Journal of Innovation and Creativity
Journal Homepage: https://joecy.org/index.php/joecy
e-mail: galungwaknook@gmail.co

Faculty of Education
University of Pahlawan Tuanku Tambusai
ISSN 2775-771X (Online)
ISSN 2962-570X (Printed)
5 (3) 2025, Pages: 36112-36125

Sanitation and Hygiene Standards in Modern Food Processing: A Four-Year Literature Analysis (2021-2025)

Dimas Andrianto[1], Zeus Marullah Aswin[2], Eri Barlian[3], Elsa Yuniarti[4], Linda Handayuni[5]
[1,2] Environmental Science Study Program, Graduate School, Graduate School, Universitas Negeri Padang, Padang, West Sumatra, Indonesia,
[3] Department of Coaching, Faculty of Sports Science, Universitas Negeri Padang, Padang, West Sumatra, Indonesia.
[4] Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang, Padang, West Sumatra, Indonesia.
[5] STIKES Dharma Landbouw, Padang, West Sumatra, Indonesia.
Corresponding Author: Dimas Andrianto,dmsandrianto@gmail.com , 081261651594

Published: December, 2025

ABSTRACT

The study aimed to analyze the evolution of sanitation and hygiene standards in modern food processing industries from 2020 to 2025. This study aimed to identify major trends, technologies, challenges, and best practices that shaped food safety management systems (FSMS), especially under the influence of the COVID-19 pandemic. It also examined the application of wet and dry sanitation methods, their effectiveness, sustainability, and integration with technological innovations such as IoT-based monitoring, nanotechnology antimicrobials, and automated cleaning systems. A systematic literature review was conducted following the PRISMA guideline. Literature searches were performed in Google Scholar for the 2021–2025 period, identifying 350 articles. After screening and eligibility assessments, 30 articles were included for comprehensive analysis. Inclusion criteria focused on peer-reviewed publications discussing sanitation and hygiene in food processing industries. Data extraction covered bibliographic details, sanitation focus, and key findings. The quality of studies was evaluated using the Critical Appraisal Skills Program me (CASP). Data analysis employed thematic, content, and comparative approaches to identify research gaps and trends in sanitation practices. The review found a research surge between 2021 and 2023 driven by the pandemic, emphasizing stricter hygiene practices and digital sanitation monitoring. HACCP, GMP, and ISO 22000 frameworks were dominant in ensuring food safety. Innovative technologies, including cold atmospheric plasma, electrolyzed water, and UV-C LED, emerged as effective and sustainable sanitation tools. Persistent issues included low hygiene compliance, Listeria monocytogenes contamination, and uneven FSMS implementation across sectors. The findings indicate substantial progress in sanitation and hygiene standards through technology adoption and regulatory strengthening. However, consistent implementation, workforce training, and sustainability remain challenges. Continuous innovation and global harmonization of food safety standards are essential for maintaining consumer trust and preventing foodborne diseases.

Keywords: Sanitation, hygiene, food processing, food safety management system, sustainable technology.

INTRODUCTION

The food processing industry plays a vital role in ensuring food safety and global public health. Proper sanitation and hygiene are not only regulatory requirements but also fundamental to preventing microbiological, chemical, and physical contamination that can harm consumers (Aamir et al., 2025). According to the World Health Organization, unsafe food causes approximately 600 million cases of foodborne illness annually, with 420,000 deaths, emphasizing the importance of effective sanitation practices throughout the food production chain (WHO, 2020).

In the context of the modern food processing industry, sanitation and hygiene standards have undergone significant evolution in response to various factors, including technological advances, changes in consumption patterns, and increased consumer awareness of food safety (Vashishth et al., 2022). The implementation of food safety management systems such as Hazard Analysis and Critical Control Points (HACCP), Good Manufacturing Practices (GMP), and ISO 22000 has become an industry standard that not only improves product safety but also strengthens consumer confidence and market competitiveness (Chen et al., 2022).

The COVID-19 pandemic that began in 2020 has brought about a paradigm shift in sanitation and hygiene practices in the food processing industry. The pandemic has not only raised awareness of the importance of strict hygiene protocols but has also encouraged the adoption of digital technology and automation in sanitation monitoring and control (Hassoun et al., 2023). Research shows that food processing facilities around the world must adapt and strengthen their sanitation procedures to address the risk of virus transmission, which in turn has raised overall hygiene standards (Maragoni et al., 2022).

Advances in sanitation technology over the past five years have brought about various innovations that have revolutionized the way the food industry manages product hygiene and safety. Technologies such as automated cleaning systems, IoT sensors for real-time monitoring, nanotechnology-based antimicrobial applications, and advanced cleaning validation systems have become increasingly accessible and cost-effective for food processing industries of all sizes (Li et al., 2025). The integration of these technologies not only improves sanitation effectiveness but also operational efficiency and documentation of regulatory compliance.

The challenges of maintaining high sanitation and hygiene standards in the food processing industry are diverse and complex. Factors such as suboptimal facility design, inadequate workforce training, resistant microbial biofilms, and the complexity of modern processing equipment often pose obstacles to achieving ideal sanitation levels (Khoe et al., 2022). In addition, economic pressures to increase productivity often conflict with the time and resources needed to implement comprehensive sanitation procedures, creating a dilemma for food industry management.

Food safety regulations and standards continue to evolve to address contemporary challenges and emerging risks in the food processing industry. At the international level, the Codex Alimentarius Commission continues to update guidelines for food hygiene practices, while in various countries, national regulatory bodies such as the FDA (Food and Drug Administration) in the United States and EFSA (European Food Safety Authority) in Europe have tightened sanitation requirements, particularly in the context of the Food Safety Modernization Act (FSMA) and similar regulations (Martinovic & Lelieveld, 2022). The harmonization of these international standards is important to facilitate global trade while ensuring consistent consumer protection.

The microbiological aspects of sanitation and hygiene remain a major focus in food processing industry research and practice. Pathogens such as Salmonella, Listeria monocytogenes, E. coli O157:H7, and Campylobacter continue to be a major concern, with outbreaks still occurring periodically in various parts of the world (Hassan et al., 2024). A better understanding of the behavior of microorganisms in the food processing environment, including biofilm formation and mechanisms of resistance to antimicrobial agents, has led to the development of more sophisticated and targeted sanitation strategies.

