Food and Agriculture
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Early warning tools and systems for emerging issues in food safety

Technical background

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Abbreviations

AI	artificial intelligence
ASEM	Asia–Europe meeting
ASEAN	Association of Southeast Asian Nations
ARASFF	ASEAN Rapid Alert System for Food and Feed
BFR	Bundesinstitut fur Risikobewertung
BN	Bayesian network
CBRN	chemical, biological, radiological and nuclear
EC	European Commission
EFSA	European Food Safety Authority
EWARSs	early warning and response systems
ERKEP	emerging risk knowledge exchange platform
FAIR	findability, accessibility, interoperability and reusability
FAO	Food and Agriculture Organization of the United Nations
FDA	US Food and Drug Administration
FFN	Food Fraud Network (hosted by the EU)
GCC	Gulf Cooperation Council
GRASFF	GCC Rapid Alert System for Food and Feed
INFOSAN	FAO/WHO International Food Safety Authorities Network
IoT	internet of things
IT	information technology
JRC	Joint Research Centre
LMICs	low- and middle-income countries
MedISys	Medical Information System

MedISys-FF	Medical Information System for food fraud
ML	machine learning
NN	neural network
PMM-Lab	Predictive Microbial Modelling Lab
RFID	radio frequency identification
RASFF	Rapid Alert System for Food and Feed of the European Commission
RCA	root cause analysis
SELAMAT	safety enhancement of edible products, legislation, analysis and management, with ASEM countries, by mutual training and research
SGDs	Sustainable Development Goals
UN	United Nations
WFSR	Wageningen Food Safety Research
WHO	World Health Organization

Summary

The United Nations 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) rank highly on policy agendas, where the importance of attaining food security is acknowledged as an enabler for achieving many SDGs. Food safety is an integral and vulnerable component of food security. The globalization of food supply and the implementation of new technologies and other dynamic changes in agrifood systems, together with factors such as climate change and dietary shifts, necessitate greater attention to food safety hazards, which can enter the food chain at any stage.

Early warning systems play a critical role in reducing the potential risks from various hazards. The capability and capacity to identify early signals and emerging food safety risks, and to provide timely warnings allowing for the implementation of mitigation measures, has become vital for national and international authorities and organizations dealing with food safety. Recent developments in early warning reflect a shift away from reactive towards proactive systems, with the latter focusing mainly on predicting food safety risks that may emerge in the (near) future, while the former focus solely on existing food safety incidents. Modern warning systems fed by numerous, real-time and diverse data, and enhanced by advancements in artificial intelligence (AI) and machine learning (ML) techniques, are capable of food safety early warning and analysis. It is therefore important to increase awareness of these evidence-based innovative digital tools and to provide background information that will support their use for food safety early warning.

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This technical background report has four main objectives:

- Enhance awareness and understanding of early warning tools and systems for emerging issues in food safety.
- Promote exploration of the application of Big Data and AI in food safety early warning systems and emerging risk identification processes.
- Provide an overview of available food safety early warning tools and consider prospects and innovative solutions for addressing gaps to their implementation in low- and middle-income countries (LMICs).
- Offer practical examples of open access tools to support food safety early warning and identification of emerging issues.

Different methods and systems can be used for the timely prediction and identification of hazards in food and associated risks to human health. These include early warning and response systems (EWARSs) and foresight. Such methods and systems may differ in terms of the time horizon at which they operate – present, near or far future – and whether their focus is on a particular hazard (e.g. a disease-causing bacteria) or the effects on health following exposure (e.g. acute or chronic foodborne diseases).

Substantial progress has been made with Big Data and AI applications in food safety early warning and emerging risk identification. This report discusses these advances and provides case studies of biosensor, Internet of things (IoT) and Blockchain technologies. Machine learning techniques (i.e. Bayesian and neural networks) are also explained with applicative examples. In addition, a section is dedicated to gaps and barriers to the uptake of tools for food safety early warning and emerging risk identification, summarizing identified gaps in the literature and drawing on a survey and workshops. It also addresses technical and socioeconomic challenges to the development and uptake of these tools. The report also explores prospects and innovative solutions that can contribute to closing the gaps, while emphasizing the need to pay attention to ethical and policy challenges (e.g. privacy and surveillance, bias and discrimination, trust and intellectual property rights) in the implementation of AI.

The report highlights and presents a range of tools and methods for food safety early warning and emerging risk identification, and provides detailed practical information for professionals on three open access tools – MedISys, MedISys-FF and SGS DIGICOMPLY – covering their functionalities and usage. The aim of this approach is to provide background information that may be helpful for authorities in LMICs. Nevertheless, care should be taken when interpreting such information prior to making managerial decisions, as these tools are limited in the data they currently collect from LMICs.

Conclusions

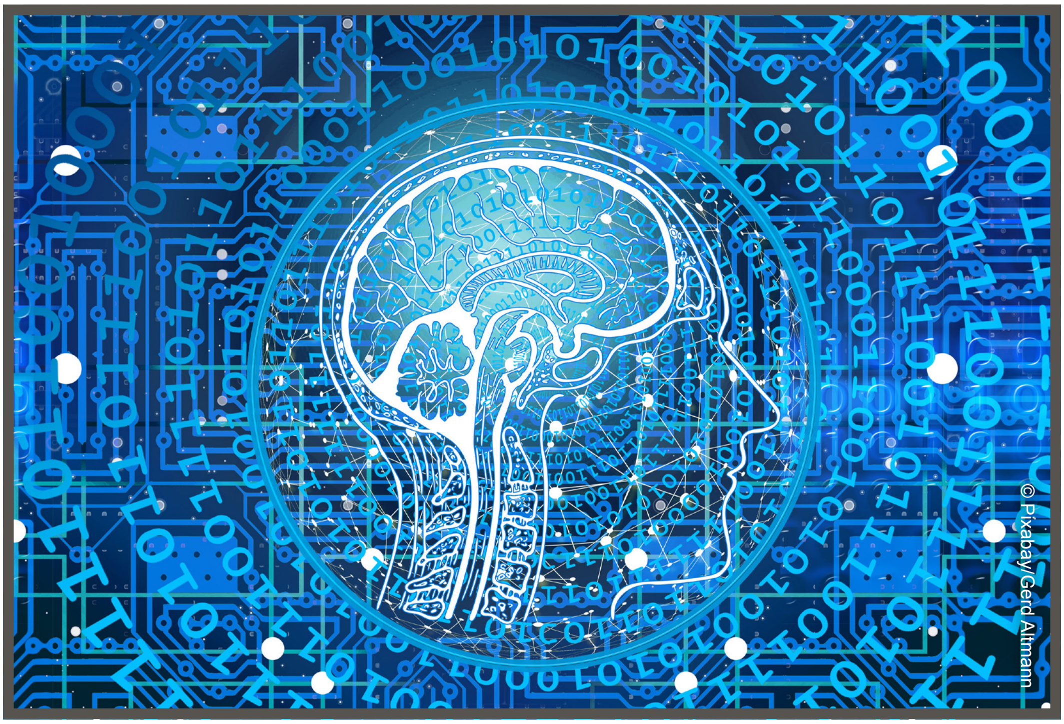
- Sufficient amount of real-time evidence, data and food chain intelligence from production through post-consumption are fundamental for **early warning systems, and** for **detection** and **understanding** of **emerging issues** in **food safety.**

- Awareness of the importance for effective collection and consolidation of **Big Data** to apply **artificial intelligence** for food safety early warning systems and emerging risk identification needs to be promoted.

- Identification of **early emerging signals of food safety risk** in food and feed for early warning purposes is considered as **important**, but not always prioritized, so **awareness needs to be further enhanced** in tandem with **capabilities for early warning digital tools application.**

- **Prospects and innovative solutions** for addressing **gaps** in the implementation of **early warning tools** in low- and middle-income countries need to be prioritized.

- Awareness and hands-on training **on open-access tools** to support **food safety early warning** and identification of **emerging issues** could support their wider uptake and use.



Glossary

Artificial intelligence (AI)
Artificial intelligence is the theory and development of computer systems to enable them to carry out tasks commonly associated with human intelligence. AI includes specific fields such as machine learning, perception, robotics and natural language processing. Computer vision and deep learning can be used to support visual perception (HLPE, 2022).

Blockchain
Blockchain is a decentralized, distributed ledger where the data units are broken up into shared blocks that are chained together with unique identifiers in the form of cryptographic hashes (HLPE, 2022).

Big Data
High-volume, high-velocity, high-variety and/or high-veracity information assets that demand cost-effective, innovative forms of information processing for enhanced insight, decision-making and process automation (Gartner, 2023; HLPE, 2022).

Bayesian networks
A Bayesian network, Bayes network, belief network, Bayes(ian) model or probabilistic directed acyclic graphical model is a probabilistic graphical model (a type of statistical model) that represents a set of variables and their conditional dependencies via a directed acyclic graph (DAG). For example, a Bayesian network could represent the probabilistic relationships between diseases and symptoms. Given symptoms, the network can be used to compute the probabilities of the presence of various diseases (Marvin *et al.*, 2019).

Crowdsourcing
Crowdsourcing is the practice of engaging a group of people (i.e. a "crowd"), usually via the internet, to assist in collecting information, ideas, opinions or other resource for a common goal, such as problem solving, innovation, etc. (HLPE, 2022).

Early warning signals
Early warning signals consist of initial information suggesting that a potential ongoing or emerging food safety hazard or threat is occurring or could occur. Signals can be generated by traditional food safety surveillance systems (e.g. food inspection, laboratory surveillance)

or less traditional food safety intelligence (e.g. foresight). Early warning signals may be difficult to detect and analyse, and care must be taken to avoid spurious information (e.g. not indicative of a true food safety threat or adverse event) (FAO, 2015).

Early warning system

In the context of food safety, early warning systems include various tools, technologies, processes, and resources used to monitor, detect, and verify early warning signals, analyse data and information arising from such signals, and disseminate and communicate alerts to stakeholders at appropriate levels for the purpose of informing risk management actions and decision-making (FAO, 2015).

Emerging risks

An emerging risk to human, animal and/or plant health is understood as a risk resulting from a newly identified hazard to which a significant exposure may occur or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard (EFSA, 2007).

Foresight

Foresight is the activity of looking forward to gain insight about what may happen in the future. This insight is often integrated into planning and risk management (FAO, 2014a).

Horizon scanning

Horizon scanning is a foresight method that acquires information about broad signals or trends via direct (e.g. research) or indirect (e.g. opinion) means to provide decision-makers with a view of future conditions that may challenge the established assumptions and beliefs, which form the basis of current decisions and processes (FAO, 2014a).

Information technology (IT)

Information technology (IT) is the use of computers to create, process, store, retrieve and exchange all kinds of data and information.

Internet of Things

The Internet of Things (IoT) is a network of physical objects that have sensors, software and other technologies to connect and exchange data with other devices and systems over the internet. IoT is often used together with other technologies such as machine learning, analytics, computer vision and robotics (HLPE, 2022).

Machine learning (ML)

Machine learning deals with the study, design and development of algorithms that give computers the capability to learn without being explicitly programmed. These techniques are particularly suitable in the field of risk assessment to extract knowledge and identify patterns in situations where large collections of data or large, multidimensional and heterogeneous datasets are available and/or no recommended mathematical approach exists (IZSTO *et al.*, 2017).

Neural networks

Neural networks, also known as artificial neural networks (ANNs) or simulated neural networks (SNNs), are a subset of machine learning and are at the heart of deep learning algorithms. Their name and structure are inspired by the human brain, mimicking the way that biological neurons signal to one another (IBM, 2020).

Rapid alert systems

Rapid alert systems are mechanisms for reporting on issues with food, feed and non-food consumer products. They allow for speedy detection of problems within the region, which then provide the appropriate authorities with the means to act in time to minimize any risk to consumers.

Remote sensing

Remote sensing encompasses all the techniques related to the analysis and use of data from environmental and earth resources satellites (e.g. Meteosat, NOAA-AVHRR, Landsat TM, SPOT and ERS-SAR) and from aerial photographs. The main objective of remote sensing is to map and monitor the Earth's resources. Compared with traditional survey techniques, satellite remote sensing is accurate, fast and cost-effective.

