



General Interest

Science and Communication as the Foundation of Food Safety

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ABSTRACT

The reliability of scientific information and the appropriateness of its communication across stakeholders are essential for effective food control systems. Reliable science supports risk assessment, informs evidence-based decision-making and policy development, and provides the basis for implementing effective controls across the global food supply chain. However, scientific data may contain limitations or uncertainties that must be carefully assessed and addressed when used as the basis for food safety management and regulatory decisions. This paper emphasizes the need for robust science and for its clear, reliable communication across all stakeholders to support and advance food safety. It is structured around four objectives: first, it describes the role of science in ensuring safe food and clarifies some relevant concepts. Second, it encourages scientists seeking new research directions to consider generating data aligned with regulatory needs, illustrated by one case study. Third, it addresses the shared responsibility of stakeholders in the early stages of the scientific process to guarantee the generation of high-quality data and the accurate and unambiguous communication of scientific findings. Finally, it briefly discusses scientific and communication challenges in food safety. The article targets scientists, policymakers, and professionals interested in food safety, in strengthening science-based approaches and effective risk communication across the food system.

The role of science in ensuring food safety

Science provides the foundation for sound food safety decision-making by supplying the knowledge and tools needed to protect public health. In its Procedural Manual (FAO & WHO, 2025), Codex Alimentarius defines the risk analysis framework, which informs the development of its food safety standards. It has also adopted “Working Principles for Risk Analysis for Food Safety for Application by Governments”, CXG 62-2007, to guide national competent authorities in developing and implementing risk-based food safety measures. Scientific contributions can support diverse areas, including:

- Risk assessment: Science provides data, tools, and methods to identify and evaluate food safety risks. The output of such assessments is used to inform risk managers of national regulatory bodies (policymakers) and standard-setting organizations (e.g., Codex Alimentarius), allowing them to develop food safety standards, guidelines, and regulatory limits, such as maximum residue limits (MRLs) for pesticide or veterinary drug residues. Risk assessment results are

also used in food production by food safety teams, for example, when developing and implementing Hazard Analysis and Critical Control Points (HACCP) plans.

- Detection and monitoring of food safety hazards: In routine official control and industry monitoring activities, testing (e.g., physical, microbiological, chemical, or molecular) is used to determine whether measured levels of hazards comply with regulatory limits or other risk-management criteria. These hazards include, for example, pathogens, food contaminants (e.g., mycotoxins, heavy metals, compounds generated by food processing such as acrylamide), agrochemical residues (pesticides, veterinary drugs), undeclared food allergens, and foreign material. Testing also supports monitoring the effectiveness of safety control measures and investigating food safety incidents.
- Surveillance of foodborne disease and antimicrobial resistance: Epidemiological science helps track and investigate outbreaks, allowing for source attribution and improved response strategies. Science also enables the monitoring of antimicrobial resistance throughout the food chain.

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- Early detection and identification of emerging issues improve the efficiency and effectiveness of preventive and mitigation activities.
- Food surveillance: Scientific principles guide the collection, quality control, integration, and analysis of traceability data to investigate outbreaks, manage recalls, and track the movements of ingredients and foods.
- Technology development: Science drives innovation in primary production, processing, packaging, and preservation technologies that reduce contamination risks and extend shelf life. However, economic incentives and market demand often determine which technologies are developed, adopted, and implemented in food production.
- Policy support: Science provides the foundation for evidence-based policymaking, ensuring that interventions and regulations are proportionate and effective.
- Training and capacity building: Scientific knowledge informs curricula and training programs for food handlers, inspectors, and laboratory personnel.
- Development of best practices: Scientific information forms the basis for guidelines that support the implementation of effective, efficient measures to prevent, control, and mitigate risks in food production environments.

Given the impact and relevance of scientific information for decision-making by regulators, industry, and national authorities, science must be rigorous, transparent, and clearly communicated to protect public health. However, regulatory and political decisions are complex and often depend on several factors alongside scientific evidence, including legal requirements, feasibility, economic considerations, and societal priorities. Clear scientific evidence remains essential for informing these decisions and supporting accountable risk management.

The focus of this communication is specifically about science informing food safety decision-making processes. In this article, we emphasize the critical importance of robust, high-quality scientific data for accurately characterizing food safety risks, as well as the need for effective communication of scientific information among stakeholders involved in food safety governance. We begin by clarifying key concepts, followed by a case study illustrating the aspects scientists need to consider when conducting research useful for regulatory purposes, as well as the limitations of data derived from novel technologies for risk assessment. In addition, the article also describes the shared responsibility of stakeholders during the early stages of the scientific process to ensure the production of high-quality data and the transparent, accurate communication of scientific findings. Finally, it discusses current and emerging scientific and communication challenges in food safety.

