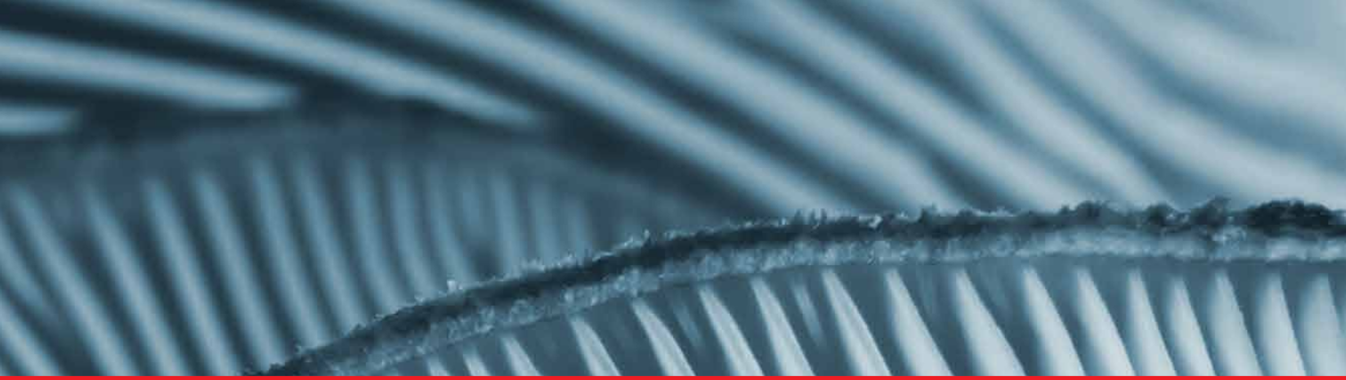

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Food Safety

New Insights

Edited by Rabia Shabir Ahmad

Food Safety - New Insights

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Aims and Scope of the Series

The significance of food is undeniable, especially in light of the impending challenge facing humanity: ensuring there will be enough food to meet the basic needs of a population expected to reach approximately 10 billion by 2050. These food-related challenges align with some of the United Nations' sustainable development goals, with a target to achieve them by 2030. One thing is certain: food should be not only nourishing and safe but also tailored to the diverse needs of individuals throughout their lifetimes, all while meeting consumers' sensory expectations. Understanding the diverse chemical composition of food, often referred to as biodiversity, and how these components can contribute to human health by considering factors like bioaccessibility, bioavailability, and bioactivity at the organ level, is crucial for grasping and promoting a healthy diet. Thanks to the continuous evolution of analytical methods and interdisciplinary research, significant strides have been made in the field of food science and nutrition.

Meet the Series Editor

Maria Rosário Bronze has been working in Analytical Chemistry since 1986. Her Ph.D. in 1999 contributed to the study of food products using capillary electrophoresis. The main goal of her research since 1999 has been focused on Analytical Chemistry applied mainly to the analysis of foods and by-products of food industry. She conducted research in collaboration with national and international research groups, at iBET and ITQB Technology Division. From 2017 until 2021 she was head of Food & Health Division at iBET and head of the Food Functionality and Bioactives Laboratory. MR Bronze has been an Associate Professor at the Pharmacy Faculty of Lisbon University and head of the Structural Analysis Laboratory since 2012. As a researcher, MR Bronze is a Senior Scientific Advisor at Food & Health Division at iBET and Head of Food Functionality and Bioactives Laboratory at the same Institute, Collaborator at iMED and Researcher at ITQB NOVA. Her current research is focused on quality and beneficial health effects of food components. Gas and liquid chromatography associated with mass spectrometry are used by MR Bronze in the characterization of samples. Sensory evaluation is also an important area of her research. The main food products studied by her are olive tree products (olive, olive oil, leaves), cereals such as maize, legumes (faba bean, pea, chickpea, lentils) fruits (apple, grapes, opuntia ficus), fruit juices and wine, among others. More recently her interests have also involved biodiversity, bioaccessibility, and bioavailability studies on food products and their components, mainly phytochemicals as phenolic compounds, using different analytical tools such as mass spectrometry. As a senior scientific advisor at Food & Health Division at iBET she is involved in different areas: (i) isolation, characterization and formulation of bioactive and functional compounds or extracts from natural sources and wastes from food and other related industries; (ii) pre-clinical assays to provide support to understand health claims related with the beneficial effects of food nutrients/bioactive components; (iii) establishment of analytical methodologies including mass spectrometry state-of-the-art to fully characterize different matrices, from food products, natural extracts or biological fluids (Food Functionality and Bioactives Laboratory).

Meet the Volume Editor

Dr. Rabia Shabir Ahmad has a strong academic, teaching, and research background. She has excellent communication and organizational skills and has the ability to develop, execute, and complete projects. She completed doctoral research funded by the Indigenous Fellowship Program, Higher Education Commission (HEC), Pakistan. She also participated in the Start-Up Research Grant Program (SRGP) and the National Research Program for Universities (NRPU) as a principal investigator in the area of functional foods. Along with her teaching and research supervising responsibilities, Dr. Ahmad is also a journal reviewer. She has numerous journal articles and edited books to her credit.

Contents

Preface

Food safety refers to actions or procedures taken from handling up to the consumption of food material with the purpose of avoiding foodborne diseases. In this way, food safety starts from the handling of raw materials and includes processing and preservation of food to ensure safe products. This book, *Food Safety – New Insights* provides a comprehensive overview of food safety. Written by experts from around the world, the book includes eight chapters organized into five sections. Chapters address topics such as the safety of food and various types of safety hazards and food safety systems. They also discuss the effect of changing climate on food safety and food safety in restaurants.

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Section 1

Introduction

Chapter 1

Introductory Chapter: Food Safety

Rabia Shabir Ahmad, Hamza Munawar, Hafiza Saima and Farzana Siddique

1. Introduction

Food safety deals with the practical measures and scientific discipline taken to make certain that food products are safe for consumption of mankind, free from contamination and do not pose any risk to public health [1]. It encompasses a range of practices, processes, and regulations designed to prevent foodborne illnesses and hazards arising from chemical, physical agents and biological that may be present in food. The ultimate goal of food safety is to prevent consumers from the inauspicious health effects of consuming unsafe or contaminated food [2].

2. Significance of food safety

Food safety is a very critical aspect of daily life that often goes unnoticed until a crisis occurs. It encompasses a set of practices, procedures, and regulations aimed at ensuring that we are consuming food which is safe for consumption, free from contamination, and poses no harm to human health. This is a global concern, as food is a fundamental necessity, and unsafe food can lead to a wide range of health issues, from mild food poisoning to severe diseases, and even fatalities [3]. Food safety measures are essential to safeguard public health. The food that is contaminated can lead to outbreaks of foodborne illnesses, affecting individuals and communities. Ensuring food safety reduces the burden on healthcare systems and prevents suffering.

Food safety is integral to international trade. Unsafe food can have severe economic consequences. Recalls, lawsuits and damage to brand reputation can lead to significant financial losses for food producers and businesses, affecting both local and global economies [1]. Compliance with food safety standards is often a requirement for accessing global markets. Ensuring the safety of exported and imported food products is crucial for maintaining trade relationships. Consumers need assurance that the food they purchase is safe to eat. Effective food safety measures build trust between consumers and food producers, leading to increased confidence of the customer in the food supply chain.

Food safety practices are closely linked to sustainable agriculture. By promoting safe and responsible farming practices, we can shelter the environment and ensure food security for the next generations. Many countries have established stringent food safety regulations to hold food producers accountable for the safety of their products. Compliance with these regulations is not only a legal obligation but also a moral one [2, 4].

3. Historical perspectives of food safety

Food safety has been a serious concern throughout human history, although our understanding of it and the methods employed to ensure safe food have evolved significantly over time.

3.1 Ancient civilizations

In ancient civilizations like Egypt, Greece and Rome, there were rudimentary food safety practices. People would inspect food for visible signs of spoilage and use preservation methods such as drying, salting, and fermentation to increase the shelf life of perishable foods. The earliest recorded food regulations date back to Babylon, where a code of laws, known as the Code of Hammurabi (circa 1754 BC), and included provisions related to food quality and safety [3].

3.2 Middle ages

During the middle ages, food safety was a significant concern, especially in densely populated urban areas. There were instances of food adulteration and contamination. The Black Plague in the 14th century raised awareness about the importance of food safety, as people began to recognize the link between unsanitary food practices and disease outbreaks.

3.3 Industrial revolution

The Industrial Revolution brought very noticeable changes in the production of food and its distribution. Along with the growth of urban populations and mass production, concerns about food safety escalated. In the mid-19th century, scientists like Louis Pasteur and Robert Koch made groundbreaking discoveries about the role of microorganisms in food spoilage and illness, laying the foundation for modern food microbiology and safety practices [5].

3.4 Twentieth century and beyond

The 20th century witnessed the establishment of regulatory authorities such as the World Health Organization (WHO) and U.S. Food and Drug Administration (FDA), which played crucial roles in setting food safety standards and regulations on a global scale. Advances in food science, technology, and inspection methods have allowed for more effective monitoring of food safety, including the development of food safety management systems like Hazard Analysis and Critical Control Points (HACCP) [6].

4. Understanding foodborne illnesses

Foodborne illnesses, also known as food poisoning or foodborne diseases, are major health problems that are caused by the usage of contaminated food. These illnesses can result from various biological agents, including bacteria, viruses, parasites, and fungi [7]. Here is an overview of common foodborne pathogens associated with these agents.

4.1 Common foodborne pathogens

a. Bacteria:

- Salmonella: This bacterium is a leading reason for foodborne problems globally. Contamination often occurs in raw poultry, eggs, and unpasteurized dairy products [8].

- *Escherichia coli*: Many known strains of *E. coli* can cause disturbing food poisoning. Contaminated ground beef, fresh produce and raw milk are common sources of foodborne pathogens [9, 10].

- *Listeria monocytogenes*: Listeria can grow in at normal refrigeration atmosphere and causes a risk in ready-to-eat foods, deli meats, and soft cheeses [11]

- Campylobacter: Often found in undercooked poultry and contaminated water, Campylobacter infections can lead to gastroenteritis [12, 13].

b. Viruses:

- Norovirus: Highly contagious, norovirus is a common cause of gastroenteritis outbreaks, often associated with contaminated shellfish and prepared foods [14, 15].

- Hepatitis A: This virus can transmit through contaminated food or water. It can lead to hepatitis and jaundice [16, 17].

c. Parasites:

- Giardia: This parasite can cause giardiasis and is often transmitted through contaminated water and poorly cooked food [18].

- Cryptosporidium: A protozoan parasite, Cryptosporidium can lead to gastrointestinal illness and is linked to contaminated water and produce.

d. Fungi:

- Aspergillus: Certain species of Aspergillus can produce mycotoxins that contaminate grains, nuts, and dried fruits.

- Botrytis: This fungus can affect various fruits and vegetables, causing rot and spoilage.

These pathogens can contaminate food at various stages of production, processing, and preparation. Proper food handling, cooking, and hygiene practices are essential to prevent foodborne illnesses [19]. Additionally, regulatory agencies and food safety measures are in place to monitor and control these pathogens in the food supply chain [8].

4.2 Factors contributing to food-borne illnesses

Foodborne illnesses are often the result of a complex interplay of various factors within the food supply chain. These contributing factors can be classified into several key areas. First, improper food handling practices by individuals, such as inadequate hand washing, cross-contamination, and undercooking, can introduce pathogens into the food. Secondly, the prevalence of foodborne pathogens in raw ingredients or contaminated water sources can lead to contamination during food production and processing. Additionally, lapses in sanitation and hygiene within food establishments, including restaurants and food processing facilities, can contribute to the spread of foodborne pathogens. Moreover, temperature control, both during the storage of food and its distribution, is critical to preventing the growth of harmful microorganisms [20]. Lastly, global food supply chains and increasing consumption of raw or minimally processed foods pose challenges in ensuring food safety. Addressing these factors through proper food safety measures, regulations, and public education is essential in mitigating the risk of foodborne illnesses [19].

4.3 Influence on public health and economy

Foodborne hazards have a profound impact on both public health and the economy. In terms of public health, these hazards are responsible for a significant burden of illness, including foodborne infections and diseases that can range from mild gastroenteritis to severe and sometimes fatal conditions. Week populations, such as the very young, elderly, and immune-compromised individuals, are particularly at risk. Foodborne outbreaks can also strain healthcare systems and public health resources [21].

On the economic front, the consequences of foodborne hazards are substantial. Food recalls and outbreaks can result in massive financial losses for the food industry, including costs associated with product recalls, legal liabilities, and damage to brand reputation. Moreover, the loss of consumer confidence in food products can lead to reduced sales and market share. Food safety regulations, while necessary for public health, can also impose compliance costs on businesses. Overall, the economic impact of foodborne hazards underscores the importance of robust food safety measures and regulations to protect both public health and the food industry's economic stability.