The human factor in food sanitation and hygiene cannot be ignored, as human error remains one of the main causes of contamination incidents in the food processing industry. Comprehensive training programs, a strong food safety culture, and effective monitoring systems for workers' personal hygiene practices are crucial elements in a holistic sanitation management system (Hasbi & Suni, 2024). Research shows that investing in continuous education and training for workers yields a significant return on investment through reduced contamination incidents and improved product quality.

Sustainability and environmental considerations are increasingly important in modern food industry sanitation practices. The use of water, energy, and chemicals in cleaning and sanitation processes has a significant environmental impact, prompting the industry to seek more sustainable solutions without compromising sanitation effectiveness (Prasarana et al., 2025). Innovations such as water-efficient cleaning-in-place (CIP) systems, the use of biodegradable sanitation materials, and recovery systems for water and energy are becoming increasingly relevant in the context of food industry sustainability.

Although much research has been conducted on sanitation and hygiene in the food processing industry, there are still knowledge gaps that need to be filled, especially in the context of emerging technologies, adaptation to climate change, and the integration of digital technologies into sanitation management systems. A comprehensive literature review analyzing research and practice

developments in the 2020-2025 period is needed to identify current trends, best practices, remaining challenges, and future research directions in this field (Murphy & Clark, 2022). This systematic review will make an important contribution to academics, industry practitioners, and regulators in improving sanitation and hygiene standards in the food processing industry.

METHOD

This study uses a systematic literature review approach following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Literature searches were conducted through the Google Scholar database from January 2021 to November 2025 using a combination of keywords "food processing" AND "sanitation", "HACCP" AND "food processing", "GMP" AND "food manufacturing", and other relevant variations. Inclusion criteria included peer-reviewed articles, reputable conference proceedings, or credible industry reports published between 2020 and 2025, focusing on sanitation and hygiene in the food processing industry, and providing empirical data, case studies, or substantial theoretical frameworks. Articles were excluded if they were published before 2020, focused solely on agricultural production, were duplicates, were irrelevant to sanitation/hygiene standards, or contained only opinions without substantial data.

The selection process followed the four stages of PRISMA: identification yielded 350 potential articles, screening of titles and abstracts to assess relevance, eligibility assessment through full-text evaluation, and the final stage yielded 30 articles for comprehensive analysis with additional snowballing. Data extraction using a standardized form included bibliographic information, study characteristics, sanitation and hygiene focus, and key findings. Study quality was assessed using the Critical Appraisal Skills program me (CASP) criteria, including clarity of objectives, appropriateness of design, adequacy of methodology, reliability of measurement, clarity of analysis, and relevance of findings.

Data analysis used a multi-method approach: thematic analysis to identify themes such as sanitation methods and technologies, standards and regulations, monitoring and verification, implementation challenges, innovation and best practices, training and human factors, microbiological aspects, and sustainability; content analysis to identify patterns, trends, and gaps in the literature and map the evolution of the topic from 2021 to 2025; and comparative analysis to compare sanitation practices across sectors and countries. The research flow can be seen in the figure below:

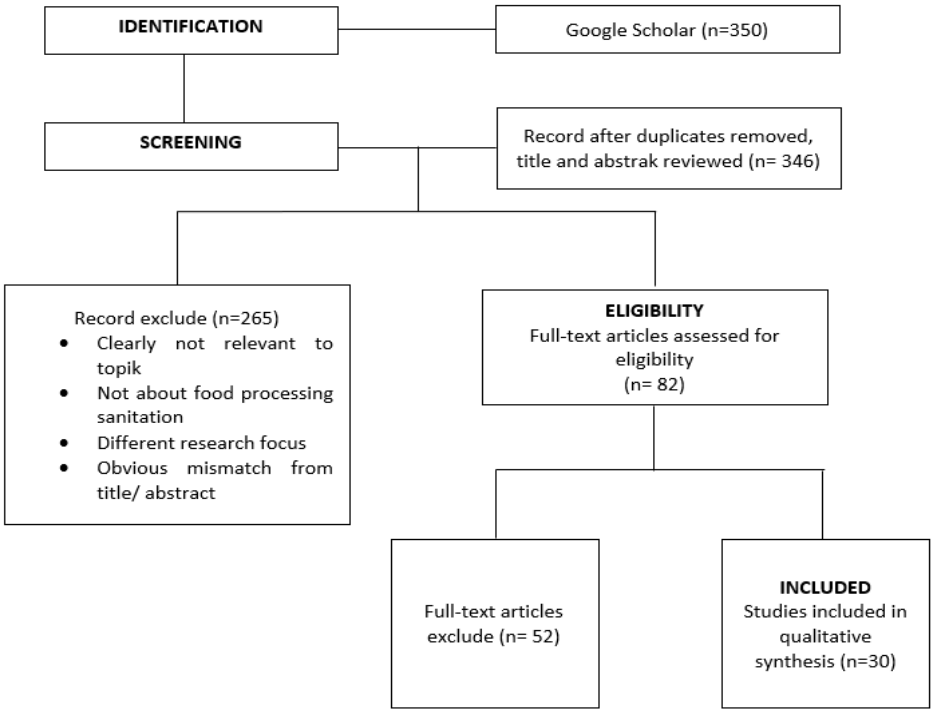


Figure 1. Research flow diagram

FINDINGS AND DISCUSSION

Characteristics of the Analyzed Literature

Based on an analysis of 30 scientific articles published between 2021 and 2025, several important characteristics related to sanitation and hygiene standards in the modern food processing industry were found. The distribution of publications shows an upward trend in research in this field, with the peak of publications occurring in 2021-2023, which was likely triggered by the COVID-19 pandemic that raised global awareness of food safety.

