EU Food Safety Platform
MULTI-STAKEHOLDER PLATFORM FOR FOOD SAFETY IN EUROPE

Strategic Research and Innovation Agenda for Food Safety in Europe

FoodSafety4EU input for fast-response SRIA on priority challenges in emerging/novel food hazards and risks

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Introduction

Food safety is facing several important challenges from both within and outside food systems such as climate change, globalization, resource depletion, growing inequalities, geopolitical instabilities, e-commerce, amongst many others.

Policies, guidelines, standards, and regulations related to food safety need to be kept up to date or further developed to reflect the changing needs within the current system. Managing critical food safety deficiencies will foster the efficiency and resilience of agrifood systems and ultimately help achieve food security while ensuring global public health.

To "realize our shared vision for a better world" (UN Food Systems Summit, 2021) and to be better prepared to mitigate potential shocks and disruptions, there is a need to develop and maintain a deep understanding of the future opportunities, challenges, and threats to our agrifood systems. The FAO food safety foresight programme is geared towards the proactive identification, evaluation and prioritization of emerging trends and drivers within and around agrifood systems that can have food safety implications. The 18 key drivers identified by FAO's Corporate Strategic Foresight Exercise were grouped in 4 categories: systemic (overarching) drivers, drivers directly affecting food access and livelihoods, drivers directly affecting food and agricultural production and distribution processes and drivers regarding environmental systems (FAO, 2022). Major drivers and trends relevant to agrifood systems and food safety identified are: climate change and global warming, circular economy, new food sources and food production systems, microbiomes and food safety perspectives, growing urbanization with growing plastics residues, pollution in terrestrial and aquatic ecosystems and urban agriculture, technological innovations and scientific advances and consumer behaviour and food consumption patterns.

The EU Food Safety Forum was designed by a multi-stakeholder working group consisting of representatives of FoodSafety4EU project core partners being direct connected with the FS4EU Platform and its activity, as the main tool for co-creation and participatory process. This connection is made especially through the four Food Safety Operational Labs (FSOLabs) in which Food Safety System Stakeholders to be engaged to contribute for efficient and effective EU food safety system management. A huge interest in Food System Stakeholders was observed in putting together information related to food safety and connections between food safety data with other fields, such as climate change, efficiency of resources, sustainability, in general, and One Health approach.

Three main actions are foreseen to feed annually EU Food Safety Forum: (i) identifying hot food safety research and innovation (R&I) topics from relevant information collected during one year; (ii) setting up a range of supporting activities addressed to all Food Safety System Stakeholder - policy initiatives, good practice and lessons learned, facilitating the implementation of regulations, programmes and policies, improve communications initiatives facilitate synergies with the other initiatives and EU funded projects strengthening the evidence base for food safety and evaluate the effectiveness of actions, etc (iii) lesson learnt from these participatory multi-actor processes in four FSOLab as given input for the next year EU Food Safety Forum. Overall, these actions generate input to update the Food Safety Strategic Research and Innovation Agenda (SRIA).

The SRIA on Food Safety emerging/novel food hazards and risks outlines the framework for future research, development, and innovation to achieve the EU's food safety policy goals: to ensure safe, nutritious food, high animal health and welfare standards, plant protection, and clear product information.

Looking at the big challenges of the food systems transformation from the food safety angle, the new SRIA envisages the future research needs to ensure a SAFE transition towards sustainable food systems under the edge of the new sustainability regulation.

The co-creation methodology

FoodSafety4EU designed and piloted a process for co-creation of a coherent Food Safety Strategic Research and Innovation Agenda (SRIA) by a multi-stakeolder group. The process was intended to enable a multi-actor (and multi-level) group to generate a shared vision of food safety challenges while preserving a multi-perspective approach to the solution of these challenges.

The steps of the workflow are relevant outcomes are depicted in Figure 1.

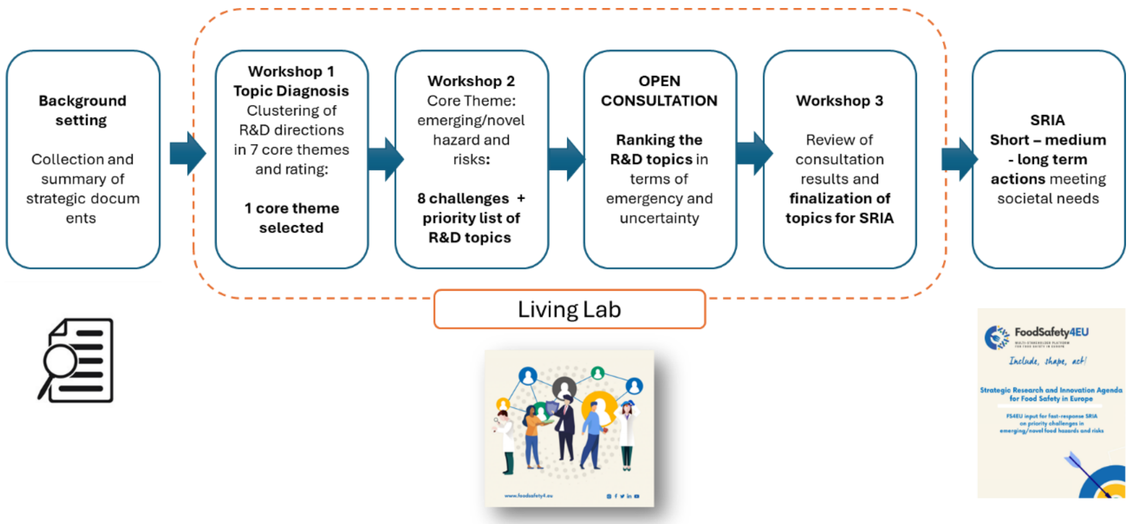

Figure 1: scheme of the participartory process implemented for the co-creation of the SRIA

The *iterative* process has been conducted involving more than **30 experts** in the discussion and confrontation, supported by professionals in social innovation, who have facilitated the implementation of the methodology. Starting from the existing strategic documents and addressing the needs of diverse stakeholders, the methodology allows to identify and prioritize challenges, to validate the selection made by the experts through an extensive consultation, to co-create shared topics as input for the SRIA with short-medium-long term action plans.