Sensors

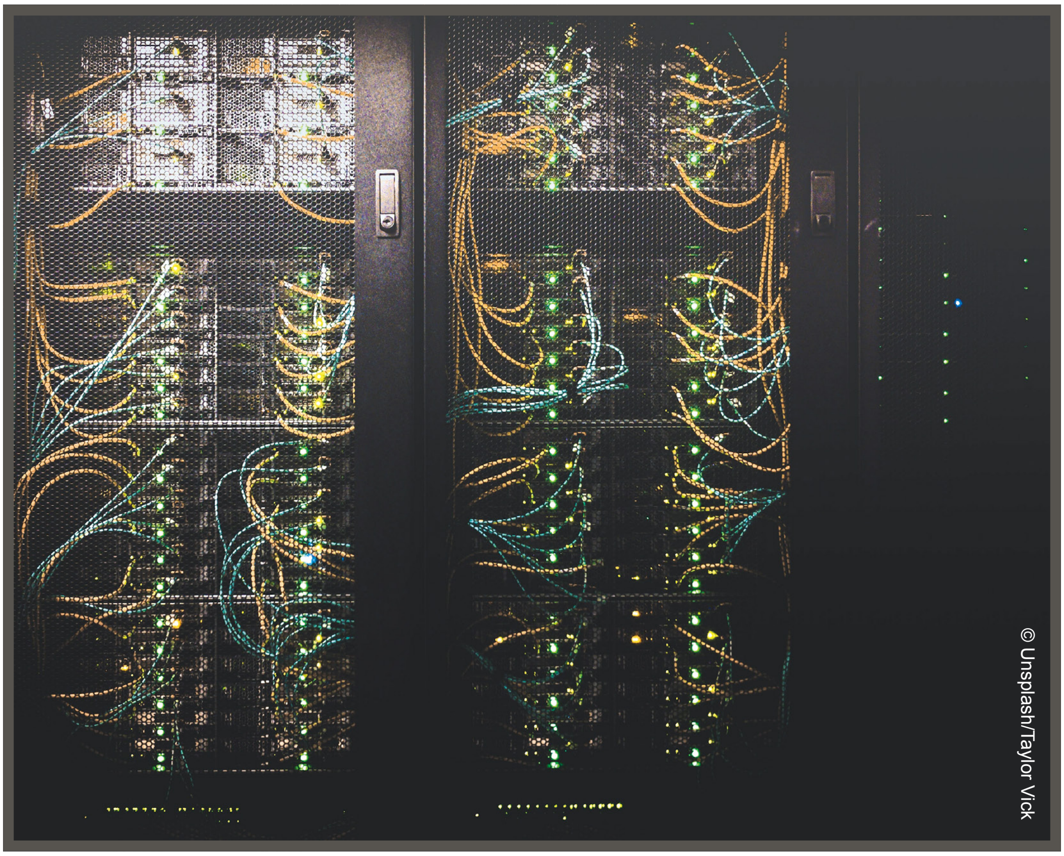
A sensor is a device that measures a physical or chemical feature. Sensors include but are not limited to: standard sensors (e.g. for soil moisture or for tracking animals), weather stations and remote sensing (e.g. via satellite technology). Digital images or video (RGB or hyperspectral) are increasingly used to capture reality. These sensors can be fixed or mobile (on tractors, robots, drones, etc.). The development of nano-computers (e.g. Raspberry) and microcontrollers (e.g. Arduino) has facilitated and popularized the use of these sensors, making them accessible to a wide population. Sensors are commonly used in IoT applications (HLPE, 2022).

Text mining

Text mining is the process of automatically extracting information from different written resources. Its paradigm involves lexical analysis to study word frequency distributions, pattern recognition, tagging/annotation, sentiment analysis, information extraction, data-mining techniques (including link and association analysis), visualization and predictive analytics. The overarching goal is to turn text into data for analysis, via the application of natural language processing (NLP) (FAO, 2020).

Web scraping

Web scraping is a data acquisition method, whereby a custom-developed computer program is initially used to read the code of a website page, usually written in HTML, and then decodes it in order to extract the required data (Skoulikaris and Krestenitis, 2020).



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Chapter 1
Introduction

1.1 Background

The United Nations (UN) 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SGDs) rank highly on policy agenda, where the importance of achieving food security is acknowledged as an enabler for achieving many SDGs. Food safety is a prerequisite, an integral part and contributing factor to food security that needs consistent emphasis, investment and updated capacity development. FAO has set strategic priorities for food safety for the period 2022–2031 that include continuous work on raising awareness of the strong linkages between food safety, food security and adequate nutrition, as well as on the unfavourable consequences of unsafe food for people, economies and environment. Without food safety, there can be no food security (FAO, 2023). The provision of safe food is an important objective for all food supply chain actors including governments, food safety authorities, food businesses at all scales, scientific experts and consumers.

The globalization of food supply and the utilization of new food technologies have shaped an increasingly complex food sector. Factors such as climate change and dietary shifts have compounded this complexity and made the food system more vulnerable to food safety hazards that can enter the food chain at any stage (FAO, 2022a). Early warning systems play a critical role in reducing the potential risks from various hazards. The capability and capacity to provide timely warnings, allowing for the implementation of mitigation measures, has become vital for national and international authorities and organizations dealing with food safety (FAO, 2022a). Recent developments in early warning systems reflect a shift away from reactive towards proactive systems, with the latter focusing mainly on predicting food safety risks that may emerge in the (near) future, while the former focus solely on responding to and managing food safety risks once they have occurred, with the aim of preventing further spread or the recurrence of related hazards (Marvin and Kleter, 2014). The FAO/WHO International Food Safety Authorities Network (INFOSAN) has also emphasized the need for a proactive approach to emerging risk identification (WHO and FAO, 2019).

In 2015, an FAO training handbook on enhancing early warning capabilities and capacities for food safety emphasized the importance of establishing linkages between early warning systems and existing infrastructure elements of national agrifood production and food control systems. The handbook also underlined the importance of continued collaboration, coordination and communication between multiple sectors and stakeholders (FAO, 2015). In addition, the handbook presented the fundamentals of early warning systems and laid out the key components of an effective and efficient national early warning system for food safety, offering practical tools and approaches for improving early warning capability and capacity. However, the rapid development of modern systems fed by real-time and diverse data, as well as advancements in AI and machine learning (ML) techniques, have resulted in the advent of tested and validated digital methods and models for food safety early warning and analysis. It is therefore important to increase awareness of these evidence-based innovative digital tools and to provide technical background information to support their wider and consistent use for food safety early warning.

The theme of this technical background report refers to three accelerators under the FAO Strategic Framework 2022–2031 (FAO, 2021), namely: data, technology and innovation. It is relevant for the Priority Programme Areas (PPAs) "Safe food for everyone", "Transparent markets and trade" and "One Health", and supports the implementation of the FAO Strategic Priorities for Food Safety 2022–2031 (FAO, 2023).

1.2 Objectives

This technical background report has four main objectives:

- Enhance awareness and understanding of the early warning tools and systems for emerging issues in food safety.
- Promote exploration of the application of Big Data and AI in food safety early warning systems and emerging risk identification processes.
- Provide an overview of available food safety early warning tools and consider prospects and innovative solutions for addressing gaps to their implementation in low- and middle-income countries (LMICs).
- Offer practical examples of open access tools to support food safety early warning and identification of emerging issues.

1.3 Target audience

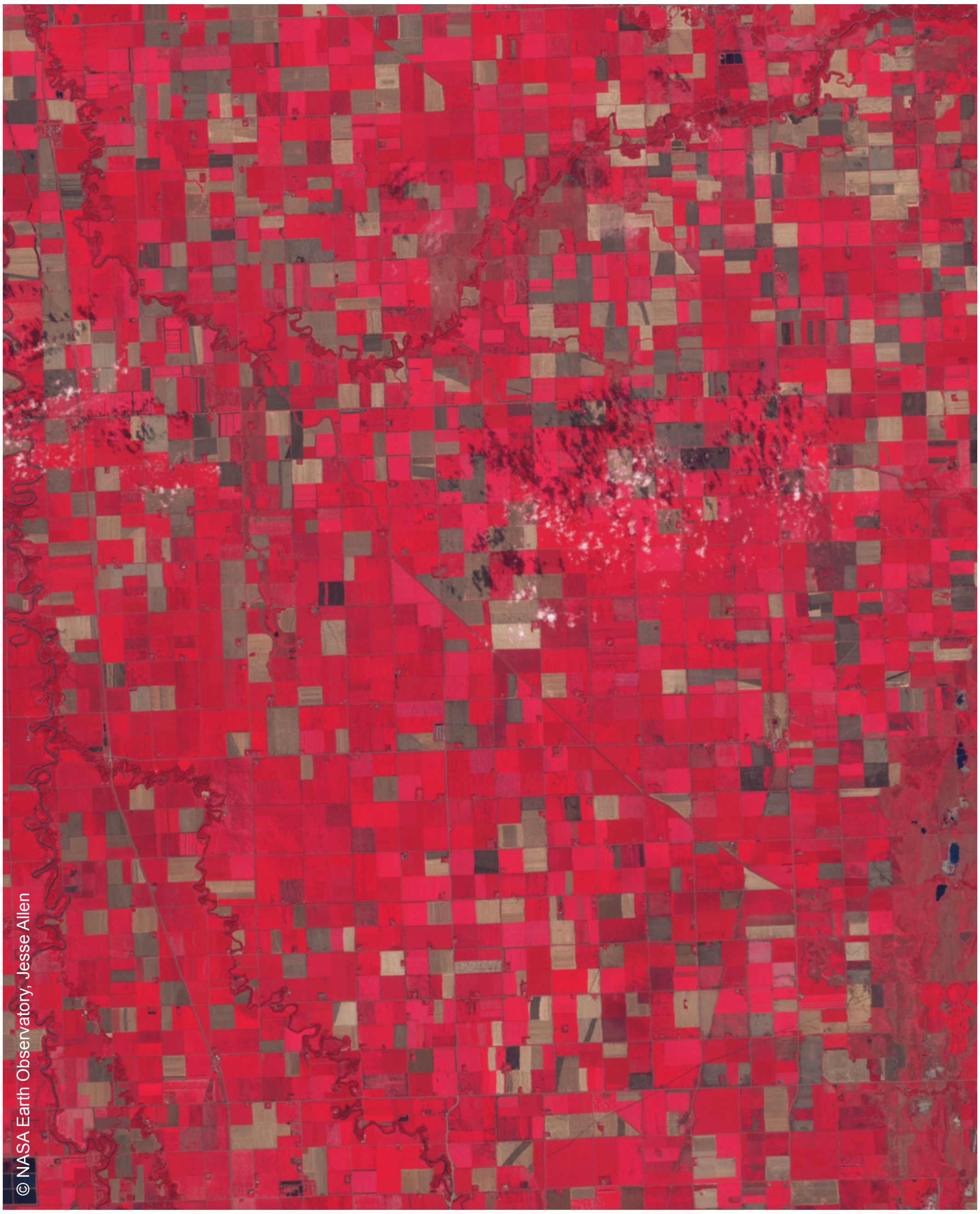
The target audience for this technical background report are professionals from the competent food safety authorities, practitioners and the scientific community. A basic working knowledge of food safety and food safety risk management is assumed.

1.4 How this document was developed

This document was developed through the collective efforts of FAO's Agrifood Systems and Food Safety Division (ESF) and Wageningen Food Safety Research (WFSR). The development process involved an extensive literature review, the outcomes of which fed into an overview of food safety early warning and emerging risk identification tools and methods, and an assessment of gaps, user needs and barriers to the uptake of open access tools and methods. An online survey was sent to experts working in the field of food safety within the competent authorities, ministries, research institutes and academia, especially in low- and middle-income countries (LMICs). The objective was to ascertain the current status and progress of real practices with early warning systems in use across different countries. The survey was disseminated by FAO through the FAO/WHO International Food Safety Authorities Network and by the WFSR through the food safety network "Safety Enhancement of Edible products, Legislation, Analysis and Management, with ASEM countries, by mutual Training & Research (SELAMAT)". In total, 83 completed questionnaires were submitted by respondents from 59 countries (see Annex 1). Finally, several virtual workshops were organized with experts from LMICs to obtain an in-depth understanding of the uptake of early warning tools for food safety and associated barriers, and to discuss with participants the findings from the literature review. Experts from 22 countries across the world attended the workshops and provided inputs which informed the development of this technical report (Annex 2). The review of relevant publications as well as outputs form conducted survey and workshops served as a basis for a scientific analytical publication (Mu *et al.*, 2024).

1.5 How to use this report

This technical background report consists of four chapters. The current Chapter 1 starts with the section introducing the background of the FAO/WFSR project and highlights the importance of developing and enhancing the capabilities and capacities for food safety early warning systems and emerging risk identification as well as the prospects for considering using Big Data and AI in this domain. Following the present chapter, Chapter 2 provides an in-depth introduction to early warning systems and tools for identification of emerging risks in food safety, and offers several case studies and examples. Chapter 3 introduces the topics of Big Data and artificial intelligence and explores their applications in food safety early warning and emerging risk identification, as well as gaps and barriers to uptake of these tools in LMICs. It also examines current prospects and proposes innovative solutions, including a list of available tools for addressing gaps and barriers. Chapter 4 provides a description of the selected open access tools as well as practical information on their scope and use. At the end of the document, the survey questionnaire, a workshop overview and a list of tools for food safety early warning and identification of emerging risks are provided as annexes.



