, heterogeneous information between risks and benefits and the selection of metrics to evaluate and compare these risks and benefits is challenging. It is also a challenge to estimate the impact on health of the synergy in total diet exposure from all dietary components versus looking at dietary components in isolation or a food substitution. Additional challenges include the time that it takes and deciding on which factors should be considered in the process. For example, the question of whether RBA should be limited to public health or include other factors such as personal preferences, the economy, sustainability or other aspects. Multi-disciplinary teams will be required in this effort and it can take a significant amount of time. To continue advancing the application of RBA, efforts should keep ensuring it is fit-for-purpose and conducted in a timely manner. Once an RBA has been completed, data and scientific discoveries related to the underlying model and assumptions may need to be monitored and incorporated, to ensure the assessment reflects the best available science. Emerging consumer practices [23,34•], possible global transformations of the food system [26•], and agri-food innovation [47] are likely drivers for future research in risk-benefit applications. Examples are studies on consumption of raw food products [48], fermented foods [49], plant-origin protein based products, and nanotechnology [50]. With the methods developed and the international experience gained, it is now possible to more fully exploit the potential of risk-benefit analysis and increasingly apply quantitative RBAs to support decision making in food safety and nutrition.

Conflict of interest statement

Nothing declared.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as

- • of special interest
- •• of outstanding interest

1. •• Thomsen ST, de Boer W, Pires SM, Devleesschauwer B, Fagt S, Andersen R, Poulsen M, van der, Voet H: **A probabilistic approach for risk-benefit assessment of food substitutions: a case study on substituting meat by fish**. *Food Chem Toxicol* 2019, **126**:79-96

Risk-Benefit Assessment applied to food substitution with comprehensive presentation of the data used and the modelling approach developed.

2. Anses: *Opinion Concerning Recommendations on the Benefits and Risks of Fishery Product Consumption in the Context of the PNNS Nutritional Guideline Update (in French)*. 2013. Available at: https://www.anses.fr/en/content/summary-agencys-recommendations-fish-and-fishery-products. [Accessed on 15 May 2020].

3. Verbeke W, Vanhonacker F, Frewer LJ, Sioen I, De Henauw S, Van Camp J: **Communicating risks and benefits from fish consumption: impact on Belgian consumers' perception and intention to eat fish**. *Risk Anal* 2008, **28**:951-967.

4. VKM: *Benefit-risk Assessment of Fish and Fish Products in the Norwegian Diet – an Update*. Scientific Opinion of the Scientific Steering Committee; 2014. Available at: https://vkm.no/download/18.2994eb15cc07161ea1a/1498222018046/0a646edc5e.pdf. [Accessed on 15 May 2020].

5. FAO/WHO: *Food Safety Risk Analysis: a Guide for National Food Safety Authorities*. 2006. Available at: http://www.fao.org/3/a-a0822e.pdf. [Accessed on 15 May 2020].

6. Hoekstra J, Hart A, Boobis A, Claupein E, Cockburn A, Hunt A, Knudsen I, Richardson D, Schilter B, Schütte K *et al.*: **BRAFO tiered approach for benefit–risk assessment of foods**. *Food Chem Toxicol* 2012, **50**:S684-S698.

7. Nauta M, Sletting Jakobsen L, Persson M, Thomsen ST: **Risk-benefit assessment of foods**. In *Risk Assessment Methods for Biological and Chemical Hazards in Food.* Edited by Perez Rodriguez F. Taylor and Francis; 2020.

8. •• Hollander A, De Jonge R, Biesbroek S, Hoekstra J, Zijp MC: **Exploring solutions for healthy, safe, and sustainable fatty acids (EPA and DHA) consumption in The Netherlands**. *Sustain Sci* 2019, **14**:303-313

Study covering both public health and environmental impact with detailed information on the methodology to build all criteria.

9. De Oliveira Mota J, Boué G, Guillou S, Pierre F, Membré J-M: **Estimation of the burden of disease attributable to red meat consumption in France: influence on colorectal cancer and cardiovascular diseases**. *Food Chem Toxicol* 2019, **130**:174-186.

10. Hoekstra J, Hart A, Owen H, Zeilmaker M, Bokkers B, Thorgilsson B, Gunnlaugsdottir H: **Fish, contaminants and human health: quantifying and weighing benefits and risks**. *Food Chem Toxicol* 2013, **54**:18-29.

11. EFSA: *The EFSA's 6th Scientific Colloquium Report - Risk-benefit Analysis of Foods: Methods and Approaches*. EFSA Supporting Publications; 2007:116E.

12. Boobis A, Chiodini A, Hoekstra J, Lagiou P, Przyrembel H, Schlatter J, Schütte K, Verhagen H, Watzl B: **Critical appraisal of the assessment of benefits and risks for foods, 'BRAFO Consensus Working Group'**. *Food Chem Toxicol* 2013, **55**:659-675.