The co-creation process based on the living lab methodology delivered results in a concrete and pragmatic way, despite the complexity of the topic. A particular effort in elaborating the SRIA was dedicated to unravelling and addressing different needs of Food Safety System stakeholders considering, in this way, their different perspectives. In this respect, stakeholders from research and academia, policy, non-governmental organizations and industry with different level of responsibility in their organizations (high, medium, and low), participated either in the living lab or in the open consultation. The implemented methodology therefore successfully enabled the multi-actor and multi-level approach. The participation of industry representatives in the co-creation process was acknowledged, being industry users relevant target groups to drive R&I towards its implementation into practice.

The methodology includes 6 steps of collaborative work, whose core was represented by a living lab (Figure 1), called Food Safety Operational Lab (FSOLab).

Step 1. Setting the multi-actor expert group

A multi-stakeholder group included experts from different backgrounds: Research& Academia, Food Safety Authorities and risk assessors, Food Business Operators, EU policy makers, Consumers associations, Experts participating in relevant European platforms. The multi-stakeholder group was also a multi-level one including representatives from the different levels of the EU FSS from high level experts to PhD students, research fellows and representatives of newborn Food Safety Authorities.

Step 2. Background setting

A core group started from the analysis of the main available Food Safety Strategic documents (period 2021-2023). Outcome if this step was a background document summarizing food safety related R&D directions, topics, needs and/or proposed actions across the main Food Strategic Documents (including EC policies, SRIAs and foresight reports). This document was provided in advance to the living lab participants to ensure proper preparation and a straightforward discussion in the first workshop of the living lab cycle.

Step 3. Living lab Workshop 1: analysis of available strategic documents, identification of the most relevant R&D directions and clustering in core themes

Based on the strategic documents' review the experts were asked to identify, according to their perspective, the most relevant challenges in the food safety domain and associated R&D directions to solve/minimize the effect of the challenge itself.

The discussion within the group resulted in the identification of **7** so called **"core themes"** covering the multiple perspectives of the FS actors' categories represented by the experts and their specific objectives and needs as well as and food environment influences. The seven identified core themes are listed in Figure 2.

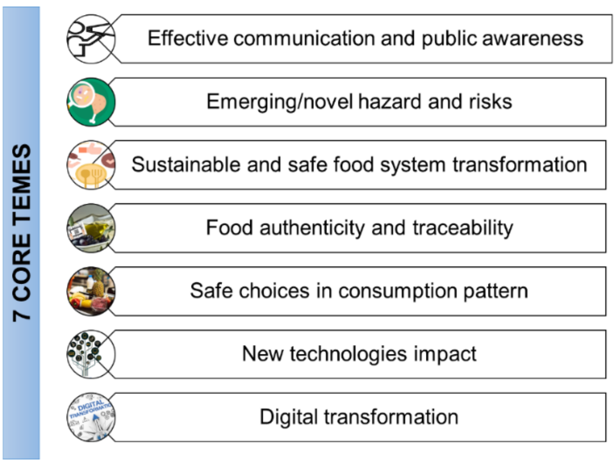

Figure 2. Core themes identified as a result of the strategic documents review

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Then the experts ranked the core themes in terms of importance and uncertainty. The core theme with the higher importance and low uncertainty, namely: **Emerging Food Hazards and Risks was selected for the follow up**.

Step 4. Living Lab Workshop 2. Emerging/novel hazard and risks: challenges and priority list of R&D topics

In the second workshop, focusing on "emerging novel hazards and risks", the group tasks were:

1) Identification, discussion of the challenges

2) Identification of hazards and formulation of relevant actions for the main challenges

This work resulted in **8 main challenges**, each of them unfolded in a list of hazards and proposed action plan/measures (i.e. R&I topics) to be taken in long, medium- or short-term perspective for ensuring the transition towards a more comprehensive Food Safety System in Europe.

Step 5. Open Consultation

A survey to rank the R&I topics in terms of emergency and uncertainty is circulated in high-level expert networks and social networks and to collect input from a wider and diverse audience. Out of over 300 participants, 136 respondents covered all eight challenges, while the others provided partially completed surveys according to their field of expertise.

During the open consultation the respondents were asked to rank the R&I topics taking into account two criteria: emergency and uncertainty.

- **Emergency** as a situation that poses an immediate risk to health or environment. Some emergencies require urgent intervention to prevent a worsening of the situation, although in some situations, mitigation may not be possible, and agencies may only be able to offer palliative care for the aftermath.
- **Uncertainty as** a way of understanding the dynamics shaping the future (Economic shifts, Social changes, Technological progress and Policies). Investigating those four uncertainties, along with R&D uncertainties, is a good way to see our plausible futures in advance of them occurring.

The result was a list of 112 R&I topics linked to the 8 challenges.

Step 6. Living Lab Workshop 3: SRIA Finalization

After reviewing the consultation results, the working group finalized the topics for the SRIA. According to the votes received during consultation, topics were clustered in short-, medium- and long-term impact actions. Interlinkages between the topics were highlighted, as well as expected outcomes were envisaged. Then, the main society needs related to food safety were also discussed and clustered around the short-term action plan R&I topics.

This step also included a **consultation workshop** with representatives from institutional actors from EFSA, EC-JRC, EC DG RTD and DG SANTE, FSA and representatives from EC initiatives (e.g. FoodPathS project - working on the definition of a SRIA supporting Food2030 priorities)

Food Safety System Challenges, related R&I topics

According to the implemented methodology the main result of the co-creation process was a **priority list of R&I topics clustered in 8 challenges relevant to the core theme "Emerging risks and hazards"**. The result was a list of 112 R&I topics linked to the 8 challenges, that were then fine tuned and clustered in short-, medium- and long-term impact actions. For R&I topics prioritized in the short-term action plan, link with the identified societal needs were envisaged.

Table 1 reports the whole overview of challenges, hazards and actions (R&I topics) and their classification as short-term actions (green cells) and medium/long-term actions (orange cells). No short-term actions were identified for challenge 1 - Climate change and food security.

Table 1. Challenges, hazards and R&I topics (actions) identified for the core theme "Emerging risks and hazards", and their classification as short-term actions (green cells) and medium/long-term actions (orange cells). Numbers in the last column indicate the envisaged links with societal needs.