Regulatory science. Risk assessment

To understand this section, it is important first to introduce key concepts and basic information related to scientific rigor and risk assessment before presenting a case study that illustrates issues that can affect scientific bias and integrity.

What is scientific rigor? The National Institutes of Health of the United States of America (NIH) defines scientific rigor as “the strict application of the scientific method to ensure unbiased and well-controlled experimental design, methodology, analysis, interpretation and reporting of results” (NIH, 2024). Scientific rigor supports the generation of high-quality data and makes it more likely that independent researchers can reproduce studies, thereby helping validate the original results (Casadevall & Fang, 2016; Hofseth, 2018). Scientific advice carried out under the auspices of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) is based on six core principles, of which four are of scientific relevance (FAO & WHO, 2007). Soundness requires both high scien-

tific competence and procedures that can withstand peer scrutiny. Responsibility covers process integrity and accountability, including proper use of scientific information and caution in data interpretation. Objectivity requires that conclusions remain independent and evidence-based, with any differing views weighed according to the strength of supporting data and kept separate from risk-management decisions. And lastly, transparency involves clear documentation of methodologies, data sources, and decision-making steps.

What are hazards and risks? *Hazard* is “a biological, chemical, or physical agent in, or condition of, food with the potential to cause an adverse health effect” (FAO & WHO, 2025). Examples include *Listeria monocytogenes* (biological), methylmercury (chemical), and glass shards (physical). *Risk* is the likelihood and severity of adverse health effects resulting from exposure to a hazard (FAO & WHO, 2025). For methylmercury in fish, the risk of illness depends on the severity caused by methylmercury (hazard), the level present, and the frequency and amount consumed. In this respect, it is important that the risk assessment process considers susceptible subpopulation groups, such as children, pregnant women, older adults, and immunocompromised individuals (in whom the probability or severity of harm can be greater), as well as high consumers of the specific food/s under evaluation.

Risk analysis framework. Food safety decision-making should be based on risk assessment, within the broader framework of risk analysis. This has been stated by, for example, the Codex Alimentarius Commission (FAO & WHO, 2025), European Regulation 178/2002 (European Commission, 2002) and the USA's Food Safety Modernization Act (U.S. Food and Drug Administration, 2011). Risk analysis provides authorities and food producers with a consistent, transparent method for assessing, managing, and communicating food-related risks. It also helps ensure that measures remain proportionate to the level of risk. It comprises three interconnected components (FAO & WHO, 2025) (Fig. 1):

Risk assessment estimates the risk that food hazards pose to human health. It follows four steps (FAO & WHO, 2025): *Hazard identification* (identifying the agent capable of causing adverse health effects); *Hazard characterization* (evaluating the nature and severity of its effects); *Exposure assessment* (estimating dietary exposure); and *Risk characterization* (integrating the previous steps into an overall estimate of the likelihood and severity of harm in a given population). This process should be transparent, objective, consistent, and based on available scientific information, often involving expert judgment and uncertainty analysis. It is also dynamic and iterative: new scientific evidence, methods, and technologies (e.g., omics, new approach methodologies, probabilistic models) drive the evolution and revision of assessments. In quantitative risk assessment, appropriate simulation design, attention to model stability, and adequate representation of low-probability events are important to ensure that risk estimates remain robust and informative for risk managers. However, it is acknowledged that introducing new risk assessment methodologies could add another challenge for developing countries to fully engage in the global competition to market their products. Because not all scientific data are fit for regulatory use, assessors apply protocols to select reliable, relevant studies and to exclude those with nonrelevant exposure contexts, immature or unvalidated methods, or methodological and reporting flaws.

Risk management is the decision-making process of developing and applying measures to prevent, control, and mitigate food safety risks. Risk managers base their decisions on risk assessment results together with other factors such as risk-benefit analysis, economic and trade impacts, and implementation feasibility. Risk managers include national authorities setting legal safety requirements and monitoring controls, the Codex Alimentarius Commission acting as an international standard-setter, and food business operators deciding on hazard controls, supplier approval, product release, and corrective actions. Because risk management measures are implemented in com-

