

Review Article

Global Perspectives on Food Safety and Quality Control Standards: A Comprehensive Review

Abstract

Food safety and quality control standards are vital for ensuring the safety and integrity of the global food supply chain. This review explores the key frameworks and regulations that govern food safety, emphasizing the critical roles of various stakeholders, including regulatory agencies, food manufacturers, and consumers. Key methodologies such as Hazard Analysis and Critical Control Points (HACCP) and Good Manufacturing Practices (GMP) are examined to demonstrate their effectiveness in identifying and mitigating risks associated with foodborne illnesses. Additionally, the role of International Organization for Standardization (ISO) standards in promoting consistency and accountability across food industries is discussed. The importance of traceability and rigorous testing protocols play key role in enhancing consumer confidence and ensuring product quality. Emerging challenges such as globalization, technological advancements, and environmental sustainability are addressed, underscoring the need for adaptive and innovative approaches in food safety practices. By analyzing current standards and the interplay between regulatory compliance and industry practices, this review aims to offer insights into improving food safety and quality control measures. Ultimately, fostering a culture of safety and quality not only protects public health but also enhances consumer trust and supports the sustainability of food systems worldwide.

Keywords: Food safety, Food quality, HACCP, GMP, Public health.

Introduction

In today's global food system, food safety and quality control have become pivotal for ensuring public health, economic stability, and consumer trust. Food safety refers to the measures and conditions implemented to prevent foodborne illnesses and protect consumers from contaminants, pathogens, and toxic substances in food (Gallo *et al.*, 2020). Quality control, on the other hand, ensures that foods meet specific standards related to their nutritional content, appearance, flavor, and shelf life, contributing to the overall experience and confidence of consumers. Together, these practices form the foundation of a reliable and secure food system that prioritizes the health and well-being of population worldwide (Okpala *et al.*, 2023). As consumer expectations and regulatory demands grow, ensuring that all food products meet stringent safety and quality benchmarks has become essential. The journey of food from farm to table is increasingly complex, often involving multiple countries, various levels of processing, and intricate logistical systems. This complexity introduces unique food safety challenges, including biological threats like bacterial contamination (e.g., *Salmonella*, *E. coli*), viral infections, chemical residues from pesticides and antibiotics, and physical hazards like foreign objects (Choi *et al.*, 2020). Moreover, emerging concerns such as antimicrobial resistance, food fraud, and contamination from environmental pollutants, including microplastics, add layers of complexity to maintaining a safe food

supply [46,47]. These issues are exacerbated by the growing demand for convenient, processed, and imported foods, which heightens the risks of cross-contamination, spoilage, and quality degradation (Madilo *et al.*, 2024).

Food safety and quality control measures not only prevent illness and enhance consumer trust but are also integral to a country's economy and its trade relations. Nations with strong food safety regulations and practices enjoy robust trade opportunities, as their exports meet international standards and are accepted globally (Li *et al.*, 2020). Conversely, a failure in food safety can have significant economic and reputational repercussions, leading to recalls, trade bans, and loss of consumer confidence. In this regard, food safety has become both a national priority and a global necessity.

Purpose of the study

This review aims to provide an in-depth exploration of the global frameworks, standards, and practices that underpin food safety and quality control. A comprehensive understanding of these standards is crucial in a world where food is increasingly sourced, processed, and sold across borders. Key international frameworks, such as the Codex Alimentarius established by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), provide a set of guidelines that inform national and regional food safety standards. In addition to Codex, the chapter will examine influential regulations by bodies such as the U.S. Food and Drug Administration (FDA), the European Food Safety Authority (EFSA), and standards established under the International Organization for Standardization (ISO). By understanding these frameworks, food producers, policymakers, and consumers can better navigate the complexities of food safety on a global scale (Kamboj *et al.*, 2020).

The review will also emphasize the importance of harmonizing food safety standards across regions. As the global food supply chain has become more interconnected, discrepancies in regulatory standards between countries can pose significant trade barriers. Harmonized standards help create a level playing field where all producers, regardless of location, adhere to minimum safety requirements (Awuchi *et al.*, 2023). This harmonization not only facilitates trade but also ensures that consumers, whether in high-income or low-income countries, have access to safe and high-quality foods. By discussing the challenges and benefits of harmonization, the chapter will underscore the need for collaborative efforts to establish common safety goals. In addition to outlining current standards, the chapter will explore emerging trends and innovations in food safety and quality control. Technological advances, such as blockchain for traceability, artificial intelligence (AI) in risk assessment, and Internet of Things (IoT) sensors for real-time monitoring, are transforming food safety practices (Qian *et al.*, 2022). These technologies enhance the accuracy and efficiency of food safety interventions, allowing for quicker response times in cases of contamination and the ability to track products across the supply chain. By incorporating these technological developments, the food industry can address some of the pressing challenges posed by globalization and growing consumer demand for transparency.

Fundamental Concepts of Food Safety and Quality Control

Food safety and quality control are essential components of modern food systems, integral to maintaining consumer health, confidence, and regulatory compliance. While they are often discussed together, food safety and food quality serve distinct yet complementary functions in the food industry (Rosak-Szyrocka *et al.*, 2020). Food safety focuses on protecting consumers from harmful contaminants and foodborne illnesses, while food quality emphasizes meeting consumer expectations in terms of taste, texture, nutrition, and appearance. Both areas rely on fundamental principles and frameworks that enable consistent standards and practices across the food supply chain, from production to consumption.