Challenge 1. Climate change and Food security		
Climate change leads to complex associations with a number of food safety hazards, potentially leading to increased risks of foodborne illnesses and affecting access to safe and nutritious food for people. R&I should provide new approaches to understand food systems under climate change and how they can be transformed to ensure food safety and nutritional security for all, while reducing their environmental footprint.		
Hazards	**R&I topics**	**Societal needs**
Loss of biodiversity and degradation of ecosystems	To explore alternatives to conventional pesticides	
Environmental pollutants	To identify and manage sources of contamination during food production or *via* packaging materials	
Pesticides, antimicrobials, harmful nutrients, fertilizers	To standardize, improve and extend surveillance systems on these contaminants	
Environmental contaminants (from soil, water)	To develop and integrate new approach methodologies (NAMs) and omics for regulatory risk assessment	
Gaps in systematic analysis of food contamination, particularly in relation to environmental contamination	To explore the need to include soil microbiomes in risk assessment	
Interactions between food contaminants and the gut microbiota	To improve food safety, hygiene standards, microbiological criteria, and refine risk assessment approaches for food allergies.	
Potential hazards (for human, animals and environment) from alternative proteins: allergenic potential, anti-nutrient' properties, toxic aggregates or excessive number of toxic compounds)	To evaluate nutritional properties and food safety of emerging protein sources, including plant-based, microbial, marine, insect proteins, cultured meat and fish derived from animal stem cells, and synthetic proteins produced from CO2 or other chemical processes.	
	To integrate life-cycle analysis of conventional and alternative protein sources	
	To develop new Product Environmental Footprint (PEF)-based categories and diet assessment frameworks for health impacts	

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Challenge 2. Food Supply chain: traceability and transparency		
Future R&I should support the development and implementation of traceability systems along the food chain exploiting available and new technologies. Digital innovation is expected to play a pivotal role in improving traceability, transparency, and risk communication.		
Hazards	**R&I topics**	**Societal needs**
Inefficient control and monitoring of hazards and associated risks along the food chain	To advance monitoring and hazard assessment methodologies through dynamic control in storage and transport systems	**2**
	To implement digital systems of on-line data collection on agricultural side streams and wastes	**1, 4**
	To develop combinatorial (hurdle) approach to food preservation by combining multiple methods for enhanced safety and quality.	**3**
	To implement a holistic farm-to-table strategy to ensure food safety and quality throughout the entire supply chain	
	To boost biotechnology-based approaches such as Whole Genome Sequencing (*WGS*) DNA and Next Generation Sequencing (*NGS*) to manage outbreaks, or contaminated food products.	**4**
Food fraud	To integrate Blockchain Technology, IoT, other digital technologies	**2**
Citizen trust	To foster co-creation approaches and education to increase citizens' trust in food industry and public services related to food safety.	**2**
	To improve and exploit the existing e-Platforms for engaging with stakeholders at national/regional/local level	**2**
Challenge 3. Integration and improving risk assessment methodologies		
Improved and integrated risk assessment is a pillar for robust food safety regulatory frameworks, including those addressing new and emerging food safety risks. Future R&I should deliver novel methodologies assessing cumulative effects of toxic and biological agents, as well as risk-benefit. Data interoperability is an enabling factor to achieve this goal.		
Hazards	**R&I topics**	**Societal needs**
Data gaps in risk assessment	To integrate cheminformatics and bioinformatic approaches, technologies, and data into next generation risk assessment	
	To elaborate new approaches to systematically collect, analyze, and interpret and re-use data	**5**
	To develop predictive toxicology	**4, 5**
	To develop biomonitoring and biomarker-based approaches	**4, 5**
	To update/improve risk assessment methodologies: e.g., by developing risk assessment of combined exposure to multiple chemicals	
	To collect comprehensive data on micro-ecology throughout the entire food system, including food chain composition, environmental factors, existing quality and safety management practices, and consumer interactions via packaging and mobile technologies	
	Generating and using Big Data to gain new biological insights, such as estimating the Burden of Disease and conducting risk-benefit analyses. To leverage omics technologies through Big Data	

Lak of harmonized risk assessment methodologies	To include evaluation of the health impact of new technologies in risk assessments for priority food hazards	**4**
	Developing guidance for a systematic, tiered approach to rapid risk assessment for emerging and emergency issues, ensuring methods are "fit for purpose."	**6**
Changing landscape of chemical and microbial risk assessment	To advance toxicology and chemical/microbiological safety assessment in humans by integrating scientific progress—such as chemical mixture analysis—and emerging technologies, including Big Data and (Quantitative) Structure-Activity Relationship (QSAR) models used by agencies like the European Chemicals Agency (ECHA).	
	Understanding of microbial ecologies by cutting-edge technologies in the field of "Omics"; detailing functional metabolic networks in their entirety (not only in single species of microorganisms, but in entire communities)	
	To develop risk assessment approaches to address sustainable food systems and One Health approach	
Challenge 4. Rapid technological advancements and emerging technologies		
Fostering use of novel technologies in food production is expected to improve the safety of food systems and empower consumers. However, technological advances are not always aligned among the stakeholders, thus systemically affecting on leveraging the impact of innovation.		
Hazards	**R&I topics**	**Societal needs**
Physical, chemical, biological hazards	To make available improved on-line and at-line technologies for food safety monitoring	**2,3**
Nanotechnologies may bring potential new risks to both human and environmental health	Nanotechnologies in food processing: understanding the mechanisms and food safety issues	
Controversial food additives, such as sodium nitrate or titanium dioxide added in food processing	To evaluate safety of food additives and possible replacement with natural food additives To develop clean label technologies	
Unregulated issues: if not covered by regulation and standards, it may become a risk for food safety	To conduct risk characterization and assessment of unregulated areas, such as indoor cultivation, cellular agriculture, precision fermentation and alternative protein sources. To apply AI - digital twins - sensors - AI technologies to emerging food safey issues	
Challenge 5. Sustainable production/processing		
Developing and assessing new technologies to transform the food system safely towards increased sustainability and circularity is imperative to align with the EC sustainability framework. Innovation in food packaging will be crucial to improve food safety by reducing bacterial contamination, prolonging shelf life, thus ensuring convenience in distribution and handling. Sustainable and circular solutions should be implemented while retaining food quality with high nutritional values for health.		
Hazards	**R&I topics**	**Societal needs**
Shorter self-life obtained by mild technologies/minimal processing	Advancing hurdle technology combining mild preservation methods for gentle while effective preservation of foods, ensuring food safety, e.g., mild heating and cold storage in combination with packaging in low oxygen atmosphere.	
Short shelf life due to mild technologies; processing contaminants from ultra-processing	Mild technologies *vs* ultra processing: evaluating risks and benefits	