Chapter 2

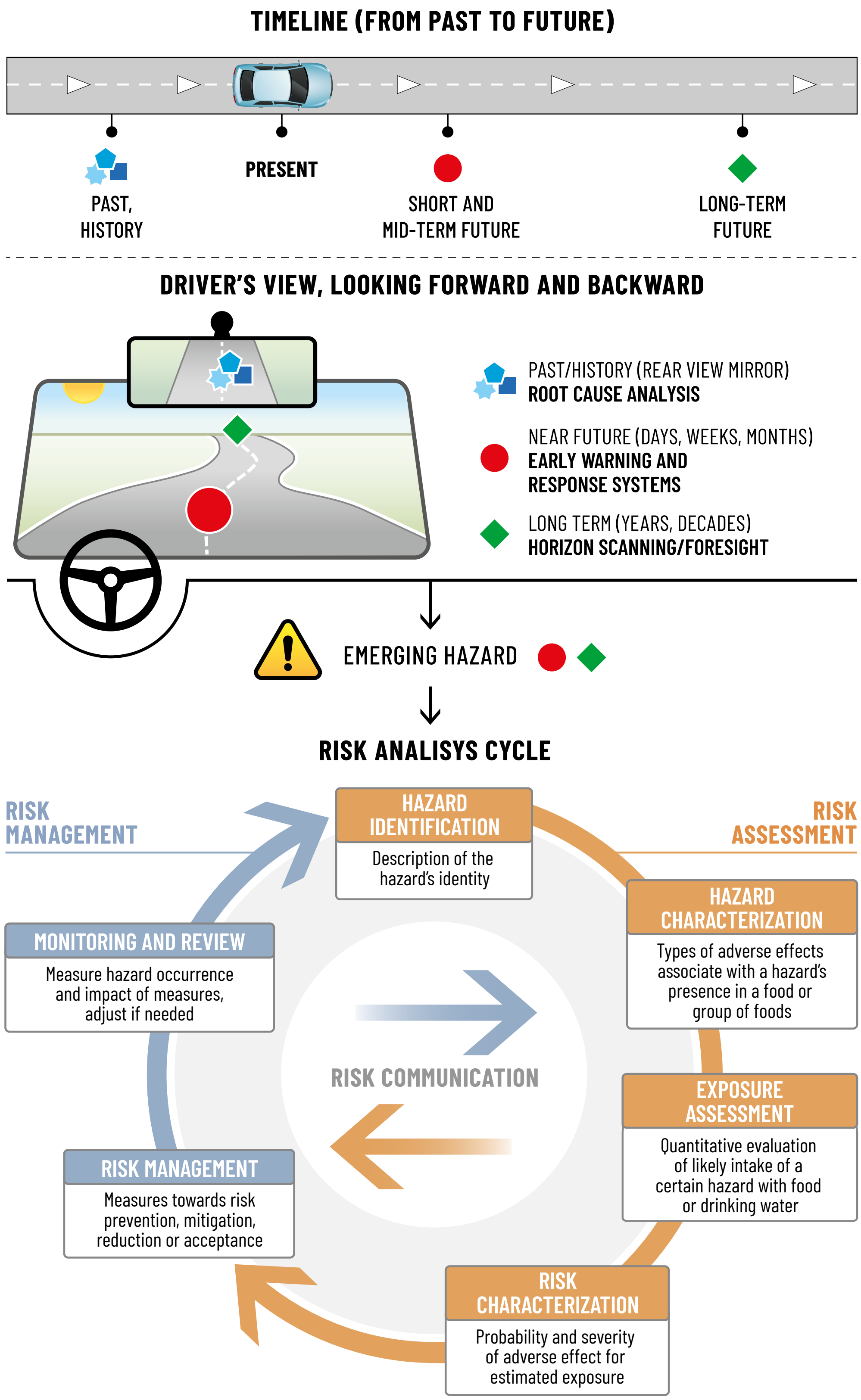
Current methods and systems for identifying emerging issues in food safety

2.1 Introduction

A variety of different methods and systems can be used for the timely prediction and identification of hazards in food and the risks that they pose to food safety. These include early warning and response systems (EWARSs) and foresight. The identification of hazards at an early stage allows measures to be taken to prevent them from becoming a major risk. It can also prevent the further spread or recurrence of an established hazard. These methods and systems may differ in terms of the time horizon at which they operate – present, near or far future (Figure 1) – and whether the focus is on a particular hazard (e.g. a disease-causing bacteria, a chemical) or on health effects following exposure through consumption of contaminated food (e.g. acute or chronic foodborne diseases). The various methods and systems are discussed in more detail in the following sections.

In addition to the early warning systems discussed in this section, a key approach is retrospective "root cause analysis" (RCA), also known as "environmental assessment". This approach traces the causes of an historic incident to identify lessons that can help prevent the incident from reoccurring. Environmental assessments for microbial food contamination are performed routinely by the US Centers for Disease Control and Prevention (CDC), for example. The CDC's National Environmental Assessment Reporting System (NEARS) database contains RCAs of microbial food infection outbreaks filed by the CDC, and by federal and state health departments of the US Food and Drug Administration (FDA). For each incident, the assessment lists "contributing factors" as well as the disease-causing microbe strain (CDC, 2022).

Figure 1. Different time horizons for retrospective, early warning and horizon-scanning/foresight systems, and their input into the risk analysis process



Source: Authors' own elaboration.

2.2 Immediate and short-term: early warning and response systems

There is no general unified definition of EWARSs. However, the various EWARSs (for all types of hazards and disasters) and their existing definitions have a number of things in common. These systems commonly use input data on hazards, which are subject to interpretation and prioritization by experts. The expert opinion, in turn, informs decision-making. Some of these systems also disseminate warning information to stakeholders, which helps prevent or reduce the harm potentially caused by the hazard (Kelman and Glantz, 2014).

Regarding the broad range of EWARSs for food safety, three categories of systems (and combinations thereof) can be distinguished:

- **Risk-based predictive systems** such as predictive modelling are based on existing knowledge of hazards which may develop into risks (e.g. mycotoxin formation in crops based on agronomic and meteorological data) (FAO, 2014b). In general, such systems take into account a number of factors, aside from the hazards, related to exposure, vulnerability (i.e. susceptibility to damage from a hazard) and lack of coping capacity (Marin-Ferrer, Poljanšek and Vernaccini, 2017).
- **Reactive food safety-hazard focused EWARSs** focus on the identified presence of hazards in foodstuffs (e.g. microbiological pathogens, chemical contaminants, and allergens) (FAO, 2014b). Examples of these systems include rapid alert systems for food, as operated in various parts of the world (see Annex 3).
- **Reactive foodborne illness ("event")-focused EWARSs** (WHO, 2014) detect anomalies in reported public health incidences of foodborne disease or poisoning, including from hospital admissions or intoxication centre calls. They focus on cases where the incident has already taken place with the aim of preventing further occurrences and spread. Information inputs may come from both traditional disease surveillance systems and syndromic surveillance as well as from open media sources. Syndromic surveillance is based on general clinical signs and symptoms, which may not be specifically linked to a particular hazard but warrant further inspection into the specific causes of a food safety incident.

EWARSs and the related risk management procedures can be effective in helping authorities take appropriate measures. Examples include the three following retrospective cases reported via the Rapid Alert System for Food and Feed (RASFF) of the European Commission (EC) (FCEC, 2016):

- In 2008, incidences of milk adulterated with melamine (toxic to infants) were reported in the People's Republic of China. Melamine has been also found in the composition of dairy products in the European Union (EU). In total, 19 alerts and 70 follow-up notifications were filed through RASFF, which proved instrumental in the formulation of emergency management measures. In addition to RASFF notifications, alerts were disseminated by the FAO/WHO International Food Safety Authorities Network (INFOSAN) to members.

- In 2010, as a result of own-checks, a food business operator recalled instant coffee in glass jars due to the presence of glass fragments in the coffee. The RASFF network issued an alert and kept its members and other countries' authorities informed through 23 follow-up notifications with details of the food business operator's recall action, and checks and measures undertaken by the authorities.
- In 2011, contamination of fenugreek seeds with Shiga toxin-producing *Escherichia coli* (*STEC*) O104:H4 led to more than 4 000 cases of foodborne infection. RASFF shared available information about the source in order to help track down the cause while the foodborne infection was ongoing. Two initial alerts were issued followed by 107 follow-up notifications.

In general, stakeholders interviewed for the retrospective analysis were satisfied with the speed and quality of the RASFF notifications. However, one exception was the *STEC* O104:H4 incident, where a faulty, unconfirmed laboratory outcome (informing about the presence of *STEC* in cucumbers) was posted and then retracted. This example highlights the trade-off between the need for fast transmission of information and the time required to confirm cases (FCEC, 2016).

Time is a critical factor in early warning systems. For some food safety risks, the warning time may be very short and insufficient to take preventive measures and action. In order to be both practicable and effective, any proactive early warning system operating in the food safety domain must take into account the need for sufficient advance warning time and the time necessary to implement the required preventive action. The effectiveness of preventive action will depend on the type of hazard contained in the food and associated health risk, and the required actions of food business operators, the competent food safety authorities, and consumers. Furthermore, for early warnings to be effective and capable of being acted upon, they should come from a reliable and trustful source, such as a food safety authority.

Some recent initiatives have added additional features and measures to existing EWARS systems. The Singaporean authorities, for example, have used data science to investigate recalls of aflatoxin-contaminated peanut products in order to prevent repeated occurrence of contamination. The outcomes showed that peanut products from certain sources were particularly implicated in recalls, leading the authorities to raise awareness about the origins of contaminated products and to start implementing internal food safety procedures (SFA, 2021). A good practice is applied in Canada, where federal and regional authorities and food safety laboratories share information via the nationwide Canadian Food Safety Information Network (CFSIN). This network allows for vertical data sharing in real time as well as the provision of expert opinion and intelligence, management tools, and mapping of analytical capacities to support early warning and alerting (CFIA, 2020).

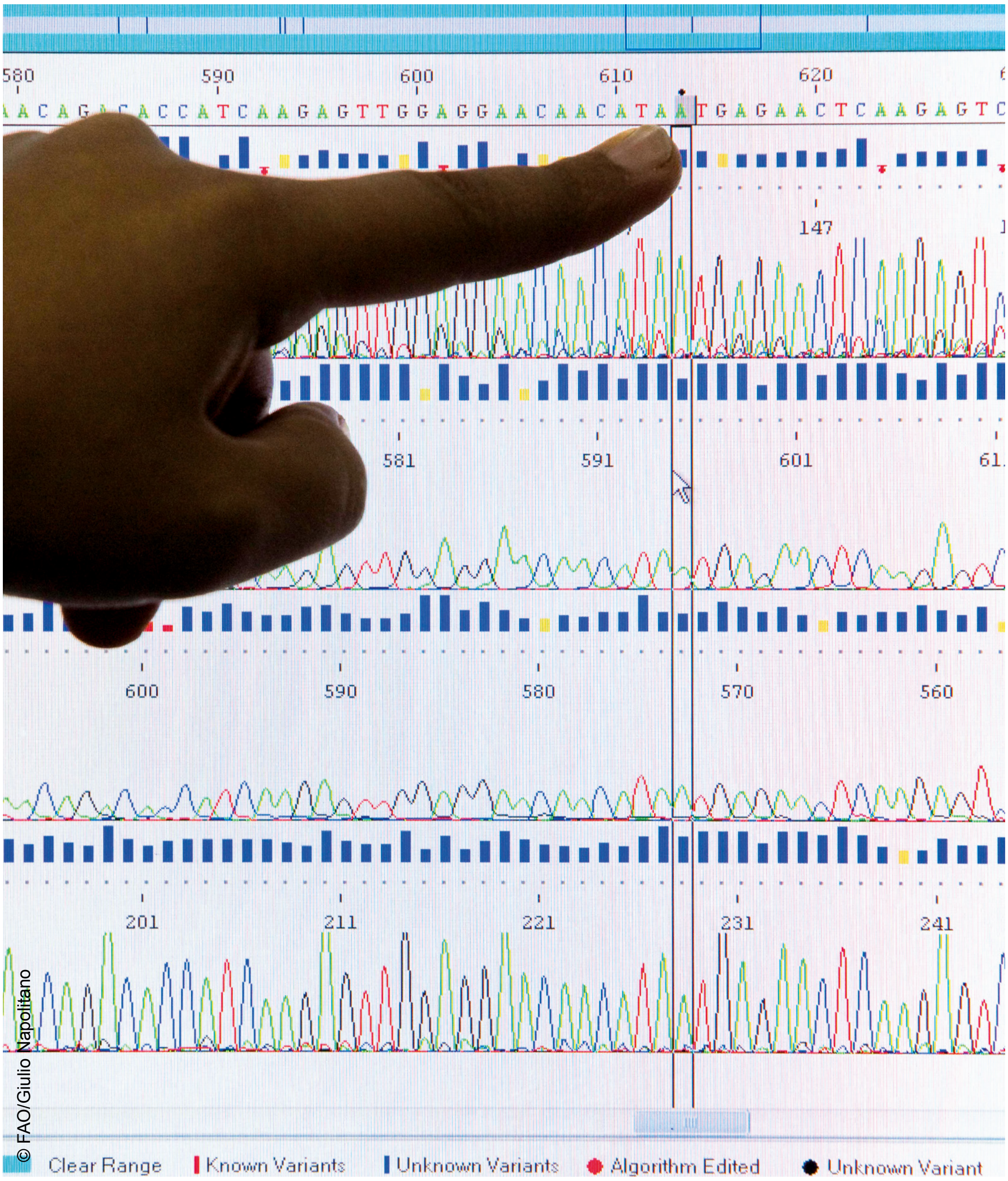
With regard to emergency response preparedness, joint FAO/WHO efforts assist authorities with a framework (FAO and WHO, 2010) and capacity development for the elaboration of response plans for food safety emergencies (i.e. to address serious, uncontrolled food incidents that require urgent attention). In addition to gathering incident-related data, the FAO/WHO framework provides information on how to coordinate collaborative efforts among a variety of partners (e.g. government, the legislature, public health and veterinary health institutions, laboratories and other relevant parties).