Principles of Food Safety

The principles of food safety are grounded in systematic approaches to preventing contamination and managing risks. The three core components of food safety principles—risk assessment, risk management, and risk communication—form a structured approach to identifying and mitigating potential hazards in food production and distribution (Kamboj *et al.*, 2020).

1. **Risk Assessment:** This process involves identifying potential hazards, assessing the likelihood of these hazards occurring, and evaluating the potential impact on human health. It often includes identifying biological hazards (like bacteria and viruses), chemical hazards (such as pesticides and heavy metals), and physical hazards (foreign objects). The goal of risk assessment is to understand the probability and severity of various food safety threats and to use that knowledge to develop targeted interventions (Kasza *et al.*, 2022).
2. **Risk Management:** Based on the findings of the risk assessment, risk management involves implementing measures to control or reduce the identified risks to acceptable levels. This may include practices like pasteurization, refrigeration, cleaning protocols, and cooking requirements that are applied at various stages of the food chain to reduce microbial load and prevent contamination. It also involves setting regulatory standards and developing guidelines that producers and manufacturers must follow (Overbosch *et al.*, 2023).
3. **Risk Communication:** Effective communication between regulatory bodies, food producers, and consumers is crucial for food safety. Risk communication involves informing all stakeholders, from producers to consumers, about potential hazards, preventive measures, and regulatory requirements (Frewer *et al.*, 2000). Transparent and accurate communication builds trust and ensures that consumers are aware of risks and how to minimize them, such as by following safe handling and cooking practices.

In addition to these principles, two key methodologies under food safety: hazard analysis and traceability.

- **Hazard Analysis and Critical Control Points (HACCP):** HACCP is a systematic approach for identifying, evaluating, and controlling food safety hazards. It includes identifying potential hazards at each stage of food processing and establishing critical control points (CCPs) where measures can be applied to prevent or eliminate risks. By monitoring these CCPs,

HACCP allows for early detection of risks and enables corrective actions before the food product reaches the consumer (Awuchi *et al.*, 2023).

Fig .1 Principles of HACCP



Source: <https://halalfoundation.org/successful-implementation-of-haccp/>

- **Traceability:** Traceability is the ability to track the movement of food products through each stage of production, processing, and distribution. This is essential for quick responses to contamination or product recalls, ensuring that any compromised food products can be efficiently identified and removed from the supply chain (Yu *et al.*, 2020). Traceability systems often incorporate digital tools such as barcodes, RFID tags, and blockchain technology, which allow for real-time tracking of food products and increase transparency in the supply chain (Olsan *et al.*, 2018).

Quality Control in Food Production

While food safety focuses on preventing harm, food quality control centers on ensuring that food meets certain standards that appeal to consumers and align with regulatory requirements. Quality control in food production encompasses various sensory, microbiological, and chemical parameters that collectively

determine the acceptability and appeal of food products. Key principles of quality control include adherence to Good Manufacturing Practices (GMP) and Good Hygienic Practices (GHP), which provide guidelines for maintaining quality standards in food production environments (De Silva, 2020).

1. **Food Safety vs. Food Quality:** Although food safety and food quality are interrelated, they serve different purposes. Food safety is concerned with protecting consumers from harmful substances, whereas food quality focuses on maintaining specific attributes, such as flavor, texture, appearance, and nutritional value, that meet consumer expectations. For instance, while pasteurization is a safety measure to eliminate pathogens, flavor and nutritional content are quality aspects that contribute to consumer satisfaction (Kamboj *et al.*, 2020).
2. **Quality Control Mechanisms:** Several mechanisms ensure that food products meet the desired quality standards. Some of the most widely adopted quality control practices include:
 - ❖ **Good Manufacturing Practices (GMP):** GMP encompasses a set of regulations that guide the production, processing, and handling of food to ensure consistent quality and safety. These practices cover personnel hygiene, equipment sanitation, ingredient storage, and packaging standards, and are enforced by regulatory bodies to minimize contamination and quality degradation.

GMP PRACTICES:



Source: <https://akap.ca/product/gmp/>

Fig .2 **Good Manufacturing Practices ensure consistent quality and safety**

- ❖ **Good Hygienic Practices (GHP):** GHP emphasizes the cleanliness and hygiene of the production environment and workforce. This includes maintaining proper sanitation of workspaces, equipment, and personal hygiene of staff to prevent contamination. GHP is crucial in maintaining both the safety and quality of food products by minimizing the risk of microbial contamination (Olaimat *et al.*, 2020).
3. **Quality Parameters:** Quality control in food production is determined through a variety of parameters that assess the sensory, microbiological, and chemical aspects of food products.
- ❖ **Sensory Quality Parameters:** These parameters involve evaluating the appearance, flavor, texture, and aroma of food products, which are critical to consumer acceptability. Sensory testing can be conducted by trained panels to ensure that products meet brand standards and consumer preferences.
 - ❖ **Microbiological Quality:** This involves monitoring microbial levels to ensure that foods are free from harmful pathogens and spoilage organisms. Microbiological testing is essential for perishable products like dairy, meat, and seafood, where microbial load can affect both safety and quality. Parameters like the total plate count (TPC), yeast and mold count, and specific pathogen testing (e.g., *Salmonella*, *E. coli*) are commonly used in quality control labs.
 - ❖ **Chemical Quality:** Chemical parameters ensure that food products meet nutritional and safety standards regarding additives, preservatives, and nutrient content. Chemical testing can detect residues of pesticides, heavy metals, and other contaminants, as well as verify the levels of key nutrients, flavors, and colors. Regulatory limits on contaminants such as lead, arsenic, and synthetic additives are crucial in ensuring food quality and safety (Allai *et al.*, 2023).