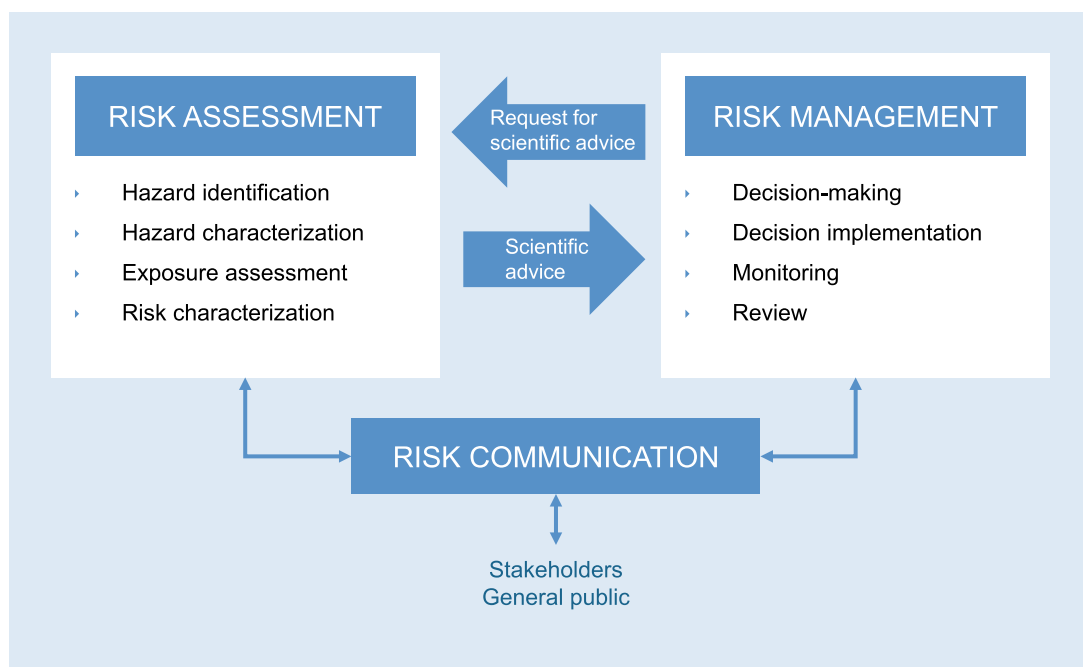


Figure 1. Risk analysis framework.

plex socioeconomic and trade environments, they can sometimes have unintended consequences or inequitable effects if these contexts and the needs of vulnerable consumers are not sufficiently considered.

Risk communication is the interactive, ongoing exchange of information and opinions on risk among assessors, managers, industry, consumers, and other interested parties, including explanation of assessment findings and the basis for management decisions (FAO & WHO, 2025). It should build shared understanding, support transparent, consistent decisions, and help build trust in the safety of the food supply.

Case study. Opportunities and challenges in using gut microbiome data for chemical risk assessment

Many scientific investigations are not conceived with regulatory applications in mind, leading to gaps in the methodological considerations needed for such purposes. Scientists who wish their work to be usable in regulatory contexts must therefore explicitly design, conduct, and report their studies with regulatory needs in mind, taking into account key aspects such as methodological validity, transparency, reproducibility, and relevance to risk assessment and risk communication requirements. At the same time, even when studies are well designed and executed, some data generated using novel technologies introduce additional uncertainties that may make them unsuitable for regulatory purposes. We illustrate these points using a case study on gut microbiome exposure to regulated chemicals, which clarifies how study design, data quality, and technological maturity affect the regulatory usability of scientific evidence.

The gut microbiome is the microbial community that colonizes the gastrointestinal tract and interacts with the host (human or animal), participating in some physiological activities such as digestion, metabolism of some ingested compounds (including drugs), immune system development, production of essential compounds (e.g., vitamin K), intestinal barrier function, and protection against pathogens (Lynch & Pedersen, 2016). Microbiome disturbances have been observed in individuals with certain disorders, such as metabolic and immune conditions. The relationship between the gut microbiome and health has generated significant interest, creating opportunities for the develop-

ment of commercial and clinical applications. However, it is important to note that many reported findings are based primarily on associations that sound biologically plausible, rather than on demonstrated mechanistic or causal links (Fan & Pedersen, 2021). This means that not everything discovered through research or stated in the public domain about the microbiome's role in health and disease has been confirmed. In addition, despite the tendency to report unidirectionality, i.e., microbiome disturbances that contribute to adverse health outcomes, it is often unclear whether microbiome changes are the cause or a consequence of disease (McBurney et al., 2019; Zheng et al., 2020).

A substantial amount of research has investigated the potential influence of chemical-microbiome interactions on the gastrointestinal microbial community and physiological responses. The recognition of the gut microbiome capacity to participate in metabolic functions, modify the activity and toxicity of certain chemicals, and potentially influence health outcomes has led to several initiatives that evaluate the robustness and suitability of gut microbiome data for food safety chemical risk assessments (Anklam et al., 2022; FAO, 2023a, b, c, 2024a, 2025; Moreno et al., 2024).