2.3 Medium- and long-term warning systems: foresight

Foresight extends beyond the forecasting of risks; it combines data gathering, the exploration of various plausible future scenarios and vision building to determine the space available for policy options. In so doing, it provides governments with possibilities to help them choose the best policies to achieve their goals in the most suitable way. Foresight supports decision-making by allowing for higher preparedness and the possibility to implement mitigating policies (OECD, 2016), as well as the allocation of resources and the development of strategies to cope with future issues (FAO, 2022b). Accordingly, foresight approaches commonly include two components: understanding trends and directing decision-making processes towards certain goals. The methods used in foresight can differ in some respects, as follows (FAO, 2022b):

- *Qualitative methods* are based on subjectivity and creativity, and can be used for the subjective interpretation of data and events, gathered from horizon scanning, expert panels, workshops, conferences and surveys,
- *Semi-quantitative methods* apply mathematical principles (e.g. weighing) to expert opinions, judgements, etc., to allow subjectivity to be quantified.
- *Quantitative methods* are based on the measurement and processing of reliable statistical data as inputs for projections of the future, such as trend extrapolation and benchmarking.

A report published by FAO (2022b) summarizes the outcomes of the organization's Food Safety Foresight Programme, which identified major drivers and trends that may affect global food safety in the future. These include climate change which has a significant impact on natural resources driving, for example, water scarcity, shifting consumer behaviours, new food sources (e.g. edible insects) and production methods (e.g. closed hydroponic systems), urbanization and urban agriculture, innovative technologies (e.g. analytical techniques, food packaging), advances in microbiome science (e.g. knowledge to inform current risk assessment processes), circular systems (e.g. re-use of water in food production) and food fraud (e.g. focus on building resilience into agrifood systems to reduce vulnerabilities). This foresight exercise drew on a variety of data sources including scientific literature, newsletters, information from partners both internal to the organization and external, news releases and monitored websites. Criteria for prioritization included potential impacts (different dimensions such as food safety, environmental, social, trade), likelihood of occurrence (soundness of source), timeframe, scale (global, regional) and novelty.



Chapter 3

Big Data and AI applications in food safety early warning and emerging risk identification

This chapter presents an overview of developments in Big Data and AI applications for food safety early warning and emerging risk identification. Gaps and barriers for uptake of these digital tools are described and discussed, alongside prospects and innovative solutions for addressing them. A list of available tools is provided in Annex 3.

3.1 Definition of Big Data

In recent years, the food safety literature and practice have witnessed the rapid development of modern systems fed by numerous, real-time and diverse data. The use of "Big Data" has become a growing trend in addressing food safety issues. However, no single uniform definition of "Big Data" exists in the literature. The World Health Organization (WHO) defines "Big Data" as "the emerging use of rapidly collected complex data in such unprecedented quantities that terabytes, petabytes or even zettabytes of storage may be required" (Ward and Barker, 2013). Meanwhile, the European Commission employs the three Vs concept (i.e. Volume, Velocity and Variety): Big Data refers to large volumes of different types of data produced with high velocity from a high number of various types of sources. Handling today's highly variable, voluminous and real-time data sets requires new tools and methods, such as powerful processors, software and algorithms (European Commission, 2014).

3.2 Emerging data sources and infrastructure for Big Data in food safety

In addition to conventional data sources (e.g. food safety hazard monitoring data collected by food inspectors and companies), diverse food safety data can be obtained from multiple other sources via the Internet of Things (IoT) and radiofrequency identification (RFID). These new developments make it possible to gather real-time food safety and quality data from the field, which can then be further processed by early warning and emerging risk identification tools. Furthermore, the development of blockchain promises to make data storage immutable, which facilitates transparency through tracking and tracing products and thereby enhances food safety. Successful examples are provided in Boxes 1 and 2.

Box 1. Biosensors and camera surveillance in the meat production chain

Biosensors are used at different stages (e.g. at farm level) of the supply chain to measure the prevalence of certain pathogens (e.g. through antibody binding). Besides having common parameters (e.g. body temperature), biosensors could help, for example, to detect anomalous behaviour, such as the physical activity of livestock, as well as biochemical parameters (e.g. glucose levels in blood) (Zhang *et al.*, 2021). Biosensors are connected to smartphones for ease of access to the information obtained and processed (Nastasijević and Vesković Moračanin, 2021). The use of computer vision systems in farm and abattoirs adds complementary information to the data provided by biosensors and allows for a better interpretation.

Notes:

Zhang, M., Wang, X., Feng, H., Huang, Q., Xiao, X. & Zhang, X. 2021. Wearable Internet of Things enabled precision livestock farming in smart farms: A review of technical solutions for precise perception, biocompatibility, and sustainability monitoring. *Journal of Cleaner Production*, 312: 127712. https://doi.org/10.1016/j.jclepro.2021.127712

Nastasijević, I. & Vesković Moračanin, S. 2021. Digitalization in the meat chain. *Acta Agriculturae Serbica*, 26: 183–193. https://dx.doi.org/10.5937/AASer2152183N

Source: **Mu, W., Kleter, G.A., Bouzembrak, Y., Dupouy, E., Frewer, L.J., Al Natour, F.N.R., Marvin, H.J.P.** 2024. Making food systems more resilient to food safety risks by including Artificial Intelligence, Big Data, and Internet of Things into food safety early warning and emerging risk identification tools. *Comprehensive Reviews in Food Science and Food Safety*, 23, 1–18. https://doi.org/10.1111/1541-4337.13296.

Box 2. Internet of Things (IoT) and blockchain applications in food safety

IoT has been applied in many areas, for example the use of RFID tags to trace pigs from farm to abattoir (Xu, Li and Wang, 2013). RFID has also been used in combination with humidity sensors to allow the real-time tracking in meat cold chain logistics (Ren *et al.*, 2022). Blockchain offers more possibilities to obtain secure information by making it impossible to change or tamper with different data once entered into the system. The concept of blockchain and digitalization is applied in the food chain to ensure food integrity. Its combination with portable and smartphone-based food diagnostic technologies, has made a new generation of miniaturized equipment for food fraud detection possible (Soon, 2022). Vimalajeewa *et al.* (2020) also provide a case study where blockchain is applied in combination with IoT and nanotechnology to sense the level of a chemical in the soil.

Notes:

Xu, B., Li, J. & Wang, Y. 2013. *A pork traceability framework based on Internet of Things*. Berlin, Heidelberg Springer [pp. 159-166].

Ren, Q-S., Fang, K., Yang, X-T. & Han, J-W. 2022. Ensuring the quality of meat in cold chain logistics: A comprehensive review. *Trends in Food Science & Technology*, 119: 133–151. https://doi.org/10.1016/j.tifs.2021.12.006

Soon, J.M. 2022. Food fraud countermeasures and consumers: A future agenda. In: R. Bhat, ed. *Future Foods*. Cambridge, USA, Academic Press [Chapter 34 in this volume].

Vimalajeewa, D., Thakur, S., Breslin, J., Berry, D. P. & Balasubramaniam, S. 2020. Block chain and Internet of Nano-Things for optimizing chemical sensing in smart farming. https://ui.adsabs.harvard.edu/abs/2020arxiv201001941v [Accessed 1 October 2020].

Source: **Mu, W., Kleter, G.A., Bouzembrak, Y., Dupouy, E., Frewer, L.J., Al Natour, F.N.R., Marvin, H.J.P.** 2024. Making food systems more resilient to food safety risks by including Artificial Intelligence, Big Data, and Internet of Things into food safety early warning and emerging risk identification tools. *Comprehensive Reviews in Food Science and Food Safety*, 23, 1–18. https://doi.org/10.1111/1541-4337.13296.

3.3 Data used in food safety

Data on food safety can be obtained through a variety of sources including food inspection and control, food chain monitoring, public health surveillance, veterinary health surveillance, environment health surveillance and food research. Data collected through monitoring programmes for food safety hazards are often structured so that they can be fitted neatly into rows and columns. Structured data also can be obtained from notification systems (e.g. RASFF, FDA), which contain information on the type of product, its origin, the different stages in the food chain, its distribution, the hazard and the risk management measures taken (FAO, 2022a). Current developments in digitalization have led to the availability of increasingly unstructured data, such as image data, sensor data and text data, generated from sources such as satellite images, the IoT and social media. For instance, Marvin *et al.* (2022) developed a real-time food fraud early warning system based on media reports (i.e. unstructured data formats) collected from all over the world using the open access tool MedISys-FF (Bouzembrak *et al.*, 2018). In addition, crowdsourcing, a new tool for obtaining information from large groups of people, especially the online community, is increasingly being new trend to collect unstructured data for food and feed risk assessments. For instance, initiatives among consumers have been initiated in the food safety field on the topic of foodborne illnesses and outbreak surveillance, with crowdsourcing activities conducted through social media and online review websites (Soon and Saguy, 2017).

In addition to data on food safety, other data are increasingly being utilized. These include data on potential drivers of change and indicators, such as climate trends, trade statistics and demographical statistics. These data provide added value by increasing the accuracy of predictions of food safety issues within a food system approach that integrates social, economic, and environmental factors. For instance, a recent study initiated the development of an early warning system for future food safety risks through the detection of anomalies in drivers of change and indicators previously selected by domain experts (Liu *et al.*, 2022). Also data from the monitoring of microbiomes can be used as an indicator of unexpected food contamination, and thereby contribute to improving food safety (Beck *et al.*, 2021).

3.4 AI applications in food safety

The analysis of structured and unstructured Big Data has led to many breakthrough developments in ML and AI. Some examples of successful applications of techniques for processing structured and unstructured data sources in the domain of food safety are provided in Boxes 3 and 4.

Box 3. Bayesian network applications in food safety

A Bayesian network (BN) is one of the most popular ML methods for analysing structured data and allows for easy incorporation of expert knowledge. For instance, a BN has been used successfully to predict food fraud type with a good accuracy of 80 percent (Bouzembrak and Marvin, 2016). A BN has also been used to make predictions on the occurrence of chemical food hazards, such as pesticide residues and mycotoxins in fruits and vegetables from three geographically distinct countries. The results showed a high prediction accuracy of 95 percent (Bouzembrak and Marvin, 2019). In addition, in a recent study, a BN was used to predict toxin concentrations in mussels, where the model was able to predict, with 82 percent accuracy, the occurrence of toxins from a specific growing site. The accuracy increased to 96 percent when only toxin concentrations of up to 0.16 µg okadaic acid/g shellfish meat were considered (Wang *et al.*, 2022c).

Notes:

Bouzembrak, Y. & Marvin, H.J.P. 2016. Prediction of food fraud type using data from Rapid Alert System for Food and Feed (RASFF) and Bayesian network modelling. *Food Control*, 61: 180–187. https://doi.org/10.1016/j.foodcont.2015.09.026

Bouzembrak, Y. & Marvin, H.J.P. 2019. Impact of drivers of change, including climatic factors, on the occurrence of chemical food safety hazards in fruits and vegetables: A Bayesian Network approach. *Food Control*, 97: 67–76. https://doi.org/10.1016/j.foodcont.2018.10.021

Wang, X., Bouzembrak, Y., Marvin, H.J.P., Clarke, D. & Butler, F. 2022c. Bayesian Networks modeling of diarrhetic shellfish poisoning in Mytilus edulis harvested in Bantry Bay, Ireland. *Harmful Algae*, 112: 102171. https://doi.org/10.1016/j.hal.2021.102171

Source: **Mu, W., Kleter, G.A., Bouzembrak, Y., Dupouy, E., Frewer, L.J., Al Natour, F.N.R., Marvin, H.J.P.** 2024. Making food systems more resilient to food safety risks by including Artificial Intelligence, Big Data, and Internet of Things into food safety early warning and emerging risk identification tools. *Comprehensive Reviews in Food Science and Food Safety*, 23, 1–18. https://doi.org/10.1111/1541-4337.13296.

Box 4. Neural network applications in food safety

A neural network (NN) is the main algorithm for analysing unstructured data due to its ability to handle both text and image-based data. For instance, Gavai *et al.* (2021) applied a NN-based word-embedding model to data from scientific literature and the European Media Monitor, and successfully identified the occurrence of illegal stimulants in food supplements. Tao, Yang and Feng (2020) provide another example, using tweets as inputs for a NN-based text mining model to process data. The trends uncovered based on the tweets indicated that potential foodborne outbreaks were consistent with true outbreaks that occurred over the same period (Tao *et al.*, 2021). In addition, a convolutional NN was applied to process pig skin images to extract the features of pork skin and increase the accuracy of pork traceability (Song, Cai and Peng, 2019).