5. Regulatory framework and standards

5.1 Government agencies and their roles

Government agencies play a vital role in establishing and enforcing food safety regulations and standards to protect public health [6]. Here is an overview of the roles of prominent government agencies involved in food safety:

5.1.1 FDA

The FDA is a key regulatory agency that is responsible to make sure the safety of most food products in the United States. They establish and enforce regulations related to food labeling, additives, contaminants, and manufacturing practices [22]. The FDA conducts inspections of food facilities, monitors food recalls, and conducts research on food safety issues. They also oversee the safety of imported food products [23].

5.1.2 USDA (United States Department of Agriculture)

The USDA primarily focuses on the safety of meat, poultry, and egg products in the United States. They regulate and inspect these products from farm to processing and distribution. The Food Safety and Inspection Service (FSIS), a branch of USDA, sets and enforces standards for food safety, ensuring that these products are safe and correctly labeled [24].

5.1.3 CDC (Centers for disease control and prevention)

The CDC is a federal agency responsible for tracking and investigating foodborne outbreaks and diseases. They provide epidemiological expertise and surveillance to identify the source of outbreaks. The CDC collaborates with state health departments to monitor foodborne illnesses, maintain the Foodborne Diseases and publish facts and statistics on foodborne disease trends [19].

5.1.4 WHO (World Health Organization)

The WHO is a global organization that sets international food safety standards and guidelines. It works in partnership with the Food and Agriculture Organization (FAO) through the Codex Alimentarius Commission to develop and harmonize global food safety standards. WHO provides technical assistance to member states, conducts risk assessments, and disseminates information to improve food safety worldwide [25].

These agencies collaborate to develop, implement, and enforce food safety regulations that protect consumers from foodborne hazards. Their roles extend beyond national borders, as international cooperation is essential in ensuring the safety of the global food supply chain. Through regulations, inspections, research, and surveillance, these agencies collectively contribute to safeguarding public health and promoting food safety at local, national, and international levels.

5.2 Food safety regulations

5.2.1 HACCP (Hazard analysis and critical control points)

HACCP is a systematic approach that helps in identifying, controlling and evaluating food safety hazards at critical points during food production, processing, and handling. It is widely recognized as a preventive system for managing food safety and is applied in various industries to minimize risks associated with biological, chemical, and physical hazards [26]. HACCP principles include conducting hazard analysis, identifying critical control points, establishing critical limits, monitoring, corrective actions, verification, and record-keeping.

5.2.2 FSMA (Food safety modernization act)

FSMA is a landmark U.S. legislation signed into law in 2011, aimed at preventing foodborne illnesses and ensuring the safety of the U.S. food supply. The act emphasizes a shift from a reactive approach to a proactive one by focusing on preventive controls, risk-based inspections, and increased regulatory authority for the FDA. Key provisions of FSMA include the establishment of preventive controls for food facilities, improved oversight of imported foods, and enhanced traceability [27].

5.2.3 Codex Alimentarius

Codex Alimentarius, often referred to as the Codex, is a collection of worldwide recognized standards, guidelines, and codes of practice for food safety, established by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO). It serves as a reference point for international trade and aims to harmonize food safety standards and regulations globally. Codex standards wrap up many important aspects of food safety, including food additives, labeling, contaminants, and hygiene [28].

5.3 International food safety standards

International food safety standards are a set of guidelines and regulations established at the global level to ensure the safety and quality of food products traded across borders. These standards, often developed through organizations like the Codex Alimentarius Commission (a joint initiative of the Food and Agriculture Organization and the World Health Organization), provide a common framework for countries to follow. They cover various aspects of food safety, including permissible levels of contaminants, food additives, labeling requirements, and hygiene practices [29]. Adherence to these international standards not only promotes food safety but also facilitates international trade by ensuring that food products meet consistent safety criteria, fostering consumer confidence, and promoting the harmonization of food regulations among nations. International food safety standards play a crucial role in protecting public health and facilitating the global movement of food products while promoting a common understanding of safe food practices worldwide.

6. Food safety management systems (FSMS)

6.1 Introduction to Food safety management

Food Safety Management Systems involve the systematic implementation of practices, procedures, and policies to ensure the safety and quality of food products. Management commitment is vital, as it sets the tone for the entire organization to prioritize food safety. Leadership should establish a culture of safety, allocate resources, and define responsibilities. Documentation and record-keeping are critical to maintaining a traceable record of food safety processes, from hazard analysis to corrective actions, ensuring transparency and accountability [29].

6.2 HACCP system

Hazard Analysis and Critical Control Points (HACCP) is a systematic and preventive approach to identifying, assessing, and controlling food safety hazards at critical stages of food production and processing. The HACCP system is based on seven principles, which include hazard analysis, determination of critical control points, establishing critical limits, monitoring, corrective actions, verification, and record-keeping. HACCP is widely applied in food processing, from manufacturing to distribution, to prevent and mitigate risks associated with biological, chemical, and physical hazards [28].

6.3 ISO 22000: A comprehensive Food safety standard

ISO 22000 is a globally recognized standard for food safety management systems that provides a comprehensive framework for ensuring food safety. Key components of ISO 22000 include communication, prerequisite programs, HACCP principles, management commitment, and continual improvement. Implementing ISO 22000 can present challenges such as resource allocation and cultural change, but it offers benefits such as enhanced food safety, regulatory compliance, and improved market access.

These elements represent critical components of Food Safety Management Systems, which are essential for safeguarding public health, ensuring the safety of food products, and maintaining consumer confidence in the food industry [28, 29]. Whether through the application of HACCP principles or compliance with ISO 22000, effective FSMS plays a pivotal role in preventing foodborne illnesses and promoting the production of safe and high-quality food.

7. Emerging challenges and technologies

Emerging challenges in food safety are continually evolving due to changes in the global food supply chain, consumer preferences, and advances in technology.

7.1 Foodborne pathogen evolution and antibiotic resistance

Foodborne pathogens, like Salmonella, *Escherichia coli* (*E. coli*), Campylobacter, and Listeria, have the ability to evolve and adapt over time. Evolution can lead to the emergence of new strains with different characteristics, including increased virulence and resistance to interventions. Resistance against antibiotics occurs when bacteria grow and develop the ability to survive exposure to these antibiotics, making these drugs ineffective in these infections [30]. Overuse and misuse of antibiotics in both human medicine and agriculture contribute to the development of antibiotic-resistant foodborne pathogens.

Antibiotic-resistant foodborne infections can result in more severe and prolonged illnesses. They may require more aggressive treatment options, leading to increased healthcare costs and potential complications [31]. Treating infections caused by antibiotic-resistant foodborne pathogens can be challenging. Limited treatment options may result in prolonged illness and, in severe cases, increased mortality rates. Resistant pathogens can spread through the food supply chain, from farm to table, and through person-to-person transmission. This transmission can lead to outbreaks that are difficult to control and contain.

7.2 Globalization and the increasing complexity

Globalization and the increasing complexity of the food supply chain have emerged as major challenges in ensuring food safety [32]. With food products now traversing the globe through intricate supply chains, the risk of contamination, adulteration, and mishandling has significantly heightened. Longer supply chains make it harder to trace the origins of food items, posing difficulties in identifying the sources of contamination or outbreaks. Moreover, diverse regulatory environments across countries add complexity for food producers and suppliers, as they must navigate varying standards. As consumers demand a wider array of exotic and imported foods, each with its unique production standards, ensuring consistent quality and safety standards throughout the global supply chain becomes a formidable task [33]. To tackle these challenges, international cooperation, transparent traceability systems, and stringent adherence to food safety regulations are essential to safeguarding the integrity of the global food supply and protecting public health.

7.3 Food fraud and authentication

Food fraud and authentication have become significant concerns in the food industry. Food fraud involves the intentional deception of consumers by altering, substituting, or misrepresenting food products for economic gain. This can manifest as adulteration, dilution, counterfeiting, or mislabeling of ingredients or origins. Ensuring the authenticity of food products is crucial for consumer trust and safety. Advanced technologies, such as DNA analysis, spectroscopy, and blockchain, are being employed to verify the authenticity of food items and trace their origins throughout the supply chain [34]. These measures not only protect consumers from health risks associated with fraudulent products but also support fair trade practices and uphold the integrity of the food industry. Public awareness and stringent regulatory enforcement are essential in combating food fraud and ensuring that consumers receive the quality and safety they expect when making food choices [35].

7.4 Emerging technologies

Emerging technologies are revolutionizing the landscape of food safety by providing innovative solutions to enhance traceability, authentication, and overall safety. Here's a brief overview of these technologies:

7.4.1 DNA-based methods

DNA-based methods involve the use of genetic analysis to identify and authenticate food products. This technology can determine the species origin of meat, fish, and other ingredients, helping to combat food fraud. For example, DNA barcoding is employed to verify the species of seafood, ensuring consumers receive the product they expect [36]. DNA sequencing and PCR techniques are used to trace the source of contamination in outbreaks, helping to pinpoint the origin and prevent further incidents [37].

7.4.2 Nanotechnology applications

Nanotechnology offers promising applications in food safety, including the development of nano-sensors and nano-filters that can detect and remove contaminants [38]. Nanoscale materials can enhance food packaging by providing barriers to oxygen, moisture, and pathogens, extending the shelf life of products. Nano-based delivery systems for antimicrobial agents and preservatives are being explored to improve food safety without altering taste or quality [39].

7.4.3 Blockchain and traceability

Blockchain technology provides an immutable and transparent ledger for tracking food products from farm to fork [40]. It enables real-time monitoring of the entire supply chain, making it easier to identify the contamination source or fraud quickly. Consumers can have detailed information about the origin, processing, and safety of products by scanning QR codes or using mobile apps, enhancing transparency and trust [41].

8. Best practices and risk mitigation

Best practices and risk mitigation strategies are crucial in ensuring food safety throughout the entire food supply chain. There are fundamental principles for ensuring food safety and minimizing the potential hazards and challenges in the food industry. Best practices encompass a set of guidelines and procedures designed to uphold the highest standards of food safety and quality throughout the production, processing, and distribution of food products. These practices include rigorous hygiene measures, compliance with regulatory standards, proper handling of ingredients, and thorough employee training [42].

Risk mitigation, on the other hand, involves identifying, assessing, and addressing potential risks and threats to food safety. It encompasses strategies and actions to prevent and manage risks, such as contamination, allergen issues, food fraud, and supply chain disruptions. Risk mitigation efforts include regular inspections, quality control measures, supplier verification, and the development of crisis management plans. Here are key practices and measures:

8.1 Good manufacturing practices (GMPs)

Good Manufacturing Practices (GMPs) are a collection of practices and guidelines aimed at ensuring the quality, safety, and consistency of food, pharmaceuticals, and other regulated products [43]. GMPs emphasize maintaining a clean and sanitary environment in facilities. This includes,

- Regular sanitizing and cleaning of surfaces, equipment and utensils, as well as proper waste disposal.

- Employees are trained in GMPs to ensure they understand and follow the procedures for handling food or products safely. Training includes personal hygiene practices, hand washing, and appropriate attire.

- GMPs require rigorous quality control measures, including product testing and inspection, to ensure that products meet specified quality standards.

- GMPs mandate the development and documentation of standard operating procedures (SOPs) for various processes, from production to packaging. These procedures serve as guidelines to ensure consistency.

- Maintaining comprehensive records is essential for tracking the source of ingredients and products, allowing for rapid recall and corrective action in case of contamination.

- Regular maintenance and calibration of equipment are vital to prevent malfunctions that could compromise product safety and quality.

- Suppliers of raw materials and ingredients must be verified to ensure they meet GMP standards and provide safe and high-quality materials.
- GMPs include guidelines for proper storage conditions, such as temperature control, to prevent spoilage or contamination. Adequate transportation practices are also essential to maintain product integrity.
- Correct and transparent labeling is crucial for informing consumers about the contents, nutritional information, allergens, and proper usage of products.
- Comprehensive documentation is required to demonstrate compliance with GMPs. Regulatory agencies conduct inspections and audits to ensure adherence.

8.2 Safe food handling and storage

Safe food handling and storage practices are necessary to escape from foodborne illnesses and ensure the quality and safety of the food we consume. These practices are crucial at all stages in the food supply chain, starting from purchase to preparation and storage.

Food items must be purchased from reputable sources, such as grocery stores and farmers' markets. Check expiration dates and inspect the packaging for damage or signs of tampering. Avoid purchasing dented or damaged canned goods. Buy perishable items last and refrigerate them promptly [44]. Washing hands thoroughly with soap and water after and before food handling, especially after using the restrooms, touching pets, or handling raw meat and poultry, or seafood is necessary. Use hand sanitizer when soap and water are not available.

Use clean cutting boards, utensils, and surfaces. Wash fruits and vegetables under running water before cutting or eating. We can avoid cross-contamination by separating and keeping raw meat, poultry, and seafood from ready-to-eat foods. Cook foods to the recommended internal temperatures to kill harmful bacteria. Refrigerate or freeze leftovers promptly. Keep the refrigerator temperature at or below 40°F (4°C) to slow bacterial growth. Store raw meat, poultry, and seafood on the bottom shelf to prevent drippings from contaminating other foods. Use a refrigerator thermometer to monitor the temperature. Keep the refrigerator clean and free from spoiled or expired items.

