The Bioscan
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
2020(3): S.I (3), 926-929, 2025 www.thebioscan.com

FOOD SPOILAGE MITIGATION THROUGH MODERN PROCESSING TECHNOLOGIES

P Aileen Sonia Dhas[1], Monish Raj R[2], Kiran Kumar S[3], S B Chandra Lekha[4], Sindhu D[5]

[1]Department of Electrical and Electronics, PERI Institute of Technology, Chennai-48

[2]Department of Pharmacy, PERI College of Pharmacy, Chennai-48

[3]Department of Physiotherapy, PERI College of Physiotherapy, Chemnai-600048

[4]Department of Nursing, PERI College of Nursing – Chennai-600048

[5]Department of Criminology, PERI College of Arts and Science, Chennai-48.

Corresponding mail id: publications@peri.ac.in

DOI: 10.63001/tbs. 2025.v20.i03.S.I(3).pp926-929

KEYWORDS
Food processing, preservation, food spoilage, Enzymes, Bacterial

Received on:

20-07-2025

Accepted on:

18-08-2025

Published on:

24-09-2025

ABSTRACT

Food spoilage is a critical issue affecting food security, public health, and the global economy. Spoilage, which results from microbial activity, enzymatic degradation, oxidation, and improper storage conditions, leads to significant quality deterioration and food waste. According to the Food and Agriculture Organization (FAO), approximately one-third of all food produced globally is lost or wasted, much of it due to spoilage. This has catalysed a growing demand for innovative and sustainable food preservation and spoilage detection technologies.

Traditional methods such as refrigeration, chemical preservatives, and thermal processing have been widely used to extend shelf life. However, these approaches often have limitations, including nutrient degradation, changes in sensory attributes, and consumer concerns over synthetic additives

Simultaneously, the integration of emerging digital tools like artificial intelligence (AI), machine learning (ML), and smart sensor networks has revolutionized the monitoring and early detection of food spoilage. These technologies enable real-time tracking of microbial activity, gas emissions, and other spoilage indicators, facilitating timely interventions and reducing food waste. In particular, hyperspectral imaging, deep learning algorithms, and nanomaterial-based sensors offer new avenues for non-invasive, accurate spoilage assessment in both production and supply chains.

Moreover, the microbiology of food spoilage has been extensively studied, with key findings on biofilm formation, quorum sensing, and the role of spoilage-specific organisms such as *Pseudomonas*, *Lactobacillus*, and filamentous fungi. Understanding these microbial mechanisms is essential for designing targeted preservation strategies, including the use of natural antimicrobials and biopreservatives derived from plants, bacteriocins, and essential oils.

This review aims to provide a comprehensive overview of recent developments in food spoilage prevention and control. It examines technological innovations in processing and preservation, explores advanced detection methods using AI and sensor systems, analyzes microbial mechanisms underlying spoilage, and highlights sustainable strategies being adopted across the global food supply chain. By synthesizing current research, this paper seeks to inform the development of safer, more efficient, and eco-friendly approaches to combat food spoilage in modern food systems.

INTRODUCTION

Recent technological advancements such as high-pressure processing (HPP), ultraviolet (UV) irradiation, pulsed electric fields (PEF), and cold plasma have emerged as promising alternatives. These techniques inactivate spoilage microorganisms and enzymes without the detrimental effects of heat-based methods. Simultaneously, the integration of digital tools—especially artificial intelligence (AI), machine learning (ML), and Internet of Things (IoT)-enabled sensor networks—has significantly improved the monitoring, prediction, and control of food spoilage in real time.

In addition, a deeper understanding of the microbiological mechanisms underlying spoilage, including the role of biofilms, quorum sensing, and specific spoilage organisms, has facilitated the development of targeted antimicrobial strategies. These include the use of natural preservatives such as essential oils, plant extracts, and bacteriocins, which align with growing consumer demand for clean-label products.

This review explores recent progress in food spoilage mitigation, emphasizing modern processing technologies, advanced detection methods, microbial control strategies, and sustainable preservation solutions. By integrating insights from microbiology, engineering, and data science, this paper aims to highlight comprehensive and innovative approaches to enhance food safety and reduce waste across the global food supply chain.

2.MODERN PROCESSING TECHNOLOGIES

The food industry is undergoing a significant transformation, driven by the need to reduce spoilage, enhance safety, and maintain the nutritional and sensory quality of food products. Modern food processing technologies are being developed and adopted to meet these goals while addressing environmental sustainability and consumer preferences for minimally processed and preservative-free foods. These technologies aim to improve the shelf-life and safety of food without compromising its quality.