This case study presents the potential use of gut-microbiome-derived data in chemical risk assessment, highlighting (1) data types that are currently suitable for integration, (2) those that remain immature due to knowledge and technical limitations, and (3) key considerations for researchers aiming to design studies with regulatory relevance. The case is built on findings from recent FAO initiatives, including a critical evaluation of the state of research on the interactions between regulated chemicals (food additives and residues of veterinary drugs and pesticides) and their potential involvement in adverse health effects, as well as the suitability of such studies for risk assessment (FAO, 2023b, c, 2025). This case study is further informed by the conclusions of an FAO-organized expert group meeting that discussed the potential and readiness of microbiome data for integration into risk assessments (FAO, 2024a).

What are the types of microbiome data currently relevant for risk assessment? Currently, the best-established use of microbiome-related data in risk assessment comes from the evaluation of veterinary drug residues with antimicrobial activity. In this context, two well-

defined microbial endpoints (i.e., disruption of the colonization barrier and increases in antimicrobial-resistant bacterial populations) have been included in a guideline developed by the International Cooperation on Harmonization of Technical Requirements for Registration of Veterinary Medicinal Products (VICH, 2019) and routinely considered by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). The VICH guideline also provides standardized protocols based on minimal inhibitory concentration (MIC) testing, which are used to derive microbiological health-based guidance values, including the microbiological acceptable daily intake (mADI). This approach is also followed by the FAO/WHO Joint Meeting on Pesticide Residues (JMPR) in assessing pesticide residues.

Assessments can also include biologically relevant data related to the role of the gut microbiome in chemical biotransformation. Certain microorganisms in the gastrointestinal tract can inactivate, activate, reactivate, or otherwise modify chemicals, thereby altering their bioavailability, toxicity, and pharmacokinetics (Anklam et al., 2022; FAO, 2024a). Although the underlying mechanisms are often not fully understood, such activities can be observed, for example, *in vitro* or inferred from *in vivo* toxicokinetic studies.

What are the limitations and challenges in integrating gut microbiome data into risk assessment? To date, there are no internationally accepted frameworks for systematically evaluating gut microbiome exposure to chemicals (Anklam et al., 2022). Multiple factors, including knowledge gaps and technical limitations, explain why gut microbiome data are not yet suitable for risk assessments. A fundamental limitation is the lack of clear, consensus definitions, particularly for what constitutes a healthy gut microbiome (or the typical microbial profiles of healthy reference populations) and for dysbiotic or dysfunctional states (Van Hul et al., 2024). Such definitions are needed to establish reference points, or baselines, for studying interactions among the microbial community, the chemicals present in food, the intestinal environment, and host physiology.

Difficulties in obtaining robust and reproducible data are due to the limited availability of methodological guidance (e.g., procedures for sample collection, handling and storage of a complex microbial community which is sensitive to environmental changes; or the selection of suitable model for the study purpose) and the lack of standardized and validated analytical methodologies (Chetty & Blekhan, 2024; FAO, 2024a; Yang et al., 2025). Omics approaches, while providing large volumes of information, face challenges such as difficulties in linking genomic potential to confirmed biological activity within the complex gut environment (Heintz-Buschart & Wilmes, 2018). Recent technological advances are enabling the development of promising analytical tools and alternatives to animal models (e.g., organoids and organ-on-a-chip systems), which are expected to expand our knowledge of gut microbiome-host interactions and, when mature enough, may contribute to evidence generation suitable for risk assessment (FAO, 2024a).

Moreover, most research continues to focus primarily on bacterial populations, while nonbacterial components of the gut microbiome, such as viruses, archaea, and fungi, remain poorly characterized (FAO, 2023b, c, 2024a, 2025). These microbial groups may play important roles in chemical-microbiome-host interactions, but their contributions remain poorly understood.

There is a need to identify, characterize, and quantify gut microbiome changes that influence the development of adverse health outcomes, supported by validated, sensitive microbiome-related metrics, biomarkers, and endpoints (FAO, 2024a). Unfortunately, many of the links reported between microbial alterations and health outcomes are often based only on statistical correlations and associations. Despite their relevance for risk assessment, causal links and the molecular mechanisms underlying the relationship between gut microbiome changes and physiological alterations are poorly or not fully demonstrated (Anklam et al., 2022; FAO, 2023b, c, 2024a, 2025). They are difficult to investigate due to the challenges posed by complex biolog-

ical systems, such as those of animals and humans. This is further complicated by challenges in animal-human translatability, as differences in microbiome composition and host physiology make it difficult to extrapolate findings from model studies (e.g., *in vitro* or *in vivo*) directly to human health outcomes (FAO, 2024a).