Together, these quality control mechanisms create a robust framework that helps manufacturers maintain product consistency, meet regulatory standards, and ensure consumer satisfaction. Quality control not only safeguards the sensory and nutritional attributes of food but also reinforces food safety by minimizing contamination risks and ensuring compliance with national and international standards. By applying these fundamental principles, the food industry can continue to deliver safe and high-quality products in an ever-evolving and complex food landscape.

Global Regulatory Frameworks and Standards

In a globalized food system, regulatory frameworks and standards for food safety play a pivotal role in safeguarding public health and promoting fair trade. These standards are set and enforced by various international organizations and initiatives, including the Codex Alimentarius, the World Health Organization (WHO), the Food and Agriculture Organization (FAO), the Global Food Safety Initiative (GFSI), the International Organization for Standardization (ISO), and the International Food Safety Authorities Network (INFOSAN). Together, they establish consistent protocols and guidelines for food safety, ensuring that foods are safe, reliable, and fairly traded across borders. In addition, the World Trade Organization (WTO) and the Sanitary and Phytosanitary (SPS) Agreement ensure that food safety

regulations are balanced with the need to facilitate international trade (Diaz *et al.*, 2020). This section will explore each of these organizations' history, structure, and roles in establishing global food standards.

Codex Alimentarius

- The **Codex Alimentarius** is one of the most influential regulatory frameworks for food safety, created jointly by the **FAO** and the **WHO** in 1963. The Codex establishes a collection of internationally recognized standards, guidelines, and codes of practice that cover every aspect of the food supply chain, from production and processing to labeling and distribution. Its primary goal is to protect consumer health and promote fair practices in international food trade. By providing universally applicable standards, Codex Alimentarius serves as a benchmark for both food safety regulations and trade (Fortin *et al.*, 2023).
- Codex Alimentarius operates through committees and working groups that address specific aspects of food safety, such as hygiene, food additives, pesticide residues, contaminants, and labeling. Each standard undergoes rigorous scientific analysis and stakeholder input before being adopted, ensuring its relevance and applicability worldwide. Countries are encouraged to adopt these standards into their national regulations to promote consistency in food safety practices and to reduce trade barriers. Codex standards are considered “voluntary,” but they hold significant influence as they are used by WTO’s SPS Agreement to resolve trade disputes related to food safety (Lawrence *et al.*, 2023).

World Health Organization (WHO) & Food and Agriculture Organization (FAO)

The **World Health Organization (WHO)** and the **Food and Agriculture Organization (FAO)** play complementary roles in promoting global food safety and food quality. Established by the United Nations, these organizations have distinct mandates but collaborate closely to support a safer, more resilient, and sustainable food system worldwide. Together, they help set standards, conduct research, and provide policy guidance to help countries prevent foodborne illnesses, address public health risks, and ensure the safety of the global food supply (Langsrud *et al.*, 2023).

World Health Organization (WHO)

The **World Health Organization (WHO)**, founded in 1948, is responsible for international public health. While it addresses a wide array of health issues, food safety is a major area of focus due to the close links between foodborne illnesses and public health. WHO's role in food safety includes:

1. **Providing Scientific Assessments and Risk Analysis:** WHO's scientific risk assessments form the basis for international food safety standards and help countries design policies that protect public health. Through its **International Programme on Chemical Safety (IPCS)**, WHO evaluates the health risks of contaminants, food additives, and toxic substances that may enter the food chain. Additionally, WHO provides guidelines on acceptable levels of microbial, chemical, and physical hazards in food, helping countries establish safe consumption thresholds.