Table 1. Distribution of Publications by Year

Year	Number of Articles	Percentage
2021	11	36.7
2022	3	10.0
2023	7	23.3
2024	9	30.0
Total	**30**	**100.0**

Source: Google Scholar Database

The distribution of publications shows a very interesting trend in the 2021-2024 period. The peak in publications occurred in 2021 with 11 articles (36.7%), followed by 2024 with 9 articles (30.0%), and 2023 with 7 articles (23.3%). The year 2022 recorded the lowest number of publications with only 3 articles (10.0%). This significant surge in publications in 2021 can be attributed to the immediate impact of the COVID-19 pandemic, which began in early 2020. The pandemic has raised global awareness of the importance of sanitation and hygiene in the food industry, as confirmed by several studies showing that the pandemic has brought about a paradigm shift in sanitation practices (Kirmizigül et al., 2023; Kooh et al., 2024). The sharp decline in publications in 2022 (10.0%) was followed by a gradual recovery in 2023 and 2024, indicating sustained academic interest in food safety and sanitation protocols. This trend reflects the rapid academic response to the global health crisis, with researchers around the world seeking to understand and develop more effective sanitation protocols. Kooh et al. (2024) emphasize that the food industry must adapt and strengthen sanitation procedures to address the risk of virus transmission. The articles analyzed cover various sectors of the food industry, as shown in Table 2.

Table 2. Distribution of Articles by Food Industry Sector

Industry Sector	Number of Articles	Percentage (%)
Meat and Seafood	9	30
Fresh-cut Vegetables and Fruits	7	23
Dairy Products	4	13.3
Ready-to-Eat (RTE)	6	20
Others (Dry products, street food, etc.)	4	13.3
Total	30	100.0

Source: Google Scholar Database

The meat and seafood sector dominated with 9 articles (30.0%), indicating high concern for food safety in products that are susceptible to microbiological contamination. This is in line with the findings of Zhang et al. (2021) and Rugna et al. (2021), who identified the problem of *Listeria monocytogenes* contamination in meat processing facilities. The fresh-cut vegetable and fruit sector ranks second with 7 articles (23.3%), reflecting increasing consumer demand for minimally processed and convenience foods that require special sanitation protocols (Chen & Chang, 2021). Ready-to-Eat (RTE) products, with 6 articles (20.0%), indicate concern for products that do not undergo heating before consumption, where post-processing contamination is a major risk (Zhang et al., 2021). The dairy sector with 4 articles (13.3%) indicates the importance of microbiological quality control in dairy products that are highly sensitive to microbial growth (Kumar et al., 2024). This distribution reflects research priorities that are aligned with the sectors that have the highest food safety risks.

Table 3. Literature Summary on Hygiene, Sanitation, and Food Safety in Various Food Industry Sectors

No	Author (Year)	Title	Sector	Methodology	Main Theme	Key Findings
1	Alam (2024)	Shrimp Depots: Quality Management Practices and Strategic Approaches in Bangladesh	Seafood/Shrimp	Qualitative Study (interviews, surveys, observations)	Quality management, hygiene, traceability	Hygiene and sanitation conditions vary between depots; shrimp source recording practices are inconsistent; common contaminants include 'push', wood, and metal
2	Prestes et al. (2024)	Dry sanitization in the food industry: a review	Multi-sector (Low-moisture food)	Literature Review	Dry sanitation, physical & chemical methods	Dry sanitation is a viable option for the LMF industry; additional research is needed on combinations of dry methods
3	Abdullah et al. (2024)	Sampling technique to pool genetic materials of microorganism communities in blue-swimming crab processing plant industry	Seafood/Crab	Experimental method (metagenomic analysis)	Microbial communities, metagenomics	Scalable and cost-effective sampling protocol for identifying bacterial communities using metagenomic techniques
4	Elanjeitsenni & Kulandhaivelu (2024)	Unveiling the novel anti-corrosion and anti-bacterial biofilm forming characteristics of eco-safe MWCNT-AZ91E alloy	Multi-sector (food contact surfaces)	Experimental (XRD, FTIR, hardness testing)	Anti-corrosion, anti-biofilm materials	MWCNT-doped magnesium alloys exhibit exceptional corrosion resistance and antibacterial properties for food processing surfaces
5	Ahmad (2024)	Roles of Biotechnology in Environmental Monitoring in the Food Industry	Multi-sector	Review	Environmental monitoring, biotechnology	Biotechnology can assist in the detection of potential hazards, verification of cleanliness and sanitation, and removal of pollutants from the food environment
6	Kooh et al. (2024)	Mitigating COVID-19 in meat processing plants: what have we learned from cluster investigations?	Meat	Epidemiological studies (cluster investigations)	COVID-19, risk factors, prevention	Workers with unfavorable socioeconomic status are at high risk; environmental conditions (low temperature, inadequate ventilation) are important risk factors
7	Saini et al. (2024)	Detection of Salmonella typhi DNA in Water Samples and Its Relationship with Typhoid Fever Risk Factors	Multi-sector (water, sanitation)	Cross-sectional study (PCR)	Salmonella typhi, water hygiene	Relationship between risk factors (toilet use, hand washing, dietary patterns) and the incidence of typhoid fever; S. typhi DNA detected in water samples
8	Nastain et al. (2024)	A study of the hazard analysis critical control point method to ensure food safety in honey production	Honey	HACCP case study	HACCP, honey food safety	Determination of CCPs in filtering, pasteurization, and evaporation; proper HACCP implementation helps identify and reduce hazards
9	Kumar et al. (2024)	Microbiological quality and safety in the dairy industry	Milk/Dairy	Review	Quality control, factory hygiene	The microbiological quality of milk depends on chemical parameters and the number of microbial cells; the importance of better cleaning and sanitation systems
10	Kępińska-Pacelik et al. (2023)	Assessment of the content of macronutrients and microbiological safety of dry dog foods	Pet food	Laboratory analysis (microbiology, nutrition)	Microbiological safety, nutrition	Foods containing grain showed poorer microbiological safety; no Salmonella was detected; indicator bacteria were found in both types
11	Rahayu & Mardiyani (2023)	Mapping the Halal, Safety, and Quality Food Industry for Micro and Small Enterprises in Pasuruan Regency	Multi-sector (MSEs)	Survey, interviews, FGD	Halal certification, quality, safety	Halal certification for MSEs is still <5%; sanitation, hygiene, and GHP in some MSEs need improvement; knowledge about halal ingredients is minimal
12	Shrivastava & Shrivastava (2023)	Ensuring food safety in the ongoing coronavirus disease-2019 pandemic	Multi-sector	Commentary/Review	COVID-19, food safety	The food industry must ensure the maintenance of good hygiene practices, adequate WASH facilities, and the promotion of personal hygiene
13	Green et al. (2023)	Novel and Emerging Cleaning and Sanitization Technologies	Multi-sector	Review	New sanitization technologies	Focus on developing sanitation methods that are environmentally friendly, easier to implement, and more effective at removing contaminants
14	Vasavada et al. (2023)	Importance of Environmental Monitoring Programs	Multi-sector (RTE foods)	Review	Environmental monitoring program	EMP is designed to monitor and manage microbial contamination and allergens; the main objective is