Table 1: Comparison of Traditional vs. Modern Food Preservation Methods

Preservation Method	Type	Key Mechanism	Advantages	Limitations
Refrigeration	Traditional	Temperature reduction	Inhibits microbial growth	High energy use; limited shelf life extension
Chemical Preservatives	Traditional	Inhibits microbial/enzymatic action	Cost-effective; widely used	Consumer resistance; synthetic nature
Thermal Processing	Traditional	Heat application	Kills pathogens	Alters texture and nutrients
High-Pressure Processing	Modern	Pressure-induced microbial inactivation	Retains nutrients and sensory quality	High equipment cost
Pulsed Electric Fields	Modern	Electroporation of cell membranes	Minimal thermal damage	Limited commercial availability
UV Irradiation	Modern	DNA damage in microbes	Effective for surface sterilization	Limited penetration depth
Cold Plasma	Modern	Reactive species inactivate microbes	Non-thermal, suitable for fresh produce	Equipment complexity

2.1 TECHNOLOGICAL ADVANCEMENTS IN FOOD PROCESSING AND PRESERVATION

Several studies have reviewed innovations enhancing the safety and quality of ready-to-eat (RTE) meals. Zhang et al. (2025) offer a comprehensive review of technological progress in RTE meal production, highlighting automation, smart packaging, and microbiological safety monitoring [1]. Pokharel et al. (2023) emphasized sustainability, nutritional retention, and minimal processing in modern food technologies [2].

Emerging sustainable preservation approaches—including high-pressure processing, pulsed electric fields, and cold plasma—are outlined in a review in *Sustainability* (2024), showcasing their potential to retain food quality and extend shelf life [4]. Additionally, the Springer Review (2025) discusses the integration of AI with advanced processing tools throughout the supply chain to optimize shelf-life and reduce spoilage [15].

Table2: Emerging Technologies for Spoilage Detection and Monitoring

Technology	Principle/Tool Used	Application Area	Key Benefits
Artificial Intelligence	Data-driven predictive modeling	Spoilage prediction, shelf-life estimation	Real-time decisions; big data integration
Machine Learning	Pattern recognition	Contaminant detection, quality assessment	High sensitivity, automation-friendly
Smart Sensor Networks	Gas, temperature, humidity sensors	Cold chain monitoring	Real-time spoilage alerts
Hyperspectral Imaging	Light spectrum analysis	Microbial spoilage detection in meat/produce	Non-invasive, high-resolution
Nanomaterial-based Sensors	Metal oxide or polymer composites	Spoilage indicator detection	High sensitivity, low detection limits
Metabolomics	Small molecule analysis	Early spoilage biomarker identification	Predictive insights before visual spoilage

2.2 NON-THERMAL AND NATURAL FOOD PRESERVATION TECHNIQUES

A 2025 review in Trends in Food Science & Technology highlights non-thermal methods such as UV light, pulsed electric fields, and ozone for reducing microbial load while preserving food nutrients [3]. Sahu and Bala (2017) summarize traditional and modern methods of spoilage prevention, emphasizing chemical preservatives, vacuum sealing, and irradiation [16]. Mahapatra et al. (2005) also discuss the efficacy of ozone, bacteriocins, and gamma irradiation for microbial control [29].

2.3 FOOD SPOILAGE MECHANISMS AND MICROORGANISMS

Classic and recent works explain the microbial ecology of food spoilage. Gram et al. (2002) focus on bacterial interactions during spoilage and their influence on food texture and odor [17]. Roller (1999) and Filtenborg et al. (1996) discuss physiological traits of spoilage microbes, especially molds and yeasts in dairy and meat products [18, 20].

Blackburn (2006) compiled an extensive handbook on spoilage organisms, including psychrotrophic bacteria and heat-resistant fungi [21]. Sevindik and Uysal (2021) further categorize microbial taxa responsible for spoilage in perishable goods [22], while Raposo et al. (2017) focus on *Pseudomonas* spp. in fresh meat and fish [23].

Korber et al. (2009) and Pitt & Hocking (2009) emphasize the role of biofilm formation and fungal ecology in persistent spoilage and resistance to sanitization [19, 30].

Table 3: Key Spoilage Microorganisms and Their Effects on Food

Microorganism	Food Affected	Spoilage Effect	Detection Challenge
Pseudomonas spp.	Meat, dairy, fish	Slime formation, off-odors	Active in cold temperatures
Lactobacillus spp.	Fermented products	Acid production, souring	Difficult to distinguish from beneficial strains
Filamentous fungi	Fruits, bread, dairy	Mould growth, mycotoxin production	Resistance to surface treatments
Yeasts	Juices, bakery products	Fermentation, gas production	Can survive in low pH environments
Bacillus spp.	Canned foods, dairy	Spoilage under aerobic/anaerobic conditions	Heat-resistant spores

2.4 MACHINE LEARNING AND ARTIFICIAL INTELLIGENCE FOR SPOILAGE DETECTION

The use of ML and AI in food safety monitoring is rapidly growing. Bongarde et al. (2024) demonstrate how AI can predict spoilage through temperature, gas sensors, and image analysis [5]. Inglis et al. (2024) reviewed AI applications for detecting mycotoxins in cereals and grains using sensor data [6]. Zhu et al. (2021) and Ghimpeteanu et al. (2025) explored deep learning and hyperspectral imaging for object detection and contamination in meat processing [7, 8].