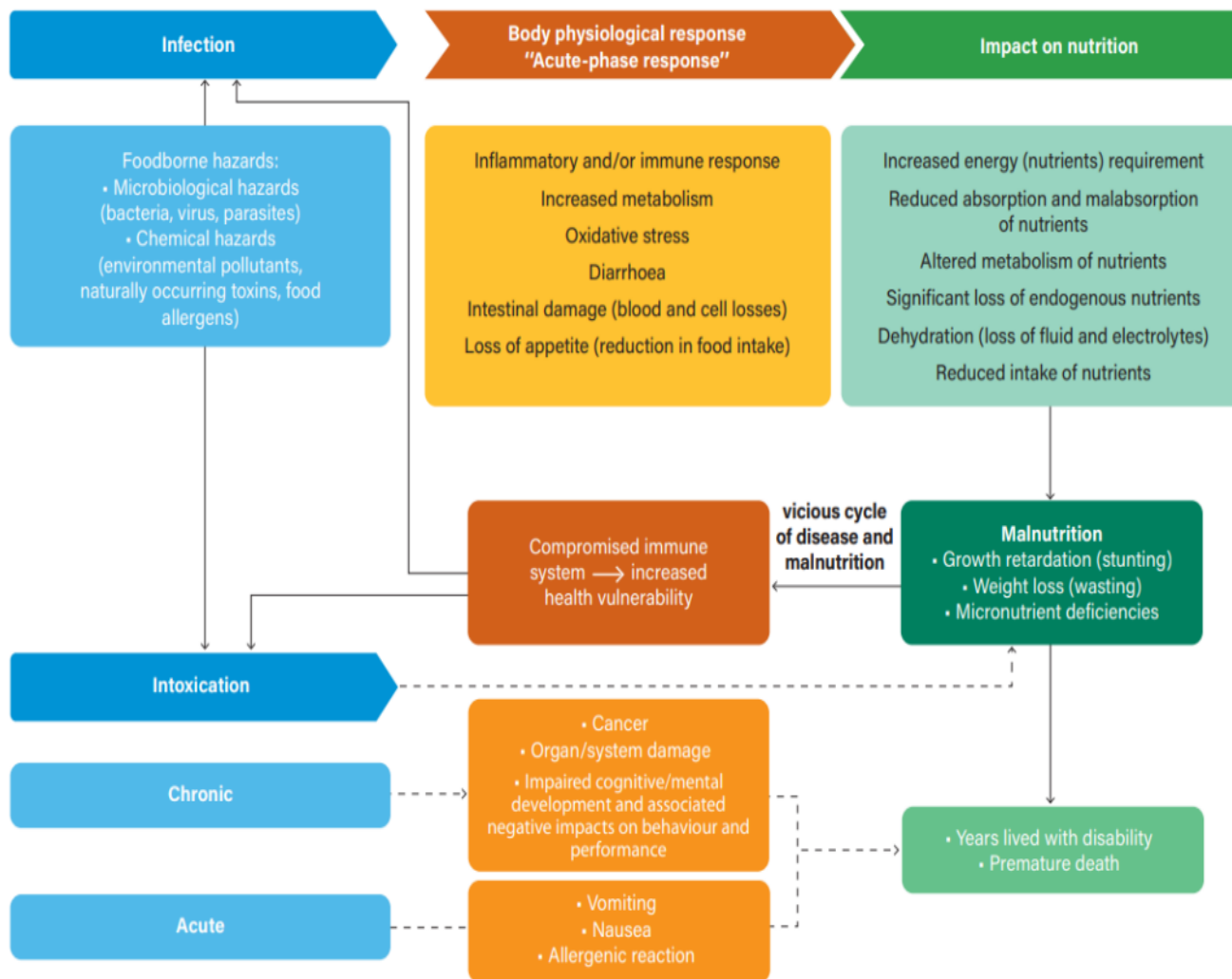
The **Joint FAO/WHO Expert Committee on Food Additives (JECFA)** and **Joint FAO/WHO Meetings on Pesticide Residues (JMPR)** are two scientific bodies that WHO co-leads with FAO. JECFA evaluates the safety of food additives, contaminants, and veterinary drug residues, while JMPR assesses pesticide residues in foods. Recommendations from these committees inform the Codex Alimentarius standards, which are adopted by countries worldwide.

2. **Developing Food Safety Guidelines:** WHO regularly publishes guidelines to help countries improve their food safety practices and respond to emerging food safety issues. For example, WHO guidelines address topics such as the reduction of foodborne pathogens, managing risks associated with antimicrobial resistance (AMR), and controlling contaminants like mycotoxins. These guidelines are designed to help countries, particularly those with limited resources, build capacity and infrastructure to manage food safety risks effectively.
3. **Supporting Foodborne Disease Surveillance:** WHO's **Global Foodborne Infections Network (GFN)** and **Global Burden of Foodborne Diseases (FERG)** projects aim to assess and track the global impact of foodborne illnesses. FERG studies quantify the global and regional burdens of foodborne diseases, helping policymakers identify the most pressing risks. GFN provides training and support for countries to establish their own surveillance systems, facilitating early detection of foodborne disease outbreaks and enabling rapid responses.
4. **Capacity Building in Developing Countries:** WHO is particularly focused on helping low- and middle-income countries strengthen their food safety systems. It provides training, resources, and

technical assistance to enhance these countries' capacity to implement food safety policies and conduct risk assessments. The WHO also collaborates with these countries to develop monitoring programs for foodborne pathogens, contaminants, and veterinary drug residues, which improves the overall food safety infrastructure.

5. **Addressing Antimicrobial Resistance (AMR):** A growing area of concern in food safety, AMR is when bacteria become resistant to antibiotics, often due to their overuse in agriculture and livestock. WHO's **Global Action Plan on Antimicrobial Resistance** highlights food as a transmission route for antibiotic-resistant bacteria, making it a significant public health risk. WHO works with FAO and other international agencies to promote responsible use of antimicrobials in food-producing animals, reduce residues in food, and develop global strategies to combat AMR.