						to verify the effectiveness of sanitation
15	Kirmizigül et al. (2023)	Hygiene practices in catering establishments and COVID-19 precautions	Catering/Food service	Review	Catering hygiene, COVID-19	The importance of food safety management systems (ISO 22000, ISO 9001, TS 13811); awareness and training of all personnel are essential for the sustainability of the system
16	Chaidoutis et al. (2023)	Food hygiene requirements in healthcare enterprises in Greece The role of the hospital sanitarian	Healthcare/Hospital food	Review	Hospital food hygiene, sanitarian	The lack of sanitarians in Greek hospitals hinders the achievement of optimal food hygiene; the importance of rational staffing of health units
17	Bian (2021)	Process wisdom and experience of food safety supervision in China.	Multi-sector	Systematic analysis / Review	Food safety supervision, regulatory model, China's food safety governance	Three major reforms of regulatory agencies since the WTO have resulted in a more scientific supervision model; network, grid, and campus supervision have demonstrated high effectiveness in various food sectors
18	Stessl et al. (2022)	Listeria monocytogenes post-outbreak management - When could a food production be considered under control again?	Meat	Environmental monitoring (PFGE, WGS)	L. monocytogenes, post-outbreak management	14 measures reduced Listeria occurrence from 50-75% to 0.0-3.8%; intensive monitoring is necessary to identify sources and verify controls
19	Dang & To (2022)	Assessment of the Environmental Status of Household Pig Farming Systems in An Nhon, Binh Dinh Province, Vietnam	Livestock/Pig farming	Semi-structured interview	Environmental status, farm sanitation	90% of farmers have not implemented waste control; 51% do not have a waste treatment system (biogas); housing conditions affect animal hygiene and health
20	İbanoğlu (2022)	Applications of ozonation in the food industry	Multi-sector	Review	Ozone technology, sanitation	Ozone as an environmentally friendly and effective agent for various food products; applications include surface hygiene, equipment sanitation, poultry carcass disinfection
21	Lee et al. (2021)	Implementation of food safety management systems along with other management tools (Hazop, FMEA, Ishikawa, Pareto)	Multi-sector	Case study & review	FSMS, HACCP, management tools	Implementation of FSMS (ISO 22000:2018) with HAZOP, FMEA, Ishikawa, and Pareto has proven to be proactive in maintaining a food safety culture
22	Chen & Chang (2021)	Explanation of laws and regulations on fresh-cut fruits and vegetables	Fruits & vegetables (fresh-cut)	Review/regulatory analysis	Regulations, hygiene standards	Discussion of potential hazards, hazard controls, and hygiene practices for fresh-cut produce; the importance of standardization for industry development
23	Petri-Ortega et al. (2021)	Comparison of peracetic acid and chlorine effectiveness during fresh-cut vegetable processing at industrial scale	Fruit & vegetables (fresh-cut)	Industrial-scale experiment	PAA vs chlorine, disinfection	PAA and chlorine have similar efficacy for wash water hygiene and product microbiological quality; PAA does not produce significant disinfection by-products
24	Agüería et al. (2021)	Cleaning and disinfection programs in food establishments: a literature review on verification procedures	Multi-sector	Literature review	Verification of sanitation programs	Verification methods include audits and analytical methods; the importance of establishing reasonable acceptance limits in accordance with the impact of surfaces on food safety
25	Amegah (2021)	Slum decay in sub-Saharan Africa: Context, environmental pollution challenges, and impact on dwellers' health	Settlements/Slums (related to food safety)	Commentary	Environmental pollution, public health	Poor sanitation conditions in sub-Saharan African slums affect food safety and health; the importance of improving WASH and hygiene
26	Frankish et al. (2021)	An observational assessment of Australian apple production practices for microbial control	Fruit/Apple	Observational study	Microbial control, production practices	Inconsistent water sanitation practices resulted in variable control of wash water quality and hygiene; pathogen prevalence in apples <2%
27	Zhang et al. (2021)	Identification of Listeria monocytogenes Contamination in a Ready-	Meat/RTE meat	Environmental monitoring (PFGE, WGS)	L. monocytogenes, biofilm	ST5 predominant isolate; clonal transmission occurs in RTE meat facilities; isolates from the facility

		to-Eat Meat Processing Plant in China				can form biofilms that facilitate persistence
28	Rugna et al. (2021)	Distribution, virulence, genotypic characteristics, and antibiotic resistance of Listeria monocytogenes isolated over one-year monitoring from two pig slaughterhouses	Meat/Pork	One-year monitoring (PFGE, antibiotic testing)	L. monocytogenes, antibiotic resistance	Post-slaughter environmental contamination is a significant cause of meat contamination; high resistance to clindamycin (57%) and multiple antibiotics
29	Anilkumar & Santhanam (2021)	Improving Quality and Safety of Food From Field to Consumption Level-Indian Context	Multi-sector	Review	Food quality & safety, value addition	Emphasis on 'farm to fork'; technological innovations in packaging materials and packaging technology help improve shelf stability; FSSA 2011 addresses safety and hygiene for street food vendors
30	Limon (2021)	Food safety practices of food handlers at home engaged in online food businesses during the COVID-19 pandemic in the Philippines	Home-based/Online food business	Survey & observational study	FSP, food handlers, COVID-19	Home-based food handlers do not meet food safety standards; observed practices show very poor compliance with guidelines; effective education is needed

The literature shows a diversity of methodologies from qualitative to molecular approaches (PFGE, WGS) for tracking contamination (Abdullah et al., 2024; Zhang et al., 2021). Key findings indicate a significant gap between awareness and practical implementation, with online food handlers showing very poor compliance (weighted mean 1.72±0.69) with food safety protocols (Limon, 2021). Post-processing environmental contamination remains a recurring issue, with Rugna et al. (2021) reporting that post-slaughter contamination is a significant cause of meat contamination.