2.5SENSOR TECHNOLOGIES AND METABOLOMICS

Pavase et al. (2018) reviewed chemical sensors using conjugated polymer nanocomposites for real-time spoilage detection [24]. Pinu (2016) emphasized metabolomics as a novel approach to detect early microbial changes before visible spoilage [25]. Dubourg et al. (2024) discuss the role of metal oxide nanomaterials in sensor development for agri-food safety applications [9].

2.6 SPOILAGE IN JUICES AND BEVERAGES

A 2024 review in Nutrients highlights how emerging methods like UV, natural antimicrobials (essential oils), and hurdle technologies help maintain juice safety and reduce spoilage without altering taste or nutrition [11].

2.7 QUORUM SENSING AND NATURAL ANTIMICROBIAL STRATEGIES

Machado et al. (2020) focus on quorum sensing among spoilage bacteria and strategies using plant extracts, enzymes, and bioactive compounds to inhibit microbial communication and biofilm formation [28]. Zhang et al. (2010) report on bamboo extracts' antibacterial activity against common spoilage organisms, suggesting potential for natural preservatives [27].

Table 4: Natural Antimicrobial Strategies for Food Spoilage Control

Source Type	Example Compounds	Mode of Action	Application in Foods
Plant Extracts	Phenolics, flavonoids, essential oils	Disrupt microbial membranes	Juices, meat coatings
Bacteriocins	Nisin, pediocin	Pore formation in bacterial membranes	Dairy, fermented foods
Enzymes	Lysozyme, glucose oxidase	Cell wall degradation, oxidative stress	Fresh produce, beverages
Bioactive Peptides	Lactoferrin, defensins	Antimicrobial and antioxidant activity	Functional foods, packaging

2.8 FOOD SPOILAGE IN SUPPLY CHAIN CONTEXT

The 2023 Frontiers in Sustainability article examines spoilage causes across food systems, emphasizing cold chain logistics and contamination control [10]. Risk mitigation strategies across production and retail stages, including HACCP and real-time tracking systems, are discussed in OnFoods Magazine (2022) [12].

CONSLUSION

Microorganism such as fungi and bacteria that damage meals by means of growing on it and generating substances that exchange the shade, texture and aroma of food. In the long run food will no longer benefit human consumption. Whilst food is saved with a bushy increase and becomes pulpy it produces a bad scent that reasons decay through the increase of mould and yeast. Damage because of mould and yeast inclusive of bitterness of milk, growth of bread mold and rot of fruits and veggies. Those insects are not often harmful to human beings, however bacterial contamination is often worse because meals does no longer always appearance terrible, even if it's miles especially contagious. Whilst microorganisms are determined in meals, they utilize the nutrients in them and their numbers develop unexpectedly. They exchange the smell of meals and prepare new compounds that may be dangerous to humans. Food spoilage at once influences the colour, flavor, aroma and consistency or texture of meals, and can be risky to devour. Terrible odor or odor from meals is a sign that it can now not be safe. A key factor in food protection is the reduction of meals spoilage. By means of corruption the meals deliver is depleted and inedible for humans or your appetite is reduced.