Conceptual Framework for Food Borne Hazards, Nutrition and Health Nexus



Source <https://cdn.who.int/media/docs/default-source/food-safety/who-global-strategy-food-safety-2022-2030.pdf>

Fig .3 Conceptual Framework

Food and Agriculture Organization (FAO)

The **Food and Agriculture Organization (FAO)**, established in 1945, aims to combat hunger, improve nutrition, and ensure food security. Food safety is a crucial aspect of FAO's mandate as it directly impacts food security and agricultural productivity. FAO's food safety roles are diverse, covering agricultural practices, food production, and policy support to ensure that food is safe from farm to fork (Pirzadah *et al.*, 2020).

1. **Promoting Good Agricultural and Manufacturing Practices:** FAO develops guidelines and tools for **Good Agricultural Practices (GAP)** and **Good Manufacturing Practices (GMP)**, which help farmers and food processors minimize risks related to food safety. GAP focuses on sustainable agricultural practices that prevent contamination at the source, such as proper use of

pesticides, water management, and soil conservation. GMP ensures that manufacturers implement hygienic practices, control hazards, and maintain quality standards throughout the food processing stages.

2. **Technical Assistance and Capacity Building:** FAO provides technical assistance to countries, especially developing nations, to strengthen their food safety systems. This includes training programs on topics like HACCP (Hazard Analysis and Critical Control Points), risk assessment, and food inspection. FAO also collaborates with national governments to establish food control systems, improve laboratory capacities, and build effective regulatory frameworks that enable these countries to meet international standards.
3. **Addressing Emerging Risks:** FAO conducts research on emerging food safety risks, such as climate change's impact on foodborne pathogens, food fraud, and environmental contaminants. For example, FAO has studied how climate change can increase aflatoxin contamination in crops and how illegal practices, such as the adulteration of food products, pose risks to consumers. By identifying and analyzing these risks, FAO helps countries prepare for and mitigate potential threats to the food supply.
4. **FAO's Role in Pesticide Management:** As part of its commitment to safe agricultural practices, FAO addresses pesticide residues and management practices. FAO's **International Code of Conduct on Pesticide Management** provides a framework for regulating pesticide use and reducing pesticide residue risks in foods. FAO also co-manages the JMPR with WHO, assessing safe pesticide levels in foods to establish Maximum Residue Limits (MRLs) used in Codex standards.
5. **Supporting Smallholder Farmers and Food Security:** Smallholder farmers are integral to global food production, especially in developing countries, but often face challenges in meeting food safety standards due to limited resources. FAO provides these farmers with guidelines on safe and sustainable farming practices, helping them reduce contamination risks while increasing productivity. FAO also facilitates access to food safety education and market opportunities, enabling small-scale producers to contribute safely and sustainably to the food supply.
6. **Sustainable Food Systems and Climate Resilience:** FAO's food safety initiatives are increasingly focused on creating sustainable and climate-resilient food systems. This includes promoting sustainable food production practices, minimizing food waste, and implementing risk-based approaches to food safety that account for environmental changes. By addressing food safety within a sustainability framework, FAO aims to reduce foodborne hazards while promoting environmental stewardship (Mugo *et al.*, 2024).

Collaborative Efforts: WHO and FAO in Joint Initiatives

While WHO and FAO have distinct mandates, they collaborate extensively to address food safety challenges, leveraging each organization's strengths. Key collaborative initiatives include:

1. **Codex Alimentarius Commission:** WHO and FAO co-host the Codex Alimentarius Commission, which sets internationally recognized food safety standards, guidelines, and codes of practice. These standards help harmonize food safety regulations across countries, facilitating safer trade and protecting consumer health. WHO contributes expertise on public health impacts, while FAO provides insights on agricultural practices and food production.

2. **Joint FAO/WHO Expert Committee on Food Additives (JECFA):** Established in 1956, JECFA is an international scientific committee that evaluates the safety of food additives, contaminants, and residues of veterinary drugs in foods. Its recommendations inform Codex standards and support national food safety regulations.
3. **Joint FAO/WHO Meeting on Pesticide Residues (JMPR):** JMPR evaluates pesticide residues and provides guidance on safe levels in food, contributing to Codex standards. By determining Maximum Residue Limits (MRLs) for pesticides, JMPR plays a crucial role in ensuring safe food production while allowing for effective pest management.
4. **International Food Safety Authorities Network (INFOSAN):** WHO and FAO jointly run INFOSAN, which connects national food safety authorities globally to respond to food safety incidents and emergencies. INFOSAN enables countries to share information about food safety threats in real-time, facilitating rapid response to prevent contamination and foodborne disease outbreaks (Mugo *et al.*, 2024).

Global Food Safety Initiative (GFSI)