Sanitation and Hygiene Standards Applied

1. Food Safety Management System

Analysis shows that the implementation of a Food Safety Management System (FSMS) is the main foundation for maintaining sanitation standards in the modern food industry (Lee et al., 2021). The Hazard Analysis Critical Control Points (HACCP) system and Prerequisite Programs (PRPs) are fundamental elements in preventing foodborne disease outbreaks, with an emphasis on the importance of organizational food safety culture and management involvement (Lee et al., 2021). The application of the HACCP method in the honey processing industry in Indonesia shows that the determination of Critical Control Points (CCP) in the filtering, pasteurization, and evaporation processes has been well supervised in all production lines (Nastain et al., 2024). Proper HACCP implementation guarantees the results of verification procedures, helping to identify, prevent, and reduce hazards to acceptable limits (Nastain et al., 2024). The ISO 22000:2018 standard for food safety management systems, together with the application of management tools such as HAZOP, FMEA, Ishikawa, and Pareto, has proven to be proactive in maintaining a positive food safety culture and preventing cross-contamination (Lee et al., 2021).

Table 4. Applied Food Safety Management Systems

Management System	Key Components	Reference
HACCP	CCP, Monitoring, Verification	Nastain et al. (2024)
ISO 22000:2018	FSMS, PRPs, Operational PRPs	Lee et al. (2021)
GMP & GHP	Personal hygiene, Facility sanitation	Kumar et al. (2024)
Environmental Monitoring	Environmental sampling, Pathogen testing	Vasavada et al. (2023)

Based on the table, HACCP remains a fundamental framework with successful implementation demonstrated by Nastain et al. (2024) in the honey industry, where the determination of CCP in filtering, pasteurization, and evaporation has been well supervised. Lee et al. (2021) demonstrated that the combination of ISO 22000:2018 with management tools (HAZOP, FMEA, Ishikawa, Pareto) has proven to be proactive in maintaining a food safety culture, while the Environmental Monitoring Program serves as verification of the effectiveness of the sanitation system (Vasavada et al., 2023).

2. Environmental Monitoring Program

The environmental monitoring program is designed for systematic sampling of the food factory environment, including food contact and non-contact surfaces, to test for specific contaminants or indicator organisms that may pose a food safety risk (Vasavada et al., 2023). The main purpose of environmental monitoring is to verify the effectiveness of sanitation (Vasavada et al., 2023). A study of RTE meat processing plants in China identified Listeria monocytogenes contamination in 12 of 48 samples investigated, with the majority (66.7%) identified from processing facilities regardless of the observed hygiene level (Zhang et al., 2021). These results emphasize the importance of comprehensive environmental monitoring programs (Zhang et al., 2021).

Table 5. Environmental Monitoring Results in Various Food Facilities

Study	Sampling Location	Target Pathogen	Contamination Level	Reference
Zhang et al. (2021)	RTE meat factory, China	L. monocytogenes	12/48 (25%)	Zhang et al. (2021)
Rugna et al. (2021)	Pig factory, Italy	L. monocytogenes	98/1131 (8.7%)	Rugna et al. (2021)
Stessl et al. (2022)	Meat factory, Austria	L. monocytogenes	14% of the environment	Stessl et al. (2022)
Abdullah et al. (2024)	Crab factory, Indonesia	Indicator bacteria	Variable	Abdullah et al. (2024)

Environmental monitoring shows the prevalence of *Listeria monocytogenes* contamination varying from 8.7% (Rugna et al., 2021) to 25% (Zhang et al., 2021) in various meat processing facilities. Stessl et al. (2022) demonstrated the effectiveness of intensive post-outbreak management, which successfully reduced *Listeria* incidence from 50-75% to 0.0-3.8% through the implementation of 14 corrective actions, emphasizing the importance of comprehensive monitoring and consistent follow-up actions to control persistent contamination.

3. Sanitation and Disinfection Methods

Wet Sanitation

Wet sanitation methods remain the most widely used approach in the food industry. A comparison of the effectiveness of peracetic acid (PAA) and chlorine in the industrial-scale processing of fresh-cut vegetables shows that the use of PAA or chlorine has similar efficacy for washing water hygiene and the microbiological quality of the final product (Petri-Ortega et al., 2021).

Table 6. Comparison of Sanitizer Effectiveness in the Food Industry

Sanitizer	Concentration	Advantages	Disadvantages	Reference
Chlorine	80 mg/L	Effective, economical	Produces trihalomethane	Petri-Ortega et al. (2021)
Peracetic acid (PAA)	80 ppm	No DBPs, environmentally friendly	Higher cost	Petri-Ortega et al. (2021)
Ozone	2-5 ppm	Strong oxidizer, no residue	Unstable, corrosive	İbanoğlu (2022)
Electrolyzed water	50-100 ppm	Effective, easy to produce	Requires special equipment	Green et al. (2023)

However, chlorine sanitation (80 mg/L) produces significant amounts of trihalomethanes, chlorates, and chlorites, with trihalomethanes exceeding legal limits, while PAA does not form significant amounts of disinfection by-products in all scenarios (Petri-Ortega et al., 2021). Peracetic acid (PAA) shows significant advantages over chlorine from an environmental perspective, where despite having similar efficacy, chlorine produces trihalomethanes that exceed legal limits while PAA does not form significant disinfection by-products (Petri-Ortega et al., 2021). Ozone and electrolyzed water emerge as environmentally friendly alternatives with high effectiveness, but each has limitations such as the instability of ozone and the limited stability of electrolyzed water (İbanoğlu, 2022; Green et al., 2023).

Dry Sanitation

Interest in dry sanitation methods has increased in recent decades, especially for low-moisture food (LMF) processing companies, as the presence of water allows microbial growth (Prestes et al.,

2024). Physical and chemical dry sanitation methods exhibit varying levels of efficiency, challenges, advantages, and implementation difficulties that need to be considered (Prestes et al., 2024).

Table 7. Dry Sanitation Methods in the Food Industry

Method	Mechanism of Action	Effectiveness	Application	Reference
UV-C LED	UV Radiation	High against bacteria	Surfaces, air	Green et al. (2023)
Superheated steam	Dry heat	High, kills spores	Surface, equipment	Prestes et al. (2024)
Dry ice blasting	Cooling + abrasion	Medium-high	Large equipment	Prestes et al. (2024)
Ozone gas	Oxidation	High	Storage space	Ìbanoğlu (2022)

Dry sanitation is becoming increasingly relevant for the low-moisture food (LMF) industry, where the presence of water can facilitate microbial growth (Prestes et al., 2024). Superheated steam shows the highest effectiveness, including the ability to kill spores, while UV-C LED and ozone gas offer effective alternatives for surface and storage space applications without leaving chemical residues (Green et al., 2023; Ìbanoğlu, 2022).