Which aspects should researchers consider when designing studies for risk assessment purposes? As mentioned above, the potential integration of gut microbiome data into chemical risk assessment is currently constrained by knowledge gaps and technical limitations. Addressing these challenges requires research efforts that generate evidence that is robust, reproducible, mechanistically informative, and regulatory-relevant. The following information provides tips and guidance for gut microbiome researchers interested in contributing to this field and exploring new research paths that advance regulatory science.

Some of the research needs aimed at closing knowledge gaps and advancing the maturation of models and analytical technologies have been mentioned above. In addition, a comprehensive list of needs and priorities can be consulted in the different reports published by the FAO (FAO, 2023b, c, 2024a, 2025).

The following are some basic aspects that researchers should consider when designing studies aligned with the needs of food safety chemical risk assessment.

Studies should reflect dietary exposure scenarios that are relevant and representative for the intended population, recognizing that individual and day-to-day consumption patterns are highly variable. These include, for example, the quality of the investigated chemical, relevant doses, oral administration, and durations of exposure:

- Researchers should ensure that the experimental chemical compound matches the quality and grade intended for its use in the human context (e.g., food-grade for food additives, technical-grade for pesticides), as impurities in lower-quality reagents can confound outcomes and affect safety conclusions.
- Dose levels and regimen (e.g., daily, *ad libitum*) should reflect real-world, long-term, low-level dietary exposures. Although no protocol fully captures exposure variability, consensus-based guidelines (e.g., OECD test guidelines) and intake estimates from food consumption surveys support study design. While single high doses lack regulatory relevance, a range of doses helps build dose-response relationships. This type of information supports the determination of health-based guidance values, such as the acceptable daily intake (ADI), which serves as the basis for setting regulatory thresholds for safe exposure.
- Longitudinal studies, including time-series sampling, are highly informative because they help assess the sequence and progression of changes in both the microbiome and the host. Sampling can begin before exposure, enabling the establishment of microbiological and physiological baselines. This type of study also allows the evaluation of microbiome resilience and observation of recovery and potential delayed effects when sampling is extended beyond the end of chemical exposure.

The selection of human-relevant models (*in vitro*, *in vivo*, *ex vivo*) should consider, for example, the research question and study purpose, the model's sensitivity to detect subtle effects, and ethical feasibility.

Finally, researchers should identify and follow available standardized and harmonized protocols (sampling, analytical methods, bioinformatics, reporting), which are essential for producing reproducible and comparable data. Scientists should regularly check for updates and guidance developments from regulatory agencies (e.g., US FDA, EFSA) and organizations (e.g., FAO), as they are actively discussing standardization and the potential incorporation of microbiome data into risk assessments. The Organisation for Economic Co-operation and Development (OECD) provides diverse guidelines for conducting toxicological studies. For example, guidelines for designing oral

semi-chronic and chronic exposures in rodents, etc, or *in vivo* toxicokinetics. Scientists can also refer to other published relevant guidelines and best practices (FAO, 2025, Annex IV), for example, to assist in study design (Smith et al., 2018), interpretation and reporting outcomes from animal research (Mirzayi et al., 2021; Percie du Sert et al., 2020), and omics data from toxicology studies (OECD, 2023).

Science and risk communication

Effective risk communication in food safety constitutes a critical component of the risk analysis framework. It is a collaborative responsibility across multiple stakeholders. Within this network, researchers, peer reviewers, and publishing entities generate and validate scientific outcomes. Triggered by the risk manager's request for scientific assistance, risk assessors interpret the scientific evidence within the context of food safety risk analysis, providing results and recommendations to policymakers, who use these insights to inform regulatory and policy decisions. Stakeholders involved in outreach (e.g., journalists, educators, and consumer organizations) further adapt the information to suit their target audiences. The continuum of communication extends to policy implementers, such as food producers, and ultimately to consumers, who must be enabled to make informed decisions based on clear, relevant, and trustworthy information. At every stage, however, the process is susceptible to distortion, oversimplification, or selective emphasis, which may alter risk perception and, consequently, affect public attitudes and behaviors. To mitigate these challenges, transparency, consistency, and robust coordination across all actors in the communication network are imperative. Here, we will focus on the reporting and publishing of scientific findings.