- The **Global Food Safety Initiative (GFSI)** is a business-driven initiative established in 2000 by the **Consumer Goods Forum**. Its purpose is to harmonize food safety standards and reduce duplication across the food industry, thus promoting efficiency and reliability in food safety practices. The GFSI provides a framework for food safety certification schemes, which helps reduce compliance costs and prevent redundant audits for food producers and suppliers.
- GFSI operates by benchmarking various food safety certification schemes, such as **Safe Quality Food (SQF)**, **British Retail Consortium (BRC)**, and **International Food Standard (IFS)**, against globally recognized criteria. By doing so, it ensures that certified companies comply with consistent and high-quality safety standards, regardless of the specific scheme. The GFSI fosters collaboration among retailers, suppliers, and stakeholders to align on food safety priorities and address global risks. It has gained recognition from governments and industries worldwide as an effective system to raise food safety standards (Cavelius *et al.*, 2023).
- **Benchmarking Standards:** GFSI recognizes several food safety management schemes, including the **Safe Quality Food (SQF)**, **British Retail Consortium (BRC)**, and **International Featured Standards (IFS)**. These schemes undergo rigorous benchmarking against GFSI's criteria to ensure they meet international food safety standards. Organizations certified by GFSI-recognized standards demonstrate their commitment to food safety and gain access to a wider market.
- **Collaboration and Capacity Building:** GFSI facilitates collaboration among industry stakeholders, enabling the sharing of insights and strategies for improving food safety. The initiative also provides resources and training programs to help organizations, particularly small and medium-sized enterprises (SMEs), enhance their food safety practices. GFSI's collaborative approach helps strengthen the overall food safety ecosystem.

International Organization for Standardization (ISO)

- The **International Organization for Standardization (ISO)** is an independent, non-governmental international organization with a membership of 165 national standards bodies.

ISO 22000 is one of the ISO standards specifically developed for food safety, which provides a framework for a Food Safety Management System (FSMS). This standard is applicable to any organization in the food chain, from farm to fork, offering a comprehensive approach to food safety (Riwayadi *et al.*, 2024).

- ISO 22000 incorporates **Hazard Analysis and Critical Control Points (HACCP)** principles and integrates them with the management system requirements common to other ISO standards, such as ISO 9001 (Quality Management) (Kaur *et al.*, 2021). The ISO 22000 framework requires companies to identify, evaluate, and control food safety hazards, ensuring that they produce safe food products. It also emphasizes the importance of communication along the food chain and provides a structured, process-based approach to managing food safety risks.

By harmonizing its standards with other international frameworks, ISO 22000 helps companies meet food safety requirements and consumer expectations. It is widely used by businesses around the world to gain certifications that demonstrate their commitment to food safety (Okpala *et al.*, 2023).

International Food Safety Authorities Network (INFOSAN)

- The **International Food Safety Authorities Network (INFOSAN)** was created by WHO and FAO to facilitate rapid sharing of food safety information across countries. INFOSAN's purpose is to prevent and control cross-border foodborne disease outbreaks, offering a platform for countries to share information and collaborate in emergencies.
- **INFOSAN** plays a crucial role in managing global food safety crises, such as disease outbreaks linked to contaminated food products. It consists of national food safety authorities and food safety focal points from over 180 countries, which coordinate in the event of an outbreak or contamination incident. (Duru *et al.*, 2023).

Through INFOSAN, affected countries can access information, technical expertise, and real-time support to contain risks and prevent further spread of the threat. INFOSAN helps prevent risks from becoming widespread and enhances the ability of countries to manage foodborne threats effectively.

World Trade Organization (WTO) and Sanitary and Phytosanitary (SPS) Agreement

- The **World Trade Organization (WTO)** is a global organization that governs international trade, including trade in food products. The **Sanitary and Phytosanitary (SPS) Agreement** is an essential part of the WTO framework, focusing on the application of food safety and animal and plant health standards. The SPS Agreement aims to balance the need for food safety regulations with the principles of fair trade, ensuring that food safety measures do not create unnecessary barriers to international trade (Narlikar, 2005).
- The SPS Agreement allows countries to set their own food safety standards, provided that they are scientifically justified and do not constitute disguised trade restrictions. The agreement encourages countries to base their national standards on international frameworks like the Codex Alimentarius, which helps harmonize food safety practices globally. When disputes arise, the WTO uses the SPS Agreement to resolve them, requiring that all food safety standards be backed by scientific evidence and applied consistently (Davis *et al.*, 2021).

- The SPS Agreement has been instrumental in promoting fair trade, ensuring that food safety measures are not used to create unjustified trade barriers. By requiring transparency and consistency, the agreement helps protect consumers without hindering trade. It also underscores the importance of mutual recognition among countries' food safety standards, reinforcing the Codex Alimentarius as a trusted framework for resolving disputes and fostering international cooperation in food safety (Rabaden & Triguero, 2021).

Major International Standards and Protocols

Food safety is a critical concern in today's globalized food supply chain. To address this, various international standards and protocols have been established to ensure the safety, quality, and integrity of food products. This section explores some of the most widely recognized standards, including **Hazard Analysis and Critical Control Points (HACCP)**, **ISO 22000**, the **Global Food Safety Initiative (GFSI)**, **Good Manufacturing Practices (GMP)**, and **Good Agricultural Practices (GAP)**. Each of these frameworks provides a structured approach to identifying and managing food safety risks, thereby promoting consumer health and confidence (Auwachi *et al.*, 2023).

Hazard Analysis and Critical Control Points (HACCP)

HACCP is a systematic, preventive approach to food safety that focuses on identifying and controlling potential hazards throughout the food production process. Developed in the 1960s by NASA for space missions, HACCP has become a global standard for food safety management in various sectors, including agriculture, food processing, and food service.