REFERENCES

- Zhang Z., Xu G., Hu S., "A Comprehensive Review on the Recent Technological Advancements in the Processing, Safety, and Quality Control of Ready-to-Eat Meals," Processes, vol. 13, no. 3, art. 901, 2025
- Pokharel B., Keerthi R. S. S., Abunamous Z. H. H., "Advancements in Food Processing Technologies: Enhancing Safety, Quality, and Sustainability," Int. J. Sci. Res. Eng. Manag., vol. 07, no. 06, pp. –, Jun. 2023.
- "A Review of Non-thermal Interventions in Food Processing," Journal (e.g. Trends in Food Sci. Technol.), 2025, (review article).
- "Innovative and Sustainable Food Preservation Techniques," Sustainability, vol. 16, no. 18, art. 8223, 2024.
- Bongarde D., et al., "Use of Machine Learning and Artificial Intelligence in Food Spoilage Detection," Int. J. Eng. Res. Appl., vol. 14, no. 4, pp. 79–85, Apr. 2024.
- Inglis A., Parnell A., Subramani N., Doohan F., "Machine Learning Applied to the Detection of Mycotoxin in Food: A Review," arXiv, Apr. 23, 2024.
- Ghimpeteanu G., Rajani H., Quintana J., Garcia R., "Hyperspectral Imaging for Identifying Foreign Objects on Pork Belly," arXiv, Mar. 20, 2025.
- Zhu L., Spachos P., Pensini E., Plataniotis K., "Deep Learning and Machine Vision for Food Processing: A Survey," arXiv, Mar. 30, 2021.
- Dubourg G., Pavlović Z., Bajac B., Kukkar M., Finčur N., Novaković Z., Radović M., "Advancement of Metal Oxide Nanomaterials on Agri-Food Fronts," arXiv, Jul. 29, 2024.
- "Fight against food waste: combating contamination and spoilage," Journal (e.g. Front. Sustainability), 2023.
- "Emerging Preservation Techniques for Controlling Spoilage and Juice Safety," Nutrients, review, (date).
- "Risk mitigation strategies in food production, processing, storage and retailing," OnFoods Magazine, 2022.
- "A Review on Food Spoilage Mechanisms, Food-Borne Diseases and Commercial Aspects," Food Sec. Agric., 2024.
- "A Review on Mechanisms and Commercial Aspects of Food Preservation Mechanisms," Agric. Food Secur., 2017.
- Springer Review, "Leveraging Artificial Intelligence and Advanced Food Processing Technologies across the Food Supply Chain," 2025.
- Sahu, M., & Bala, S. (2017). Food processing, food spoilage and their prevention: An overview. Int. J. Life. Sci. Scienti. Res, 3(1), 753-759.
- Gram, L., Ravn, L., Rasch, M., Bruhn, J. B., Christensen, A. B., & Givskov, M. (2002). Food spoilage—interactions between food spoilage bacteria. International journal of food microbiology, 78(1-2), 79-97.
- Roller, S. (1999). Physiology of food spoilage organisms. International journal of food microbiology, 50(1-2), 151-153.
- Korber, D. R., Mangalappalli-Illathu, A. K., & Vidović, S. (2009). Biofilm formation by food spoilage microorganisms in food processing environments. In Biofilms in the food and beverage industries (pp. 169-199). Woodhead Publishing.
- Filtenborg, O., Frisvad, J. C., & Thrane, U. (1996). Moulds in food spoilage. International journal of foittod microbiology, 33(1), 85-102.
- de W Blackburn, C. (Ed.). (2006). Food spoilage microorganisms. Woodhead Publishing.

- Sevindik, M., & Uysal, I. (2021). Food spoilage and Microorganisms. Turkish Journal of Agriculture-Food Science and Technology, 9(10), 1921-1924.
- Raposo, A., Pérez, E., de Faria, C. T., Ferrús, M. A., & Carrascosa, C. (2017). Food spoilage by Pseudomonas spp.-an overview. Food borne pathogens and antibiotic resistance, 41-58.
- Pavase, T. R., Lin, H., Hussain, S., Li, Z., Ahmed, I., Lv, L., ... & Kalhoro, M. T. (2018). Recent advances of conjugated polymer (CP) nanocomposite-based chemical sensors and their applications in food spoilage detection: A comprehensive review. Sensors and Actuators B: Chemical, 273, 1113-1138.
- Pinu, F. R. (2016). Early detection of food pathogens and food spoilage microorganisms: Application of metabolomics. Trends in Food Science & Technology, 54, 213-215.
- Odeyemi, O. A., Alegbeleye, O. O., Strateva, M., &Stratev, D. (2020). Understanding spoilage microbial community and spoilage mechanisms in foods of animal origin. Comprehensive reviews in food science and food safety, 19(2), 311-331.
- Zhang, J., Gong, J., Ding, Y., Lu, B., Wu, X., & Zhang, Y. (2010). Antibacterial activity of water-phase extracts from bamboo shavings against food spoilage microorganisms. African Journal of Biotechnology, 9(45), 7710-7717.
- Machado, I., Silva, L. R., Giaouris, E. D., Melo, L. F., & Simões, M. (2020). Quorum sensing in food spoilage and natural-based strategies for its inhibition. Food Research International, 127, 108754.
- Mahapatra, A. K., Muthukumarappan, K., & Julson, J. L. (2005). Applications of ozone, bacteriocins and irradiation in food processing: a review. Critical reviews in food science and nutrition, 45(6), 447-461.
- Pitt, J. I., & Hocking, A. D. (2009). The ecology of fungal food spoilage. In Fungi and food spoilage (pp. 3-9). Springer, Boston, MA.