Notes:

Gavai, A.K., Bouzembrak, Y., Van Den Bulk, L.M., Liu, N., Van Overbeeke, L.F.D., Van Den Heuvel, L.J., Mol, H. & Marvin, H.J.P. 2021. Artificial intelligence to detect unknown stimulants from scientific literature and media reports. *Food Control*, 130: 108360. https://doi.org/10.1016/j.foodcont.2021.108360

Tao, D., Yang, P. & Feng, H. 2020. Utilization of text mining as a big data analysis tool for food science and nutrition. *Comprehensive Reviews in Food Science and Food Safety*, 19: 875–894. https://doi.org/10.1111/1541-4337.12540

Tao, D., Zhang, D., Hu, R., Rundensteiner, E. & Feng, H. 2021. *Crowdsourcing and machine learning approaches for extracting entities indicating potential foodborne outbreaks from social media*. Durham, USA, Research Square. https://assets.researchsquare.com/files/rs-496521/v1_covered. pdf?c=1631868433

Song, D., Cai, C. & Peng, Z. 2019. Pork registration using skin image with deep neural network features. International Conference on AI and Mobile Services, 2019. Cham, Switzerland, Springer International Publishing [pp. 39–53 in this volume].

Source: **Mu, W., Kleter, G.A., Bouzembrak, Y., Dupouy, E., Frewer, L.J., Al Natour, F.N.R., Marvin, H.J.P.** 2024. Making food systems more resilient to food safety risks by including Artificial Intelligence, Big Data, and Internet of Things into food safety early warning and emerging risk identification tools. *Comprehensive Reviews in Food Science and Food Safety*, 23, 1–18. https://doi.org/10.1111/1541-4337.13296.

3.5 Gaps and barriers to the uptake of tools for food safety early warning and emerging risk identification

Although developments in Big Data and AI have increased the feasibility and effectiveness of early warning and emerging risk tools in practice, several challenges/conditions should be addressed to facilitate their equitable implementation, particularly for LMICs. Table 1 summarizes various gaps and barriers identified in the literature in relation to technologies used for food safety early warning and emerging risk identification (e.g. crowdsourcing, automated food safety early warning systems, artificial intelligence, Big Data, blockchain, IoT, text mining and remote sensing).

Table 1. Summary of gaps and barriers for different technologies applicable for food safety early warning and emerging risk identification

Technologies	Gaps and barriers	Sources
Automated food safety early warning systems	Expert interventions still required for regular maintenance in the event that the structure of data sources changes over time, which may result in the web scraping of wrong data without adequate warnings when websites are updated System presented in the literature is still a proof of principle, while availability of such a system remains an issue globally Facilitation needed for information sharing between different regions or countries, as well as between public and private organizations Holistic approach is needed, including the creation of suitable ontologies for each domain related to food safety, the creation of correct inference rules, and ways to extract information from different information sources and indicators	Havelaar *et al.* (2010) Liu *et al.* (2022) Marvin *et al.* (2013) Meyer *et al.* (2015)
Artificial intelligence	Lack of wide expertise in the interface between food and AI Issues of transparency and interpretability Lack of sufficient digitally labelled data in the food safety domain Lack of data that are both publicly available and reliable Lack of generalization capabilities for broader use Limitations in data updating frequency Long training time as well as hardware restrictions	Jin *et al.* (2020) Kudashkina *et al.* (2022) Marvin *et al.* (2022) Marvin *et al.* (2020) Talari *et al.* (2021) Wang *et al.* (2022b) Zhou *et al.* (2019)

Technologies	Gaps and barriers	Sources
Big Data	Insufficient data quality and quantity in the food safety domain Challenges in scalability, data storage, data integrity, data transformation, data governance, privacy and legal issues Limitations in computing capacity Challenges in data *fairness* (i.e. Findability, Accessibility, Interoperability and Reusability (FAIR)) Insufficient data contributions by the private sector Limited number of tools available within the Big Data domain applicable to food safety	Jin *et al.* (2020) Kim and Kim (2022) Marin-Ferrer, Poljanšek and Vernaccini (2017) Marvin *et al.* (2022) Marvin *et al.* (2020) Talari *et al.* (2021)
Blockchain	Insufficient background knowledge leading to lack of acceptance of blockchain technologies Difficulties with compatibility and standardization of different systems across industries Lack of a basic infrastructure system that meets all the requirements of blockchain-associated technologies adapted for food safety High implementation cost	Wang *et al.* (2020) Zhou, Zhang and Wang (2022)
Crowdsourcing	Poor data quality caused by inaccurate information provided by the crowd Lack of sufficient resources (i.e. time and technical expertise to process the information) Insufficient IT platforms to handle crowd traffic, which can lead to reduced crowd participation and loss of control	Soon and Saguy (2017)
Internet of Things (IoT)	Lack of standardized communication protocols to interpret, communicate and share data collected by IoT devices Inadequate hardware and software security High vulnerability risks of the entire IoT system to any insecure IoT nodes High requirements for financial investment, data storage, data reliability, data synchronization and data aggregation Large resources needed for real-time monitoring with the help of sensors Difficulties with cooperation in data sharing across supply chains	Jin *et al.* (2020) Terence and Purushothaman (2020) Wang *et al.* (2022b)

Technologies	Gaps and barriers	Sources
Remote sensing	Challenges in implementing cost-effective systems with well-integrated technology Need for compromise to balance the level of complexity, decision tool accuracy and the capacity of farmers to use it Difficulties dealing with large heterogeneities in soil and climate conditions, as well as management practices User difficulties in fully understanding the collected data and developing trust in the system	Jin *et al.* (2020) Wang *et al.* (2022a) Weiss, Jacob and Duveiller (2020)
Text mining	Noise (i.e. irrelevant information) in the data especially from sources such as social media Problems of standardization, verification and control across various data sources Challenges founded in ethical and legal restrictions with accessing the data Informal and ambiguous text data leading to incomplete or inaccurate results Lack of proper and sufficient ontologies Lack of large volumes of labelled data and low data representativity, which can lead to low generalization of findings	Gupta and Katarya (2020) Meyer *et al.* (2015) Tao, Yang and Feng (2020)

Note: In-text sources, see References>Table 1

Source: **Mu, W., Kleter, G.A., Bouzembrak, Y., Dupouy, E., Frewer, L.J., Al Natour, F.N.R., Marvin, H.J.P.** 2024. Making food systems more resilient to food safety risks by including Artificial Intelligence, Big Data, and Internet of Things into food safety early warning and emerging risk identification tools. *Comprehensive Reviews in Food Science and Food Safety*, 23, 1–18. https://doi.org/10.1111/1541-4337.13296.

The findings from the online survey and the workshops organized as part of the FAO/WFSR project concur with the outcomes of the literature review. For LMICs, additional barriers such as lack of coordination between agencies and absence of financial, human and material (e.g. tools and software) resources were frequently noted. Data accessibility (e.g. data from private laboratories), data quality and data integration, including across different sectors and systems, were also identified as gaps. Technical, social and economic challenges in adopting and implementing the tools were raised in the workshops.

In reference to technical issues, identified challenges include a lack of applied technologies and databases to trace back pathogens, limited access to the internet and existent data, and insufficient monitoring of foodborne hazards with subsequent hazard identification and early warning. A lack of skilled personnel to operate the aforementioned systems and insufficient analytical capacity were also cited as issues by participants. In addition, a lack of automated information systems means that manual collection of information remains the dominant practice.

In regard to socioeconomic challenges, participants mentioned lack of coordination between agencies with roles and responsibilities in food safety and data sharing, with sectors operating in silos. Support is needed to raise awareness of the available food safety early warning and emerging risk identification methods and tools, as well as the results of their successful implementation. In addition, lack of financial support was frequently mentioned. Last but not least, further improvements in collaboration among researchers, competent authorities and policy-makers are needed. Identification and early warning of food safety risks are both a national and international issue that needs more attention and concerted multidisciplinary efforts to be effectively managed.

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3.6 Prospects and innovative solutions

Challenges impeding the wide uptake and use of modern tools and technologies for food safety early warning can be addressed from both technical and socioeconomic perspectives. From the technical perspective, having sufficient infrastructure and facilities for data collection, storage and processing is essential. Reliable internet access and/or wireless connectivity in LMICs is often a challenge but it is also a prerequisite. In addition, in almost all the cases, a large computational infrastructure capable of processing large volumes of diverse datasets is necessary, especially one that can handle the long computational time needed to process Big Data (Zengeya, Sambo and Mabika, 2021). From a socioeconomic perspective, better coordination of food safety activities at national and sub-national levels, building partnerships among different stakeholders, and capacity development through the provision of sufficient training/education for all actors in food safety are important (Kendall *et al.*, 2018).

In addition to the various technical conditions and challenges, the implementation of AI in other fields (e.g. healthcare, personnel recruitment) has already shown that various ethical and policy challenges may arise. These include (Delecraz *et al.*, 2022; Naik *et al.*, 2022):

- privacy and surveillance when personal data are used, avoiding any breach of the rights of involved individuals;
- bias or discrimination, for example if certain groups (e.g. product groups, exporting countries) are unintentionally underrepresented during the training stage;
- human judgment, which may be wrongly influenced by the outcomes of AI, and *vice versa,* artificial intelligence applications with built-in safeguards to ensure ethical decision-making is desired.

One way to tackle these challenges would be to ensure that AI applications are lawful, ethical and robust (High-Level Expert Group on Artificial Intelligence, 2019). While legislation may not have caught up yet with technology, trustworthy AI applications should be developed and used in accordance with key principles, including accountability, transparency, fairness, reliability, safety, privacy and security, and inclusiveness (High-Level Expert Group on Artificial Intelligence, 2019; Microsoft, 2022).

Due to the complexity of the algorithms applied in AI and the quality of the data used, uncertainty regarding the outcome of AI-based tools and their limitations may exist, which will hamper use. Further work is therefore needed on explainable AI to increase both transparency and explicability.

Regarding decision-making efficiency, doubts have been raised regarding the centralized infrastructure of AI-based decision models because these may lead to delayed response time at the sampling site. To accelerate response time, research has been undertaken on the development of decentralized AI applications using techniques such as Blockchain (Phansalkar *et al.*, 2019).

Intellectual property (IP) is important in providing incentives to human innovation and creation, although current IP has been designed for innovations by humans. How forms of IP such as copyright should be redesigned for AI innovation and creation remains a controversial topic, with debates ongoing regarding the possible need for changes to adapt the existing IP framework (Guadamuz, 2017).

The table presented in Annex 3 provides a list of tools for food safety early warning and emerging risk identification categorized based on risk coverage. The information presented in the table includes a brief description of the tools, the cost of usage, the name of the developer and their website. Countries can select the tools that fit their specific needs and context. Not all of the tools listed in Annex 3 are applicable to LMICs, but they nevertheless provides good indications and potential future steps for digitalizing the management of food safety risks.

Chapter 4

Open access tools to support food safety early warning and the identification of emerging issues

A number of different tools and methods were highlighted in Chapter 3. Under favourable circumstances (e.g. open source and open access), these can be applied to better monitor the evolution of different hazards and to identify areas where controls need to be reinforced. This chapter provides detailed practical information on three open access tools (MedISys, MedISys-FF and SGS DIGICOMPLY), including their usage and functionalities for professionals (see Annex 3 for a full list). These tools provide background information that may be helpful for authorities in LMICs. Nevertheless, careful, and appropriate interpretation of such information is necessary prior to making any managerial decisions, as these tools are limited in the data currently collected from LMICs and may not provide a comprehensive picture.