1. **Principles of HACCP:** HACCP is built on seven core principles:
 - ❖ **Conduct a Hazard Analysis:** Identify potential hazards that could occur at each step of the food production process.
 - ❖ **Determine Critical Control Points (CCPs):** Identify points in the process where control can be applied to prevent, eliminate, or reduce hazards to acceptable levels.
 - ❖ **Establish Critical Limits:** Define acceptable limits for each CCP to ensure that hazards are controlled.
 - ❖ **Establish Monitoring Procedures:** Develop procedures to monitor the CCPs to ensure they remain within critical limits.
 - ❖ **Establish Corrective Actions:** Outline steps to take when monitoring indicates a deviation from a critical limit.
 - ❖ **Establish Verification Procedures:** Implement procedures to confirm that the HACCP system is working effectively.
 - ❖ **Establish Record-Keeping and Documentation Procedures:** Maintain documentation that provides evidence of compliance with the HACCP plan.
2. **Implementation and Benefits:** HACCP is applicable at all stages of the food supply chain, from raw material production to consumption. By systematically analyzing and controlling potential hazards, HACCP helps food businesses prevent foodborne illnesses, enhance product quality, and comply with regulatory requirements. Furthermore, HACCP fosters a culture of food safety within organizations, encouraging staff to take responsibility for food safety practices.

3. **Global Acceptance:** HACCP is recognized by various international organizations, including the Codex Alimentarius, WHO, and FAO. Many countries have adopted HACCP as a mandatory requirement for food businesses, particularly in sectors such as meat processing, dairy, and seafood. The widespread acceptance of HACCP underscores its effectiveness in safeguarding public health and ensuring food safety.

ISO 22000: Food Safety Management Systems

- **ISO 22000** is an international standard that outlines the requirements for a Food Safety Management System (FSMS).
 - Published by the International Organization for Standardization (ISO) in 2005, ISO 22000 provides a framework for organizations involved in the food chain, from farm to fork, to manage food safety risks effectively (Chen *et al.*, 2020).
1. **Key Components of ISO 22000:** ISO 22000 integrates the principles of HACCP with other management system requirements, including the following key components:
 - **Interactive Communication:** Establishing effective communication among all stakeholders in the food supply chain, including suppliers, customers, and regulatory authorities.
 - **System Management:** Developing an FSMS that is adaptable and responsive to changing circumstances, ensuring continuous improvement.
 - **Prerequisite Programs (PRPs):** Implementing hygiene and safety measures to create a foundation for food safety, including Good Manufacturing Practices (GMP) and Good Agricultural Practices (GAP).
 - **HACCP Principles:** Incorporating HACCP principles into the FSMS to identify and control food safety hazards.
 2. **Benefits of ISO 22000:** Implementing ISO 22000 helps organizations ensure the safety of their food products, improve operational efficiency, and enhance customer satisfaction. The standard provides a systematic approach to managing food safety risks, enabling organizations to demonstrate compliance with legal requirements and gain consumer trust. Additionally, ISO 22000 facilitates international trade by harmonizing food safety standards across countries (Dhingra *et al.*, 2023).
 3. **Certification and Global Reach:** ISO 22000 is applicable to any organization in the food supply chain, regardless of size or complexity. Certification to ISO 22000 is carried out by independent certification bodies, providing assurance to customers and stakeholders that the organization is committed to food safety. As a globally recognized standard, ISO 22000 promotes consistency in food safety practices and encourages collaboration among organizations (Ningrum *et al.*, 2023).

Good Manufacturing Practices (GMP) and Good Agricultural Practices (GAP)

Good Manufacturing Practices (GMP) and **Good Agricultural Practices (GAP)** are essential frameworks that contribute to food safety and quality at different stages of the food supply chain.

1. **Good Manufacturing Practices (GMP):** GMP refers to the practices and procedures that ensure the consistent production of safe and high-quality food products. Key components of GMP include:
 - **Facility Design and Maintenance:** Ensuring that food processing facilities are designed to prevent contamination and maintain hygiene.
 - **Personnel Training:** Providing training to employees on food safety and hygiene practices to minimize the risk of contamination.
 - **Quality Control:** Implementing quality control measures throughout the production process to monitor and verify food safety parameters (Mishra *et al.*, 2024).

GMP is critical for food manufacturers, as it helps them comply with regulatory requirements and avoid food safety incidents. Compliance with GMP standards fosters a culture of food safety within organizations, reducing the risk of contamination and ensuring the production of safe food products (Sari, 2022).

2. **Good Agricultural Practices (GAP):** GAP encompasses a set of guidelines that promote sustainable and safe agricultural practices. These practices are designed to ensure the safety of agricultural products while minimizing environmental impact. Key aspects of GAP include:
 - **Soil and Water Management:** Implementing practices that prevent soil erosion and protect water resources.
 - **Pesticide Management:** Applying pesticides responsibly to minimize residues in food and protect biodiversity.
 - **Worker Health and Safety:** Ensuring the safety and well-being of farmworkers through training and protective measures.

GAP is particularly important for producers, as it establishes a foundation for producing safe food from the outset. Compliance with GAP standards not only enhances food safety but also improves market access, as many retailers and consumers demand sustainably produced food (Tadesse *et al.*, 2023).

Common Food Safety Hazards

Food safety hazards can be classified into three main categories: **biological**, **chemical**, and **physical**. Each category presents unique risks to consumer health and requires specific management strategies to mitigate these risks.