New food preservation methods	Evaluating safety of new and emerging substances and technologies	
Contamination of side streams from agrifood sectors, including fisheries, because of unappropriated storage or handling	To unravel and minimize food safety risks occurring during food processing	**1**
Unsafe by-products	To explore food waste recovery through up-cycling/waste cooking	
Transferring of chemicals to food with partly unknown effects.	Developing new multidimensional tools and methods that allow for package optimization considering packaging performance in terms of, e.g., shelf life, protection, thermo-mechanical stability, and processability.	
Food spoilage and food waste	Optimizing shelf-life length while preserving food safety and quality by new packaging systems improving food management	**1,3**
Migration of unwanted substances from packaging material, environmental pollution	To explore new packaging solutions and re-use of packaging materials	**1.3**
Challenge 6. Ethics and One Health. Systemic approach		
Supporting interdisciplinary and trans-disciplinary approach for interconnection between people, animals, plants and the environment		
Hazards	**R&I topics**	**Societal needs**
New and unknown and emerging hazards	To integrate the systemic approach in new and emerging technologies in food production, postharvest treatment, and processing.	**5**
	To make available more sensitive detection methods for investigating and discovering new hazards for humans, animals and the environment	**5**
	To develop integrated approaches for risk/benefit/cost assessment including safety risk, health/nutritional benefits and costs associated with risk prevention/mitigation.	**5**
Impact of human activities on the spread of antimicrobial agents, resistance genes, and multi-drug-resistant bacteria to water (both potable water, and water in the environment), food and soils.	To develop mew management guidelines To develop bio-remediate and bio-restorative interventions (waste management techniques that involve the use of organisms to remove or neutralize antibiotic residues or antibiotic resistance genes from contaminated sites).	
	To determine the quantitative contribution of cross-contamination with antibiotic-resistant bacteria between humans, animals, or in multi-species exchanges via the surrounding environment, including water and the food chain.	
	Understanding how current practices in food production (e.g., in slaughterhouses, but also the use of heavy metals, disinfectants and biocides during food production) could contribute to the selection and spread of AMR.	
	To investigate host factors associated with colonization, persistence, and disease	
	To study the ecology of emerging pathogens	
Challenge 7. Science-based decision-making		
Increased provision of scientific advice supporting the development and implementation of food safety standards, guidelines, and recommendations is advocated. Evidence-based strategies are		

crucial to minimizing the spread of antimicrobial resistance. The Research Responsible Innovation (RRI) approach - the ongoing process of aligning research and innovation to the values, needs and expectations of society – needs to be further integrated for reducing the gap between science and society: R&I activities shall be diverse and inclusive, anticipative and reflective, open and transparent, responsive and adaptive to change.		
Hazards	**R&I topics**	**Societal needs**
Different (not harmonized) approaches and legislative food safety framework	The establishment of global food safety standards	**6**
	To generate input for regulation of Genome Engineering Methods (e.g., cisgenesis, transgenesis, CRISPR-cas9, RNA interference)	
Contamination coming from sewage and sewage treatment	To evaluate the impact of sewage (and sewage treatment) on resistance in the environment, animals, food contamination, and table water	
Foodborne diseases	To develop a comprehensive framework for determining the burden of foodborne diseases	**4,6**
	Identifying measures along the entire food-chain to decrease foodborne health risks	
	A multi-disciplinary understanding of the transmission mechanisms by which antibiotic resistance can spread between bacterial populations and between different (animal and human) reservoirs	
	To develop and implement standardized surveillance systems on antibiotic use and for resistance in humans, animals, foods, and the environment	
	Application of model systems (*in vitro* and *in vivo*) to study host/food – microbe interactions	
Challenge 8. Food safety related issues sharing information and resources		
Future R&I frameworks should foster the integration of social and communication sciences for food safety, enabling the development of innovative models for communicating science-based evidence. Ensuring global food safety implies access to global data and the ability to share data from food monitoring and other sources to better inform the development of preventive control strategies and risk-based approaches to food safety.		
Hazard	**R&I topics**	**Societal needs**
Main food safety consumers' concerns such as 1) residues in food resulting from agrochemicals and synthesis food additives. This is often linked to farming and processing methods; 2) microbiological safety and animal disease-related safety.	To encourage responsiveness to requests for information during international food safety	
	To promote the proactive reporting of food safety incidents incidents through consumers' fast alert, quick, reliable, efficient, cheap methods of analyses and control	**2**
	Improving use of social media for more effective risk communication and identification of incidents	
	To foster information release about the food safety system through commercial media as an educational effect	
	Mentoring (twinning) system for sharing of best intervention practices; Programmes to build transdisciplinary knowledge for scientists (risk assessors) and decision makers (risk managers)	**6**

Short term actions and their impact on societal needs

Based on uncertainty and emergency ranks obtained in the open consultation, a range of actions (R&I topics) among those reported in Table 1, were identified as implementable by researchers and innovators in the near future (green cells), thus representing a **short-term**

action plan (4 years) to be considered in funding programmes and research plans, and other agendas. Then, along the co-creation process (Workshop 3) the main society needs related to food safety were also discussed and clustered around the short-term action plan R&I topics, as summarized in Table 1 (last column).

The identified **societal needs** are:

1. **Reducing food loss and waste** is a priority for increasing resources efficiency and is required by **entire society**.

There are unavoidable side streams along the food chain, which could be recovered and re-introduced into the food systems which are coming with food safety issues related to the logistic flow. Digital systems for on-line data could be a tool for logistic management of agricultural side streams. For reduction/prevention of food waste, smart packaging solutions could come with innovative solutions, minimizing at the same time packaging waste which is an important challenge (e.g., re-using packaging materials for other purposes). Rethinking the "best before" concept to balance shelf-life with food safety and optimizing shelf-life duration while maintaining food quality through new packaging technologies, should become key strategies to reduce both food and packaging waste and enhance resource efficiency.

2. **Increasing food chain transparency** is necessary for **consumers' trust** in food system.

Blockchain Technology and digital solutions are important instruments for assuring food system traceability and transparency. For improved food safety monitoring, on-line and at-line technologies should be more developed and used in combination, while the control storage and transport systems should be more dynamic. Digitalization will also support rapid control systems that work in synergy with consumer fast alerts, offering quick, reliable, efficient, and cost-effective methods of analysis and monitoring. These tools are essential for enhancing public trust in the food system and related services.