The role of researchers in communicating scientific findings accurately. Researchers have the responsibility to report scientific findings to support transparency and rigor. They should follow consensus reporting guidance (Batista Leite et al., 2024; Percie du Sert et al., 2020) and the requirements of many scientific journals. The following points summarize common issues in the scientific literature that should be avoided (Andrade, 2021; Boutron & Ravaud, 2018; Brown et al., 2017; FAO, 2025):

- **A priori.** In confirmatory studies, research questions, hypotheses, and statistical methods should be defined before data collection and analysis. This is particularly relevant when results support risk assessment or regulatory decisions. Exploratory studies may adjust analytical approaches in response to data and generate hypotheses for subsequent confirmatory studies. Problems arise when results drive analytical choices, but the findings are presented as confirmatory. Examples include HARKing (establishing a *post hoc* hypothesis) and *P*-hacking (adjusting analyses or data handling to obtain statistically significant results that favor a specific outcome, often to support the hypothesis) (Andrade, 2021).
- **Transparent and complete methodologies.** Researchers should describe the study design, analytical methods, sources of variability, potential confounders, uncertainties, and limitations. Results should be clearly reported, and conclusions should remain within the limits of their data.
- **Accurate result interpretation and reporting.** Scientists should distinguish between data-supported conclusions and speculation, and avoid overgeneralization, personal opinion, spin, and cherry-picking. *Spin* presents results as more favorable or certain than the data actually support, for example, by emphasizing beneficial outcomes, understating limitations, or *cherry-picking* evidence that supports a desired conclusion while withholding contradictory results (Andrade, 2021; Chiu et al., 2017). *Null results* (nonsignificant findings, no effect, or absence of association) should also be

reported and interpreted, as focusing only on statistically significant results introduces bias and may lead to inaccurate conclusions (FAO, 2025).

- **Careful extrapolation.** Findings from experimental models should be cautiously translated to humans, given differences in physiology, exposure scenarios, and study conditions. Risk assessors account for such uncertainties when deriving human health-based guidance values.
- **Accurate titles and abstracts.** Titles and abstracts are often the only parts read by scientists, policymakers, journalists, and the general public. Misrepresenting findings (e.g., exaggerating significance, omitting limitations, or implying causality when data support only association) can distort scientific messages and erode trust in science. This risk is especially delicate in fast-moving media environments where titles and abstracts are frequently used to build narratives, especially on controversial topics, to shape public opinion and behaviors.

Publishing houses and peer reviewers. Publishing houses are responsible for enforcing consistent methodological and reporting standards as well as transparency policies. However, requirements and policies differ across publishing houses, leading to inconsistent peer-review processes and quality of published research.

The rapid growth of digital publishing has fueled the rise of predatory journals, which prioritize profit over scholarship and often apply inadequate or nontransparent quality control processes, increasing the risk of publishing false or misleading information (Casadevall et al., 2024; Richardson et al., 2025). Publishers must also detect malpractice such as plagiarism, image manipulation, and inappropriate use of AI, which can complicate authorship and scientific content authentication (Casadevall et al., 2024).

Peer reviewers act as a critical quality checkpoint, providing scrutiny to ensure scientific integrity, identify methodological flaws, assess research relevance, flag unjustified claims, address missing context, and prevent overstatements or misrepresentation that could mislead readers (Aczel et al., 2025). However, recruiting qualified peer reviewers is increasingly difficult (Aczel et al., 2025), especially for complex or interdisciplinary studies that require diverse expertise. With most journals relying on only two or three reviewers, gaps in expertise are common. Additionally, peer review remains largely unrewarded and underrecognized, limiting incentives for participation (Horta & Jung, 2024).

Scientific and communication challenges in food safety

Food safety is entering a period of transformation, driven by the rapid development of digital and data-driven tools. These advancements are likely to reshape the way food safety risks are monitored, predicted, and communicated, while also creating new challenges that require careful oversight.

Big data and emerging tools. Advanced technologies (e.g., AI, blockchain, big data analytics) have considerable potential to improve and accelerate food safety activities such as risk prediction and risk mitigation, real-time monitoring, traceability, outbreak response, and decision-making support (Mu et al., 2024; Qian, Murphy, et al., 2023; Rugji et al., 2025; Siddique et al., 2025; Singh, 2025; Yin et al., 2025). However, they also introduce new vulnerabilities. AI and machine learning models rely heavily on the quality of datasets. Incomplete or biased datasets and faulty models produce unreliable output. Additionally, many models and algorithms operate as “black boxes,” lacking transparency and making their accuracy difficult to assess. Therefore, these tools require robust validation before deployment and human oversight to reduce bias, inaccuracies, unexpected

outcomes, and adverse effects on predictions, processes, and decisions (Siddique et al., 2025; Singh, 2025).