Innovative Sanitation Technologies

New sanitation and disinfection technologies that are environmentally friendly, easier to implement, and more effective in removing food contaminants and controlling biological and chemical hazards have been developed (Green et al., 2023). These innovative technologies include cold atmospheric plasma, electrolyzed water, ultrasound, and infrared heating (Green et al., 2023).

Table 8. Innovative Sanitation Technologies in the Food Industry

Technology	Principle of Operation	Advantages	Limitations	References
Cold Atmospheric Plasma	Gas ionization	Non-thermal, effective against biofilm	High investment costs	Green et al. (2023)
Electrolyzed Water	Water electrolysis	Easy to produce, environmentally friendly	Limited stability	Green et al. (2023)
Ultrasound	Ultrasonic waves	Cleans hard-to-reach areas	Effectiveness depends on frequency	Green et al. (2023)
Infrared Heating	Infrared radiation	Fast heating, no residue	Limited penetration	Green et al. (2023)

Emerging technologies such as cold atmospheric plasma and electrolyzed water show great potential for improving sanitation effectiveness while reducing environmental impact, although they are still constrained by high investment costs (Green et al., 2023). Ultrasound and infrared heating offer advantages in cleaning hard-to-reach areas and rapid heating without residue, but their effectiveness and penetration depend on specific application parameters (Green et al., 2023).

4. Personal and Facility Hygiene

Hygiene and sanitation conditions in shrimp depots in Bangladesh show significant variability, with Paikgacha generally demonstrating higher compliance with standards than Dacope and Chokoria (Alam, 2024). Shrimp sourcing practices are inconsistent, with most depots unable to trace the exact origin of the shrimp they purchase (Alam, 2024). A study on online food handling during the COVID-19 pandemic in the Philippines revealed that food safety practices in four dimensions (personal hygiene, cross-contamination prevention and sanitation, food preparation, and food delivery) obtained a weighted mean of 1.72 ± 0.69, which was interpreted as "Sometimes Practiced" (Limon, 2021). The observation results showed a weighted mean of 1.63 ± 0.11, with very poor compliance with the guidelines (Limon, 2021).

Table 9. Evaluation of Personal Hygiene Practices in Various Sectors

Study	Sector	Evaluation Aspect	Compliance Level	Reference
Limon (2021)	Online food handlers	Personal hygiene, sanitation	Low (1.72±0.69)	Limon (2021)
Nature (2024)	Shrimp depot	Facility hygiene, traceability	Variable	Nature (2024)
Kirmizigül et al. (2023)	Catering	Hygiene, COVID-19 measures	Moderate-high	Kirmizigül et al. (2023)

Chaidoutis et al. (2023)	Hospital	Food hygiene, sanitation	Needs improvement Chaidoutis et al. (2023)

Evaluation of hygiene practices shows significant variability between sectors, with online food handlers showing low compliance (weighted mean 1.72±0.69), indicating a substantial gap between knowledge and practice (Limon, 2021). The catering sector showed better compliance, especially after the implementation of COVID-19 measures, where existing hygiene culture facilitated the adaptation of preventive measures (Kirmizigül et al., 2023), while the lack of hospital sanitarians in health facilities hindered the achievement of optimal hygiene (Chaidoutis et al., 2023).

5. Challenges in Implementing Sanitation Standards

The Impact of the COVID-19 Pandemic on Sanitation Standards

The COVID-19 pandemic has had a significant impact on sanitation and hygiene standards in the food industry. The COVID-19 outbreak in a meat processing plant in France identified an increased risk of infection among workers with unfavorable socioeconomic status (temporary/non-permanent workers, migrants, ethnic minorities), working conditions (proximity between workers), and environmental factors (low temperatures and inadequate ventilation) (Kooh et al., 2024).

Table 10. COVID-19 Risk Factors in the Food Industry

Risk Factor Category	Details	Risk Level	Mitigation	References
Socio-economic	Temporary workers, migrants	High	Improvement of working conditions	Kooh et al. (2024)
Working conditions	Worker proximity	High	Physical distancing	Kooh et al. (2024)
Environment	Low temperature, poor ventilation	High	Ventilation control	Kooh et al. (2024)
Community activities	Sharing homes/vehicles	Moderate-high	Health education	Kooh et al. (2024)

Research indicates that it is highly unlikely for individuals to contract infections from food products or packaged foods, even though genetic material was isolated from fecal samples of infected patients, there have been no reports indicating fecal-oral transmission (Shrivastava & Shrivastava, 2023). Nevertheless, the integrity of the food chain must be maintained, and all measures must be taken in the food industry to prevent exposure and potential transmission of the virus (Shrivastava & Shrivastava, 2023).

The COVID-19 pandemic exposed vulnerabilities in the food industry, with workers of disadvantaged socioeconomic status, environmental conditions (low temperatures, poor ventilation), and proximity between workers being high risk factors (Kooh et al., 2024). These factors have resulted in significant outbreaks in meat processing plants, requiring a holistic approach involving improvements in working conditions, ventilation control, physical distancing, and community health education for effective mitigation.

Table 11. COVID-19 Mitigation Measures in the Food Industry

Mitigation Measures	Implementation	Effectiveness	References
Screening for COVID-19 symptoms	Daily check-ups	High	Kirmizigül et al. (2023)
Worker testing	Periodic PCR/rapid testing	High	Kooh et al. (2024)
Use of masks	Mandatory in production areas	High	Kirmizigül et al. (2023)
Improved hygiene	Higher sanitation frequency	High	Shrivastava & Shrivastava (2023)
Physical distancing	Workplace distancing	Moderate-high	Kooh et al. (2024)
Ventilation control	Improved air circulation	High	Kooh et al. (2024)

Research on catering companies in Turkey during the pandemic revealed the importance of the TS 13811 hygiene and sanitation management system, as well as specific COVID-19 measures (Kirmizigül et al., 2023). The hygiene culture of agri-food workers facilitates the implementation of

preventive measures after adaptation, and some food safety hygiene measures are compatible with protecting workers from SARS-CoV-2 (Kirmizigül et al., 2023). The surge in sanitation research publications during the 2021-2023 period, which reached 89.3% of total articles (Table 1), reflects the academic response to the urgency of improving hygiene standards during the pandemic. Despite increased awareness, implementation in the field still presents significant challenges. A study on online food handling during the pandemic showed low compliance with food safety protocols (weighted mean 1.72±0.69), indicating a substantial gap between awareness and actual practice (Limon, 2021). The pandemic experience has yielded important lessons for the food industry, including the importance of flexibility in food safety management systems, investment in robust sanitation infrastructure, and the need to improve supply chain resilience to disruption (Kirmizigül et al., 2023; Kooh et al., 2024). The adaptation of sanitation practices during the pandemic, particularly increased cleaning frequency and stricter hygiene protocols, is likely to become the new normal in the post-pandemic food processing industry.