3. **The safety of food preservation technologies** is directly linked with nutritional security and is required by **industry**

Better food preservation could be achieved by adopting a combinatorial or hurdle approach, while integrating online and at-line safety monitoring technologies in synergy with the development of new packaging solutions.

4. **A fast reaction to food safety outbreaks** is required by **consumers** and **policy makers**

New innovative technologies for hazards and risk prevention, using Whole Genome Sequencing and innovative predictive and modelling tools should be envisaged for a fast reaction to outbreaks and contaminated food products. A comprehensive framework for determining the burden of foodborne diseases, also based on biomonitoring data, needs to be built up. All of these are in synergy with digital solutions.

5. **Interoperability of data** is required by **policy makers** and **scientists**

New harmonized approaches to systematically collect, analyze, and interpret, re-use and integrate data about contaminants at national/EU level are necessary. Integrated approaches should be also used for risk/benefit/cost assessment. Data collection and interoperability are necessary for designing predictive and modelling tools for assuring food safety along the food chain. Data handling tools for systemic approaches are also needed.

6. **Transdisciplinary and risk assessment and management** are required by the **policy makers** and **scientists**

Programs should be developed to build transdisciplinary knowledge for scientists as risk assessors and for decision makers as risk managers. Guidance from Food Safety Authorities

(FSAs) should be created to enable a systematic approach for rapid risk assessment, aligned with a comprehensive framework to address the burden of foodborne diseases. Additionally, harmonized EU and global food safety standards are essential to establish common language, approaches, and references.

Medium/long term R&I actions

About half of the identified R&I topics were classified as medium/long term actions (orange cells in Table 1) indicating that they are relevant but there is still the need for new knowledge and time to support their implementation. In this section a brief overview of the medium/long term action plan is reported, in relation to each challenge, as elaborated by the experts starting from topics reported in Table 1 (see Table 1 – orange cells)

Climate change and food security.

All identified topics were classified in the **medium-term category**. The effectiveness of the food systems is based on various input factors, e.g., natural resources and social, political, regulatory, and economic boundaries. The population growth, urbanization, social status, and values influence the achieving of the responsibility related to the Food Consumption and Production, integrated into the 12th Sustainable Development Goal (SDG) which is very much related to the 13th SDG, Climate Action. Considering the effect of climate change on the occurring of new threats related to contaminants and sanitary crises, actions in the field of Antimicrobial Resistance, infection prevention and climate change adaptation and mitigation are needed.

Food Supply Chain: Traceability & Transparency.

The implementation of a holistic farm-to-table strategy to ensure food safety and quality throughout the entire supply chain was included in the **medium-term action plan**. Hazards could be transformed into risks if they are not properly identified, monitored and assessed. Improvements related to HACCP quality systems and innovative approaches at the level of entire food chain are needed.

Integration & Improving Risk Assessment Methodologies

Topics included in the **medium-term action plan** include the generation and use of Big Data are essential for gaining new biological insights, such as estimating the burden of disease and conducting risk-benefit analyses. However, this requires appropriate time and effort for the generation of large and complex datasets to be applied in omics technologies, which study life at a large scale through fields like genomics, proteomics, and metabolomics. Applying these cutting-edge omics technologies can deepen our understanding of microbial ecologies by revealing functional metabolic networks within entire communities. These methods provide detailed data on micro-ecology across the whole food system, improving food safety and quality. Risk assessment can be advanced further by incorporating new information from cheminformatics, which combines physical chemistry with computer science, and bioinformatics, which supports managing and fully exploiting large, complex datasets.

For this challenge, as permanent need, the topic "To update/improve risk assessment methodologies" was included in the **long-term action plan**. Over the last years, agri-food systems have been facing a series of already known but also unforeseen risks, coming from hyper-connected world, changing of landscapes and climate change with a higher frequency of extreme events. The topic "To update/improve risk assessment methodologies" should identify the multiple risks and combined exposures to contaminants (e.g., to multiple chemicals) that could occur at the same time in the context of circular economy and food system sustainability. The approach of an effective risk management system at the level of the food chain must consider all the steps of the agri-food chain, the societal challenges, and their effects along the food chain, as well as the knowledge and expertise of food producers/processors and the latest scientific evidence. It can be considered that risk analysis capabilities (knowledge, expertise, methodologies, and data) are the basis for appropriate risk management. The risks, as they can be identified at this moment, are related to: (i) Food environment (climate change and natural risks; quality of the environment; high competition on resources (land, water, energy) and Economic constrains); (ii) Food safety management along the food chain (microbiological and chemical contamination and cross-contamination; food handling; food waste; market practices including food fraud; consumer behaviour).

Rapid Technological Advancement & Emerging Technologies

Topics envisaged for a **medium-term action** plan address the safety aspects of the new technologies in food productions addressing e.g., new ingredients from circular economy. The interactions between food and food contact materials should be envisaged. The application of nanoparticles as additives or sensing materials should be evaluated. Developments of new food additives from natural sources for food preservation in the context of sustainability (e.g., to reduce food waste) are required.

To provide transparency and clarity in what 'handling concepts' (including processing, distribution, home cooking, out of home preparation) are and how they function and what their risks and benefits are along the food chain (including food loss and waste).

AI - digital twins - sensors - AI technologies have shown potential promise for deciding e.g. on the antibiotics used. Using AI-machine learning to do many simple and repeatable tasks could greatly improve research efficiency, allowing researchers to focus on other more complicated scientific problems that now are emerging with the new contaminants and new generations of antimicrobials such as: high-throughput screening methods for safety and activity testing of compound libraries; molecular modelling technologies for testing *in-silico* for activity and safety, development, and testing of biosimilars.

Precision fermentation uses microbial hosts as "cell factories" for producing specific functional ingredients (alternative to animal products-*in vitro* meat-and targeted compounds). This technique needs a harmonized approach to assess its risks. Vertical and indoor farming for controlled farming of e.g., vegetables or microgreens, thus reducing contaminations and resources should be considered.

Clean label technologies using food additives, natural ingredients coming from food technologies and biotechnologies including those from circular economies means highlighting the absence of food additives and instead applying defined microorganisms.