Regarding scientific production, AI can support the design of experimental methodologies, data analysis, and the writing and publication of scientific information, for example, by automating repetitive tasks, generating preliminary outlines and drafts, and detecting errors and inconsistencies to improve manuscript quality and readability. Its use, however, requires careful oversight. AI applications can produce convincing text that is factually wrong, lacks scientific depth and context, and sometimes contains nonexistent references or plagiarized passages (Cooperman & Brandão, 2024). There are also growing concerns about deliberate misuse, including fabrication of scientific content (e.g., false data, facts, references), data tampering, media manipulation, and other unethical practices (e.g., undisclosed AI use) (Chen et al., 2024). Such practices are frequently used by *paper mills*, which sell fabricated and fraudulent manuscripts (Else & Van Noorden, 2021). Critical evaluation of AI-generated content can avoid or minimize some of these risks, but deliberate misuse is often difficult to detect. Undetected problems can weaken scientific transparency and quality (inaccurate findings, bias, reproducibility) (van Dis et al., 2023), thereby contributing to misinformation. Addressing these issues requires AI awareness and training, effective detection tools, and clear frameworks and best-practice guidelines to prevent misuse and promote responsible application (Chen et al., 2024; Izquierdo-Condo et al., 2024). Initiatives such as UNITED2ACT (united2act.org) bring together research institutions, scientists, universities, and publishing houses to act collectively against paper mills and promote scientific ethics.

Data are important assets in the hands of many stakeholders. They are essential in the context of big data and the development of emerging tools such as AI and machine learning. Data must be adequately described. Well-defined datasets, complete metadata, and traceability of provenance are prerequisites for interpreting, verifying, and combining data from different sources. They are addressed by frameworks such as the FAIR principles (FAIR, 2016). However, limited access to data (whether proprietary, fragmented, or technically inaccessible) directly compromises science-based activities, the effective and timely implementation of safety responses, and decision-making processes (Qian, Liu, et al., 2023). For example, obstacles in data sharing can negatively impact research as scientists cannot independently verify or reproduce methods and findings. It can also lead to incomplete risk characterization when data are unavailable, due to high uncertainty. Limited or restricted access to data across the supply chain also slows authorities' response to food safety incidents and delays the implementation of corrective and mitigation measures. Official authorities play an important role in facilitating data sharing by promoting the establishment of platforms, agreeing common data description and metadata standards, and setting requirements for food safety data sharing that minimize the misuse of databases while ensuring data privacy and data protection (Mu et al., 2024; Qian, Liu, et al., 2023).

Challenges for food safety, science, and risk communication. This section discusses key challenges for science, food safety, and risk communication. It considers how scientific complexity, misinformation, disinformation, and digital communication channels affect public and stakeholder understanding, and explains why institutional credibility is essential for maintaining trust in official guidance.

Scientific and risk assessment language is highly technical, designed to support accuracy and consistency, but the same specialized terminology can be difficult to interpret outside specialist settings (Baba & Esfandiari, 2023). Effective communication with policymakers, industry, and the general public therefore requires technical findings to be expressed in a language tailored to each audience, without altering relevant scientific conclusions or uncertainties. Many institutions now encourage plain-language report summaries to improve

accessibility. Some of the related terms and concepts that are often confused include *probabilities* and *uncertainty*, *hazard* and *risk*, and *associations* versus *causality* when discussing relationships between chemical exposures and adverse health effects. The concept of *evidence* is also widely used in science (e.g., evidence-based decision-making) and other fields. Still, the lack of definition can lead to different scientific interpretations (Yu et al., 2024). In risk assessment, *evidence* refers to relevant, systematically collected scientific information (e.g., experimental, epidemiological, or mechanistic data) that informs the assessment question. Assessors appraise this information for quality, relevance, and consistency across lines of evidence, then integrate it using qualitative or quantitative methods to support the risk characterization and conclusions. This appraisal and integration process is known as the weight-of-evidence approach.

Methodological variability and the availability of low-quality published studies can lead to conflicting scientific conclusions. Such contradictions contribute to public controversies (e.g., debates over the health impacts of additives or genetically modified foods). They may generate confusion, erode trust in scientific advice, and fuel the spread of misinformation.

Divergent or misaligned positions among stakeholders also affect the credibility of scientific information and institutions, as when authorities in different jurisdictions interpret the evidence on pesticide residues or approved food technologies differently, further complicating risk communication (FAO & WHO, 2016). Strengthening collaboration among scientific bodies, promoting transparency about uncertainties, and adopting clear messaging on the weight of evidence help address these challenges and improve public understanding of food safety risks.

