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Food risk assessment in the farm-to-table continuum: report from the conference on good hygiene practices to ensure food safety

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Abstract

Foodborne diseases (FBDs) are a major worldwide public health concern. In the current context of globalization, it has become crucial to establish effective collaboration between countries to reduce the incidence of FBDs, by creating knowledge-sharing activities to address this challenge. However, despite the importance of this subject, there are limited opportunities for researchers from French-speaking countries to meet and exchange expertise in this field. Researchers from the Faculty of Veterinary Medicine of the Université de Montréal (Canada) and from the Faculty of Science, University of Abdelmalek Essaadi (Morocco) took the initiative to organize the first French-speaking edition of the conference on *Good Hygiene Practices to Ensure Food Safety*, that was held virtually on May 25 and 26, 2022. Attendees ($n=122$) came from academic, food processing and government sectors. The conference was a great opportunity to showcase the practical application of the risk analysis paradigm, with concrete examples of food hazards, as well as the use of the latest high-throughput sequencing technologies as a tool for source attribution and molecular typing of some of the most important foodborne pathogens. In addition, the conference created a valuable forum for the exchange of knowledge between international food safety experts, particularly with respect to Canadian regulations compared with those of other countries. Interestingly, following the success of this first edition, the conference's scientific committee has decided to continue organizing this event on a biannual basis, to provide a unique forum for French-speaking researchers to learn about the latest advances in food safety.

Keywords Risk analysis, Chemical hazards, *Salmonella*, High-throughput sequencing technologies, Antimicrobials, Food safety

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Introduction

Foodborne diseases (FBDs) caused by pathogenic microorganisms or chemical contaminants remain a major public health and economic concern as well as a budgetary and regulatory priority for healthcare systems worldwide [1]. Consumption of food or water contaminated with microorganisms or chemical hazards, which may occur at any level of the food chain, is the main source of FBDs [2]. In 2015, the World Health Organization (WHO) has issued the first global estimation of FBDs burden reporting that about 1 out of 10 people gets ill from contaminated food, which results in 600 million foodborne illnesses, 420,000 deaths and 33 million disability-adjusted life years (DALYs), while children under 5-year old bore 40% of this burden [3, 4]. Thirty-one foodborne hazards including 29 microbial (bacteria, viruses, parasites) and 3 chemical hazards were considered in the 2015 WHO estimation of the global burden of FBDs [3]. Peanut allergens were excluded from this global burden assessment due to the paucity of data for low- and middle-income countries (LMICs). In addition, the estimation of the burden of disease from four foodborne metals: lead, methylmercury, arsenic, and cadmium were published in 2018 to complete the 2015 WHO estimation [5]. Despite the addition of these four chemical hazards to the WHO estimate of the global burden of FBDs, it seems very clear that the burden of disease associated with food chemical hazards is underestimated. Indeed, about 10,000 chemical compounds are directly (e.g., food additives) or indirectly (e.g., food contact materials) added to food in the United States, to enhance and preserve the organoleptic qualities of food, further preventing deterioration, and also to act as packaging constituents [6, 7].

Although several measures have been developed to prevent and control foodborne hazards along the food chain, FBDs remain a global concern, affecting both developed and LMICs. In fact, the U.S. Centers for Disease Control and Prevention (CDC) estimate that one in six Americans contracts an FBD each year, leading to 130,000 hospitalizations and over 3000 deaths, for economic losses reaching $97.4 billion USD annually [8]. Likewise, the Public Health Agency of Canada estimates that one in eight Canadians is affected by FBDs each year and of these cases, about 11,600 and 238 will result in hospitalization and death, respectively [9, 10]. On the other hand, little factual information is available on the burden of FBDs in LMICs [11, 12]. In fact, in many of these countries, the political commitment, the technical and financial resources as well as the data needed to estimate the burden of FBDs are still lacking, and it is anticipated that these obstacles will multiply as a result of the economic consequences left by the COVID pandemic [1], and some of the current regional conflicts. For instance, in the African region, the burden of FBDs has been estimated by the WHO to be the highest in the world [13]. Indeed, based on 31 foodborne hazards, the WHO estimated the burden of FBDs in this region of the world to be responsible for 1200 to 1300 DALYs per 100,000 population in 2010, compared with 35 to 711 in other regions [4], with 70% of the disease burden being associated with diarrheal diseases, especially non-typhoidal salmonellosis [1]. Globally, the burden of FBDs appears to be increasing in LMICs, in contrast to other infectious diseases whose burden is declining [14].