Sustainable Production/Processing

Implementation of sustainable production and processing practices will require, in the **medium term**, advancements in logistics in management of agricultural side streams including, among others: the evaluation of the existing logistics in management of agricultural side streams and develop new, modern and feasible ones (temperature-controlled infrastructures); mapping of warehouses and distribution centers; the use of information technology (IT); the logistics of perishable food products and fresh products-ensuring safety, traceability, appropriate packaging technology, real-time monitoring system; achieving of new functionalities and application markets for agricultural side streams in new value chains. New mobile processing units for in field or closer to consumption applications including delocalizing and re-dimensioning processing technologies, shall support these advancements.

In new cleaning processes biofilms will deserve attention. Ensuring their safety will imply: the study of biofilm formation and removal; sanitary equipment design; new methodologies and technologies (plasma treatments, ultrasound, light-based technologies, pulsed electric fields and high hydrostatic pressures etc.) for biofilm prevention and removal; clean-in-place (CIP) methods.

The effective introduction of new alternative food matrices (healthier alternative to food that is prepared or produced by conventional methods) will call for both new analytical methods and as well as updated regulatory framework for assessing them.

In the future the EU FS system will need to cope with novelties on hurdle technology combining mild preservation methods for effective food safety preservation (e.g., mild heating and cold storage in combination with packaging in low oxygen atmosphere). Many of today's preservation methods came into use thousands of years ago (i.e., drying, salting, boiling etc.); they are still in use, but there are also new approaches being adopted. Temperature preservation (sterilization, pasteurization, cold storage, deep freezing), modified atmosphere packaging (MAP), high pressure technology and combination of several mild preservation methods can be used instead of a single high-impact method. Other new technologies, such as: Pulsed electric fields (PEF), Ultraviolet Light (UVC), Cold plasma, Plasma-activated water (PAW) etc. can be used to improve the quality of the food, while helping to meet the demand for sustainable, healthy, and affordable food products.

Development of new multidimensional tools and methods will allow for package optimization considering packaging performance in terms of, e.g., shelf life, protection, thermo-mechanical stability, processability; new analytical methods to analyze migration contaminants in packaging materials and food.

In relation to the potential of re-introducing food waste in food system, consumer acceptance studies will be needed in the **medium-term**.

New transformation of food system in terms of sustainability while the nutritional security is assured was seen as an achievement for a **long-term action plan**: food system shall be considered in the context of rapid population growth, urbanization, growing wealth, changing consumption patterns, and globalization as well as climate change and the depletion of natural resources.

Ethics and One Health Systemic Approach

The topics identified for the **medium-** and **long-term action plans** showed that multidisciplinary approaches have crucial importance in implementing One Health. These could be clustered into 4 groups:

Cross-sector cooperation among animal health, public health, food safety, and environmental sectors is essential for addressing zoonoses and antimicrobial resistance. Strengthening this collaboration helps prevent spill-overs from animals, food, and the environment to humans. It also means advancing One Health advocacy by building and strengthening awareness of the One Health approach among citizens, scientists, risk managers, and policymakers, focusing on social research and mitigation strategies, their impacts, and policy options.

A systemic approach to preventing contamination requires better understanding of cross-contamination's role in spreading antibiotic-resistant bacteria, including how environmental factors influence antimicrobial resistance and the human health risks from antibiotic residues in the environment. Future research shall also cover how current food-production practices (e.g., in slaughterhouses, plus the use of heavy metals, disinfectants, and biocides) contribute to selecting and spreading AMR, and a multidisciplinary view of the transmission mechanisms between bacterial populations. Additionally, it should identify environmental factors that enable the emergence, development, and spread of emerging pathogens along the food chain, along with factors linked to pathogen colonization, persistence, and disease. Finally, it must consider how environmental hosts and specific conditions (temperature, pH, humidity, pressure, etc.) relate to colonization, persistence, and disease.

The process of bioaccumulation and biomagnification of contaminants in plant and animal tissues should be better understood. Bioaccumulation is defined as the accumulation of chemicals in the tissue of organisms through any route, including respiration, ingestions, or direct contact with contaminated water, sediment, and pore water in the sediment. Biomagnification is a result of the process of bioaccumulation and bio-transfer by which tissue concentrations of chemicals in organisms at one trophic level exceed tissue concentrations in organisms at the next trophic level in a food chain.

Hazards, risks, and sustainability. Systemic approach and sustainability should be considered by the Risk Assessment methodologies. Sustainability should be approched by mapping food bioresources and study the balance between existing of food bioresources and human nutritional security ensuring and, in this respect, promoting biotechnology in recovering food waste and producing proteins and other food ingredients. But, assessment of ethical issues (e.g., using insects in human food) is needed as well as assessing and identifying the emerging hazards/ risks related to new and emerging technologies along the food chain using*iIn silico* and *in vitro* methods applied for sustainable safe food systems (with the ensure of some key principles: transparency, fairness of data usage, data privacy, IPR etc.). Systemic studies on synergies and antagonisms between combination of new technologies and related hazard/risks is also required.

Hazards, risks, and sustainability should guide Risk Assessment methodologies. Sustainability should be advanced by mapping food bioresources and balancing their availability with human nutritional security, including promoting biotechnology to recover food waste and produce proteins and other ingredients. Ethical issues (e.g., insects in human food) must be considered, along with emerging hazards/risks from new technologies along the food chain. *In silico* and *in vitro* methods should be used to support sustainable, safe food systems, upholding transparency, fair data use, data privacy, and IPR. Systemic studies should also explore synergies and antagonisms among new technologies and their associated hazards/risks.

Harmonized methodologies are needed, along with new guidelines to prevent and minimize food waste. The development of bioremediation and bio-restoration strategies, such as using organisms to remove or neutralize antibiotic residues or antibiotic resistance genes from contaminated sites, should be explored.

From a socio-economic perspective, there will be the need to evaluate the impact of science-based standards on policy, production, pricing, and product availability. This should be paired with rapid-response research and communication tools for all actors along the food chain, including agriculture and online distribution, and with improved traceability platforms and alert systems across both agricultural and online channels.

For the **long-term action plan**, the prioritized action was "to implement biomarker-based approaches in risk assessment" for a better understanding the interindividual variability in susceptibility, including exosomes. Integrating diverse data and having a holistically perspective will increase the prevention capacity against foodborne illness while making linkages between the health of humans, animals, plants, and their shared environment.

Science-based Decision Making

The topics elaborated for **medium term action** plans could be grouped in 2 categories.

Harmonization. Provide scientific evidence to set regulatory bases for Genome Engineering Methods (cisgenesis, transgenesis, CRISPR, RNA interference) to ensure their responsible and ethical use. These tools have transformed genetic engineering with broad potential in medicine, agriculture, and biotech, while ongoing regulation aims to ensure responsible and ethical use.