13. Hoekstra J, Verkaik-Kloosterman J, Rompelberg C, van Kranen H, Zeilmaker M, Verhagen H, de Jong N: **Integrated risk–benefit analyses: method development with folic acid as example**. *Food Chem Toxicol* 2008, **46**:893-909.

14. Fransen H, De Jong N, Hendriksen M, Mengelers M, Castenmiller J, Hoekstra J, Van Leeuwen R, Verhagen H: **A tiered approach for risk-benefit assessment of foods**. *Risk Anal* 2010, **30**:808-816.

15. Verhagen H, Andersen R, Antoine J-M, Finglas P, Hoekstra J, Kardinaal A, Nordmann H, Pekcan G, Pentieva K, Sanders TA *et al.*: **Application of the BRAFO tiered approach for benefit–risk assessment to case studies on dietary interventions**. *Food Chem Toxicol* 2012, **50**:S710-S723.

16. Watzl B, Gelencsér E, Hoekstra J, Kulling S, Lydeking-Olsen E, Rowland I, Schilter B, Klaveren Jv, Chiodini A: **Application of the BRAFO-tiered approach for benefit-risk assessment to case studies on natural foods**. *Food Chem Toxicol* 2012, **50**:S699-S709.

17. Schütte K, Boeing H, Hart A, Heeschen W, Reimerdes EH, Santare D, Skog K, Chiodini A: **Application of the BRAFO tiered approach for benefit–risk assessment to case studies on heat processing contaminants**. *Food Chem Toxicol* 2012, **50**:S724-S735.

18. Boué G, Guillou S, Antignac J-P, Le Bizec B, Membré J-M: **Public health risk-benefit assessment associated with food consumption – a review**. *Eur J Nutr Food Saf* 2015, **5**:32-58.

19. Nauta MJ, Andersen R, Pilegaard K, Pires SM, Ravn-Haren G, Tetens I, Poulsen M: **Meeting the challenges in the development of risk-benefit assessment of foods**. *Trends Food Sci Technol* 2018, **76**:90-100.

20. Pires SM, Boué G, Boobis A, Eneroth H, Hoekstra J, Membré J-M, Persson IM, Poulsen M, Ruzante J, van Klaveren J *et al.*: **Risk-benefit assessment of foods: key findings from an international workshop**. *Food Res Int* 2019, **116**:859-869.

21. Gustafson CR, Prate MR: **Healthy food labels tailored to a high-risk, minority population more effectively promote healthy choices than generic labels**. *Nutrients* 2019, **11**.

22. EFSA: *2019 Eurobarometer on Food Safety in the EU*. 2019. Available at: https://doi.org/doi:https://doi.org/10.2805/661752. [Accessed on 15 May 2020].

23. Anses: *INCA 3: Changes in Consumption Habits and Patterns, New Issues in the Areas of Food Safety and Nutrition*. 2017. Available at: https://www.anses.fr/en/content/inca-3-changes-consumption-habits-and-patterns-new-issues-areas-food-safety-and-nutrition. [Accessed on 15 May 2020].

24. Crovato S, Mascarello G, Marcolin S, Pinto A, Ravarotto L: **From purchase to consumption of bivalve molluscs: a qualitative study on consumers' practices and risk perceptions**. *Food Control* 2019, **96**:410-420.

25. Rutsaert P, Pieniak Z, Regan A, McConnon A, Kuttschreuter M, Lores M, Lozano N, Guzzon A, Santare D, Verbeke W: **Social media as a useful tool in food risk and benefit communication? A strategic orientation approach**. *Food Policy* 2014, **46**:84-93.

26. • Willett W, Rockstrom J, Loken B, Springmann M, Lang T, Vermeulen S, Garnett T, Tilman D, DeClerck F, Wood A *et al.*: **Food in the Anthropocene: the EAT-lancet commission on healthy diets from sustainable food systems**. *Lancet* 2019, **393**:447-492

Global analysis of diets considering sustainability and health impacts.

27. WHO Metrics: *Disability-adjusted Life Year (DALY)*. Available at: https://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/. [Accessed on 15 May 2020].

28. • Santillana Farakos SM, Pouillot R, Spungen J, Flannery B, Van Doren JM, Dennis S: **Implementing a risk-risk analysis framework to evaluate the impact of food intake shifts on risk of illness: a case study with infant cereal**. *Food Addit Contam* 2021. Submitted for publication

Detailed presentation of methodology carried out while performing a risk–risk analysis in public health.

29. De Oliveira Mota J, Guillou S, Pierre F, Membré J-M: **Quantitative assessment of microbiological risks due to red meat consumption in France**. *Microb Risk Anal* 2020, **15**:100103 http://dx.doi.org/10.1016/j.mran.2020.100103.

30. De Oliveira Mota J, Tounian P, Guillou S, Pierre F, Membré J-M: **Estimation of the burden of iron deficiency anemia in France from iron intake: methodological approach**. *Nutrients* 2019, **11**:2045.

31. HHS, USDA: *2015-2020 Dietary Guidelines for Americans*. edn 8. 2015. Available at: http://health.gov/dietaryguidelines/2015/guidelines/. [Accessed on 15 May 2020].