With a view to reduce the burden of FBDs on healthcare systems worldwide, it is essential to apply a systematic, internationally recognized, farm-to-table approach to decisional and policy-making processes that will ensure food safety as well as facilitate international food trade [15]. In this context, risk analysis perfectly meets these objectives. This science-based framework provides competent food safety authorities with a systematic, well-structured approach to making evidence-based food safety decisions [16]. Risk analysis comprises three components—risk assessment, risk management and risk communication—which have evolved into independent but interactive disciplines (Fig. 1) [17]. On the other hand, the latest high-throughput sequencing technologies such as the whole genome sequencing (WGS) can now contribute to the risk analysis approach and more specifically, to the characterization of microbiological hazards. Indeed, almost in all high-income countries, public health agencies and FBDs' surveillance organizations now routinely use WGS to characterize certain selected foodborne pathogens with a view to supporting epidemiological investigations and source-attribution, allowing the implementation of evidence-based management measures along the food chain [18, 19]. Moreover, WGS offers the most advanced level of bacterial strain discrimination for hazard identification, and for more accurate typing of foodborne pathogens for risk assessment, providing more targeted risk management and communication [20]. It noteworthy that WGS has quietly replaced traditional phenotypic methods for the routine screening of foodborne antimicrobial resistance (AMR) bacteria and genes, while improving quantitative microbial risk assessment (QMRA), enabling the transition to the next generation of AMR risk assessment [21, 22].

To highlight and promote the implications and benefits of the research conducted by the French research community in food safety, in October 2022, researchers from the Faculty of Veterinary Medicine (FVM) of the Université de Montréal (Canada) and from the Faculty of Science, University of Abdelmalek Essaadi (Morocco), have taken the initiative to organize the first edition of the

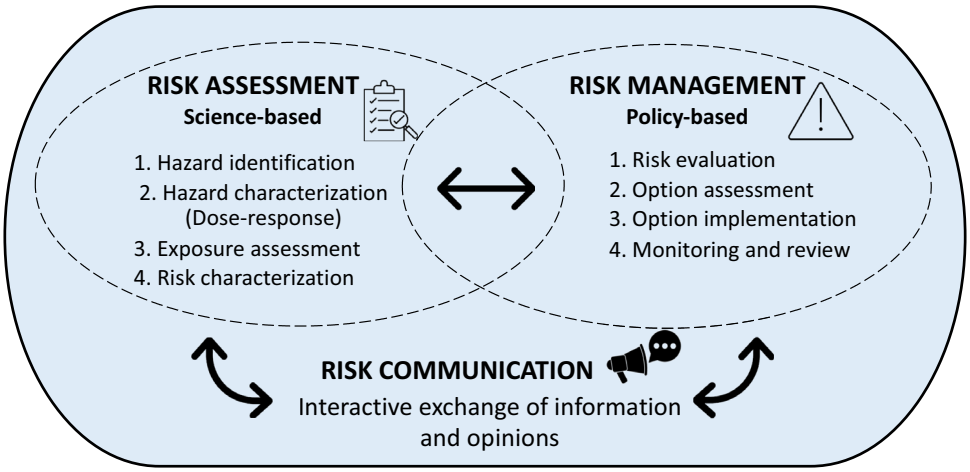

Fig. 1 The three components of the risk analysis paradigm (adapted from [16, 23])

French-speaking conference on *Good Hygiene Practices to Ensure Food Safety*. The present manuscript describes the planning and the objectives of the conference, as well as summaries of the lectures given by leading experts, including the participants' evaluation of the conference, and the conclusions.