Package foods in airtight, freezer-safe containers to prevent freezer burn. Label and date items before freezing to track freshness. Freeze foods promptly to maintain quality. Follow recommended freezing times for different foods. Thaw frozen food in the refrigerator, under cold running water, or in the microwave. Avoid thawing at room temperature, which can promote bacterial growth. Use thawed food promptly and do not refreeze unless cooked. Use food-grade storage containers that are clean and in good condition. Seal containers tightly to prevent air exposure and preserve freshness. Label containers with the date to track shelf life [45]. Consume leftovers within a safe time frame (usually 3–4 days in the refrigerator). Reheat leftovers to at least 165°F (73.9°C) to kill any bacteria.

8.3 Consumer education and food labeling

It encompasses a range of essential topics, including food safety, nutrition, allergen awareness, portion control, and label interpretation. Through consumer education initiatives, individuals learn about safe food handling practices, such as proper hand washing and cooking temperatures, reducing the risk of foodborne illnesses. Moreover, consumers gain insights into understanding nutrition facts panels, ingredient lists, and allergen declarations on food labels, allowing them to make healthier dietary choices tailored to their needs. In an era of increasing dietary concerns and food-related allergies, consumer education equips people with the knowledge and skills they need to navigate the complex world of food products, ensuring their safety and promoting overall well-being [46].

Food labeling complements consumer education by providing essential information to consumers at the point of purchase. Labels disclose detailed ingredient lists, nutritional content, allergen warnings, and date labels, enabling consumers to make well-informed decisions. For individuals with food allergies, accurate allergen declarations on labels can be life-saving. Moreover, nutrition facts panels empower consumers to monitor their calorie intake, assess nutrient content, and align their dietary choices with personal health goals. By understanding food labels, consumers can select products that meet their dietary preferences, whether it's choosing organic or non-GMO options or adhering to specific nutritional guidelines [47]. Overall, consumer education and food labeling are interdependent elements that foster food safety, transparency, and healthier eating habits in today's complex food landscape.

9. Ongoing challenges and future directions

Ongoing challenges and future directions in food safety underscore the evolving nature of this critical field. As the global food supply chain becomes more complex and interconnected, the challenges of detecting and preventing foodborne hazards persist. Emerging pathogens, antibiotic resistance, and the impact of climate change on food safety pose significant threats [33]. Additionally, the rise of e-commerce and digital platforms has introduced new dimensions to food safety monitoring and traceability. Addressing these challenges requires ongoing collaboration among governments, regulatory agencies, industry stakeholders, and researchers to develop innovative surveillance technologies, enhance traceability systems, and establish harmonized international standards. The adoption of blockchain technology, advances in DNA-based methods, and the integration of artificial intelligence in food safety management are among the promising avenues for the future [40, 41]. Ultimately, safeguarding public health and ensuring the integrity of the global food supply chain will continue to be paramount goals in the ever-evolving landscape of food safety.

10. Conclusion

In conclusion, food safety is a paramount concern with far-reaching implications for public health, the economy, and global trade. Throughout this discussion, we have explored the multifaceted aspects of food safety, including common foodborne pathogens, regulatory frameworks, emerging challenges, and technological advancements. A robust and proactive approach to food safety is essential to prevent foodborne illnesses, protect consumers, and maintain the integrity of the food supply chain. As we move forward, ongoing challenges such as pathogen evolution, globalization, and food fraud underscore the need for continued vigilance and innovation. The integration of emerging technologies, the strengthening of regulatory frameworks, and the dissemination of consumer education will be pivotal in addressing these challenges and shaping the future of food safety. By working collaboratively across sectors and borders, we can ensure that safe and wholesome food remains a fundamental right for individuals worldwide.

Ultimately, food safety is a shared responsibility that extends from farm to fork, and it demands our unwavering commitment to excellence and diligence. As we navigate the evolving landscape of food safety, our dedication to protecting public health and promoting the well-being of consumers will continue to guide our efforts toward a safer and more secure global food supply.

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Section 2

Food Safety Systems

Chapter 2

Review of the Food and Agriculture Organisation (FAO) Strategic Priorities on Food Safety 2023

Joseph Tendeukai Kunashe Ndondo

Abstract

The Food and Agriculture Organisation (FAO) endorsed its strategic framework for the period 2022–2031 during the 42nd session of the FAO conference held on 18 June 2021. The new framework for the period 2022–2031 seeks to support the 2030 Agenda for sustainable development through the transformation of agri-food systems in line with the sustainable development goals (SDGs). The FAO strategic framework 2022–2031 was developed in the context of significant global and regional challenges such as the COVID-19 pandemic. In developing the strategic framework, the Food and Agriculture Organisation (FAO) outlined Programme priority areas (PPAs) that describe how FAO's work on food safety will contribute to the 2030 Agenda for sustainable development in alignment with FAO's strategic framework 2022–2031. The strategic priorities are, in turn, organised into four strategic outcomes, which are interconnected and interdependent to achieve FAO's vision of '*safe food for all people at all times*'.

Keywords: food safety, sustainable development goals (SDGs), food waste, food loss, food and agriculture organisation (FAO)

1. Introduction

The Food and Agriculture Organisation (FAO) Strategic Framework 2022–2031 was endorsed on 18 June 2021 at the 42nd Session of FAO Conference [1]. The FAO conference is the supreme decision-making body that brings together all FAO members. Currently, FAO membership comprises 194 countries plus the European Union.

The Food and Agriculture Organisation (FAO) is a specialised agency of the United Nations that was formed in 1945 in Quebec City, Canada, when the first session of the then newly created United Nations established the FAO with the mandate of leading international efforts to defeat hunger. FAO's goal is to achieve food security for all and make sure that people have regular access to enough high-quality food to lead active and healthy lives.

Since 2010, all of FAO's work has been guided by a strategic framework, which is usually prepared for a period of 10 to 15 years and is reviewed every 4 years [1]. The new framework for the period 2022–2031 seeks to support the 2030 Agenda for Sustainable Development including the 17 sustainable development goals (SDGs),

Figure 1.
Sustainable development goals (SDGs) [3].

which are global objectives that succeeded the millennium development goals on 1 January 2016 (**Figure 1**) [2, 3].

Food safety is a critical prerequisite to ensure that all humans can enjoy a better life and better nutrition. Food safety is defined as 'the assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use' [4]. Unsafe food potentially makes consumers ill and can substantially contribute to food loss and food waste. Unsafe food causes an estimated 600 million cases of food-borne diseases (FBDs) every year, as well as 420,000 annual deaths [5].

Securing food safety is essential in advancing health, livelihoods, trade, economic growth and overall prosperity. The FAO strategic framework 2022–2031 places food safety at the core and was developed in the context of major global and regional challenges, including the COVID-19 pandemic. It was developed through an inclusive, transparent process involving extensive internal and external consultations, governing body meetings and informal consultations. The FAO strategic framework 2022-31 articulates FAO's vision of a sustainable and food-secure world for all, in the context of the Agenda 2030 for sustainable development.

2. The four B's

The FAO strategic framework 2022–2031 seeks to support the 2030 Agenda through the transformation of agri-food systems for the attainment of FAO's four aspirations namely: better production, better nutrition, a better environment and a better life. These four aspirations by FAO represent an organising principle for how FAO intends to contribute directly to the sustainable development goals. They reflect the interconnected economic, social and environmental dimensions of agri-food systems, and they also encourage a strategic and systems-oriented approach within all FAO's interventions (**Figure 2**) [6].

Ensure sustainable consumption and production patterns, through efficient and inclusive food and agriculture supply chains at local, regional and global level, ensuring resilient and sustainable agri-food systems in a changing climate and environment

End hunger, achieve food security and improved nutrition in all its forms, including promoting nutritious food and increasing access to healthy diets

Protect, restore and promote sustainable use of terrestrial and marine ecosystems and combat climate change (reduce, reuse, recycle, residual management) through MORE efficient, inclusive, resilient and sustainable agri-food systems

Promote inclusive economic growth by reducing inequalities (urban/rural areas, rich/poor countries, men/women)

Figure 2.
The four betters [6].

2.1 The priorities and outcomes of the strategic framework

In developing the strategic framework 2022–2031, the Food and Agriculture Organisation (FAO) outlined what is termed programme priority areas (PPAs), which were endorsed by the FAO Council in December 2022 [1]. These PPAs describe how FAO's work on food safety will contribute to the 2030 Agenda in alignment with FAO's strategic framework 2022–2031. FAO's food safety priorities lie in four main strategic areas which are:

1. Strong multi-stakeholder governance for food safety

2. Strong science to support food safety decisions

3. Strong national food control systems

4. Strong public-private cooperation for food safety

In turn, the strategic priorities are organised into four strategic outcomes are equally necessary to achieve FAO's vision of delivering 'Safe food for all people at all times' (**Table 1**) [1].

2.1.1 Strategic outcome 1: Intergovernmental and multi-stakeholder engagement in intersectoral coordination of food safety governance is reinforced at all levels

The first strategic outcome of FAO's strategic framework 2022–2031 is aimed at the reinforcing intergovernmental and multi-stakeholder engagement in the governance of food safety. FAO aims to achieve this by providing tailored support to all FAO

Strategic outcome 1	Intergovernmental and multi-stakeholder engagement in intersectoral coordination of food safety governance is reinforced at all levels.
Strategic outcome 2	Sound scientific advice and evidence are provided as the foundation for food safety decision-making.
Strategic outcome 3	National food control systems are further strengthened and are continuously improved.
Strategic outcome 4	Public and private stakeholder collaboration is promoted to ensure food safety management and controls throughout agri-food systems.

Table 1.
The four strategic outcomes of the strategic priorities for food safety.

members and all other stakeholders. This support is characterised by guidance and technical support on various aspects of food safety, including normative, governance, science and policy matters. Aimed at realising this outcome, FAO in collaboration with the World Health Organisation (WHO) has worked to provide technical support and guidance in the form of food standards through the work of the Codex Alimentarius Commission. The standards developed by the Codex Alimentarius provide guidance to stakeholders, and members meant to protect the health of consumers and ensure fair practices in food trade. FAO is also one of the three international standard setting organisations in the World Trade Organisation (WTO) agreement. It works on the application of sanitary and phytosanitary measures (SPS) and commits itself to continue providing support and actively contributing to intergovernmental and multi-stakeholder engagement in intersectoral coordination of food safety governance.

2.1.2 Strategic outcome 2: Sound scientific advice and evidence are provided as the foundation for food safety decision-making

FAO in collaboration with WHO has been providing neutral and independent scientific advice as the basis for the international food safety standards, guidelines and codes of practice established by the Codex Alimentarius Commission (CAC) and for supporting the development of modern food control systems by national authorities [7]. This Scientific Advice programme for food safety has been the authoritative global point of reference for evidence-based scientific information on food safety. FAO and WHO remain committed to providing scientific advice related to food safety and nutrition in response to specific requests from member countries, from Codex Committees or occasionally from specific programmes within FAO and WHO, through different mechanisms [8]. Sound scientific advice is crucial in the setting of food standards such as those developed by the Codex Alimentarius. The Codex, commonly referred to as the "food code', contains internationally agreed standards, applicable throughout the food supply chain [9]. Its purpose is to protect health and facilitate trade. Through the work of the Codex Alimentarius, more than 300 standards, guidelines and codes of practice have been developed and regularly updated [10].

2.1.3 Strategic outcome 3: National food control systems are further strengthened and are continuously improved

Around the world, most countries have established what is known as national food control systems, which have the dual objective of protecting the health of consumers and enabling fair practices in food trade. These control systems ensure that food available within a country is safe, wholesome and fit for human consumption, conforms to food safety and quality requirements and is honestly and accurately labelled as prescribed by the law of each respective country. They, in turn, protect the health and safety of consumers and help assure the safety and quality of foods being traded both nationally and internationally. It has, however, been observed that some countries have systems that are not strengthened due to a lack of stable and predictable funding to update the skills of their staff in the food control systems [11]. FA has recognised that more effort is needed to be made to build capacities to plan, monitor, evaluate and further strengthen food control programmes in a way that can create a continuous cycle of improvement. Through the strategic outcome 3, FAO intends to assist member countries to strengthen their national food control systems. It aims to achieve this outcome by providing technical support to FAO members to evaluate their national food control systems, identify needs and design integrated capacity development programmes; to support FAO members in developing and updating their food safety standards, legal frameworks and government policies, as well as operational level procedures and guidelines and to support FAO members and relevant stakeholders to embrace relevant technological developments, including digital technologies, in food control and food safety management [12].

