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Risk-benefit analysis in food safety and nutrition

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Abstract

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.

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 [6].

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 [8]. 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

[9]) and also health risks (*e.g.* heme-iron in red meat have been shown to increase the risk of colorectal cancer [10]).

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 [11]. 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 [12] and taken up by several European Union (EU) projects, such as BRAFO [13]. The RBA methodology was based on the food safety risk assessment approach (including hazard identification, hazard characterization, exposure assessment and risk characterization) [14]. In the BRAFO project, the "tiered" approach was developed [15] and applied in several case studies[16-18]. More recently, RBA has been taken up by several research groups. Boué et al. [19] published a review summarizing the available literature which indicated fish is the most widely studied food in RBA. Nauta et al. [20] 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. [21]. Participants of the workshop concluded 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. [8] , 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 [22]. 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, *etc*., 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 [23].

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 [4]. 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 [24]. 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 [25]. 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 [24,26].

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 [12], 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. [27][11][12][13][14][15][16-18]Boué et al. [19]Nauta et al. [20]Pires et al. [21]Nauta et al. [8]

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 [28]. 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 [29]. 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 4,900 DALYs (CI 90% 400; 8,800) or 0.7 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. [10,30,31] 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 [10] and 6.6 DALY from foodborne pathogen infections [30]. Evaluation of consumption of iron in the diet led to a mean estimate of 16 DALY/100.000 due to iron-deficiency anaemia (IDA) [31]. 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 [10,30,31], 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 [32]. Thomsen, et al. [1,33] 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 [8]. This example illustrates the importance of considering substitutions when conducting RBAs.

[34][35]

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 [34]. 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 [36]. This MCDA approach has been illustrated by a ranking microbial and chemical risks associated with emerging dietary practices in France [35].

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) [37]. 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 [38]. Initiatives to integrate Life Cycle Assessment (LCA) into the risk-based decision process have emerged recently [39,40]. Using a multi-faceted framework presented by Zijp et al. [41], which integrates elements of risk assessment, governance, adaptive management and sustainability assessment, Hollander et al. [9] 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 [9].

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 [42]. Similarly, Ruzante et al. [43] 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 [44]. This technique was recently applied to evaluate the trade-off between health impact, cost and personal preference when looking at fish consumption [45] and to integrate environmental, health, economic, and cultural dimensions of diet sustainability in the food supply for school meals [46]. Hollander et al. [9][9]
In the near future, risk-benefit analysis on food and health could be merged into a broader food system analysis [27,37]. 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 [27] 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 [47] 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 [7,13] and communication [24] 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 [20]. 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 [24,35], possible global transformations of the food system [27], and agri-food innovation [48] are likely drivers for future research in risk-benefit applications. Examples are studies on consumption of raw food products [49], fermented foods [50], plant-origin protein based products, and nanotechnology [51]. 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.

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Figures

Figure 1: Overview of the steps in risk-benefit analysis, with an example for risk-benefit analyses of fish.

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.

Step 1. Risk-Benefit Question

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

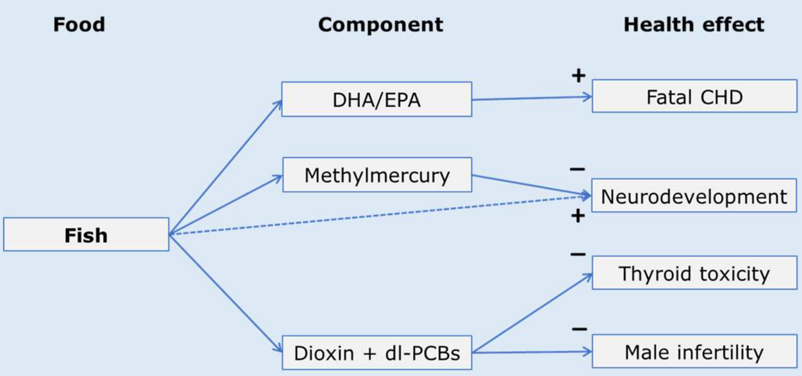
For example: What will the overall health impact be, in DALYs, of increasing the current fish consumption in a population to a recommended level? Next to the reference intake scenario (current intake), different fish intake scenarios can be defined with combinations of fish species.

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[2,3], 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 [7], the dose response relations for neurodevelopment and male infertility are for maternal intake. The dose response relations for dioxins are based on animal experiments [7].

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 [5].

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 [4].

In the ANSES [2] and VKM [5] 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).