Conference planning and preparation

The organization of the *Good Hygiene Practices to Ensure Food Safety* Conference was supported by funding from the Ministry of International Relations and La Francophonie of Quebec. This funding was received by the researchers from the two universities as part of the Quebec-Royal Morocco 2020–2021 call for projects, launched by the Government of Quebec in October 2020. The planning of the conference started with the formation of a scientific committee composed of two researchers from the FVM and one from the Faculty of Science, University of Abdelmalek Essaadi. This committee had elaborated the conference content, prepared the program, and defined the criteria that would guide the decision of the scientific committee on the mode of attendance considering the sanitary instructions regarding the COVID-19 pandemic in 2022. In fact, the conference was initially designed to be held at the University of Abdelmalek Essaadi. However, due to the lack of certainty for international travel at early 2022, the committee opted for a virtual organization of the conference. In collaboration with the communication department of the FVM, the scientific committee developed the promotional material including a conference website outlining the program, the registration instructions and the biographies of the keynote speakers: (https://fvc.umontreal.ca/Web/MyCatalog/ViewP?id=%2B4Swq3TnMa%2BePpsVDMuK8Q%3D%3D&pid=lyWiMW9HoqIQOciggmqGvQ%3D%3D). The conference was held over two morning sessions, on May 25 and May 26, 2022, to take into consideration, the time difference between the organizing countries. The conference was advertised on the web, Facebook, and LinkedIn pages of both universities (FVM and University of Abdelmalek Essaadi), as well as through the professional networks of the scientific committee members. In addition, announcement emails presenting the conference program were sent to selected contacts in other francophone universities (France, Tunisia, Algeria, Belgium), government departments (e.g., Canadian Food Inspection Agency (CFIA), Ministry of Agriculture, Fisheries and Food of Quebec (*MAPAQ*), the National Office of Food Safety of Morocco) and major players from the food-processing industry in Canada and in Morocco. Registration for the scientific event was free of charge and when registered, participants were automatically added to an email list and provided the conference Zoom link a few days before the conference. This same email list was used to send reminders about the conference dates and certificates of participation for attendees. An Information Technology (IT) professional was hired to manage registration and assist speakers during the conference. It is noteworthy that the *Ordre des médecins vétérinaires du Québec (OMVQ)*, the professional association for veterinarians in Québec, Canada, has recognized this conference as a continuing education event for veterinarians who attended. In fact, the 7-h program of the present conference has been recognized by the OMVQ as meeting its requirements in terms of continuing education for veterinarians in Quebec, while bearing in mind that the

OMVQ requires its members to complete 40 h of continuing education over a 2-year period.

Objectives of the conference and information related to the attendees

The objectives of the conference were to (1) gain advanced expertise in risk analysis related to chemical and bacteriological hazards in food, (2) explore the role of high-throughput sequencing technologies including WGS in the surveillance of foodborne bacterial diseases, and (3) outline research and training priorities in food safety. To cover the three targeted objectives, 6 speakers with nationally and internationally recognized expertise in risk analysis and food safety were invited by the scientific committee to contribute to the success of this event. A total of 122 participants attended the conference, among which 116 successfully registered on the conference webpage, while 6 were registered manually following the reception of emails indicating that they were not able to register on the platform. Participants indicated their affiliation, when registering, as the University of Abdelmalek Essaadi ($n=64$, 52.45%), Université de Montréal ($n=22$, 18.03%), CFIA and MAPAQ ($n=9$, 7.37%), food-processing industry (Canada) ($n=8$, 6.55%), National School of Veterinary Medicine (Tunisia) ($n=6$, 4.91%), Université Laval ($n=4$, 3.27%), the National Office of Food Safety of Morocco ($n=2$, 1.63%) and Ghent University (Belgium) ($n=1$, 0.008%). However, the information related to the affiliation of the 6 participants who were manually registered was not collected. The conference agenda included six presentations by speakers with nationally and internationally recognized expertise in food risk analysis along the farm-to-table continuum. Each presentation was followed by a 15-min period for questions and answers. Questions that were received in the Zoom chat were forwarded by the IT professional to the appropriate speaker for follow-up with the attendee via email.

Summary of conferences

The conference program focused on chemical hazards and on bacteriological hazards in food on the first (May 25) and second morning (May 26), respectively.

Dr. Pascal Sanders, Risk assessment of chemicals in food (objective 1)

Dr. Sanders (Scientific Director "Exposure and toxicology of chemical contaminants", French Agency for Food, Environmental and Occupational Health & Safety (Anses)), Coordinator of the partnership for assessment of risks from chemicals, www.eu-parc.eu) gave a keynote address to introduce the participants to the concept of chemical risk analysis in food (Fig. 1). This included a historical perspective on the evolution of food safety regulations, the three components of risk analysis with an emphasis on risk assessment (the scientific part of this process), the threshold of toxicological concern, as well as the role of the various competent authorities at the international level in setting Health-Based Guidance Values (HBGVs). The HBGVs can be expressed as an acceptable daily intake (ADI), a tolerable daily intake (TDI), a tolerable weekly intake (TWI) or a tolerable monthly intake (TMI) [24]. In his presentation, Dr. Sanders stressed the particularities of assessing the risk associated with carcinogenic (non-threshold) chemicals as well as with combined mixtures of chemical hazards in food. He put into perspective the development of new approach methodologies (NAM) for chemical risk assessment, based on the concept of adverse outcome pathway (AOP), using integrated approaches to testing and assessment (IATA).