2.1.4 Strategic outcome 4: Public and private stakeholder collaboration is promoted to ensure food safety management and controls throughout agri-food systems

The Food and Agriculture Organisation acknowledges that the only way to ensure food safety is if everyone involved in the whole food chain is aware of and actively works to maintain the safety of food. Both public organisations and private entities should collaborate to advance science, innovate food production and processing and advance effective operational food safety management. In addition, food safety must be achieved in a proactive way rather than in a reactive manner. It is crucial that food safety be managed in accordance with preventative principles, and thus be included in the design and implementation of overarching food-related programmes. The Food and Agriculture Organisation intends to help foster public and private stakeholder collaboration by supporting both governments and food chain actors in adopting gender-responsive and inclusive programmes of preventative food safety control and management. It also intends to support initiatives aiming to create training programmes and curricula that better reflect the complexity of food safety and the need for collaborations across disciplines and aims to provide the tools and resources for stakeholders to make informed choices and adopt food safety interventions that are specific to their countries' priorities, safety risks and their constituents' differentiated needs.

2.1.5 How developing countries fit in FAO's framework

Global International trade in food and agriculture more than doubled in value between 1995 and 2018 to US$1.5 trillion on the back of technological improvements and lower trade barriers, which both helped to spur the growth of global value chains [13]. Over a third of exports now cross borders at least twice before reaching consumers [14]. This explosion in trade has widened supply and boosted opportunities to improve livelihoods. But it has also put a renewed focus on food safety standards as higher volumes of perishable goods move across borders. Food safety concerns look certain to become a growing international priority, especially in the wake of the COVID-19 pandemic, which has further highlighted the connections between health, the environment and development. The harmonisation of food safety standards across borders, for example, or tracing the origins of food in a timely manner, is now much more demanding processes.

The African continent, for example, hosts the world's largest free trade area, called AfCFTA, which brings together the 55 countries of the African Union (AU) and eight (8) regional economic communities (RECs) [15]. As part of its mandate, the AfCFTA seeks to eliminate trade barriers and boost intra-Africa trade. It is of no surprise that much of this liberalised trade will be in food because of largely agricultural-based economies in most African countries [15]. This food needs to be safe as consumers will be more exposed to a mixture of imported and locally produced food, from an ever more diverse supply chain. Liberalisation of food trade across African countries can potentially present difficulties for national authorities in charge of food controls, who lack direct oversight of the production processes of foreign trading partners. Thus, the opening up and integration of diverse markets requires more cooperation to prevent food-related risks such as food-borne diseases (FBDs). Meeting requirements for paperless trade and certification may also be a challenge, especially in developing countries and blocs such as the AfCTA. Through its strategic priorities on food safety, FAO intends to support government authorities, international organisations and partners to promote fair trade practices, stimulate dialogue between importing and exporting countries and offer guidance on assessing food control mechanisms. FAO has already set the precedence in this, for example, through its ambitious project with six AfCTA members comprising Comoros, Eswatini, Kenya, Mauritius, Rwanda and Seychelles in assessing national food control systems [14]. Funded by the European Union, this project has already shown itself to be a uniquely valuable learning process for government authorities, academics, consumer organisations and the private sector and has helped to ensure that the food control systems in the six case countries have sufficient capacity in food control. Encouraging the strong participation of developing countries such as those in the AfCFTA is key in achieving the goals and aspirations set out by the FAO strategic framework 2022–2031 (**Figure 3**) [15].

The BRICS economic bloc is another example, where FAO's strategic framework 2023 is highly applicable. The BRICS countries comprise Brazil, Russia, India, China and South Africa, and represent the largest developing economies [13, 16]. Data shows that, as of the year 2020, the BRICS nations as a whole now contribute more towards Global Gross Domestic Product (GDP) than the G7 industrialised nations (The G7 comprises of the US, the UK, Germany, France, Japan, Italy and Canada), in terms of purchasing power parity (PPP). PPPs are the ratio of prices in national currencies of the same goods or services in different countries (**Figure 4**) [17, 18].

In addition, the BRICS countries produce more than a third of the global agricultural output and have a significant role and responsibility in ensuring the sustainability of the agriculture and food sector, global food security and nutrition [19]. By ways of deepening agricultural cooperation and promoting comprehensive development of rural areas, the member countries take actions for increased resilience of agriculture, rural areas and farmers. The BRICS also holds 42 percent of the world's population [20], and with that, the bloc is in a position to shape agricultural policies that would strengthen global food security and transform rural societies and livelihoods. FAO already has excellent working relations with all BRICS countries, and to strengthen this collaboration even further, the organisation stands ready to advise on the policies and technologies that can contribute to achieving the SDGs and make our generation the zero hunger generation.

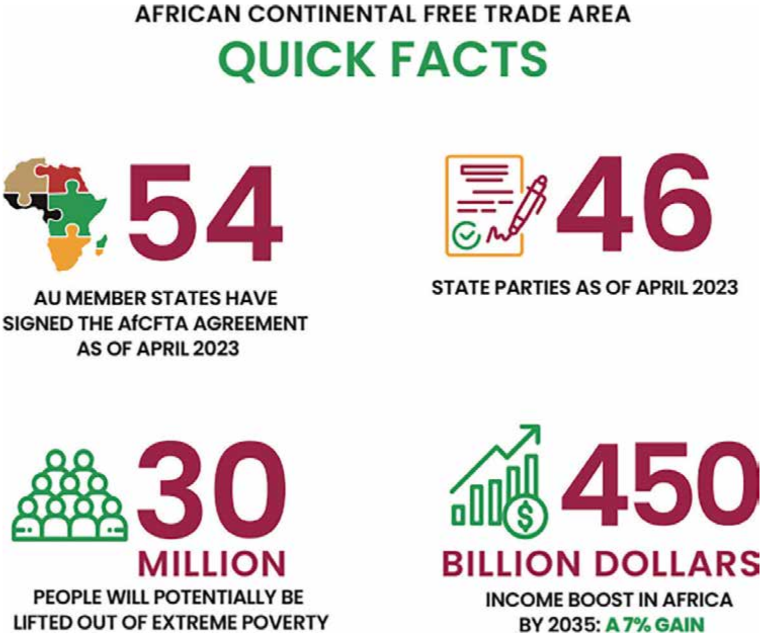

Figure 3.
Quick facts about the African continental free trade area [15].

Figure 4.
BRICS leaders during the 2019 G20 Osaka summit [17].

3. Conclusion

The world needs safer, more affordable and healthier diets for all produced in a sustainable manner along with the equitable improvement of economic outcomes and livelihoods. Emerging technologies and new food production systems, such as cell-based food production, 3D-printed food, aquaponics and vertical urban agriculture, may hold some of the answers we seek. Likewise, the global adoption of foods that were previously unique to some parts of the world, such as seaweed, algae, jellyfish or edible insects, may contribute solutions. The FAO strategic framework underlies that to achieve global food safety, cooperation and collaboration is key. The strategic priorities stem from FAO's important achievements in food safety, including those undertaken within the 2014 FAO Food Safety Strategy, and made possible thanks to its collaboration with partners. The strategic priorities focus on building stronger and more coordinated global, national and regional food safety and quality governance. It is everyone's hope that FAO's Strategic Priorities for Food Safety 2022–2031 will leverage FAO's convening power to foster trust, collaboration and results that are in the spirit of the agri-food systems that members adhere to. It will require all hands on deck in order to deliver 'Safe food for all people at all times'. The framework will support the transformation of the agri-food systems to meet the challenge of making safe and diverse food accessible to a global population of 10 billion people, 70 percent of whom are expected to be living in cities by 2050 [6].

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Chapter 3

Application of Hazard Analysis and Critical Control Point (HACCP) and Recent Technologies for Microbial Inactivation in Mozzarella Production

Muhammed Nurye and Tesfemariam Berhe

Abstract

The production of mozzarella cheese involves several steps that can lead to microbial contamination, which can pose a serious health risk to consumers. The use of Hazard Analysis and Critical Control Point (HACCP) has become a standard practice in the food industry to ensure the safety of mozzarella cheese. This involves identifying potential hazards and establishing critical control points to prevent or eliminate them. Recent technologies such as high-pressure treatment, pulsed electric fields, microfiltration, cold plasma and ultraviolet light treatment have also been developed to improve the safety and quality of mozzarella cheese by inactivating microorganisms. High-pressure treatment uses water at high pressure, while cold plasma treatment uses ionized gas to inactivate microorganisms. Ultraviolet light treatment uses UV-C light to kill bacteria and viruses, while pulsed electric field treatment uses short pulses of high-voltage current to destroy bacteria. The combination of HACCP and these technologies has proven effective in ensuring the safety and quality of mozzarella cheese. This approach has been widely adopted by the food industry to minimize the risk of microbial contamination and improve food safety. However, further research is needed to optimize the use of these technologies and provide better inactivation of microorganisms while maintaining the quality of mozzarella cheese.

Keywords: CCP cheese, HACCP, hazard, microbial inactivation, mozzarella

1. Introduction

The application of food safety guidelines plays an important role in producing wholesome and good quality cheese products because food safety in the dairy industry is a technical discipline that describes how milk is acquired, processed, handled, stored, and marketed in a way that prevents foodborne illness [1]. Food safety and prevention of foodborne diseases are promoted through the implementation of the Hazard Analysis and Critical Control Points (HACCP) system from dairy product production to consumption [2]. It has been internationally recognized and accepted as an effective food safety management system [3], which has had a positive impact on minimizing economic losses and food poisoning outbreaks from all steps in the dairy production process via a systematic approach [2].

The Codex Alimentarius Commission has standardized the HACCP system [4] as a preventive approach that identifies, maintains, evaluates, controls, and monitors each production point that is crucial for food safety [5]. HACCP is governed by seven principles, including conducting a hazard analysis, identifying the process critical points, establishing critical limits, CCP monitoring requirements, corrective action verification, record-keeping procedures, and system documentation. The term "hazard" in the HACCP framework refers to substances or food-related conditions that affect consumer health. According to Suherman et al. [6] all physical, chemical, and biological hazards in the product might originate from raw milk, other raw materials, environmental contaminants, manufacturing equipment, and personnel. Therefore, implementing food safety standards like HACCP has been an effective and rational means of ensuring food safety and eliminating public health risks. It is appreciated as a worldwide systematic and defensive tactic to address biological, chemical, and physical hazards through deterrence and anticipation instead of end-product testing and inspection [1].

The critical control point is important in preventing, eliminating, or reducing a food safety hazard to an acceptable level. CCPs must be determined based on potential hazards that are reasonably likely to cause illness or injury if not controlled. The FDA stated that identifying CCPs in a complete, accurate, and timely manner is essential for controlling food safety hazards [7]. According to reports in the literature, the researcher's use decision tree was used to identify CCP in cheese production [1, 8]. The most significant CCPs identified in mozzarella cheese manufacturing are Milk reception, pasteurization temperature, salt and rennet addition, coagulation, and cheese cutting [2, 8, 9]. While most countries develop regulations to ensure food safety through a preventive approach, such as HACCP principles, Codex, and ISO standards, the requirements' fulfillment depends on many factors. Hazard identification and CCPs are the most crucial steps that need careful analysis and knowledge in HACCP implementation. HACCP plans to use Hazard Analysis to ensure product safety during and after processing to improve shelf life and make products safe for consumption [1]. The CCPs decision tree plays an important role in identifying the CCPs in each step of mozzarella cheese processing. Once the CCPs have been identified, they are monitored for critical limits and their frequency determined, and corrective actions can be taken if any critical limits fail. Temperature control checks, pH monitoring, microbial testing of the end product, and equipment calibration are required when a CCP fails because of improperly functioning equipment.

Moreover, effective microbial inactivation is essential in milk processing to eliminate harmful microorganisms and maintain product safety. Traditional thermal methods, such as pasteurization, have been widely used for microbial control in the dairy industry. However, there has been a growing interest in nonthermal processing techniques due to their potential to achieve microbial inactivation while minimizing the impact on milk quality attributes. Pulsed electric fields (PEF), high-pressure processing (HPP), and nonthermal plasma (NTP) technologies are among the notable nonthermal processing methods being explored for microbial control in milk. These techniques utilize electrical discharges, high pressures, or plasma to inactivate microorganisms while preserving the nutritional and sensory qualities of milk. However, challenges remain in optimizing these technologies for large-scale industrial applications. Therefore, the implementation of HACCP and utilization of nonthermal processing methods have a significant impact on the production of excellent-quality products that are wholesome and suitable for human consumption by preventing contamination and using microbial inactivation. This chapter aims to review recent findings on CCPs in mozzarella cheese processing plants and microbial activation using nonthermal processing.

2. Literature review

2.1 HACCP

HACCPs are management systems that analyze, control and prevent biological, chemical, and physical hazards in everything from raw material production, procurement, and handling to final product manufacturing, distribution, and consumption [7]. According to the HACCP framework, the term "hazard" refers to any food agent or condition that has the potential to cause adverse health effects. Hazard analysis is the appraisal of the degree of severity of a hazard and its likelihood of occurrence. It is necessary to assess the survival and proliferation of potentially harmful bacteria, as well as the factors that lead to the existence or persistence of food. Therefore, this technique can be applied to a production line to determine the critical control points that can be measured and corrected [10]. In spite of this, HACCP has been shown to have greater effectiveness when used in conjunction with a quality management system and standard operating procedures, such as Good Manufacturing Practices (GMPs) and good hygiene practices (GHPs). In order to direct and control an organization's food safety, the ISO introduced the Food Safety Management System (FSMS). This system has interrelated elements and was introduced to help organizations establish policies and objectives [11]. A wide variety of HACCP-based systems, including ISO 22000, BS PAS 220:2008, and other auditable commercial standards, have been used in the dairy industry for the implementation of cheese of many types [12–15].