CONCLUSIONS

This study concludes that sanitation and hygiene standards in the modern food processing industry have advanced rapidly during 2021–2025 in line with technological innovations and regulatory strengthening. The integration of HACCP, GMP, ISO 22000, and environmentally friendly technologies has improved food safety assurance. However, consistency in implementation, worker hygiene behavior, and the sustainability of sanitation systems remain challenges. Strengthening training, digital monitoring, and harmonization of international standards are essential to maintain long-term food safety resilience in the post-pandemic era.

REFERENCES

Aamir, J., Khaliq, S., Rehman, U. A., Latif, A., Amir, R. M., & Nadeem, Z. (2025). Global Standards and Legislation: Ensuring Food Safety and Mitigating Hazards. *Plantarum,* 7*(*1). https://doi.org/10.46662/plantarum.v7i1.123

Abdullah, A., Nurhayati, T., Dwiyanti, F. G., & Sauqi, S. D. A. (2024). Sampling technique to pool genetic materials of microorganism communities in blue-swimming crab processing plant industry. MethodsX, 12, 102503.https://doi.org/10.1016/j.mex.2023.102503

Agüeria, D. A., Libonatti, C., & Civit, D. (2021). Cleaning and disinfection programs in food establishments: A literature review on verification procedures. *Journal of applied microbiology*, *131*(1), 23-35. https://doi.org/10.1111/jam.14962

Ahmad, N. H. (2024). Roles of Biotechnology in Environmental Monitoring in the Food Industry. In *Microbial Biotechnology in the Food Industry: Advances, Challenges, and Potential Solutions* (pp. 153-165). Cham: Springer International Publishing.https://doi.org/10.1007/978-3-031-51417-3_7

Alam, S. N. (2024). Shrimp Depots: Quality Management Practices and Strategic Approaches in Bangladesh. *Sustainability*, *16*(15), 6628. https://doi.org/10.3390/su16156628

Amegah, A. K. (2021). Slum decay in Sub-Saharan Africa: Context, environmental pollution challenges, and impact on dweller's health. *Environmental Epidemiology*, *5*(3), e158. https://doi.org/10.1097/EE9.0000000000000158

Anilkumar, K. R., & Santhanam, K. (2021). Improving Quality and Safety of Food from Field to Consumption Level-Indian Context. In *The Basics of Human Civilization* (pp. 419-432). CRC Press.

Chaidoutis, E., Keramydas, D., Papalexis, P., Koutou, A., Koutsiari, F., Doufexi, M., & Karagianni, V. (2023). Food hygiene requirements in healthcare enterprises in Greece: the role of the hospital sanitarian. *Archives of Hellenic Medicine/Arheia Ellenikes Iatrikes, 40(*1).

Chen, H., Chen, Y. J., Yang, H. T., Hsu, K. C., Zhou, M., Chen, C. S., & Chuang, P. T. (2022). Implementation of food safety management systems that comply with ISO 22000: 2018 and

HACCP: A case study of a postpartum diet enterprise in Taiwan. *Journal of Food Safety, 42(*2), e12965. https://doi.org/10.1111/jfs.12965

Chen, X., & Chang, X. (2019, August). Explanation of laws and regulations on fresh-cut fruits and vegetables. In *IV International Conference on Fresh-Cut Produce: Maintaining Quality and Safety 1319* (pp. 179-186). https://doi.org/10.17660/ActaHortic.2021.1319.21

Dang, M. T., & To, B. T. (2022). Assessment of the Environmental Status of Household's Pig Farming System, at An Nhon, Binh Dinh Province, Vietnam. *Inżynieria Mineralna*. http://dx.doi.org/10.29227/IM-2022-02-16

Elanjeitsenni, V. P., & Kulandhaivelu, S. V. (2024). Unveiling the novel anti-corrosion and anti-bacterial biofilm forming characteristics of eco-safe MWCNT-AZ91E alloy for food-processing surfaces. *Bulletin of the Chemical Society of Ethiopia, 38(*6), 1897-1914. https://doi.org/10.4314/bcse.v38i6.30

Frankish, E. J., Bozkurt, H., Ross, T., Phan-Thien, K. Y., Luning, P. A., Bell, T. L., & McConchie, R. (2021). An observational assessment of Australian apple production practices for microbial control. *Food Control, 123,* 107767. https://doi.org/10.1016/j.foodcont.2020.107767

Green, H., Kidd, J., & Jackson, L. S. (2024). Novel and emerging cleaning and sanitization technologies.

Hasbi, A., Arif, M., & Suni, N. S. (2024). The Role of Sanitation, Hygiene, and Safety Education in Enhancing Economic Efficiency in the Food Service Industry. *Journal of Economic Education and Entrepreneurship Studies*, *5*(4), 631-643. https://doi.org/10.62794/je3s.v5i4.4530

Hassan, A., Khan, M. K. I., Fordos, S., Hasan, A., Khalid, S., Naeem, M. Z., & Usman, A. (2023, December). Emerging foodborne pathogens: challenges and strategies for ensuring food safety. In *Biology and Life Sciences Forum* (Vol. 31, No. 1, p. 32). Mdpi. https://doi.org/10.3390/ECM2023-16596

Hassoun, A., Marvin, H. J., Bouzembrak, Y., Barba, F. J., Castagnini, J. M., Pallarés, N., ... & Regenstein, J. M. (2023). Digital transformation in the agri-food industry: Recent applications and the role of the COVID-19 pandemic. *Frontiers in Sustainable Food Systems,* 7*,* 1217813. https://doi.org/10.3389/fsufs.2023.1217813