32. Thomsen ST, Pires SM, Devleesschauwer B, Poulsen M, Fagt S, Ygil KH, Andersen R: **Investigating the risk-benefit balance of substituting red and processed meat with fish in a Danish diet**. *Food Chem Toxicol* 2018, **120**:50-63.

33. Van der Fels-Klerx HJ, Van Asselt ED, Raley M, Poulsen M, Korsgaard H, Bredsdorff L, Nauta M, D'Agostino M, Coles D, Marvin HJP *et al.*: **Critical review of methods for risk ranking of food-related hazards, based on risks for human health**. *Crit Rev Food Sci Nutr* 2018, **58**:178-193.

34. • Eygue M, Richard-Forget F, Cappelier J-M, Pinson-Gadais L, Membré J-M: **Development of a risk-ranking framework to evaluate simultaneously biological and chemical hazards related to food safety: application to emerging dietary practices in France**. *Food Control* 2020, **115**:107279

Original framework to prioritise food safety risks based on MCDA approach.

35. Ruzante JM, Grieger K, Woodward K, Lambertini E, Kowalcyk B: **The use of multi-criteria decision analysis in food safety risk-benefit assessment**. *Food Prot Trends* 2017, **37**:132-139.

36. European Commission: *Food 2030 - European R&I for Food and Nutrition Security*. 2016. Available at: https://doi.org/10.2777/069319. [Accessed on 15 May 2020].

37. European Commission: *The Future of Food and Farming*. 2017. Available at: https://doi.org/10.2777/069319. [Accessed on 15 May 2020].

38. Kesse-Guyot E, Chaltiel D, Wang J, Pointereau P, Langevin B, Allès B, Rebouillat P, Lairon D, Vidal R, Mariotti F *et al.*: **Sustainability analysis of French dietary guidelines using multiple criteria**. *Nat Sustain* 2020, **3**:377-385.

39. Dong Y, Miraglia S, Manzo S, Georgiadis S, Sørup HJD, Boriani E, Hald T, Thöns S, Hauschild MZ: **Environmental sustainable decision making – the need and obstacles for integration of LCA into decision analysis**. *Environ Sci Policy* 2018, **87**:33-44.

40. Zijp MC, Posthuma L, Wintersen A, Devilee J, Swartjes FA: **Definition and use of solution-focused sustainability assessment: a novel approach to generate, explore and decide on sustainable solutions for wicked problems**. *Environ Int* 2016, **91**:319-331.

41. FAO: *Food Safety Risk Management Evidence-informed Policies and Decisions, Considering Multiple Factors. FAO Guidance Materials*. 2017. Available at: http://www.fao.org/3/i8240en/I8240EN.pdf. [Accessed on 15 May 2020].

42. Ruzante JM, Davidson VJ, Caswell J, Fazil A, Cranfield JAL, Henson SJ, Anders SM, Schmidt C, Farber JM: **A multifactorial risk prioritization framework for foodborne pathogens**. *Risk Anal* 2010, **30**:724-742.

43. Gazan R, Brouzes CMC, Vieux F, Maillot M, Lluch A, Darmon N: **Mathematical optimization to explore tomorrow's sustainable diets: a narrative review**. *Adv Nutr* 2018, **9**:602-616.

44. Persson M, Fagt S, Nauta MJ: **Optimising healthy and safe fish intake recommendations: a trade-off between personal preference and cost**. *Br J Nutr* 2019, **122**:206-219.

45. Eustachio Colombo P, Patterson E, Schäfer Elinder L, Lindroos A, Sonesson U, Darmon N, Parlesak A: **Optimizing school food supply: integrating environmental, health, economic, and cultural dimensions of diet sustainability with linear programming**. *Int J Environ Res Public Health* 2019, **16**:3019.

46. EFSA, Bronzwaer S, Kass G, Robinson T, Tarazona J, Verhagen H, Verloo D, Vrbos D, Hugas M: **Food safety regulatory research needs 2030**. *EFSA J* 2019, **17**:e170622.

47. Frewer LJ: **Consumer acceptance and rejection of emerging agrifood technologies and their applications**. *Eur Rev Agric Econ* 2017, **44**:683-704.

48. Assunção R, Pires S, Nauta M: **Risk-benefit assessment of foods**. *EFSA J* 2019, **17**:e170917.

49. Nicklaus S, Divaret-Chauveau A, Chardon ML, Roduit C, Kaulek V, Ksiazek E, Dalphin ML, Karvonen AM, Kirjavainen P, Pekkanen J *et al.*: **The protective effect of cheese consumption at 18 months on allergic diseases in the first 6 years**. *Allergy* 2019, **74**:788-798.

50. Bi YQ, Marcus AK, Robert H, Krajmalnik-Brown R, Rittmann BE, Westerhoff P, Ropers MH, Mercier-Bonin M: **The complex puzzle of dietary silver nanoparticles, mucus and microbiota in the gut**. *J Toxicol Environ Health B Crit Rev* 2020, **23**:69-89.