Figure 1

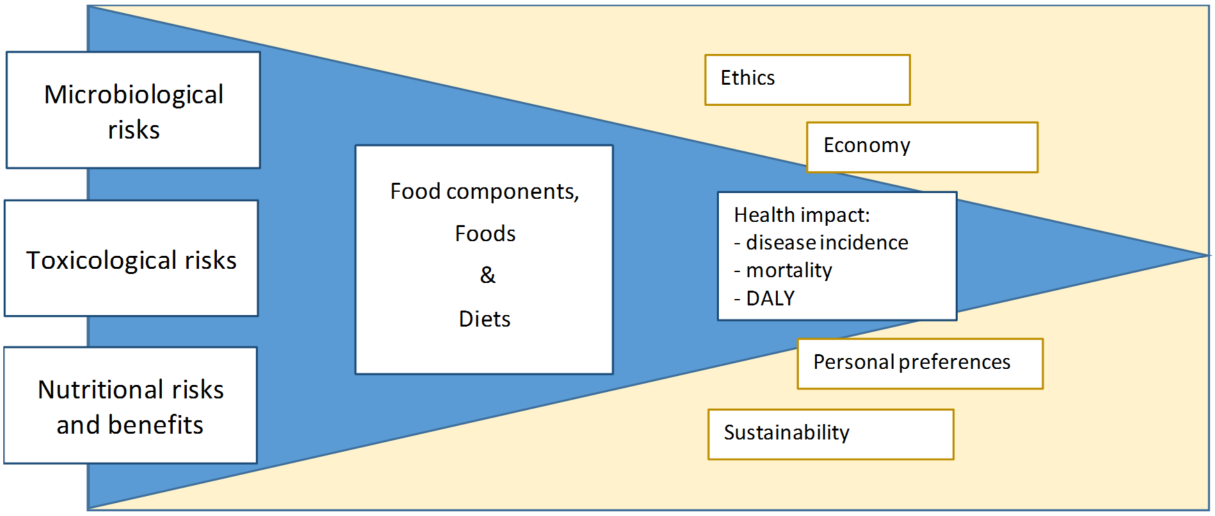
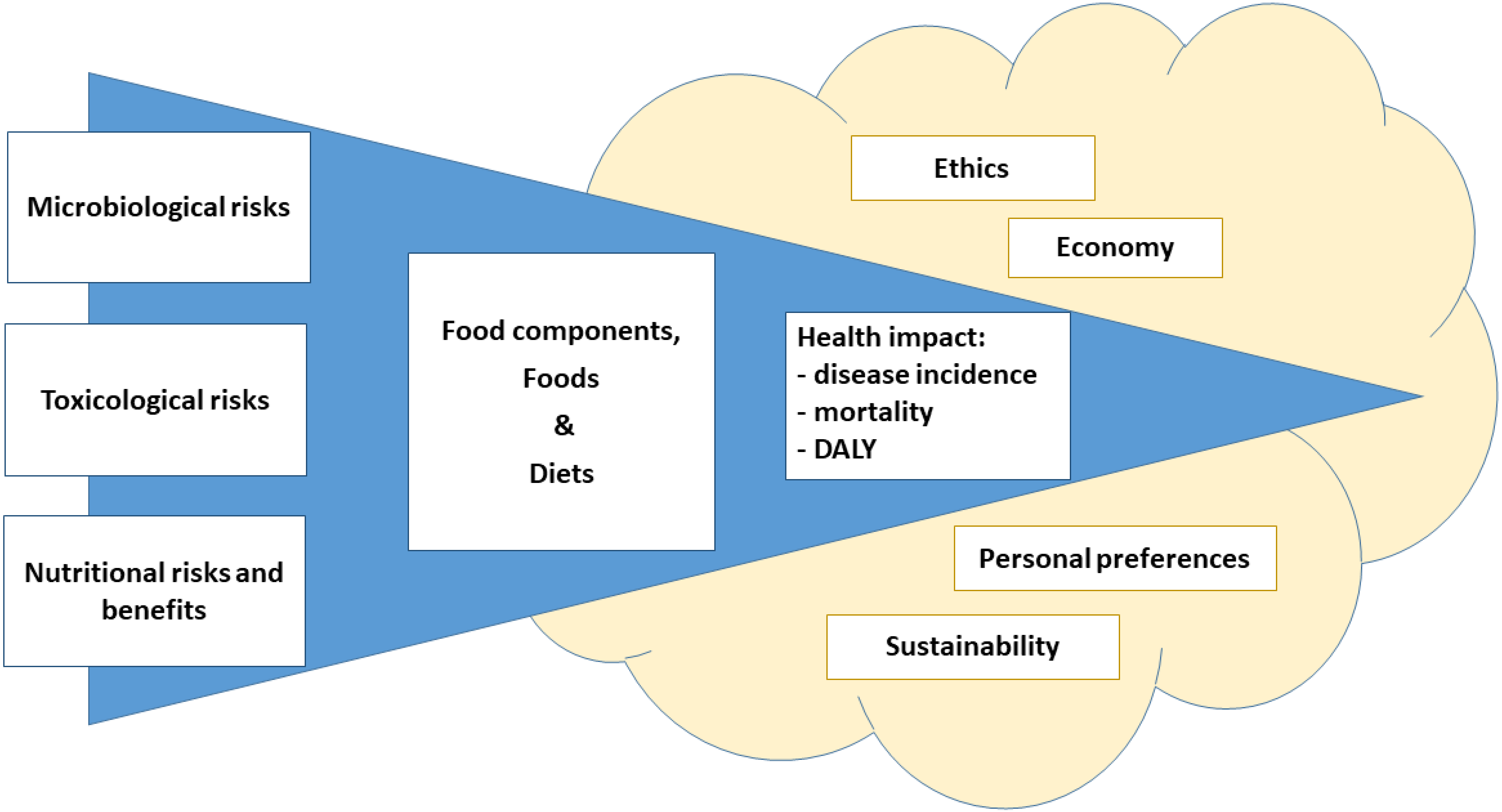

Microbiological risks
Toxicological risks
Nutritional risks and benefits
Food components,
Foods
&
Diets
Ethics
Economy
Health impact:
- disease incidence
- mortality
- DALY
Personal preferences
Sustainability

Figure 2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