In the same view, developing standardized surveillance for antibiotic use and resistance across humans, animals, foods, and the environment will ensure data comparability and enable effective interventions. This shall include harmonized procedures to monitor emergence and spread of resistance.

Methodologies and tools to support international alignment of policy advice and the consistent implementation of sustainability regulations are needed. This entails analyzing existing regulations and enforcement, identifying national gaps, and proposing strategies for alignment.

Food system approach. The food systems transformation calls for developing and strengthening transdisciplinary expertise among next-generation scientists, risk assessors/managers, and policymakers to effectively implement One Health and other systemic, integrative approaches.

Food systems studies should map the connections and interdependencies across the entire system to: assess efficiency, quantify externalities, understand behaviors, track the evolution of food systems, and evaluate the consequences of changes. This interdisciplinary framework will support research and policy for sustainable, healthy food supply, emphasizing the comprehension of advantages and limitations of food systems analysis versus single-chain views, highlighting relationships among system components and the socio-economic and environmental outcomes of production and consumption. Feedback loops between production, processing, distribution, and consumption, as well as their socio-economic and environmental effects (e.g., food security, soil depletion), will support decisions within the system.

Food Safety Related Issues and Information and Resources

The elaborated topics for the medium-term action plan were as follows.

Improving food-safety incident management through proactive reporting, responsive information requests, and interoperable social media platforms can enhance transparency in systems like RASFF. Leveraging social media and traditional media for risk communication to help counter misinformation and fake news, which threaten society. Research should explore ways to encourage reporting of misinformation and support platform providers, with social norms as a potential remedy.

Crisis decision interfaces can be accelerated using advanced data gathering, synthesis, and analysis with AI, machine learning, and other next-gen computational tools to support foresight and prepared action. Strengthening multi-stakeholder collaboration and harmonizing reporting systems and databases is essential.

Smart tagging and packaging should be fostered to improve traceability and authenticity, enabling sharing of best practices and boosting consumer trust. Intelligent packaging can also serve as a marketing tool, while ensuring proper use at home.

Understanding social and psychological factors behind risk perception and decision-making allows risk communicators to tailor messages for different audiences. Coupled with effective training and lifelong learning programs for consumers, this research will play a crucial role in empowering individuals to make informed decisions, adapt to a rapidly changing world, and enhance their overall quality of life.

Conclusions and the way forward

The prioritized topics show food safety as cross-cutting issue across the major EU Food System challenges. Addressing these R&I needs is expected to contribute to a **future-proof EU food safety system** and to make EU food market safer and healthier. The multi-actor expert group participating in the co-reation exercise, envisaged for the FoodSafety4EU proposal for SRIA the following main contributions.

Enhancing the multidisciplinary approach *by fostering:*

Understanding climate related-risks. Understanding how climate change affects food-system safety and its key value-adding activities will reveal the complex interactions and generate new knowledge. This involves building models from large datasets and applying artificial intelligence, using a multi-disciplinary approach that draws on climate science, toxicology, epidemiology, data science, and policy. This work aligns with European priorities, including the Green Deal, Farm to Fork, and the 2030 Agenda for Sustainable Development Goals, as well as EU climate targets for 2030 and 2050.

One Health concept, taking on board human, animal, and environmental health sciences. This requires both multidisciplinary and transdisciplinary approaches. Given the complexity of the food system, embracing One Health calls for broad collaborative efforts across disciplines. requires multidisciplinary and transdisciplinary approaches.

Transdisciplinary Knowledge and Collaboration. Designing and implementing programmes to build transdisciplinary knowledge for scientists, risk assessors, and decision-makers will promote collaboration and a comprehensive understanding of risks. This will facilitates effective risk assessment, management, and decision-making embedding multiple perspectives and expertises.

Integrated and Systemic Thinking. Building and improving transdisciplinary expertise and promoting an understanding of the advantages and limitations of food systems analysis encourage integrated and systems thinking. This approach considers the interconnectedness and interdependencies of various factors within the food system, including production, processing, distribution, and consumption. It will lead to holistic decision-making, identifying opportunities for innovation, optimizing resource allocation, and addressing sustainability challenges in a comprehensive manner.

Implementation of co-creation participative process

All prioritized topics require the involvement of all food system stakeholders to address the identified systemic challenges. Foresight methodologies, monitoring and modelling existing data for anticipating the new or re-emerging hazards and risks, will have a major importance in mitigation and adaptation next future measures.

Through smart cooperation and collaboration, finding the complementarities and synergies between them, food system stakeholders will be driven to design tools for efficient strategies and action plans.

Promoting cooperation between different stakeholders and harmonizing reporting systems and databases will foster a more coordinated approach to food safety, facilitating data sharing, collaboration, and the development of consistent standards.

At the end of the agrifood chain, consumers are the most important stakeholders who should be encouraged to be engaged within the R&I process. That's why training and education initiatives for consumers, emphasizing the concept of lifelong learning, will empower individuals to make informed choices regarding food safety. By providing accessible and relevant information, consumers will become more knowledgeable about risks, prevention measures, and safe food handling practices.

Fostering R&I advances in developing integrated new approach validated and standardized for risk assessment methodologies

The proposed R&I topics are expected to contribute to the development and implementation of integrated approaches for detecting, assessing, and mitigating food safety risks influenced by climate change. Future work will identify new resources to ensure food and nutritional security while evaluating their sustainability and associated risks. Key areas to assess include: food contact materials, additives, enzymes, flavourings, and smoke flavourings; GMO considerations in food and feed; nutrition topics such as novel and traditional foods, health claims, infant formula, allergens, and nutrient sources; biological hazards and decontamination substances; and feed additives with predictive toxicology. The proposed action plan is also meant to expand human biomonitoring through analysis of urine, blood, and saliva; implement biomarker-based risk assessment to understand interindividual variability, including exosomes; and advance toxicology and chemical safety assessment for chemical mixtures, leveraging big data and initiatives like the European Chemicals Agency to enhance monitoring.

Collectively, these topics will advance toxicology and chemical risk assessment in the context of a changing climate.

Integrating social science research for effective risk communication

The proposed agenda foresees utilizing social science research as the basis for risk communication strategies to enhance their effectiveness. Understanding public perceptions, attitudes, and behaviors enables the development of targeted and tailored communication approaches that resonate with different audiences, increasing the likelihood that risk messages are understood and followed.