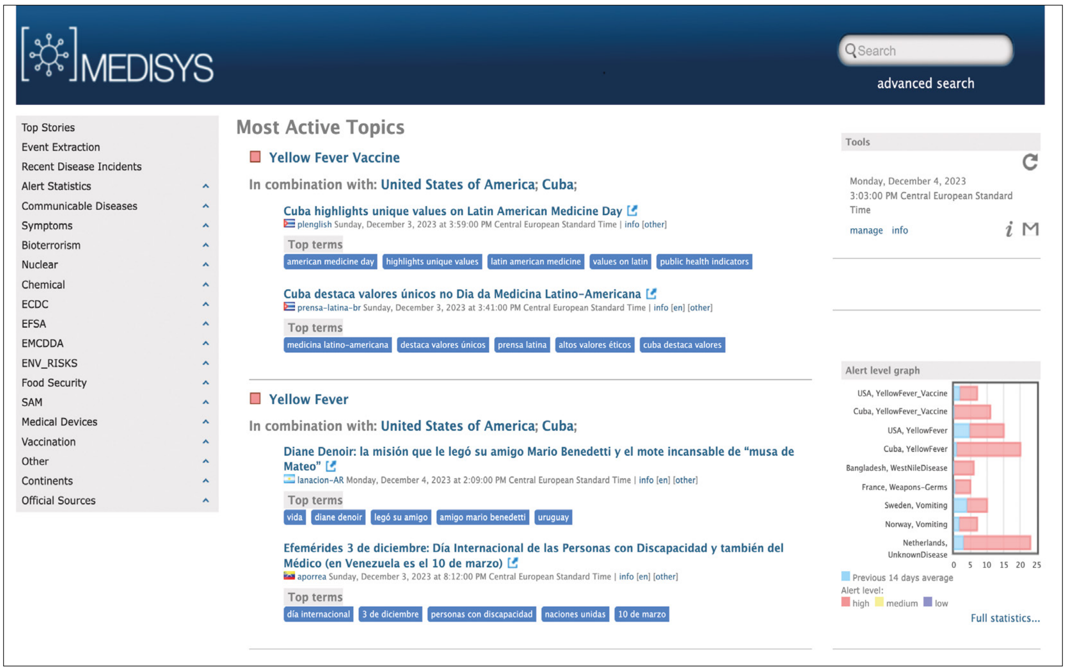
4.1 The Medical Information System (MedISys)

MedISys is a 24/7 media monitoring system that assists professionals (e.g. authorities) in conducting incident-based surveillance by monitoring reports of incidents in the media (e.g. online newspapers, specialist blogs). Such incidents may include human and animal infectious diseases; chemical, biological, radiological, and nuclear (CBRN) threats; and food and feed contamination. MedISys collects and analyses information provided by Europe Media Monitor (EMM) based on automatically pre-defined preferences set by professionals (e.g. topic, food hazard, language, news sources, country). MedISys processes approximately 90 000 news articles each day from more than 2 200 news sites in 72 languages. Users can further organize articles and create newsletters to share with their target audience. MedISys is license/access-free.

The main page of MedISys displays the most active topics (see Figure 2). In the left-hand menu, users can search for information based on aggregated categories. The category ***Top stories*** links to the ten biggest stories over the last 24 hours, ***Event Extraction*** links to current events and ***Recent Disease*** links to ongoing global overview of disease incidents. Further down the menu, the ***Alert Statistics*** category allows users to view statistics (average of previous 14 days) for different regions and see the types of alerts reported in which country. ***Communicable Diseases*** provides a dropdown list where topics can be searched for by specific disease category (e.g. foodborne, waterborne, zoonosis). The ***Symptoms*** category allows users to make searches based on specific symptoms (e.g. gastroenteric syndrome), while ***Bioterrorism*** and ***Nuclear and Chemical*** allows users to search for topics that belong to specific categories (e.g. toxins, bacteria, viruses, nuclear and chemical hazards). Additional categories enable users to search topics by organization, such as the European Centre for Disease Prevention and Control (ECDC), the European Food Safety Authority (EFSA), and the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA). The category ***ENV_RISKS*** provides different environmental risks related to air, soil and water; ***SAM*** offers the possibility to search microplastic categories; and ***Continents*** allows users to search for information by continent.

MedISys affords professionals in LMICs the possibility to access relevant media news according to their areas of interest. The platform provides hyperlinks to the original news item and shows the top terms mentioned in the article (see Figure 2). Food safety professionals can select

Figure 2. Main page of MedISys.



Source: https://medisys.newsbrief.eu/medisys/homeedition/en/home.html.

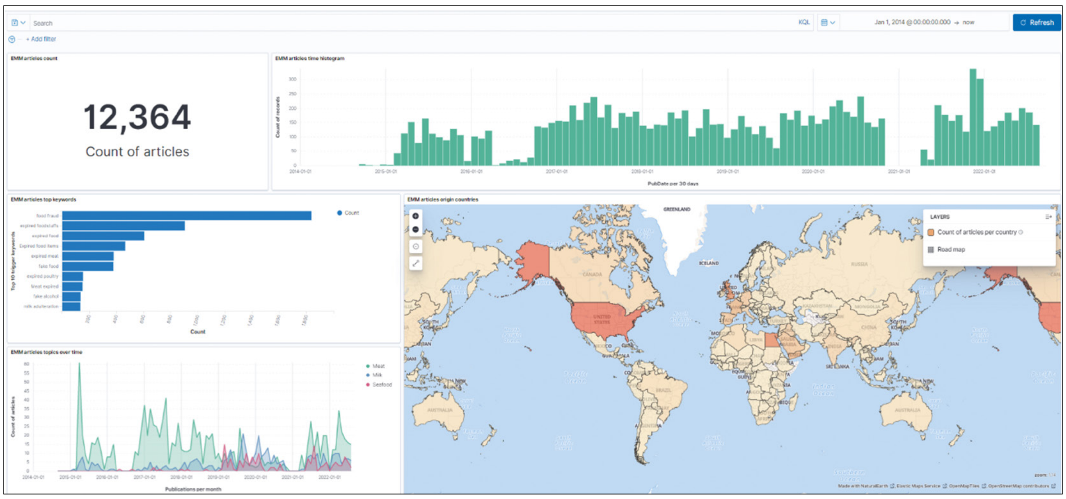
news articles relevant to their topic, then classify them according to different predefined groups in order to process the information contained within. In so doing, users of MedISys can identify early warning signals for food safety risks as well as identify emerging food safety issues. However, the articles accessible via MedISys are not stored on the platform and are only displayed temporarily on the website. Users are therefore advised to save the information locally for further analysis, and to regularly maintain the records in a systematic manner. For countries with good IT capacities, the process of gathering information via MedISys can be automatized. MedISys can also be contacted to design a filter for customized searches based on the specific interests and requirements of professionals.

4.2 MedISys-FF

MedISys-FF is a dashboard built based on a MedISys filter that was customized for food fraud (FF). The dashboard displays information on relevant articles, their countries of origin, top keywords, and publication dates. Available articles draw on data sources provided by MedISys. MedISys-FF is updated every 10 minutes, 24 hours a day, 7 days a week, and is license-free.

The main page of the MedISys-FF dashboard is shown in Figure 3. The bar chart on the top right provides users with a quick overview of article distribution across different years starting from September 2014 until the present. The counter displayed on the top-left gives the total number of articles collected (i.e. 12 364). The bar chart underneath shows the top 10 keywords based on frequency of appearance in the articles as well as their distribution. A global map displays the countries of origin for the articles. Users can create a filter by clicking on a specific keyword

Figure 3. Main page of MedISys-FF.



Source: https://bigdata-wfsr.wur.nl/2020/09/18/medisys-for-food-fraud.

in the keyword bar chart. This will customize the map to show countries of origin for articles with the preselected keyword. Darker shades on the map indicate a higher count intensity of articles. The keyword bar chart can also be customized by clicking on a specific country to show the top keywords for that country. The filter can be removed by clicking on a cross on the filter box located at the top left of the main page. Users can enter any food item in the search bar at the top of the page and select a time period for the search.

MedISys-FF can be used by professionals to obtain a quick overview of important topics related to food fraud reported in the media. For example, users can identify the most fraudulent commodities in a predefined country/region and monitor for emerging food fraud issues in a certain area of the world. Similarly, users can identify the most problematic countries for certain food fraud issues. In addition, by analysing the historical records of food fraud cases, users may determine trends that can aid in developing a better targeted monitoring process. In this way, the MedISys-FF dashboard helps users to identify hotspots for detecting and controlling food fraud along the global food supply chain.

4.3 SGS DIGICOMPLY

SGS DIGICOMPLY is a horizon-scanning platform that monitors and aggregates relevant food safety, food security and trading information from more than 3 000 qualified sources distributed across 160 markets. The sources include reports from food safety authorities, scientific publications, standards, legislation and social media. To date, more than 5 million documents have been collected, extracted and enriched to allow users accessing the platform to support food security and food safety across the world. SGS DIGICOMPLY can provide preventive and proactive solutions for managing food safety risks by aggregating information on regulations, supply chains, testing, media, trading and the environment. The basic version of SGS DIGICOMPLY is license/access-free. Figure 4 shows the layout of the main page of the SGS DIGICOMPLY dashboard, which can be customized by the user.

Users start by customizing SGS DIGICOMPLY based on their role and needs. Users can choose from two role-based options: regulatory specialist and quality assurance.

If a user selects "regulatory specialist", the dashboard offers three further options based on the user's daily tasks:

1. Learn about a specific country's regulatory framework to help with exports.
2. Search for specific regulations, provisions, or requirements within regulation texts in English.
3. Monitor regulatory changes.

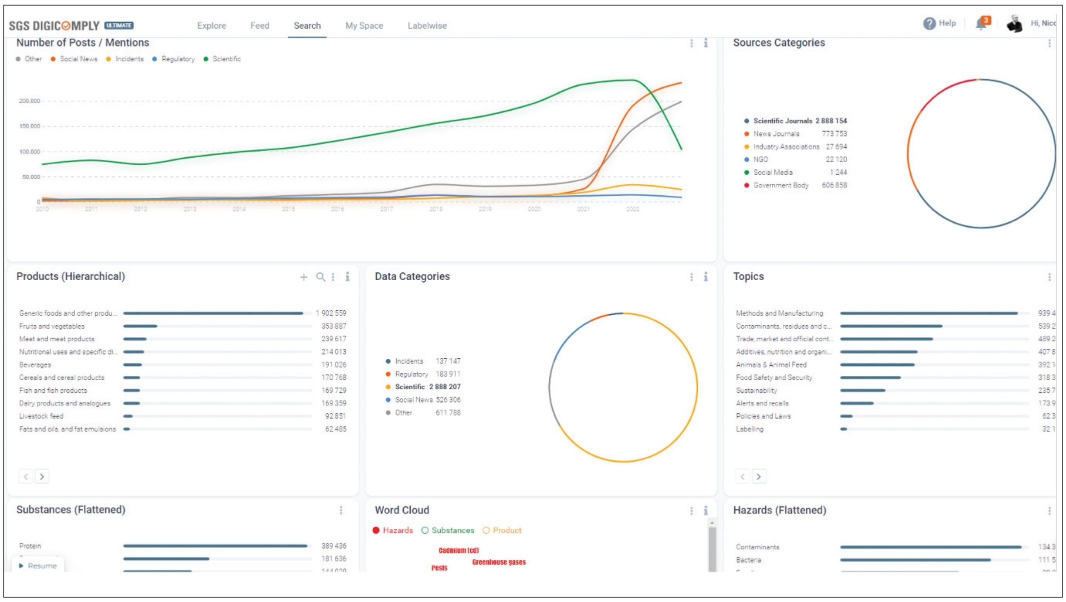
If option 1 is selected, SGS DIGICOMPLY provides information on legal definitions, legislative frameworks, specific local regulations, labelling requirements, roles and responsibilities of regulatory bodies, rules for active/non-active ingredients, restricted and prohibited ingredients, as well as notification procedures of global markets. If option 2 is chosen, the user is directed to a page where search and data retrieval functions are explained in detail. If option 3 is selected, the user is directed to a page explaining how to create or edit a Feed that will allow them to monitor regulatory changes.

If a user selects "quality assurance", the dashboard again offers further information based on the user's daily tasks:

1. Perform horizon scanning to obtain relevant news and data about food safety risks from around the world.
2. Access a database of food fraud-related incidents by country and product to assist with vulnerability assessments.

If option 1 is selected, SGS DIGICOMPLY provides information on how to create or edit a personalized feed for the search, which can be categorized based on the user's needs. This action creates a corresponding dashboard, which can be customized to add, for example, a map that shows where the content comes from and a chart listing the source categories (e.g. scientific journals, social media). There is also an option to receive summary notifications

Figure 4. Main page of SGS DIGICOMPLY.



Source: www.digicomply.com.

that provide a quick overview of all content entering the system within a selected period. This notification can be set based on a threshold (i.e. the number of relevant articles). For example, the user can choose to receive notifications if there are more than ten articles on a defined search term. If option 2 is selected, SGS DIGICOMPLY provides information on how to create a feed that monitors food fraud records.

Data available on the platform span incidents, regulations, policy news, scientific publications and social media. Users can also choose from among topics including policies and laws, labelling, additives, official controls, standards and many others. Experts from SGS DIGICOMPLY have provided a session for FAO/WHO INFOSAN members on the platform's structure, demonstrating how to create a dedicated search query based on a user's areas of interest. The developer has also offered interested participants from LMICs free one-year advanced Ultimate Licenses, which give them access to all food safety data hosted on the platform, a feature not available under the BASIC free-of-charge version.

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Annex 1

Questionnaire on expert opinions: food safety authorities and practitioners, the scientific community and academia

Global emerging food safety risks: evidence-based innovative digital tools and guidance to support food safety early warning

Survey of expert opinions: food safety authorities and practitioners, the scientific community and academia

Unsafe food has high costs for people, the economy, and the environment (FAO and WHO, 2020). Ensuring food safety requires continuing vigilance and management of current and emerging food safety risks. Emerging food safety risks may be chemical, allergenic, microbiological, physical or radiological in nature, and may originate from various sources including domestically produced and traded food and beverages, drinking water, food supplements and imported food. The capability to identify early warning information and predict emerging food safety risks is critical for their adequate management. A proactive outlook would help address prospective food safety issues with a potential impact on health that may require increased targeted monitoring, surveillance, research and regulation.