Moreover, HACCP has been widely comprehended and adopted on a global scale as a trade promotion tool for effectively implementing the food safety management system, where countries face high levels of competition as well. The implementation of the HACCP plan in the global food market strengthens companies' positions and improves their competitiveness [16]. This method identifies potential contaminants, evaluates the steps that must be taken to maintain food quality, and then develops a systematic approach to preventing food contamination. However, the effectiveness of the approach to preventing contamination depends on how it is implemented and applied [17]. The literature on food safety claims that a complex blend of managerial, organizational, and technical skills is required for the development, installation, monitoring, and verification of the HACCP system [18]. These significant flaws must also be present in medium-sized and small dairy businesses, while there are several factors that hinder its effectiveness, such as technical staff training, poor physical conditions, and the cost of implementing HACCP [19]. The HACCP system was implemented on the 12 steps given by the Codex Alimentarius Commission mentioned below.

1. **Establish a HACCP team:** The initial phase in implementing HACCP in the milk processing facility was to put together a team that has the knowledge and experience necessary to build a HACCP plan. The interdisciplinary team that was formed included employees from the production/sanitation, quality assurance,

microbiology, engineering, and inspection departments; all of this expertise was internal to the plant. HACCP teams that are highly effective have clearly defined roles and ensure proper representation of the team in order to achieve success.

2. **Define the product:** The HACCP team developed a comprehensive overview of the product based on the ingredients, processing methods, packaging materials, etc., utilized in the manufacturing process that would help in determining the presence of all potential hazards relating to the product.

3. **Identifying intended use**: Intended use refers to the use a product would be intended for by consumers or end users, such as infants, the elderly, or sick people. A few examples of this are: processed milk was used by infants to make baby foods, health drinks, and beverages such as tea and coffee, and all of these had to be kept ice-cold or cooked to be consumed; cheese was used in pizelles (or boiled and cooled dishes), etc.

4. **Establish a flow diagram:** Developing a flow diagram that represented the entire process made it easy to figure out any possible contamination streams and recommend control strategies. The purpose of a flow diagram is to provide a clear, concise overview of the paths involved in the operation. Every one of the stages in the production line that will be opened under the company's control was included in the flow diagram's coverage area. A schematic representation of the products has been established for the particular items based on the potential sequence components and their processing phases.

5. **On-site flow diagram verification:** Once a flow diagram had been developed, the HACCP team leader had to verify it on-site for accuracy and completeness. The flow diagram should be carefully examined by the HACCP team leader and other team members to ensure that it accurately depicts the actual processes that took place on-site. The various adjustments in procedures or actions that required on-site validation involved transporting raw materials and ingredients via machinery, manufacturing channels, and facility redeployment should also be clearly described. New ingredients used or products manufactured, product transfer to another line or piece of equipment, storage conditions for packaging, etc.

6. **List all the potential hazards and conduct a hazard analysis:** This is the most significant step of the HACCP plan, which ensures the safety of the product before and after processing, improves the product's shelf life, and makes it safe to consume. The HACCP team performs a hazard analysis based on the HACCP checklist (as recommended by the FAO), and all plausible risks associated with raw materials, components, processing steps, and postprocessing steps should be identified and labeled as biological (B), chemical (C), and physical (P) risks. Identification of potential biological, chemical, and physical dangers that could appear throughout each stage of processing is advantageous.

7. **Identifying CCPs:** Identifying CCPs in the HACCP plan is the most important part of the protocol, and the Codex decision tree in the appendices is used to identify CCPs. The use of decision trees varied depending on the type of procedure, such as production, processing, storage, transportation, or others.

8. **Establish a critical limit for each CCP**: In this step, a critical limit was defined and given for each CCP discovered. The parameters that were used to determine if a process was generating safe goods were referred to as critical limits. A number of parameters, including temperature, time, product measurements, water activity (ah), humidity level, etc., had critical limitations defined. The product's safety will be confirmed if these criteria are kept within acceptable limits. To decrease microbiological contamination and prevent foodborne illness, numerous nations have created various quality and safety standards. The tolerable microbial load in mozzarella cheese is summered in **Table 1**.

S/N	Quality	Requirement Cfu/g	Test method
1.	Total plate count /g	max 2 × 104 cfu/g	ISO 4833
2.	*Listeria monocytogenes*	Nil per gram	KS ISO 4833
3.	*Salmonella* spp	Nil per gram	KS ISO 4833
4.	*Shigella*	Nil per gram	KS ISO 4833 KS ISO 21,567
5.	*Clostridium botulinum*	Nil per gram	KS ISO 4833
6.	*Staphylococcus aureus*	Nil per gram	KS ISO 4833
7.	*E. coli*	Nil per gram	KS ISO 4833
8.	Fecal coliforms: max	Nil per gram	KS ISO 4832
9.	Nonfecal coliforms, max	100 cfu/g	KS ISO 4832
10.	Mold, max	100 cfu/g	KS ISO 6611
11.	Yeast, max	10 cfu/g	KS ISO 6611
12.	Mycotoxin residues (aflatoxin M1)	0.5 μg/kg	ISO 14501:2007/ AOAC 980.21
13.	Antibiotics (total antibiotic)	10.0 ppb	AOAC 962.16

Source: [9].

Table 1.
Microbiological requirements for mozzarella cheese.

9. **Establish monitoring procedures:** The producer relies on monitoring to demonstrate that the HACCP plan is being implemented. It gives the producer precise reports that the manufacturer can use to demonstrate that the production conditions adhere to the HACCP plan. The HACCP team primarily evaluated time–temperature treatments (thermograph), pH, moisture level, equipment, and suitable processing processes. These activities were monitored weekly and monthly. It was possible to take action in the case of a loss of control or to make a process modification if there was a trend toward a loss of control thanks to monitoring procedures that were carried out during the operation and recorded in documents for future reference.

10. **Establish corrective action:** Corrective actions will be taken to bring the process back under control, whenever the monitoring procedures detect a deviation from the CCP, based on the specific critical limit established for each CCP found during the process.

11. **Establish verification procedure**: The term "verification" refers to the systematic and diligent approach to methods, procedures, checks, and other appraisals, as well as the scrutiny of the HACCP plan to ensure compliance with it. The verification of contingency procedures is done on a daily, weekly, and monthly basis by a quality analyst and supervisor of the food safety team to ensure there are adequate procedures in place when critical limits are exceeded.

12. **Establish documentation and record-keeping**. Documentation is necessary for evaluating the HACCP plan's suitability and the HACCP system's devotion to the HACCP plan. A complete set of records was maintained for every step of the HACCP plan, including processing charts, written records, computerized records, and records generated by the HACCP system, including microbial and analytical testing records, verification records, and validation records. These records should be kept well and up-to-date in the industry's record books.

2.2 Implementation of HACCP in mozzarella cheese processing plant

The successful implementation of a HACCP plan is facilitated by the commitment of top management. Establishing a strategy that outlines the person in control of designing, implementing, and maintaining the HACCP system is the next action. The HACCP coordinator and team are initially chosen and trained as needed. The team is then in charge of creating the initial plan and coordinating its execution. HACCP plans for specific products can be developed by product teams. After the HACCP plan is completed, operator procedures, forms, and procedures for monitoring and corrective action are developed. Implementing the HACCP system entails continuing to use the monitoring, record-keeping, corrective action procedures, and other activities outlined in the HACCP plan [20]. Peristeropoulou et al. [2] claim that a HACCP system must take into account raw materials, ingredients, food manufacturing practices, the role of manufacturing processes in controlling hazards, the likely end use of the product, the categories of consumers of concern, and epidemiological evidence regarding food safety during the identification, evaluation, and subsequent operation stages.

In the manufacturing of mozzarella cheese proper understanding of potential hazards and its preventive strategies, processing steps, and identifying primary ingredients has a significant impact on designing and implementing HACCP. According to Suherman et al., [6], milk, rennet, starter culture, and salt are the primary ingredients for cheese processing. The processing steps include milk reception, pasteurization and cooling, rennet addition and coagulation, cutting and whey draining, cooking and stretching, dry salting, molding, brining, packaging, and storage. Then the identification of the CCPs will be the next step for implementing the HACCP plan.

2.3 The hazard analysis and critical control point framework for mozzarella cheese manufacture

2.3.1 Hazard identification

Identification of potential hazards and their sources have a significant role in describing the full process of risk assessment, which includes three important steps: (1) identify hazards and risk factors that have the potential to cause harm (hazard identification), (2) analyze and evaluate the risk associated with that hazard (risk analysis, and risk evaluation) and (3), determine appropriate ways to eliminate the hazard, or control the risk when the hazard cannot be eliminated (risk control) [21]. Hazard identification is helpful in identifying potential microbiological, chemical, and physical hazards that may occur during each step of processing mozzarella cheese [22]. Microbiological hazards are pathogens or harmful bacteria introduced during production, *E.coli,* and *Staphylococcus aureus*, are harmful bacterial in the raw milk, and *Salmonella* could contaminate the end product. These microbiological hazards may be originated from a different source [21]. Microbial potential hazards include pathogenic bacteria such as *Listeria monocytogenes, verotoxigenic E. coli, S. aureus*, and *Salmonella* from raw materials and *Salmonella, Cl. perfringens, Cl. botulinum, B. cereus,* and *L. monocytogenes* from ingredients. Besides, mycotoxins and bacterial toxins such as *staphylococcal enterotoxin* are found in certain raw milk and ingredients. Additional hazards associated with flavoring foods such as spices, herbs, ham, fruit, mushrooms, etc., pathogens that may be transferred from staff, re-contaminating molds, and pathogenic bacteria from the processing and packaging environment are also considered biological hazards [6, 23].

Chemical contaminants include plant toxins and chemicals added during processing and other chemicals originating from the raw materials [21]. Chemical hazards in the cheese manufacturing industry include pesticide residues, environmental contaminants in raw materials and ingredients (e.g., products high in fat, dioxins, and dioxin-like PCBs, heavy metals), contaminants from processing activities (coolants, lubricants, sanitizers), carryover additives (with numerical ADIs specified) from raw materials and ingredients, and contaminants from food contact materials, including coatings, waxes, and soft plastics like ripening films [1, 23]. Physical contamination is foreign material that could come from incorrect personal handling or bad environmental conditions. The hazards originated from the raw material and the processing steps [21]. Physical hazards include glass, bone or insect debris, metal fragments, hard plastic, etc.; the glass may come from unsecured windows, lamps, bulbs, neon tubes, thermometers, laboratory glass, spy holes on the tanks, insect-killing tubes, or other glass equipment; the insect debris may come from raw materials, ingredients, and packaging material; the metal may come from improperly built or maintained machines or equipment; the stones may come from damaged floors or walls; the wood from pallets or wooden equipment; and the plastic from buckets, boxes, and brushes are among the potential physical hazards in cheese manufacturing industries [1, 23]. The potential hazard, source, and preventive measures in the processing line are summarized in the **Table 2**.

2.3.2 Critical control points (CCPs) in mozzarella cheese

According to evidence in the literature, different researchers identify different CCPs in cheese manufacturing plants depending on the type of product produced, the sophistication of the manufacturing plant, the ingredients added during production, and the legislation of the country and international standards. For instance, Peristeropoulou et al. [2] established four CCPs in the storage of raw milk during its stay in self-cooler tanks in the factory, pasteurization of raw milk, heating of whey with stirring and Transport and distribution to consumers for the mizithra cheese production, whereas milk reception, dry salting, and brine salting also considered as CCP areas by other authors. Critical points are controlled through a monitoring system of planned measurements and observations for early detection of any deviations from the critical limits of CCPs and to ensure each CCP is always under control [8].