Effective risk communication will continue to be a crucial part of risk analysis. Leveraging social and commercial media platforms for risk communication enhances the dissemination of accurate and timely information to the public. By identifying and addressing fake news, misinformation, and rumors, public trust is maintained, and the understanding of incidents and appropriate actions is improved.

Encouraging responsiveness to requests for information and promoting proactive reporting of food safety incidents will improve the speed and efficiency of responses, enabling swift identification, containment, and mitigation of risks, thus protecting public health and minimizing incident impact. This will enhance risk communication by inuding timely and proactive responses to food safety incidents.

Increasing food supply chain visibility

Transparency and traceability are essential for supply chain visibility in a globalized economy. They enable prompt communication with stakeholders and allow mapping of every supply-chain tier using data from multiple sources. Moreover, consumers increasingly demand

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transparency about who makes products, where they come from, and the technologies used (e.g., conventional, organic, low-input, sustainable), with particular focus on the quality of raw materials and inputs.

By addressing facilitating data interoperability, the proposed actions will contribute to strengthen traceability and transparency across the food system, improving certification processes, reducing food fraud, and supporting policy and regulation, including tracking of food products and pesticide use. Data interoperability will help assess food safety's impact on wellbeing and environmental health, contributing to new policy frameworks.

Beyond visibility, the new technologies will generate real-time, distributed data across the food chain in multiple formats. The growing data flow enables interoperability among diverse information systems, data integration from multiple sources, and automated processing with artificial intelligence.

Voluntary certification schemes (e.g., designation of origin PDO, geographical indications PGI, and traditional specialty guaranteed TSG) relying on data from the specific food chain for control, evaluation, and certification are expected to be increasingly adopted.

Facilitation of food system transformation

Food systems should be more resilient, sustainable, and capable of delivering safe and nutritious food for a growing population amid climate change and finite resources. The new technological developments, promoted by the proposed SRIA, will support meeting the following urgent requirements:

- advanced food system sustainability through innovative packaging solutions (e.g., recyclable paper bottles for liquids and alternatives to traditional metal caps) and other eco-friendly design approaches.

- improved resource efficiency by using side streams from existing food products and enhanced coordination along: collection, transportation, agro-waste logistics, processing, safety analysis, and assessing consumer acceptance.

The proposed SRIA will support the triple goals of sustainability, nutritional security, and food safety.

Improving Public Health

The comprehensive burden framework, along with standardized surveillance systems on antibiotic use and resistance, will allow for a better understanding of the burden of foodborne diseases and the spread of antibiotic resistance. The knowledge generated through the implementation of the prioritized R&I actions will lead to targeted interventions, improved risk management, and the development of effective public health strategies to mitigate foodborne diseases and combat antibiotic resistance.

The concept of systemic thinking and integration and risk-based food safety management system are expected to drive the development of novel solutions helping public health policy.

Contribution to the improvement of food safety controls

The SRIA action plan will boost the development of rapid methods to support food monitoring, thus adding value and guaranteeing a more agile control of food safety and quality. Implementation and use these rapid methods along the control points in food industries and development of skills such as "Problem Solving" and "Critical Thinking" will faster decision-making. Sustainability considerations are also embedded, since the use of these methodologies may reduce not only the time of analysis and loss of products, but also the chemicals required to perform the contaminants analysis

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The implementation of fast, reliable, efficient, and cost-effective methods of analyses and control for consumers will lead to enhanced safety and consumers protection, enabling them to make informed decisions regarding food choices and consumption.

The establishment of EU/global food safety standards, coupled with a comprehensive burden framework and regulation of genome engineering methods, ensures higher levels of consumer safety by minimizing the risk of foodborne diseases and ensuring the safety of genetically engineered food products. By providing input for the regulation of genome engineering methods, the SRIA focuses on responsible and ethical use of these technologies. This shall ensure that genetically engineered food products meet safety standards and ethical considerations, fostering consumer trust and promoting the sustainable development of the food industry.

Contribution to digitalization of food safety management

The proposed research topics are positioned to accelerate the digitalization of food safety management by advancing predictive and modeling tools, harmonizing data collection and analysis, and providing rapid risk-assessment guidance. In predictive and modeling work, developments in toxicology testing, toxicokinetics, and toxicodynamics—such as physiologically based pharmacokinetic modeling and quantitative in vitro to in vivo extrapolation—will yield more efficient, human-relevant risk assessments and reduce reliance on animal testing. Integrating artificial intelligence into assessments, along with organ-on-a-chip and in silico toxicology, enables scalable, data-driven decision support across the food system. Next-generation risk assessment and first-in-human pharmacokinetic prediction approaches will inform safer product development and faster market decisions.

New harmonized approaches for data collection, analysis, and integration at national and EU levels will enhance transparency and interoperability. This includes methodologies for assessing exposure to chemical mixtures (including biological and physical stressors), improving interagency and cross-border cooperation, and developing guidance for aggregate and probabilistic exposure assessments. Non-target chemical analysis and broad screening of chemical mixtures will support proactive hazard identification and characterization, while methods to account for deviations from dose addition—through biologically based and statistical models—will improve accuracy in mixture risk assessments.

Evidence-Based Decision Making

The combination of all these initiatives will promotes evidence-based decision making across the food system. By integrating scientific research, data analysis, and rigorous risk assessments, decision-makers can make informed choices grounded in evidence to ensure food safety, sustainable practices, and public health outcomes.

Supporting the international harmonization of policy advises related to sustainability of food systems will foster global collaboration and cooperation. It will promote the sharing of best practices, the exchange of information, and the alignment of policies and regulations, resulting in more efficient and effective approaches to food safety, sustainable agriculture, and environmental preservation.

Smart Packaging for Information Sharing and Trust

Implementing smart packaging technologies, such as smart-tags and other traceability tools, enhances information sharing and ensures product authenticity. The proposed actions will improve trust and transparency in the supply chain, enabling consumers to make informed decisions, while strategies to promote proper use of packaging at home will contribute to reducing food safety risks.

Accelerated Scientific Advice and Crisis Management

Integrating computational tools and artificial intelligence (AI) in the interface between scientific advice and crisis management enables faster information gathering, synthesis, and analysis. This action plan will facilitate evidence-based decision-making during food safety incidents, leading to more efficient crisis management, resource allocation, and response strategies.