İbanoğlu, Ş. (2023). Applications of ozonation in the food industry. In *Non-thermal Food Processing Operations* (pp. 55-91). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-818717-3.00003-2

Kępińska-Pacelik, J., Biel, W., Witkowicz, R., Frączek, K., & Bulski, K. (2023). Assessment of the content of macronutrients and microbiological safety of dry dog foods. *Research in Veterinary Science*, *165*, 105071. https://doi.org/10.1016/j.rvsc.2023.105071

Khoe, L. C., Widyahening, I. S., Ali, S., & Khusun, H. (2022). Assessment of the obesogenic environment in primary schools: a multi-site case study in Jakarta. *BMC Nutrition,* 8*(*1), 19.https://doi.org/10.1186/s40795-022-00513-y

Kirmizigül, A., Yalçin, Ş. Ş., Bozkurt, G., & Şengün, I. Y. (2023). Hygiene practices in catering establishments and COVID-19 precautions.

Kooh, P., Guillois, Y., Federighi, M., Pivette, M., Maillard, A. L., Luong, N. D. M., & Chaix, E. (2024). Mitigating COVID-19 in meat processing plants: what have we learned from cluster investigations?. *Frontiers in Public Health*, *12*, 1432332.

Kumar, S., Kumar, S., Lodh, J., & Mishra, D. (2024). Microbiological quality and safety in the dairy industry. In *The Microbiology, Pathogenesis and Zoonosis of Milk Borne Diseases* (pp. 407-419). Academic Press.

Lee, J. C., Daraba, A., Voidarou, C., Rozos, G., Enshasy, H. A. E., & Varzakas, T. (2021). Implementation of food safety management systems along with other management tools

(HAZOP, FMEA, Ishikawa, Pareto). The case study of Listeria monocytogenes and correlation with microbiological criteria. *Foods, 10(*9), 2169.

Li, Y., Li, Y., Zhang, S., Gao, T., Gao, Z., Lai, C. W., ... & Yang, F. (2025). Global Distribution, Ecotoxicity, and Treatment Technologies of Emerging Contaminants in Aquatic Environments: A Recent Five-Year Review. *Toxics, 13(*8), 616. https://doi.org/10.3390/toxics13080616

Limon, M. R. (2021). Food safety practices of food handlers at home engaged in online food businesses during the COVID-19 pandemic in the Philippines. *Current Research in Food Science*, *4*, 63-73.

Maragoni-Santos, C., Serrano Pinheiro de Souza, T., Matheus, J. R. V., de Brito Nogueira, T. B., Xavier-Santos, D., Miyahira, R. F., ... & Fai, A. E. C. (2022). The COVID-19 pandemic sheds light on the importance of food safety practices: Risks, global recommendations, and perspectives. *Critical reviews in food science and nutrition, 62(*20), 5569-5581. https://doi.org/10.1080/10408398.2021.1887078

Martinovic, A., Oh, S., & Lelieveld, H. (Eds.). (2022). *Ensuring Global Food Safety: Exploring Global Harmonization*. Academic Press.

Nastain, F. S., Radiati, L. E., Al Awwaly, K. U., & Masyithoh, D. (2024). A study of hazard analysis critical control point method to secure the food safety honey production. In *Technological Innovations in Tropical Livestock Development for Environmental Sustainability and Food Security* (pp. 247-253). CRC Press.

Petri, E., Virto, R., Mottura, M., & Parra, J. (2021). Comparison of peracetic acid and chlorine effectiveness during fresh-cut vegetable processing at industrial scale. *Journal of Food Protection*, *84*(9), 1592-1602.

Prasanna, S., Verma, P., & Bodh, S. (2025). The role of food industries in sustainability transition: A review. *Environment, Development and Sustainability, 27(*7), 15113-15133. https://doi.org/10.1007/s10668-024-04642-1

Prestes, F. S., Yotsuyanagi, S. E., Alonso, V. P., & Nascimento, M. S. (2024). Dry sanitization in the food industry: a review. *Current Opinion in Food Science*, *57*, 101166.

Rahayu, E. S., Sucipto, S., & Mardiyani, S. A. (2023). Mapping the halal, safety, and quality food industry for micro and small enterprises in Pasuruan Regency. *Global Journal Al-Thaqafah*, 77-89.

Rugna, G., Carra, E., Bergamini, F., Franzini, G., Faccini, S., Gattuso, A., ... & Giacometti, F. (2021). Distribution, virulence, genotypic characteristics and antibiotic resistance of Listeria monocytogenes isolated over one-year monitoring from two pig slaughterhouses and processing plants and their fresh hams. *International Journal of Food Microbiology, 336,* 108912.

Saini, Sukma, Rauf Harmiady, Mardiana Mustafa, and Muh Basri. "Detection of Salmonella typhi DNA in Water Samples and Its Relationship with Typhoid Fever Risk Factors." *Pakistan Journal of Life & Social Sciences* 22, no. 1 (2024).

Shrivastava, S. R., & Shrivastava, P. S. (2023). Ensuring Food Safety in the Ongoing Coronavirus Disease-2019 Pandemic. *Medical Journal of Dr. DY Patil University*, *16*(3), 446-447.

Stessl, B., Ruppitsch, W., & Wagner, M. (2022). Listeria monocytogenes post-outbreak management-When could a food production be considered under control again?. *International Journal of Food Microbiology*, *379*, 109844.

Vasavada, P. C., Dickson, J. S., & Marshall, D. L. (2024). Importance of Environmental Monitoring Programs.

Vashishth, R., Pandey, A. K., Kaur, P., & Semwal, A. D. (2022). Smart technologies in food manufacturing. In *Smart and sustainable food technologies* (pp. 125-155). Singapore: Springer Nature Singapore.https://doi.org/10.1007/978-981-19-1746-2_5

World Health Organization. (2020). *Food safety: Key facts*. WHO. https://www.who.int/news-room/fact-sheets/detail/food-safety

Zhang, H., Que, F., Xu, B., Sun, L., Zhu, Y., Chen, W., ... & Zhang, X. (2021). Identification of Listeria monocytogenes contamination in a ready-to-eat meat processing plant in China. *Frontiers in Microbiology*, *12*, 628204. https://doi.org/10.3389/fmicb.2021.628204