Processing steps	Hazards	Preventive measure
Milk reception	**Microbial**: Insects, pests, antibiotic residues, microbe aflatoxin **Chemical**: urea, detergents, boric acid, ammonium sulfate, sugar, hydrogen peroxide, melamine, salicylic acid, benzoic acid, NaCl, antibiotic and insect side residues **Physical**: Stones, husk, hair, glass, metal, plastic fragments, wood chips	proper equipment setting, sanitize all the transfer equipment
Pasteurization	**Microbial:** *Bacillus* spp., *Clostridium* spp.*iCoxiella burenetti*, spores, and *thermoduric* bacteria **Chemical:** Cleaning disinfectant, sodium hypochlorite, hydrogen peroxide, iodine, isothiazolinones, ozone, peracetic acid, phenolics, and surfactants. **Physical:** Stones, husk, hair, glass, metal, plastic fragments, wood chips	72°C, 15 s, proper pasteurizer setting, sanitize all the equipment
Rennet	**Microbial:** *Bacillus* spp., *Clostridium* spp., *Coxiella burenetti*, spores, and *thermoduric* bacteria **Chemical:** Cleaning disinfectant, sodium hypochlorite, hydrogen peroxide, iodine, isothiazolinones, ozone, peracetic acid, phenolics, and surfactants. **Physical:** Stones, husk, nut, bolt	sanitize the container used for diluting rennet, proper personal hygiene and handling
Coagulation	**Microbial:** *Bacillus* spp., *Clostridium* spp., *Coxiella burenetti*, spores, and *thermoduric* bacteria, **Chemical:** Cleaning disinfectant, sodium hypochlorite, hydrogen peroxide. **Physical:** Stones, husk, nut, bolt	40°C, 60 min, proper personal hygiene and handling
Cutting	**Microbial:** *Bacillus* spp., *Clostridium* spp., *Coxiella burenetti*, spores, and *thermoduric* bacteria **Chemical:** Cleaning disinfectant, sodium hypochlorite, and hydrogen peroxide **Physical:** Stones, husk, nut, bolt	correct knife size for optimum curd size, sanitize the cutting tools and the cutter's hands and arms, proper personal hygiene, and handling
Salting	**Microbial:** *Bacillus* spp., *Clostridium* spp., *Coxiella burenetti*, spores, and *thermoduric* bacteria **Chemical:** Cleaning disinfectant, **Physical:** Corrosive equipment	2.5–4.5% salt, moisture content is optimum at 60–65%, sanitize the salt container and the stirring tools, supply quality water, proper personal hygiene and handling
Storage and distribution	**Microbial:** Pseudomonas, **Chemical:** Cleaning disinfectant, sodium hypochlorite, hydrogen peroxide, iodine, isothiazolinones, ozone, peracetic acid, phenolic, and surfactants. **Physical:** Falling shocks, vibration, unsuitable temperature, humidity, glass, bone or insect debris, metal fragments, and plastic	The temperature of storage is ≤45°F. Distributed using refrigerated (≤45° F), proper building setting, proper storage condition setting, pest control

Source: [1, 6, 21–23].

Table 2.
Hazard analysis in mozzarella cheese processing steps.

HACCP implementation requires the completion of a special form in order to create monitoring files in all CCPs, including:

Processing stage

- Type of the CCPs
- The controlling parameter and its limits
- The method, frequency, records, and the monitoring agent
- The corrective action in case the control parameter is out of control, verification/evaluation of the effectiveness of the applied corrective action, and the person responsible for the corrective action
- The evaluation officer of the corrective action

Generally, documentation plays a significant role in verifying that HACCP controls are being adhered to and maintained in accordance with their objectives. The CCPs in mozzarella cheese manufacturing plants are summarized in **Table 3** [1, 2, 6, 9, 22–24].

2.4 Nonthermal milk microbial in activation and preservation techniques

The conventional method of microbial elimination and inactivation process cause major change in some nutritional components and physical and chemical properties of the food products, which leads to the development of detrimental flavor, loss of vitamins, and volatile flavor compounds [25]. Consumers also want foods that have undergone minimal processing with clear labels and goods made without the use of heat, which led to the invention and introduction of nonthermal processing methods to the food industry. The nonthermal processing is a revolutionary processing approach that is used not only in the milk processing industry but also in other food products. These processes eliminate microbes or other biological organisms without raising the temperature significantly and preventing a sequence of undesirable reactions in foods. Due to their capacity to produce safe, wholesome foods with a longer shelf life that are fresh and nutritious, nonthermal processing technologies can be utilized as a replacement for thermal processing. High-pressure processing (HPP), nonthermal plasma (cold plasma), ultrasonic, pulsed electric field (PEF), ultraviolet irradiation, and membrane microfiltration techniques are some common nonthermal procedures that are used in milk processing [26].

2.4.1 High-pressure processing (HPP)

HPP is a nonthermal technique of inactivating microbes and enzymes in food products using high pressure. HPP is a nonthermal technique for inactivating microbes and enzymes in food products using high pressure. It is an ideal substitute for conventional heat processing because it has no effect on the nutritional or sensory qualities of food. Sousa et al. [27] conducted an experiment to evaluate the impact of HPP on human milk and found that only ionic and hydrophobic interaction of macromolecules (proteins) was disrupted without denaturation of biologically active proteins. The microbial inactivation has been revealed with very little to no effect on the

CCPs	Hazards	Preventive measure	Critical limits	Monitoring procedure	Monitoring frequency	Corrective action
Milk reception	Microbial chemical and physical contamination e.g.	Reception of natural raw milk at ≤4 −6°C, milk clarification, preheat treatment, separation	No unqualified material be used	Apply supply quality assurance	Each supply	Refusing raw materials with defects Cleaning the reception area and equipment Operator training & cooling <4
	Total plate count/g	Proper transfer equipment Sanitize equipment Proper personal	Max 2 x 104 cfu/g	Inspection of personal and equipment hygiene	Every time during collection and reception	Cleaning of milk collection and storage equipment, pasteurization
		hygiene and handling				Operator training & cooling <4
	Clostridium botulinum	Avoid cross-contamination and contact with the soil	Nil per gram	Inspection of personal, environmental, and equipment hygiene	Every time during collection, reception, and at the end of production	Inspection of personal, environmental, and equipment hygiene
	Mycotoxin residues (aflatoxin M1) checking	Checking the feed staff and another source of contamination	0.5 μg/kg	Regular detection	Each supply and collection center	
	Antibiotics (total antibiotics)	Checking the supply and proper withdrawal	10.0 ppb	Regular detection	Each supply and collection center	Discard
Pasteurization	Survival of pathogens such	Pasteurizer checks: Check the heat plate,	Temperature set at 72°C, 15 s,	Check thermometer and time,	Each batch	Adjust the temperature and time by setting
	As *E. coli*, *Staphylococcus aureus*, *Bacillus cereus*, etc.	Check the temperature Controller, and Check the flow diversion	and pathogenic bacteria must be Nil per gram, phosphatase test negative	Check equipment is properly running Supervisor managing and record Keeping	Routinely Each batch	The equipment well Call the engineer to repair

CCPs	Hazards	Preventive measure	Critical limits	Monitoring procedure	Monitoring frequency	Corrective action
Starter culture and Rennet addition	Microbiological contamination	Proper additional rate	Rennet: 100 ml/100 kg concentrate agitator set	Check the additional rate of the rennet and pH	Each batch	Applying more testing on ph adjust agitate rate and store temperature <−40°C
	Physical contamination	Agitate properly	At medium	Check the rate of the agitator record-keeping	Each batch	Operator training
Coagulation	Microbiological, physical, and chemical contamination	Proper time setting and recording	Temperature set at 40–45°C Time is set at 30–60 min	Check the temperature/time and the stirring tools	Each batch	Reject product
		Take the stirring tools out of the tank	Tools prevent coagulation	Record keeping	Each batch	Operator training
Cutting	Microbiological Contamination	Proper time and temperature setting		Check the temperature/time record-keeping	Each batch	Adjust the heater to change the temperature Operator training
Dry salting	Microbiological contamination e.g. Salmonella	The correct level of salt Correct mixing during salting The salt-free from any contamination	Salt% = 5.0% The product must be free from Salmonella and shigella	Records and testing	Each batch	Incorrectly salted curd must not be allowed To progress
Scalding	Microbiological, physical, and chemical	Proper time and temperature setting	Temperature is set at 38°C, scalding for 30 min, Stirring for 20 min	Check the temperature and the time, record keeping, check fine cutting of coagulum into cubes	Carried out after every 15 minutes	Adjust the heater to change temperature
Molding	Microbiological contamination	Proper temperature Setting	Temperature set at 32°C	Check thermometer and record-keeping	Each batch	Adjust the heater to change the temperature

CCPs	Hazards	Preventive measure	Critical limits	Monitoring procedure	Monitoring frequency	Corrective action
Packaging	Microbiological, physical, and chemical	screens, filters Use specific sizes for the products Low-level shocks, less impact with other packages		Visual inspection of packages and packing material	Every 3 Hour	Build proper structural frame Cabinet for placement of pallets in warehouse
Storing & Distribution		Maintain refrigeration temperature, control	Temperature 4 °C	Record keeping, documentation	Check after every 60 min	Avoid fluctuations during cold storage
		humidity, cooling				
		the facility in the carrier vehicle				

Source: [1, 2, 6, 9, 22–24].

Table 3.
HACCP for mozzarella cheese processing plant.

small molecules of milk components (vitamins, taste, and amino acids), color, and other nutritional components. However, microbial inactivation is irreversible due to changes in membrane protein and other factors under greater pressure in microbial cellular membranes.

Moreover, HPP brought about some important modifications, such as denaturation, coagulation, and protein aggregation, which can influence the final product yield. Several researchers have successfully used HPP to increase the shelf life of milk [28] and milk products, including cheddar cheese [29], gorgonzola cheese [30], and queso fresco cheese [31]. In recent years, HPP has been demonstrated to be an effective tool for changing milk's functional properties and pressure-induced molecular changes and successfully applied in the sector [32].

A majority of research studies on milk processed using HPP were focused on determining whether harmful and spoilage microorganisms had been eliminated. Due to the resistance of spores to high pressure, the process at 400–600 MPa was comparable to heat pasteurization (72.8°C, 15 s) [33, 34]. By contrast, sterilized milk could not be compared to 400–600 MPa processing. While no research was conducted on the effect of HPP on mozzarella cheese, the experiment conducted on Turkish white cheese by treating with high pressure from 50 to 600 MPa for 5 or 10 min at 25°C found reductions in *L. monocytogenes*, total aerobic *mesophilic* bacteria, molds and yeasts, *Lactococcus* spp., and *Lactobacillus* spp. [35]. The process had no effect on pH and water activity of the cheese. Another study conducted on goat's milk cheese manufactured from raw milk processed at 450 MPa for 10 minutes or at 500 MPa for 5 minutes showed that the counts of *L. monocytogenes* were reduced by more than 5.6 log cfu g^{-1} without significantly altering the organoleptic properties of the final product.

The HPP process at 400 to 600 MPa for 7 minutes has been shown to eliminate *mesophilic* and aerobic bacteria, *Enterobacteriaceae*, lactic acid bacteria, and *Listeria spp*. and have no effect on the cheese's texture [36]. However, trained panelists and customers failed to notice the differences between the control and pressure-treated samples. According to Lopez-Pedemonte et al. [37], ultrahigh-pressure homogenization (UHPH) and high-pressure homogenization (HHP) are effective methods for inactivating *S. aureus* CECT 976 in milk used for cheese production. A primary and secondary homogenization stage using the UHPH was conducted at 300 and 30 MPa, respectively, and was then followed by an HHP treatment at 400 MPa/10 min/20°C. They discovered that cheese contained *S. aureus* at a starting load of 8.5 log10 CFU/g in control. Following UHPH and HHP treatment of the milk, the cheese showed full inactivation of S. aureus and its enterotoxin after 15 days of ripening.

A study on Gorgonzola cheese rind by pressure treatment between 400 to 700 MPa for 1 to 15 min at 30°C inactivated seven hemolytic strains belonging to serotype 1/2a of *L. monocytogenes*.

In addition, De Lamo-Castellvi et al. [38] revealed that all viable cells of *E. coli* O59:H21 and O157:H7 were eliminated in washed-curd cheese after being treated at 500 MPa. Besides, pressures of 300 and 400 MPa applied to cheese at a pH of around 4.8 completely inactivate both *S. Enteritidis* CECT 4300 and *S. Typhimurium* CECT 443 [39].

In general, milk and its products retain significant flavor, color, and nutrients after being pressure-treated. However, a strategic combination of HPP with other thermal and nonthermal treatments may be considered in order to prevent the recovery of injured cells during storage (**Table 4**).

Product	Target microorganisms	Treatment conditions	References
Washed-curd cheese	*Yersinia enterocolitica* CECT 4055 (serotype O3) CECT 559 CECT 4054	Strain CECT more baro tolerant at 300 MPa	De Lamo-Castello et al. [38]
Washed-curd cheese	*Listeria monocytogenes* NCTC 11994 Scott A	Strain NCTC 11994 was more sensitive to HPP at 400–500 MPa for 10 min	Lopez-Pedemonte et al. [37]
Swiss cheese slurry	Coliforms, yeasts, molds, presumptive coagulasepositive *Staphylococcus*, starter lactic acid bacteria	The counts of all microbial groups reduced greatly at 345–550 MPa for 10–30 min	Ding et al. [40]
Gouda cheese D-values	*Aeromonas hydrophila*	D-value of 32.05, 12.97, and 2.43 min at 100, 200, and 300 MPa at 50 °C, respectively	Fonberg-Broczek et al. [41]
Washed-curd cheese	*Staphylococcus aureus* CECT 4013 ATCC 13565 *Staphylococcal enterotoxin* A (artificially inoculated)	Rate of inactivation increased with increasing pressure from 300 to 500 MPa	Lopez-Pedemonte et al. [37]
Mato cheese	*Staphylococcus carnosus* 4491	No remarkable decrease in counts of bacteria at 500 MPa for 30 min at 10 or 25 °C. 7 log reduction at the same pressure at 55 °C for 5 min	Capellas et al. [42]

Table 4.
Effect of high hydrostatic pressure on the inactivation of some pathogenic bacteria in cheese.