Dr. Mohamed Rhouma, Food chemical risk analysis: application to antimicrobials used in farm animals (objective 1)

Dr. Rhouma, professor of veterinary hygiene at the FVM of the Université de Montréal, gave a talk, describing in its first part the main groups of chemical hazards likely to contaminate food (Fig. 2), as well as the different metrics used to estimate the burden of FBDs associated with chemical hazards, including the quality-adjusted life year (QALY), the DALY, and the healthy life expectancy (HALE). Indeed, the DALY has been more widely used, as a summary measure of population health and for helping guide national and international decision making regarding FBDs [25, 26]. Moreover, Dr. Rhouma explained the different methods used to prioritize chemical hazards in food according to their public health consequences. This prioritization scheme is of crucial importance for national monitoring programs of chemicals in food [27]. Finally, Dr. Rhouma presented the various actions that have been carried in farm animals, especially over the past decade, to limit the spread of antimicrobial resistant (AMR) bacteria and to preserve the effectiveness of antimicrobials form a One Health perspective [28–30]. In his presentation, Dr. Rhouma stressed the importance of the risk assessment step for the selection of both AMR bacteria/determinants and chemical hazards to be included in a national food monitoring program, while considering the availability of human and financial resources.

Dr. Marie-Lou Gaucher, Molecular risk analysis applied to the control of *Salmonella* along the broiler chicken production chain in Quebec (objective 1 and 2)

Dr. Gaucher, professor in sustainable animal production and control of foodborne pathogens at the FVM of the Université de Montréal, gave a talk on the application of

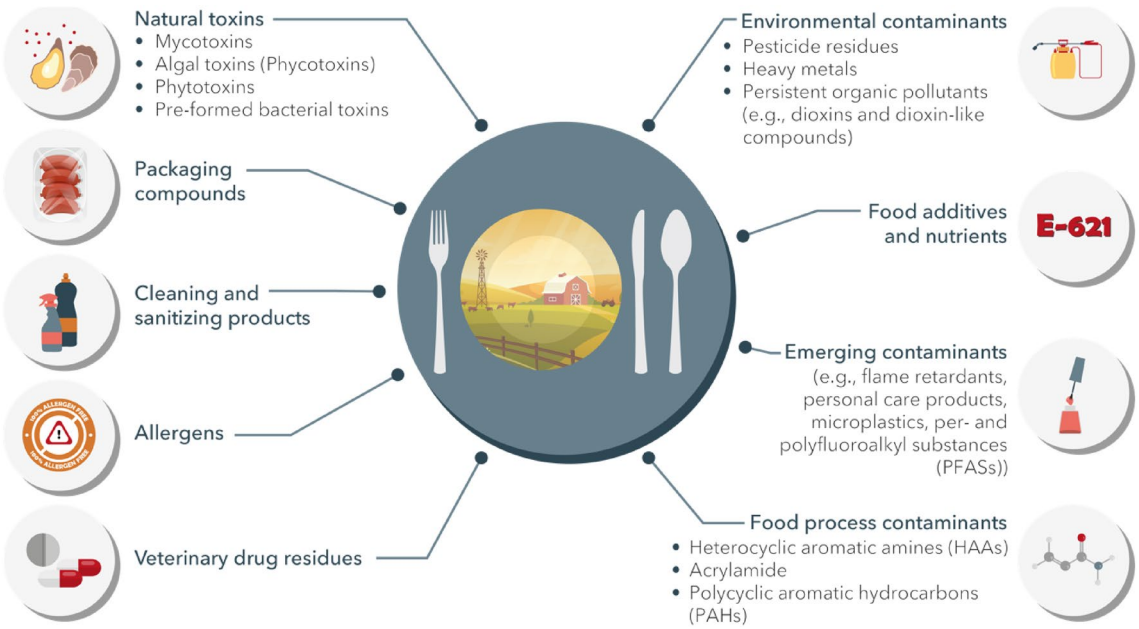

Fig. 2 Main groups of chemical hazards likely to contaminate food

the latest sequencing technologies in the context of a risk analysis approach for the study of *Salmonella* contamination dynamics in broiler chicken production. As opposed to the United States where the broiler industry is fully integrated, this partial level of integration in Quebec makes the control of *Salmonella* more challenging and sources of contamination are present at every step of the production chain, including the breeder flock, the hatchery, the broiler farm, the slaughterhouse, and live hauling. Dr. Gaucher presented the attendees how the application of a risk analysis approach applied to the broiler chicken production chain broken down in its main contributing steps listed above could help better understand *Salmonella* epidemiology in poultry. In her presentation, Dr. Gaucher emphasized the importance of using the high-throughput sequencing technology, targeting specific loci in the *Salmonella* genome, enabling rapid determination of the *Salmonella* diversity present in samples recovered at the main steps of the broiler production chain, as well as a precise characterization of the subtypes of the pathogen, and hence facilitating source attribution.