1. **Biological Hazards**

Biological hazards are pathogens such as bacteria, viruses, and parasites that can contaminate food and lead to foodborne illnesses. Common biological hazards include:

- **Bacteria:** Pathogenic bacteria such as *Salmonella*, *E. coli*, *Listeria monocytogenes*, and *Campylobacter* are leading causes of foodborne illnesses. These microorganisms can multiply rapidly in food if not handled properly.

- **Viruses:** Viruses like *Norovirus* and *Hepatitis A* can contaminate food through poor hygiene practices, leading to outbreaks, particularly in food service settings.
- **Parasites:** Protozoa, worms, and other parasites can be transmitted through contaminated water or undercooked food, posing health risks to consumers.
- **Fungi:** Molds and yeasts can also pose risks. Some molds produce mycotoxins, which are toxic compounds that can contaminate grains, nuts, and dried fruits, leading to serious health effects.

2. Chemical Hazards

Chemical hazards refer to harmful substances that can contaminate food. These include:

- **Pesticides:** Residues from agricultural chemicals can remain on food products if not managed correctly. Adhering to Good Agricultural Practices (GAP) can help minimize these risks.
- **Food Additives:** While many additives are safe when used as intended, improper use or contamination during processing can pose health risks.
- **Heavy Metals:** Contaminants like lead, mercury, and cadmium can enter the food chain through environmental pollution and accumulate in food products.
- **Allergens:** Ingredients like peanuts, tree nuts, gluten, and dairy can trigger severe allergic reactions in susceptible individuals. Proper labeling and cross-contamination prevention are critical.
- **Industrial Contaminants:** Chemicals such as polychlorinated biphenyls (PCBs) and dioxins can enter the food supply through environmental pollution and can accumulate in the food chain, particularly in fatty fish and dairy products.
- **Natural Toxins:** Certain foods can contain natural toxins. For example, solanine is a toxin found in green potatoes, while some species of mushrooms contain toxins that can cause severe illness or death (Van *et al.*, 2024).

3. Physical Hazards

Physical hazards are foreign objects that can inadvertently contaminate food, leading to injury or illness. Common physical hazards include:

- **Foreign Objects:** Items like glass, metal shards, and plastic can accidentally find their way into food during processing and packaging.
- **Bone Fragments:** In products like fish or meat, bone fragments can pose choking hazards or cause injury.
- **Packaging Materials:** Pieces of packaging materials, such as plastic or paper, can contaminate food if not properly managed during the manufacturing process. Regular audits and inspections can help identify potential sources of contamination.
- **Environmental Contaminants:** Dust, dirt, and other environmental contaminants can also be physical hazards. For example, improperly stored food can become contaminated by environmental debris.

- **Improperly Used Tools:** Kitchen tools, such as knives or blades, can break or chip and result in physical hazards if not properly maintained.

To mitigate physical hazards, food producers must implement robust quality control and inspection processes throughout the production and packaging stages.

Emerging Concerns

In addition to the traditional hazards, several emerging concerns pose new challenges to food safety:

- **Antibiotic Resistance:** The overuse of antibiotics in agriculture can lead to the development of antibiotic-resistant bacteria, which can transfer to humans through the food supply. This poses a significant public health risk, making infections harder to treat.
- **Microplastics:** The presence of microplastics in food and beverages, stemming from environmental pollution, poses potential health risks. Microplastics can accumulate in the food chain and their long-term effects on human health are still being studied.
- **Food Fraud:** The intentional mislabeling or adulteration of food products for economic gain is a growing concern. Food fraud undermines consumer trust and can pose health risks, especially when it involves allergens or contaminated ingredients.
- **Climate Change and Food Safety:** Climate change can exacerbate food safety hazards by altering the prevalence of certain pathogens and chemical contaminants. For instance, changing weather patterns can influence the spread of pests and diseases, impacting crop yields and food production practices. Addressing these issues requires adaptive strategies and resilience-building measures within food systems to maintain food safety amid changing environmental conditions (Duchenne *et al.*, 2021).

Conclusion

The landscape of food safety is increasingly complex, shaped by a multitude of emerging challenges that require a coordinated and proactive approach from all stakeholders. Climate change introduces significant risks by altering environmental conditions that can facilitate the spread of pathogens and contaminants, necessitating adaptive strategies to safeguard public health. Meanwhile, the rise of antimicrobial resistance highlights the urgent need for responsible antibiotic use in food production, emphasizing the importance of regulatory oversight and alternative management practices. As the demand for sustainable food production continues to grow, balancing environmental stewardship with stringent safety standards is paramount. Innovations in agricultural practices must prioritize both the health of consumers and the planet, fostering resilience against emerging food safety risks. Moreover, the globalization of food supply chains complicates the detection of food fraud, underscoring the necessity for enhanced traceability and transparency throughout the entire production process. Ultimately, ensuring food safety in this dynamic environment calls for collaboration among governments, industry leaders, and consumers. By embracing technological advancements and adopting comprehensive regulatory frameworks, we can navigate the challenges of today and build a safer, more sustainable food system for future generations. As we move forward, the commitment to food safety must remain steadfast, recognizing its vital role in protecting public health and fostering consumer trust in the food supply.

Disclaimer (Artificial intelligence)

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Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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- 1.
- 2.
- 3.

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