2.4.2 Microfiltration (MF)

Microfiltration is a type of membrane filtration that uses an open membrane structure and is operated at low pressure on the filter material [26]; it uses porous membranes with typical pore sizes of between 0.1 and 10 m. MF membranes can retain particles, cells, and large macromolecules (e.g., polymers). The dairy industry uses MF membranes for a variety of purposes, including the removal of bacteria [43, 44], whey defatting [45], and the production of concentrates enriched in casein micelles [44]. It extends the milk storage lifespan by decreasing the microbial load and eliminating spores, while preserving organoleptic quality. The low cost and fouling of cellulose acetate membranes make them very popular. Membrane separation was first used to separate milk components in the late 1960s and is now routinely used in whey and cheese processing.

MF can be used to reduce the microbial load in liquid milk and increase its shelf life without any changes in its composition and sensory qualities [46]. Using modified membrane structures, the microbial load can be reduced significantly without affecting milk composition [47]. García and Rodríguez [48] developed a process for extending the shelf life (ESL) of milk by 33 days using a combination of microfiltration and thermal treatment. There was a minimal change in the main composition of ESL milk compared to that of raw untreated milk. Low-fat milk is preferred for microfiltration processing, although slight changes in protein, calcium, and lactose levels were observed after the treatment [47].

Several studies have been conducted to verify the efficiency of microfiltration in microbial and spore removal [49–54]. However, García and Rodríguez [48] claimed that the exclusive utilization of MF is not granite for the removal of spores and some pathogenic bacteria because of the survival nature of some bacteria, which multiply during the ripening and storage periods. Bacteria are maintained and concentrated in the retentate if the milk quality is poor and membrane pore sizes of 0.1 μm are not used in the separation of milk proteins. In contrast, Skrzypek and Burger [55] revealed that ceramic-membrane-based microfiltration is risk-free and nonintrusive.

According to France et al. [56] the dairy sector frequently filters at temperatures where microorganisms can flourish, which, combined with high TMP, a lack of mechanical cleaning, and constant feed flow, makes membranes vulnerable to biofilm formation. The temperature at which filtration is performed is an important consideration for processors because it influences microbial growth and diversity. High temperatures (45–55°C) provide optimal conditions for the growth of *thermophilic* bacteria that can produce heat-stable proteases and lipases. These bacteria can affect the quality of dairy products, produce acid on growth, and reduce pH [57, 58]. The growth of microorganisms and formation of biofilms can be more rapid at high temperatures than at low temperatures. As reported by Chamberland et al. [59], skimmed milk processing at 15°C led to a much slower occurrence of biofilms on UF membranes than at 50°C. *Psychrophiles* and *psychrotrophic* bacterial genera can grow at low temperatures, but their optimal growth temperature is–20-30°C. The authors revealed that the number of 16S rRNA gene copies on the membrane increased from 3.21 0.12 to 8.83 1.58 log10 gene copies per cm^2 after 15 hours of processing, indicating that bacterial growth was much higher at 50°C. A study conducted by Rodríguez-González et al. [60], using a cross-flow MF of 1.4μm pore size, reported a reduction of 2.1-log in mesophilic microorganisms in skim milk. Another study by Maubois [61] also revealed that the vegetative cells of skim milk showed a reduction of >3.5-log after MF processing at 55°C in 1.4μm pore size. The MF-treated milk was free from somatic cells, and the spore reduction was >4.5-log.

Conversely, psychrophiles and psychrotrophic bacterial species, such as *Pseudomonas*, *Psychrobacter*, and *Corynebacterium*, can be developed during milk filtration at low temperatures (15°C). Schiffer and Kulozik [62] examined microbial growth under feed-and-bleed filtration of skim milk at temperatures of 10, 14, 16, 20°C, and 55°C and a sudden drop in pH, associated with microbial activity, forced them to stop filtration at 55°C after 10 h. In cold MF, multiplication is minimal because most psychrotrophic bacteria prefer temperatures in the range of 20 to 30°C. Higher temperatures (15–20°C) facilitate the growth of mesophilic bacteria and are close to the optimal metabolic activity of psychrotrophic bacteria; therefore, microbial filtration during dairy processing is generally avoided. However, the bacterial communities responsible for increasing microbial counts at 16°C and 20°C were not determined, making it unclear whether mesophilic bacteria significantly contributed to microbial counts at the upper end of the cold MF range.

Moreover, the effectiveness of MF in eliminating microbes, spores, and somatic cells from skim milk at cold temperatures was examined by several scholars and found a positive result [62–65]. According to an experiment conducted by Fritsch and Moraru [64] the entire vegetative cells and spores were eliminated after MF processing, while the skimmed milk initially had a count of 5.25 and 2.15-log CFU/mL of vegetative bacteria and spores, respectively, following the application of MF treatment (pore size of 1.4 μm at 6°C) and somatic cell count was reduced to 3.0-log. Gosch et al. [65] conducted an experiment to examine the impact of pore size on the elimination of microorganisms and discovered that a membrane with a pore size of 0.8 μm was more effective than a membrane with a pore size of 1.4 μm in terms of >3.5 log decrease in the count and > 5.4-log reduction in the total viable count.

Conversely, two MF treatments reduced the total viable count of skim milk to >2.3 log CFU/mL. When compared to a ceramic membrane with 1.4 mm pores, MFs with 0.14 mm and 0.2 mm pore diameters showed a similar drop in bacterial cell density in their permeate.

Sterilox membranes (Pall-Exekia Company) are much more effective because of their narrower pore distribution sizes and can reduce the microbial load by 5–6-log and 3–4-log CFU/mL, respectively, with 0.8 and 1.4 mm microfiltration filters. Elwell and Barbano [63] used ceramic membranes with 1.4 m pore sizes to investigate the quality and storage stability of skim milk after MF. They discovered a 3.79-log reduction in the bacterial count and reported that the spore count decreased from an initial count of 2-log CFU/mL in raw milk to an undetectable level.

Another investigation found that filtering skim milk at 50°C via a membrane with a pore size of 1.4 μm resulted in >3.5-log reductions in the bacterial count and retention of all somatic cells. Comparing the results with 0.5 μm membrane processing, the bacterial reduction was increased to 2–3-log when a smaller pore-size membrane was used [66]. After filtering skim milk with a 1.4-μm membrane. Trouvé et al. [67] observed a > 4.5-log reduction in spore-forming bacteria. Furthermore, Brans et al. [68] investigated the use of 0.5 μm micro-sieves, an advanced membrane filtering device. The narrow pore size distribution of this membrane is able to work at low trans-membrane pressure and has achieved a 6.6-log reduction in the amount of *Bacillus subtilis* inoculated in SMUF.

2.4.3 Pulsed electric fields (PEF)

Pulsed electric fields is nonthermal processing technique that includes passing brief bursts of a strong electric field through fluid or semi-fluid meals. This breaks the microbial cell membrane, leading to cell rupture and, ultimately microbial cell death [69]. Milk is a suitable product that can receive PEF treatment because it is a fluid food. According to Bendicho et al. [70], milk that had PEF treatment underwent fewer unfavorable alterations and had a lower bacterial burden. According to research by Sharma et al. [71], the effects of PEF treatment were found to rise as the treatment temperature rose. According to Sharma et al. [71], PEF-treated milk has microbiological stability comparable to thermally treated pasteurized milk but without any thermally caused damage.

The main purpose of PEF processing milk samples is to examine the impact of PEF on various bacteria that are probably present in milk. One of the earlier investigations used PEF with 36.7 kV cm^{-1} and 40pulses for 25 minutes to inactivate Salmonella Dublin in homogenized milk. The desired microbe was totally destroyed inactive under these circumstances in samples kept at 7 to 9 °C for eight days; nevertheless, a 3-log reduction was achieved in *E. coli* cells under the same circumstances [72]. Untreated milk had an increase in the population of native milk microflora to 107 cfu ml^{-1}, whereas PEF treatment reduced the bacterial load to about 4102 cfu ml^{-1} [73]. Skim milk (SM) and whole milk (WM) were subjected to PEF processing (30.76 to 53.84 kV cm^{-1} electric field intensity and 12, 24, and 30 pulse numbers), along with light heating (20, 30, and 40oC), which resulted in minor alterations in the physicochemical parameters of both milks after processing. After PEF processing, mesophilic bacteria grew more slowly in both SM and WM than they did in psychrophilic bacteria, reaching up to 6 and 7 log cfu ml^{-1} growths after 25 days of storage at 4oC, respectively [74].

Despite the fact that the majority of studies have concentrated on PEF processing of milk, a small number of studies have also looked into PEF's potential applications in the dairy industry. For instance, *Lactobacillus brevis*, *Streptococcus thermophilus*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, and *Saccharomyces cerevisiae* counts were reduced by approximately 2 log cfu g^{-1} when yogurt was processed using PEF [73]. There were no appreciable variations in L, a, and b values, oBrix, pH, or a few selected sensory qualities between the control and treated samples after PEF and heat processing (at 60°C for 30 s). In comparison to the control samples held at 4 or 22°C, the microbial counts of the samples treated with heat (at 60°C) and PEF were reduced [75].

PEF-treated dairy products show strong customer acceptability and sensory characteristics that are comparable to those of heat-treated products [76, 77]. The flavor profile of cheddar cheese created from PEF-treated milk was superior to that of cheese samples made from milk pasteurized at 63°C for 30 minutes. The values of the cheese's hardness and springiness increased while those of the other textural characteristics, such as adhesiveness and cohesiveness, remained unchanged [78].

The amount of proteolysis in cheese curds made from milk that had undergone PEF treatment (2 s pulse width, 2 Hz pulse frequency, and up to 120 pulses) was higher than that of cheese curds created from pasteurized milk but lower than that of cheese curds made from raw milk. The rennet coagulation time of milk treated with PEF was recently reported to have increased by 10% [79]. The potential of PEF treatment on the inactivation rate of selected pathogens in milk and milk products is summarized in **Table 5**.

Product	**Target microorganism**	**Processing conditions**	**References**
Homogenized milk	*Salmonella* Dublin (full reduction) *Escherichia coli* (3 log reduction)	36.7 kV cm^{-1}, 40 pulses, 25 min	Dunn [72]
Raw skim milk	*Listeria innocua* (4.3 log reduction)	30 and 40 kV cm^{-1}, 1–30 pulses, 20–72°C, <10 s. Best balance of inactivation was achieved at 55°C with 40 kV cm^{-1}	Guerrero-Beltrán et al. [80]
Raw skim milk	*Listeria* innocua (2.5 log reduction)	30, 40 or 50 kV cm^{-1}	Calderon-Miranda et al. [81]
Raw skim milk	*Listeria* innocua (2.0, 2.7 and 3.4 log reductions)	30, 40 or 50 kV cm^{-1} plus 10 IU nisin application	Calderon-Miranda et al. [81]
UHT milk	*Geobacillus stearothermophilus* (3 log reduction)	60 kV cm^{-1}, 26–210 μs	Shin et al. [82]
UHT milk	*Pseudomonas fluorescens*, *Bacillus cereus*, *Lactococcus lactis* (0.3–3.0 log reductions)	35 kV cm^{-1} with 64 pulses of bipolar square wave for 188 μs	Michalac et al. [83]
UHT milk (whole)	*Pseudomonas* isolates (complete inactivation)	31 kV cm^{-1}, 20 μs, 55°C	Craven et al. [84]
Cheese whey *Zygosaccharomyces* bailii	*Listeria* innocua, (3.0–5.0 log reductions)	(7.9–8.8 log reductions) 40 kV cm^{-1}, 4937 μs PEF plus UV (with 7.7 s, 229 mJ ml^{-1} dosage)	Dave et al. [85]

Table 5.
Effect of PEF treatment on the inactivation rate of selected pathogens in milk and milk products.

2.4.4 Ultraviolet light (UV)

The wavelength of the ultraviolet (UV) radiation employed for food processing ranges from 100 to 400 nm. Raw milk absorbs UV light at a rate of 290 cm^{-1} at a wavelength of 253.7 nm. Milk is photosensitive; hence, UV light radiation usually has a detrimental effect on it [86]. However, Krishnamurthy et al. [87] revealed that pulsed UV radiation has the capacity to completely inactivate *Staphylococcus aureus*, a milk pathogen. Moreover, ultraviolet (UV) light has shown promise as a nonthermal method for microbial inactivation in various food products, including dairy items. Recent studies have explored the antimicrobial effects of UV-A light on processed cheese, demonstrating its potential as a surface decontamination method. According to Altic et al. [88], milk flowing through a UV chamber caused *Mycobacterium avium* subsp. *paratuberculosis* cell clumps to break apart. The synthesis of vitamin D may be aided by short-wavelength UV radiation. Matak et al. identified some alterations in sensory perception and dietary habits.