With the aim of providing a practical document on tools and solutions for effectively managing early warning on emerging food safety risks, we would like to consult your opinions on the current status of relevant tools and methods in your country or your organization.

The survey takes about 20 minutes to complete in one go. Please note that you cannot save your answers in between. Received answers will be analysed and reported anonymously.

This study is carried out by the FAO in collaboration with Wageningen Food Safety Research (the Netherlands). If you have any questions, please do not hesitate to contact us (hans.marvin@wur.nl, Eleonora.Dupouy@fao.org).

We would appreciate receiving your complete questionnaire **before 25 April 2022**.

Thank you for taking the time to participate in this consultation.

SECTION A: General information

1. Contact information

- Country:
- Name of institution:
- Type of institution:
  - Public authority – national level
  - Public authority – sub-national level
  - Academy
  - Public research institute
  - Private research institute
  - Food business operator (MSME:[1] 1–10 employees)
  - Food business operator (SME:[2] 10–250 employees)
  - Food business operator (>250 employees)
  - Non-governmental organization
  - Professional association
  - Other
- Experience in your area of work: 1–5 years; 5–10 years; >10 years

2. How do you rate the level of implementation of the following components in your national food control system

Scale: 1 = "very bad" to 5 = "very good", or "I don't know". Please score for each component separately

- National food safety management system (food control coverage along the food chain)
- Food safety laboratories
- Food legislation
- Food inspection
- Information education and communication
- Food safety research

3. Do you have a single food safety agency for the national food control system?

a. Yes
  - If yes, please specify which agency

b. No

c. I don't know

---

[1] Micro, small and medium enterprises.

[2] Small and medium-sized enterprises.

4. If the national food control system has a multi-agency structure, please specify:

a. Which agencies and institutions have food control responsibilities and their areas of competence? Please list them: ____

b. Does the system operate in an integrated manner?

- Yes
- If yes, what is the coordinating institution? ________________________________
- No
- I don't know

5. Do you have entire food chain coverage for the food control system in your country?

a. Yes

If yes, do they cover?

- animal feed (yes/no)
- primary production (yes/no)
- storage (yes/no)
- transportation (yes/no)
- traditional markets (yes/no)
- processing (yes/no)
- retail (yes/no)
- food services (yes/no)

b. No

If no, please explain ____

c. I don't know

6. How would you grade the condition of the following items in your country? (This question refers to the general condition of the items, not specifically in the food safety domain.)

Scale: 1 = "very bad" to 5 = "very good", or "I don't know". Please score for each item separately.

- IT infrastructure: ____
- Internet: ____
- WIFI: ____
- Mobile phone network: ____

Please add any related comments____

7. Which types of food incident reporting systems are operational in your country? (please tick as many as appropriate)

( ) Rapid alert systems for food law enforcement action

( ) Foodborne disease outbreak surveillance

( ) Adverse effect and complaint reporting

( ) Zoonotic disease surveillance (in animals that can be consumed)

( ) Other(s), please specify: ____

8. Choose a system from the following list (by ticking one box) for which you will answer the questions below (question 9 onwards)

( ) Rapid alert systems for food law enforcement action

( ) Foodborne disease outbreak surveillance

( ) Adverse effect and complaint reporting

( ) Zoonotic disease surveillance (in animals that can be consumed)

( ) Other(s), please specify ____

9. Please score the development of the food safety incidents databases in your country in terms of the following aspects:

Scale: 1 = "very bad" to 5 = "very good" , or "I don't know". Please score each item separately.

a. Country level

- Accessibility
    - For governmental authorities
    - For researchers
    - For industry
    - For consumers
- Updating frequency:
- 24/7 warning service:
- Automated data collection:

b. Region (sub-national) level

- Accessibility
    - For governmental authorities
    - For researchers
    - For industry
    - For consumers
- Updating frequency:
- 24/7 warning service:
- Automated data collection:

c. Your organization level

- Accessibility
  - For governmental authorities
  - For researchers
  - For industry
  - For consumers
- Updating frequency:
- 24/7 warning service:
- Automated data collection:

d. I don't know

10. Does your country have a rapid alert system in place to which national food safety incidents can be reported?

a. Yes

If yes, please specify:

- INFOSAN
- ARASFF
- EC RASFF
- GRASF
- Others____

b. No

If no, please share your view

c. I do not know

SECTION B: Early warning signals of food safety

Early warning systems

In the context of food safety, early warning systems include various tools, technologies, processes and resources used to monitor, detect, and verify early warning signals, analyse data and information arising from such signals, and disseminate and communicate alerts to stakeholders at appropriate levels for the purpose of informing risk management actions and decision-making (FAO, 2015).

1. Is the identification of early warning signals in food and feed a prioritized activity in your organization or country ?

a. Organization
   a. Yes, No, I don't know
   b. Remark: ____

b. Country
   a. Yes, No , I don't know
   b. Remark:____

2. Does an early signal capturing system for food safety risks exist in your organization or country?

a. Organization
   a. Yes, No, I don't know
   b. Remark: ____

b. Country
   a. Yes, No , I don't know
   b. Remark: ____

3. To what extent do you agree or disagree with use of the following techniques in your organization for processing and analysing data to identify food safety early warning signals in food and feed?

Scale: 1 = "completely disagree" to 5 = "completely agree", or "I don't know". Please score each item separately:

- Simulation modelling: ____
- Machine learning: ____
- Expert elicitation methodologies: ____
- Others (please specify): ____

4. What gaps and needs exist in current early warning systems for managing food safety risks?

Please list below:

a. Gaps:____

b. Needs: ____

5. Can you specify which software tools or packages your organization uses for the identification of food safety early warning signals in food and feed?

a. Software tools or packages used (please specify): ___________________________________

b. None

c. Don't know

SECTION C: Emerging food safety risks

Emerging risks

An emerging risk to human, animal and/or plant health is understood as a risk resulting from a newly identified hazard to which a significant exposure may occur or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard. Emerging risks do not include risks characterized by a sudden appearance or risks associated with the inadvertent or accidental intake of food or feed that are not in compliance with recognized safety requirements (EFSA, 2007).

6. Is the identification of emerging risks in food and feed a prioritized activity within your organization or country?

a. Organization
   a. Yes, No, I don't know
   b. Remark: ____

b. Country
   a. Yes, No , I don't know
   b. Remark: ____

7. Is there a tool or platform for identifying signals and predicting emerging risks in food and feed in your organization or country?

a. Organization
   a. Yes, No, I don't know
   b. Remark: ____

b. Country
   a. Yes, No , I don't know
   b. Remark: ____

8. Are the enabling policy environment, technical skills and capacities (e.g. human, financial and infrastructure) adequate and suitable to build/improve identification tools for emerging risks?

a. Yes

   If yes, please explain why ____

b. No

   If no, please explain why not ____

c. I don't know

9. To what extent do you agree or disagree that the following techniques applied in your organization can facilitate processing and analysing data to identify/predict emerging risks in food and feed

Scale: 1 = "completely disagree" to 5 = "completely agree" or "I don't know". Please score each item separately:

- Simulation modelling:____
- Machine learning: ____
- Expert elicitation methodologies:____
- Others (please specify): ____

10. Does your organization use AI to detect emerging food safety risks in food and feed?

a. Yes

If yes, please specify?____

b. No

If no, please elaborate____

c. I don't know

11. What gaps and needs related to tools/methods for managing emerging risks in food and feed exist in your organization and country?

Please list them below:

a. Organization
  - Gaps
  - Needs

b. Country
  - Gaps
  - Needs

c. I don't know

12. Does your organization use software tools for the identification of emerging food safety risks in food and feed?

- Yes
  - If yes, please specify the software tool(s) used ___________________________________
- No
  - If no, please elaborate ____
- I don't know

Thank you for sharing your opinions through this questionnaire!

Annex 2
Workshop on food safety early warning and emerging risks identification tools and methods

Food and Agriculture Organization of the United Nations

WAGENINGEN UNIVERSITY & RESEARCH

FAO/WFSR Workshop on food safety early warning and emerging risk identification tools and methods

12 May 2022 (online)

1. Introduction

A virtual workshop on food safety early warning and emerging risk identification tools and methods was held on Thursday, 12 May 2022, with representatives of competent authorities for food safety and academia from low- and middle-income countries (LMICs), as part of a collaborative framework between the Food and Agriculture Organization of the United Nations (FAO) and Wageningen Food Safety Research (WFSR) in the Netherlands. The workshop follows the expert survey "Global emerging food safety risks: Evidence-based innovative digital tools and guidance to support food safety early warning", conducted in March 2022. The survey aimed to obtain an overview of the degree of use of tools and methods for food safety early warning and emerging risk identification, in order to determine user needs and barriers for uptake.

As a complement to the conducted survey, the workshop aimed to discuss the preliminary results of a literature and web review on early warning and emerging risk identification tools and methods for food safety. This review was undertaken by the research team to establish the scope and focus of a planned technical information document to support the broad use of these tools across regions.

The outcomes of the workshop discussion will also feed into the preparation of an Analytical paper on food safety early warning tools, methods and characteristics.

2. **Participants**

A total of 83 experts from 23 countries who completed the survey questionnaire were invited to attend the workshop.

The 3-hour workshop was held in the English language in two sessions to facilitate the participation of experts from various geographical regions and continents. The two sessions were scheduled at 8.00-11.00 (CET) and 15.00-18.00 (CET). The workshop was recorded for the purposes of administration and verification of inputs.

2.1. Morning sessions (8.00–11.00 CET)

Eight food safety experts from competent authorities and/or research institutes from the following ten countries participated in the morning session of the workshop: Croatia, Kyrgyzstan, Mauritius, New Caledonia (France), North Macedonia, Nigeria Somalia, People's Republic of China, Uganda and the United Arab Emirates.

2.2. Afternoon session (15.00–18.00 CET)

The afternoon session involved 15 food safety experts from authorities and/or research institutes from the following 12 countries: Anguilla, Brazil, Chile, Colombia, Dominica, Liberia, Russian Federation, Senegal, Sierra Leone, South Africa, and Trinidad and Tobago.

3. **Workshop objectives**

The objectives of the workshop were as follows:

1. To present and discuss the preliminary results of the literature and web review on food safety early warning and emerging risk identification tools and methods.
2. To share experiences, challenges and needs related to these tools.
3. To inform the development of a technical information document on tools and methods for food safety early warning.

4. **Workshop agenda**

1st Plenary session with all participants. Duration: 1 hour

1. Welcome and introduction round: Hans Marvin (WFSR) and Eleonora Dupouy (FAO)
2. Introduction to the overall project: Eleonora Dupouy (FAO)
3. Summary of the literature and web review on early warning and emerging risks tools and methods: Wenjuan MU (WFSR)
4. Technical questions and answers

Short break

Break out groups. Duration: 1 hour

Guiding questions:

1. What do you think of the study's findings?
2. Are these findings applicable to your country?
3. Would you like to see smart methodologies adopted in your country?
4. Have smart technologies for food safety early warning/or emerging risks already been adopted in your country? If so, describe your experience
5. If not, what possible barriers exist to their implementation?

In the morning session, a number of participants conducted a discussion in plenary. In the afternoon session, two breakout rooms were arranged to discuss the preliminary results and shared experiences and needs.

1. Breakout group 1: Moderator Hans Marvin, rapporteur Gijs Kleter
2. Breakout group 2: Moderator Yamine Bouzembrak, rapporteur Wenjuan Mu

2nd Plenary session with all participants. Duration: 1 hour

1. Report back from the breakout groups
2. Wrap-up and workshop conclusions
3. Closing

5. Output of the workshop

A workshop report summarizing the feedback and presentations of the consulted experts has been prepared. This will be used by the project team to prepare an *Analytical paper on food safety early warning tools, methods, and characteristics*, and informs the content of the present technical information document on tools and methods for food safety early warning.

5.1. Main findings from the general plenary discussion (morning session)

One important finding related to emerging risks concerns the need for a better and common understanding of various concepts, such as early warning, horizon scanning, foresight and the place of risk assessment in the warning process when placed in a timeframe perspective. The One Health approach (animal, plant and human) was considered important and in some countries (e.g. the United Arab Emirates) is already being applied. The collection and circulation of data via various media to better understand situations in different contexts is emerging as a potential source of information for risk communication, but is not yet fully developed or broadly applied.

The workshop participants agreed on the importance of early warning for emerging risks and associated tools, but noted that their implementation depends on the availability of local data and information, the state of digitalization developments and available infrastructure. The participants also emphasized the need to determine the reliability of information.

Many participants indicated that ***lack of coordination between agencies with a role and responsibility for food safety and data-sharing represents a major challenge***. The risk is that sectors will continue to work in silos. ***Support is needed*** to raise awareness about available food safety early warning and emerging risk identification methods and tools, as well as to ensure their successful implementation. FAO may have a role to play in supporting the development of capacities in this area.