Dr. Sadjia Bekal, Whole genome sequencing (WGS) for the monitoring of foodborne bacterial pathogens (objective 2)

Dr. Bekal, researcher at the *Laboratoire de santé publique du Québec* (LSPQ), gave a talk on the importance of WGS as an increasingly used approach by public health agencies in Quebec and Canada. As a member of PulseNet Canada, the LSPQ adopted WGS as a comprehensive tool for the identification, serotyping, typing and AMR prediction of enteric bacterial isolates. Whole genome MLST (wgMLST), core genome MLST (cgMLST) and core genome single-nucleotide variant (cgSNV) typing have been evaluated for their usefulness in the surveillance of FBDs. Dr. Bekal pointed out that these three methods showed high discrimination power, while wg/cgMLST were selected as the primary subtyping tool by PulseNet-Canada, for routine surveillance. Dr. Bekal highlighted that additional typing tools; prophage sequence typing (PST) and CRISPR, combined with wg/cgMLST or cgSNV, were able to resolve inconclusive results and confirm events to their respective sources. In her presentation, Dr. Bekal emphasized that *Salmonella* in silico typing resource (SISTR) and ECTyper pipelines are used for *E. coli* and *Salmonella* serotyping, respectively [31, 32]. Finally, Dr. Bekal underlined the relevance of the genomic studies to assess the contribution of food animals, retail meat and companion animals to human infections by AMR genes in the context of One Health AMR surveillance [33].

Dr. Badredine Souhail, Safety of materials used for food packaging (objective 3)

Dr. Souhail, professor of chemistry at the Faculty of Science, University of Abdelmalek Essaadi, presented, in the first part of his talk, the major types of food packaging (e.g., plastic, metal, paper/fiber and glass) while outlining the advantages and inconveniences of each type. Dr. Souhail pointed out that glass remains the healthiest

material, while other materials raise several issues, such as sorption, permeation or migration, which could affect the nutritional qualities of food and the health of the consumer, particularly following chronic exposure. In the second part of his talk, Dr. Souhail highlighted the importance of packaging materials for the food-processing industry, helping to maintain the safety and longevity of food products, while enabling better food preservation and promoting trade between countries worldwide. As a perspective for innovation in this field, Dr. Souhail has stressed the characteristics of a sustainable food packaging material, including efficient design (recyclability), ability to contain, protect and preserve the food product, facilitate recall and provide consumers with information on food quality and safety, while reiterating the importance of research on new biodegradable materials [34, 35]. Finally, Dr. Souhail underlined the relevance of current research regarding the manufacture of packaging materials from more sustainable components, using edible proteins, polysaccharides and lipids derived from food waste.

Mrs. Céline Myre, HACCP: how to understand its application in food processing establishments through the various quality standards? (objective 3)

Mrs. Myre, Trainer—Continuing professional training at *Institut de technologie agroalimentaire du Québec* (*ITAQ*), was invited by the scientific committee to give a talk regarding the steps to be followed when implementing a Hazard Analysis and Critical Control Point (HACCP) system in Canadian food-processing establishments. It is noteworthy that the HACCP system is recognized internationally as the best science-based approach toward preventing, eliminating or reducing, to an acceptable level, the presence of hazards (biological, physical, and chemical) in food [36]. First, Mrs. Myre explained the principles of the HACCP system as defined by the Codex Alimentarius Commission, including a review of the prerequisite programs related to the operating environment at the food establishment level (e.g., premises, food conveyances, personnel, sanitation and pest control, recall system and operational prerequisite programs). In the second part of her talk, Mrs. Myre provided guidance, using concrete examples, on implementing the HACCP plan in food-processing establishments, including a hazard analysis step, followed by the determination of critical control points (CCP) and critical limits, the establishment of monitoring procedures and correctives actions, as well as the establishment of verification and record-keeping procedures. Moreover, the participants were exposed, during this talk, to the differences between some food quality assurance systems. Finally, Mrs. Myre underlined the relevance of implementing HACCP systems in food establishments to comply with the new *Safe Food for Canadians Regulations* that came into force in Canada on January 15, 2019.