Misinformation and *disinformation* in the context of food safety refer to the dissemination of false or misleading claims about food safety practices or health risks not supported by scientific evidence. Misinformation is shared without intent to mislead, while disinformation is created or shared deliberately to deceive (Bekele-Alemu et al., 2025; Veflen et al., 2023). They can originate from sources such as social media, personal communications, websites, TV, newspapers, or other news sources. Misinformation can range from completely fabricated claims with no scientific basis to pseudo-scientific narratives that mimic the language of science but rely on selective data, misrepresentation of research, emotive messaging, and oversimplification. Unfortunately, nonspecialists or pseudo-scientific messengers often frame their messages in absolute, emotionally compelling terms, making them appear more convincing to the public than messages from scientific and official institutions, which aim to use cautious, conditional language to reflect the complexity and uncertainty inherent in evidence-based research. However, these institutions must also scrutinize their own messaging, as nuance may be lost when findings pass through institutional channels. As a result of misinformation and disinformation, public understanding of food safety becomes distorted, with several consequences. These include the establishment of misconceptions and public confusion around topics such as genetically modified organisms (GMOs), which have shaped opinions more strongly than decades of robust scientific consensus (Bekele-Alemu et al., 2025). It also increases the risk of ineffective or counterproductive consumer behaviors (Melios et al., 2025), such as avoiding pasteurized products, relying on unregulated "natural" preservatives, or rejecting standard hygiene practices in favor of anecdotal advice.

The rise of digital communication channels - including social media platforms, online news sites, and video-sharing networks - has transformed food safety risk communication, enabling rapid and widespread dissemination of information. These channels have democratized the food safety dialog, connecting stakeholders with different audiences. However, they have also been exploited as an effective tool to amplify the voices of uncredentialed influencers and

sensational headlines, contributing to the viral spread of unsubstantiated claims and increasing consumer confusion and the risk of unsafe practices.

Addressing these challenges requires strengthening trust in science-based institutions and policies by promoting transparent and consistent risk communication from trusted organizations (FAO & WHO, 2016; Jaskiewicz et al., 2023; Mucević et al., 2025), providing basic scientific understanding, and educating consumers to evaluate food safety information more critically.

Risk communication depends not only on the message but also on the credibility of the issuing institution and the messenger. Even when scientific evidence is sound, if institutions are perceived as not independent and politically or commercially biased, messages may be questioned or ignored. Institutional credibility (and overall consumer trust in food safety systems) can be further damaged by delayed, ineffective, and inconsistent information delivered by different staff from the same or related organizations, for example, those involved in food safety incidents or recall events (Wall & Chen, 2018).

Today, questions on what counts as evidence and who has the authority to call something evidence or expert knowledge are increasingly contested, for example, in science-related populism and *alternative facts* movements. This contestation reduces trust in scientific institutions, amplifies conspiracy theories, and contributes to what many scholars describe as an epistemological crisis, in which shared criteria for distinguishing knowledge from opinion are weakened (van der Meer & Hameleers, 2026). In this context, transparent and explicitly defined weight-of-evidence approaches are not merely technical tools. They also show the standards and decision rules that institutions use, thereby supporting scrutiny and accountability. In addition, institutions designate experts through defined selection procedures that include relevant qualifications and experience, a documented track record of scientific work, and declarations of interest. In this line and as part of the efforts to support policy decisions based on sufficient, relevant, and credible scientific evidence, FAO has recently published “Guidance on strengthening national science-policy interfaces for agrifood systems” (FAO, 2024b).

Conclusion

Food safety depends fundamentally on the integrity, transparency, and reproducibility of science, and how it is communicated, understood, and used. The generation and application of high-quality scientific evidence form the basis of every aspect of modern food safety systems, from risk assessment to policymaking and public communication. As food production and global trade continue to evolve, so must the scientific foundations supporting them. Advances in analytical technologies and data science offer new opportunities to refine risk assessment, but they also require sufficient maturity and the validation of new tools.

The collective commitment to quality and transparency across all stages of research and regulatory processes is necessary to maintain scientific credibility. Researchers must adhere to robust methodological standards and communicate findings with clarity and accuracy. Peer reviewers and publishers must ensure that scientific findings and reporting are rigorous and meet established standards. Risk assessors and policymakers must continue to base decisions on transparent, evidence-driven processes while remaining responsive to new scientific findings. Finally, effective, accurate, consistent, and transparent communication of food safety risks is essential to support informed decisions and preserve public confidence.

Ensuring food safety in a rapidly changing global food system is not only a scientific challenge but also an institutional and societal responsibility. Strengthened collaboration among international bodies, national authorities, academia, and industry is essential to ensuring

that science continues to form the basis for food safety governance and public health protection.

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