Other challenges mentioned by participants:

1. Lack of skilled personnel to make use of various methods and tools
2. Insufficient access to data
3. Other more urgent societal and sanitary issues that compete for available resources, such as food security, animal diseases, etc.
4. Lack of collaboration between research, competent authorities and policy-makers.

Wrap-up morning session

The participants identified the following needs:

1. Better and common understanding of the major concepts related to food safety early warning
2. Implementation of a One Health approach
3. Adoption of a holistic food system approach
4. Strengthened governance for food safety.

5.2. Main findings of the breakout rooms (afternoon session)

5.2.1. Breakout group 1

Generally, participants agreed that the presented tools, which draw on data sources, machine learning and artificial intelligence, offer real potential to predict potential issues provided that the required data are available to the competent authorities with mandates for food safety policy and decision-making in food safety risk management. The participants also emphasized that any adopted tools and methods supporting the identification of emerging food safety risks and early warning should form part of a broader risk management system connected to a national food safety authority and a platform where different agencies can share information in a synchronized manner.

Any recommendations should at least include a stepwise approach for putting things into practice. Some experience already exists in this regard, such as the use of Big Data for red tide[3] warnings. The following recommendations emerged from the breakout group:

- Emerging food safety risk identification and early warning are both a national and international issue, and require more attention and concerted multidisciplinary efforts to be effectively managed.
- Some nations (e.g. Small Island States, importing nations) depend on third countries for data. Improved access to these data would facilitate risk-based monitoring of imported food products, and help avoid or reduce food safety incidents in international food trade, as well as the incidence of foodborne diseases
- Regarding stakeholder involvement, it is essential to raise awareness of current and emerging risks in food safety. In addition, communication of food safety risks requires commitment at the political level, in order to break through silos.

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[3] Red tide is a discolouration of seawater caused by a bloom of toxic red dinoflagellates.

- Other challenges mentioned included finance, human resources (lack of skilled staff), analytical capacity and technical requirements (e.g. to implement HACCP-based food safety management systems and to ensure food safety compliance in resource-limited contexts).
- Exports may function as a driver for policy-makers to take consistent and preventive measures towards better food safety controls.

5.2.2. Breakout group 2

The participants agreed on the potential usefulness of the presented data collection tools and technologies, but noted that training (on Bayesian Network and other tools) would be necessary to facilitate uptake.

The participants also identified some limitations including lack of technology (e.g. a database to track and trace pathogens), lack of internet access, lack of skilled personnel, lack of systems automation, social factors (reluctance to adopt systems automation) and lack of finance.

The participants also discussed whether reluctance to adopt and use new technologies was dependent on age, and agreed that this was likely the case, citing the example of uptake of mobile phones among young farmers in Africa. On this basis, they felt that new technology would likely be accepted.

5.3. Wrap up

This workshop provided an opportunity to discuss an emerging area of research and practice – the use of technology to identify and prevent emerging risks, better prepare to manage food safety incidents and protect consumers. The common objective is to ensure that the food that arrives to our tables is safe, both in terms of international exports and imports and food produced and marketed domestically. As the technology is developing at a rapid pace, a solid understanding of its application and uses is essential. The workshop highlighted a variety of tools and methods available on an open source and open access basis, which can be applied to better monitor the evolution of different hazards and to identify spots where controls need to be reinforced.

The workshop also underscored the fundamental need for a food safety culture and an understanding of the hazards. Access to quality data is essential, as is having monitoring, identification, and early warning systems in place. The workshop encouraged LMICs to adopt operational early warning systems and to ensure the involvement of and collaboration among different sectors. The participants were encouraged to share their narratives and ideas about new technologies in relation to food safety early warning systems, and to specify which technologies could allow for a step-by-step approach to implementation in LMICs.

The participants broadly agreed on the potential benefits of the presented approach and tools, but conceded that challenges to their implementation needed to be overcome. Removal of these barriers will take some time, although the use of Big Data and AI for early warning may accelerate implementation. These technologies also increase the possibility of increased data-sharing with other countries for conversion into knowledge amenable to the prediction of food safety issues.

5.4. Follow up

A few follow-up activities to the expert workshop were identified:

- Finalize the Analytic paper on food safety early warning tools, methods, and characteristics, considering and incorporating inputs from the workshop participants.
- Devise a set of selected open-access tools for food safety early warning and emerging risk identification for use by LMICs.
- Compile methodologies and training materials for the identified tools to support uptake.
- Develop the draft outline of a document and training materials for using the identified tools.
- Prepare a second workshop on the practical use of the selected tools for food safety early warning and emerging risks.

Annex 3
Tools for food safety early warning and identification of emerging risks

Tools	Coverage	Description	Developer	Access	Website link
All types of risks					
HorizonScan	All hazard types and product categories	24/7 access to real-time data on food safety hazards covering over 500 commodities, 180 countries and 22 000 suppliers. Customize daily or weekly updates keeping the user up to date with relevant issues for data preferences.	Fera Science	Subscription cost	https://horizon-scan.fera.co.uk
FOODAKAI	All hazard types and product categories	An intelligent online system that minimizes the food safety risks in your supply chain by delivering insights about hazards in raw materials and products. FOODAKAI provides access to more than 56 000 food safety incidents announced by official sources. Information on food incidents date back to 1980 and cover more than 170 countries.	Agroknow	Subscription cost	www.foodakai.com
SGS DIGICOMPLY	All hazard types and product categories	Powering a one-stop knowledge base to keep food compliant and consumers safe, SGS DigiComply is the regulatory intelligence network that helps you adhere to government regulations and industry standards for food quality and safety. Based on machine learning, SGS DIGICOMPLY is able to extract information from a document at a deep level. The system reads the document and recognizes hazards, consequences, locations of incidents, impacted products and substances. When combined with new forms of data visualization with customizable dashboards, users are better able to quickly identify incidents that could have a major impact on their business.	SGS	Basic version free, advanced version subscription on cost	www.digicomply.com

Tools	Coverage	Description	Developer	Access	Website link
Rapid Alert System for Food and Feed (RASFF)	All hazard types and product categories	Created in 1979, RASFF enables information to be shared efficiently between its members (EU Member State national food safety authorities, EU Commission, EFSA, ESA, Norway, Liechtenstein, Iceland and Switzerland) and provides a round-the-clock service to ensure that urgent notifications are sent, received and responded to collectively and efficiently.	European Commission	Free	https://webgate.ec.europa.eu/rasff-window/screen/search
ASEAN Rapid Alert System for Food and Feed (ARASFF)	All hazard types and product categories	This web-based application with a regional scope enables the competent authorities in food safety and public health of all ASEAN Member States to rapidly notify and exchange information on direct or indirect risks to humans deriving from food or feed being traded in ASEAN countries and measures taken to prevent them from entering the food chain. ARASFF also collects and compiles essential data exchanged on the website and makes them available to ASEAN Competent Authorities in Food Safety and Public Health.	Association of Southeast Asian Nations (ASEAN)	Free	www.arasff.net
Gulf Cooperation Council Rapid Alert System for Food and feed (GCC-RASFF)	All hazard types and product categories	The function of the GCC Rapid Alert System for Food (GRASF) is to facilitate communication regarding existing direct or indirect risk to consumer's health from food or food contact material and feed. This information is submitted through the system to other members of the network (GCC national contact points) efficiently and rapidly.	Secretariat General of the Gulf Cooperation Council The Cooperation Council for the Arab States of the Gulf GCC	Free	https://grasf.sfda.gov.sa
Foodborne Outbreaks Dashboard	All hazard types and product categories	The Foodborne Outbreaks Dashboard visualizes foodborne outbreak data reported annually to EFSA by EU Member States and other reporting countries. Its interactive interface shows metric values such as number of outbreaks, human cases, hospitalizations and deaths, grouped by one or more attributes. The dashboard displays information on seven attributes: reporting year, strength of evidence, type of outbreak, reporting country, causative agent, food vehicle and place of exposure.	EFSA	Free	www.efsa.europa.eu/en/microstrategy/FBO-dashboard

Tools	Coverage	Description	Developer	Access	Website link
Medical Information System (MediSys)	Infectious diseases, bioterrorism, and chemical, biological, radiological and nuclear (CBRN) threats	MedISys is a fully automatic 24/7 public health surveillance system monitoring infectious diseases, bioterrorism, and chemical, biological, radiological and nuclear (CBRN) threats through open source media.	European Commission	Free	https://medisys.newsbrief.eu/medisys/homeedition/en/home.html
Emerging Risk Knowledge Exchange Platform (ERKEP)	Emerging food safety risks	ERKEP is a prototype demo of a technical platform developed within the DEMETER project that aims to support current (and future) European Food safety Authority (EFSA) procedures for emerging issue and risks identification. It provides a community resource that allows EFSA and EU Member State authorities to share data, data mining knowledge and methods in a rapid and effective manner.	EFSA	Free	www.erkep.eu
Microbiological risk					
FoodChain-Lab	Microbiological risk	FoodChain-Lab helps users to collect, handle and analyse the huge amounts of food delivery data needed in the investigation of foodborne disease outbreaks. This tool can map and analyse global food and feed supply chains.	Bundesinstitut fur Risikobewertung (BFR)	Free	https://foodrisklabs.bfr.bund.de/foodchain-lab_de
Predictive Microbial Modelling Lab (PMM-Lab)	Microbiological risk	PMM-Lab aims to ease and standardize the statistical analysis of experimental microbial data and the development of predictive microbial models.	BFR	Free	https://foodrisklabs.bfr.bund.de/pmm-lab_de
FoodProcess-Lab	Microbiological risk	FoodProcess-Lab helps the food and feed industry to monitor microbial development in production processes and to aid public authorities in assessing risks.	BFR	Free	https://foodrisklabs.bfr.bund.de/foodprocess-lab_de/
ComBase	Microbiological risk	ComBase is an online tool for quantitative food microbiology. Its main features are the ComBase database and ComBase models. The tool describes and predicts how microorganisms survive and grow under a variety of primarily food-related conditions.	United States Department of Agriculture	Free	www.combase.cc/index.php/en

Tools	Coverage	Description	Developer	Access	Website link
Food fraud					
MEDISYS for food fraud (MEDISYS-FF)	Food fraud	MEDISYS-FF displays articles linked to Food Fraud, analyses respective news reports and sends users automatically generated alerts. Information processed by MEDISYS is derived from the Europe Media Monitor (EMM), developed by the European Commission's Joint Research Centre. Customized filters built at WFSR can target a specific topic in media reports.	Wageningen Food Safety Research	Free	https://bigdata-wfsr.wur.nl/2020/09/18/medisys-for-food-fraud
JRC Food Fraud Reporter	Food fraud	The JRC Food Fraud Reporter is a media monitoring system that searches for incidences of food fraud on the Internet to warn authorities of potential food fraud cases. This predictive tool has been adopted by many countries to complement existing food safety surveillance systems.	European Commission	Free	www.foodauthenticity.global/blog/jrc-monthly-food-fraud-summary-for-november-2020-is-published
TRACES	Food fraud	TRACES is an efficient tool used to ensure traceability (monitoring movements of consignments, both within the EU and from non-EU countries); information exchange (enabling trade partners and competent authorities to easily exchange information on the movements of their consignments and significantly speeding up administrative procedures); and risk management (reacting rapidly to health threats by tracing the movements of consignments and facilitating the risk management of rejected consignments).	European Commission	Free	https://webgate.ec.europa.eu/cfcas3/tracesnt-webhelp/Content/Home.htm
Food Fraud Network (FFN)	Food fraud	The EU Food Fraud Network works in close consultation with the EC Knowledge Centre for Food Fraud, which provides expertise in food science, including research on the authenticity and quality of food supplied in the EU. The EU Food Fraud Network also engages in joint operations with the European Union Agency for Law Enforcement Cooperation (Europol) targeting fake and substandard food and beverages and counterfeit pesticides.	European Commission	Free	https://ec.europa.eu/food/safety/agri-food-fraud/eu-food-fraud-network_en

Tools	Coverage	Description	Developer	Access	Website link
Networks					
Food Fraud Network (FFN)	All hazard types and product categories	A network comprising the European Commission, Europol, liaison bodies designated by Member States, and, where relevant, the EU's Judicial Cooperation Unit (Eurojust).	European Commission	Free	https://ec.europa.eu/food/safety/agri-food-fraud/eu-food-fraud-network_en
FAO/WHO International Food Safety Authorities Network (INFOSAN)	All hazard types and product categories	The International Food Safety Authorities Network (INFOSAN) is a global voluntary network of national authorities with a role in food safety, coordinated by a joint FAO/WHO Secretariat. National authorities of almost all FAO and WHO Member States are part of the network. The mission of INFOSAN is to strengthen prevention, preparedness and response to food safety incidents and emergencies by fostering a global community of practice among food safety professionals.	FAO/WHO	Free	www.who.int/groups/fao-who-international-food-safety-authorities-network-infosan/about

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