Speakers' evaluations and overall participant satisfaction

At the end of the conference, on May 26, the IT professional sent out a survey to participants via the mailing list. The first part of the survey included an assessment of the quality of each speaker's presentation rated on a scale of 0 (poor) to 4 (excellent) for 4 evaluation criteria (Table 1). It is worth noting that one speaker refused to be evaluated and his name was thus withdrawn from this survey. The second part of the survey included 4 yes–no questions related to the overall satisfaction with the conference (Table 1). The third part of the survey included 3 three short questions to better plan the next edition of this conference (Table 1). Participants were given 1 week to complete this electronic survey. At the end of this timeframe, 44 participants had responded to the survey, 17 of whom had suggested some topics for the next edition of the conference.

To analyze the results of the survey regarding the evaluation of the presentation of each of the 5 speakers, the mean and standard deviation (SD) were calculated for the 4 evaluation criteria, showing a similarity in the overall quality of the 5 presentations with means ranging from very good to excellent (Table 2). Moreover, participants agreed that the conference met their expectations (43 (yes) and 1 (no)) and its duration was appropriate (38 (yes) and 6 (no)). In addition, participants agreed that the conference meet the stated objectives (44 (yes)) and the concepts learned were relevant to their practice (41 (yes) and 3 (no)). On the other hand, 40 participants stated that they had been informed of the conference announcement on the websites of the two faculties (Faculty of Science, University of Abdelmalek Essaadi and the FVM of the Université de Montréal), while the other 4 participants reported other sources (colleague, employer, training supervisor, other). Finally, some participants asked for more breaks between the talks and to receive the speakers' presentations as well as for more time to the Q&A session, while encouraging students to ask questions. Moreover, a few topics were suggested by participants for the next edition of this conference, including the application of a quality assurance system (e.g., HACCP) in meat-processing plants, more in-depth study of toxicological consequences regarding chemical hazards in food, particularly food additives, and the risk assessment of organic food products.

Table 1 The survey questions sent to participants

First part of the survey	
Assessment of the quality of each speaker's presentation	
Style and quality of the talk	0 to 4*
In-depth coverage of the subject	0 to 4
Clarity of explanations	0 to 4
The quality of interaction with attendees	0 to 4
Second part of the survey	
Assessment of the overall satisfaction with the conference	
Did the conference meet your expectations?	Yes/No
Was the duration of the conference appropriate?	Yes/No
Did the lectures meet the stated objectives?	Yes/No
Were the concepts learned relevant to your field of activity?	Yes/No
Third part of the survey	
Planification of the next edition of this conference	
How did you hear about the conference?	
Do you have any comments or suggestions for improving this conference?	
What topics would you like to be covered at the next edition of this conference?	

* 0 (poor) to 4 (excellent)

Table 2 Evaluation of the five speakers' presentations ($n = 44$)

Evaluation criteria	Mean	Standard deviation
Style and quality of the talk	3.53	0.66
In-depth coverage of the subject	3.45	0.71
Clarity of explanations	3.44	0.7
Quality of interaction with attendees	3.37	0.73

The quality of each speaker's presentation rated on a scale of 0 (poor) to 4 (excellent). Poor = 0, fair = 1, good = 2, very good = 3, and excellent = 4

Conclusions

This conference was an opportunity for French-speaking experts in the field of risk analysis and high-throughput sequencing approaches applied to food safety to meet and exchange on the latest research and findings on these subjects. The conference evaluation revealed that participants appreciated the different presentations and had deepened their knowledge with regard to food safety. This conference has succeeded in bringing together French-speaking scientists and students working in the field of food safety to learn from recognized experts and establish opportunities for collaboration. The present manuscript bears witness to the willingness of the researchers from the FVM of the Université de Montréal, the Faculty of Science, University of Abdelmalek Essaadi, the *Institut national de santé publique du Québec*, and the Anses to initiate collaborative projects in the field of food safety, while continuing to hold this conference on a biannual basis, to provide a unique forum for French-speaking researchers to learn about the latest advances in food safety and to present their work related to this field.

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Availability of data and materials
Data will be made available on request addressed to the corresponding author.

Declarations

Ethics approval and consent to participate.
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no conflict of interest.

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