When UV light treatment is utilized for pasteurization, milk turbidity is a significant difficulty. Turbidity in milk reduces microbial inactivation because it allows less UV radiation to penetrate. Milk becomes turbid when suspended and colloidal materials are present in high concentrations, which results in milk's opaqueness. Two methods have been employed in contemporary UV reactors to boost the UV light penetration into milk based on fluid flow, opening the door for the employment of this technology in the dairy and food industries for pasteurization. The first method uses the laminar flow of milk or fluid to create an extremely thin film over a UV-irradiated surface, allowing light to pass through the milk. The second method uses turbulent milk flow to reduce the necessary route length and increase UV light penetration in milk [89]. It does this by placing all liquid components in close proximity to UV-exposed surfaces. The studies on the impact of UV processing on the quality of whole milk found no significant changes in the milk's viscosity, color, pH, soluble solid contents, or viscosity. When pasteurized whole milk was exposed to UV light with a dose of 10 mJ/cm^2 for 12 to 235 minutes, the pH range of the milk treated with UV light was 6.66 to 6.70, the viscosity was typically 2.00 0.01 (m Pa s), the color change E* was in the range of 0–0.5, and the contents of soluble solids were 12.78 0.10 (% g/g) [90].

The primary goal of UV light processing of milk and other dairy products is the elimination of harmful and spoilage bacteria. According to Krishnamurthy et al. [87], the effectiveness of pulsed UV light at 5, 8, or 11 cm from a UV light strobe with a 20, 30, or 40ml min^{-1} flow rate up to three times via recirculation for continuous flow milk treatment resulted in a 0.55 to 7.26 log cfu ml^{-1} reduction in *S. aureus* counts. Raw cow's milk was processed in a continuous flow coiled tube ultraviolet reactor for 17 seconds at a cumulative dose of 16.822 mJ cm-2, which reduced the total microbial count by 2.3 log cfu ml^{-1} but had no discernible effect on the odor compounds in the treated, untreated, or control samples. Milk samples treated with UV caused a detectable change in odor, but no significant difference in malondialdehyde or other reactivity was detected after treatment or during storage between untreated and UV-treated milk samples. Moreover, Bandla et al. [91] revealed that UV-treated milk had higher lipid oxidation products than fresh or untreated raw milk samples.

Recently Hales and Bastarrachea conducted a research to determine the antimicrobial mechanism and microbial inactivation kinetics of UV-A light on processed cheese inoculated with *Escherichia coli* K12 and *Listeria innocua*. The results revealed that an exposure of approximately 70 minutes of UV-A light was required to achieve an ~6 log reduction in *E. coli* K12, while *L. innocua* L2 required around 130 minutes of exposure. The UV-A light exposure also led to increased oxidative stress and membrane damage in both bacteria. Furthermore, infrared spectroscopy indicated no significant changes in the surface chemistry of processed cheese after UV-A exposure, except for a decrease in moisture content and an increase in lipid concentration. The study concluded that UV-A light could be a suitable alternative for surface decontamination of dairy products, including processed cheese [92].

In general ultraviolet (UV) light has emerged as a nonthermal method for microbial inactivation in various food products, and recent studies have investigated its effectiveness on processed cheese. UV light shows promise as a nonthermal method for microbial inactivation in dairy products. However, its effectiveness can vary depending on the target microorganism and specific product characteristics. Further research and optimization of UV treatment parameters are necessary to fully harness its potential for preserving dairy products' quality and safety.

2.4.5 Cold plasma

Plasma (quasi-neutral gas) technology (PT) is one of the most recent technologies with numerous uses in the food sector. It is defined as the fourth stage of matter, which is electrically charged or ionized but does not have a fixed shape or volume [93, 94]. It is an entirely or partially ionized state made up of neutrally charged molecules and atoms, free radicals, negatively and positively charged ions, intermediate highly reactive species, and negatively and positively charged ions [95].

The most appealing characteristics of PT are its low-temperature properties and increased efficacy in microbial inactivation [96]. The fundamental idea behind PT is a straightforward physical one: by feeding the gas with extra energy through an electrical discharge, the gas is transformed into an energy-rich plasma state, the fourth state of matter. The application of PT enhances the product's quality and maintains its safety from pathogenic and spoilage-causing bacteria without compromising its functional, sensory, or nutritional profile [97]. Furthermore, it is crucial to remember that PT only causes changes to the food's surface because plasma-reactive species lack penetrating power [98]. PT is frequently used in the food industry for enzyme inactivation, wastewater treatment, food packaging modification, hazardous elimination, and food decontamination [99].

Despite its widespread use in the medical, chemical, and polymer industries, cold plasma has yet to be tested in the dairy industry, and little research has been conducted. A study was conducted on whole, semi-skimmed, and skimmed milk stored at 4°C for 42 days by applying plasma at 20 kV to determine its potential for reducing *E. coli*, *S. Typhimurium*, and *S. aureus* inactivation rates and found a reduction of 3.63 log cfu, 2..00 log cfu ml^{-1}, and 2.62 log cfu ml^{-1} for *E. coli*, *S. Typhimurium*, and *S. aureus*, respectively. Neither the pH nor the color of the milk samples changed significantly. It was found that no viable cells were detected in whole milk samples after a one-week examination and that the samples remained stable after being stored for more than six weeks.

The rate of microbial reduction increased with increased input power and plasma exposure time, as evidenced by the inactivation of *L. monocytogenes* inoculated into sliced cheese by atmospheric pressure plasma (APP), which is capable of operating at atmospheric pressure in air with 75, 100, 125, and 150 W input powers and 60, 90, and 120 s plasma exposure times. After 120 s of APP treatments at 75, 100, and 125 W, the viable cells of *L. monocytogenes* in sliced cheese were reduced by 1.70, 2.78, and 5.82 log

Microorganisms	Dairy food	Reduction	References
E. coli O157:H7 ATCC43895	Milk	≥ 3.94-log	Ruan [101]
Salmonella (5 strain mixture)		2.95-log	
Listeria monocytogenes (5 strain mixture)		2.74-log	
B. cereus (3 strain mixture)	Skim milk	0.18-log	
E. coli O157:H7 (5 strain mixture)		4.36-log	
Salmonella (5 strain mixture)		5.55-log	
L. monocytogenes (5 strain mixture)		4.73-log	

Table 6.
Effect of plasma technology on different microbes in milk.

cfu g^{-1}, respectively. When employing APP (with 75, 100, 125, and 150 W), the exposure times needed to inactivate 90% of the cheese's microbial population were 71.43, 62.50, 19.65, and 17.27 s, respectively. When sliced cheese was treated with 125 and 150 W of APP, no viable cells were detected [100]. **Table 6** provides an overview of how plasma technology influences certain milk bacteria.

2.5 Cost effectiveness of non-thermal technologies

The cost-effectiveness of high-pressure processing, pulsed electric field, microfiltration, cold plasma, and ultraviolet light treatment in dairy industries depends on several factors. The initial cost of equipment, maintenance costs, and the cost of energy and materials are important considerations. However, these technologies are generally considered cost-effective because they improve the safety and quality of dairy products, reduce waste, and extend shelf life. According to a recent article, although the initial investment in non-thermal processing equipment is higher, it can result in long-term cost savings by reducing energy consumption and extending product shelf life, thereby reducing waste and production costs [102]. In addition, researchers reported that non-thermal treatments are energy efficient [103] and have a lower environmental impact compared to traditional thermal processing, which is in line with the sustainability goals of the dairy industry [103, 104].

Although the study is somewhat older, Campus [105] reports that capital and operating costs of HPP plants will continue to decline in line with demand for the plants. For example, the average processing cost (depending on processing conditions) of HPP is US$0.05–0.5 per liter or kilogram of various foods, which is lower than the cost of thermal processing. HPP technology is suitable and can be used cost-effectively for high-value products [106]. Jermann et al. [107] found that HPP is the second most widely used non-thermal technology in the world after microwave treatment. Microfiltration is the most widely used non-thermal processing, and its cost is even lower than that of UHT. According to Skrzypek and Burger [55], the installation of a microfiltration with a capacity of 25,000 l/h with a cream heater costs about €600,000, while a UHT ESL installation for the same capacity costs about €1,000,000, which have a significant effect on wide application of this technique in the dairy industry.

On the other hand, the cost of PEF is higher than that of the conventional method, which must be compensated by a high-priced product [108]. PEF can effectively accelerate the drying process in the food industry compared to conventional drying with elevated heat by precisely controlling the process temperature, which leads to a reduction in energy costs and gas consumption [109]. Therefore, upscaling of PEF systems for dairy applications remains a challenge and should be a topic of future studies. The same is true for HPP, cold plasma, and ultrasound [110, 111].

In general, non-thermal processing in the dairy industry is not only effective in maintaining product quality and safety by removing or inactivating microorganisms, but can also be cost-effective in the long term, making it a valuable option for dairy producers. Therefore, research and development of these non-thermal processes for food processing should focus on cost-effectiveness, food safety, especially spore inactivation, and customer appeal.

3. Conclusion

In recent years, the demand for dairy products has increased dramatically, especially mozzarella cheese, due to the popularity of pizza. Despite this, these products are also known to have the potential to pose a threat to consumers due to several sources of contamination, including equipment, personnel, additives, packaging materials used during the production process, and nonconforming conditions. The integrated implementation of Hazard Analysis Critical Control Point (HACCP) principles and nonthermal processing for microbial inactivation in Mozzarella cheese manufacturing is critical for guaranteeing food safety and quality. In the HACCP system, hazards and risks are identified and assessed as well as the appropriate controls are implemented at specific points within the production line in order to eliminate or reduce these hazards from occurring during the manufacture, storage, and distribution of food. Once the identification of potential hazards, the critical limit monitoring procedures, and frequency are established, corrective actions can be taken if the CCP fails. This includes temperature control checks, pH maintenance, microbial testing of the end product, and equipment calibration when a failure occurs due to improper equipment operation. The application of HACCP in the mozzarella cheese-making industry proved beneficial and profitable because the industry was able to reduce raw material (milk) and final product (cheese) losses while also increasing consumer confidence by producing safe cheese of improved and consistent quality.

In addition to the HACCP system, the incorporation of nonthermal processing procedures is beneficial for eliminating microorganisms during the production of mozzarella cheese. Nonthermal processing methods, such as high-pressure processing, pulsed electric fields, and ultraviolet light treatment, can be an alternative to traditional thermal processes such as pasteurization. These methods can successfully inactivate pathogenic and spoilage microorganisms but have little influence on product quality. These processing methods can be used at specific, important control points specified by the HACCP system, providing an additional layer of microbiological control and maintaining the safety of mozzarella cheese. Therefore, implementing HACCP procedures and nonthermal processing techniques for the production of mozzarella cheese plays an important role in maintaining the quality of the cheese as well as extending its shelf life.

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Section 3

The Effects of Climate Change on Food Safety

Chapter 4

Climate Change and Food Safety

Suneeta Chandorkar

Abstract

Climate change causes an increase in global temperatures and a shift in weather patterns. Increased carbon emissions are one of the leading causes of climate change. Temperature and humidity increases are conducive to the growth of potentially toxin-producing microorganisms and may favor invasive alien species detrimental to the health of plants and animals. This is causing foodborne illness outbreaks. The acidification of ocean and sea water, the proliferation of toxic phytoplankton, and the contamination of seafood are all caused by rising ocean temperature. The degradation of water and soil quality has led to over 600 million cases of waterborne and infectious diseases. Extreme temperatures and increased precipitation also result in decreased fodder, overcrowded livestock accommodation, an increase in morbidity, and an increase in the use of pharmaceuticals, specifically antibiotics. Pathogens from effluent and heavy metals contaminate the water and soil, and the increased absorption of heavy metals by fish is correlated with ocean warming, hypoxia, and increased salinity. Bioaccumulation of heavy metals higher up the food chain poses a larger threat to human health. The threat of climate change can be mitigated by reducing greenhouse gas emissions or by modifying human behaviour to account for inevitable climatic changes.

Keywords: climate change, food safety, heavy metals, pesticide residue, antimicrobials, mycotoxins

1. Introduction

Climate change has been defined as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability, observed over comparable time periods” [1]. Climate change is a global phenomenon that extends beyond environmental and ecological concerns, impacting all natural systems and posing a threat to global development goals. Climate change refers to the increased severity and frequency of meteorological phenomena such as extreme temperatures, heavy precipitation, intense cyclones, drought, and flooding, as well as global warming. Floods, droughts, and cyclones are estimated to have caused 15 times more damage in regions with high vulnerability than in regions with low vulnerability over the past decade. Moreover, socioeconomic disparities within a region or nation can have a disproportionately negative effect on vulnerable groups [2]. Climate change has an impact on every aspect of our environment, including the air, water, soil, food systems, and livelihoods. According to the Sixth Assessment Report of the

Intergovernmental Panel on Climate Change (IPCC), up to 3.6 billion people reside in areas that are extremely vulnerable to the effects of climate change. Foodborne and waterborne illnesses are brought on by the degradation of soil and water quality. Worldwide, there are reportedly more than 600 million cases of infectious disease. Additionally, foodborne illnesses cause 125,000 child deaths annually, with children under the age of five bearing 40% of the burden [3]. Climate change has led to the loss of agriculture and marine productivity, loss of biodiversity, disruption in food supplies, and food price volatility, thereby affecting the quantity and quality of food consumed, thus jeopardizing food and nutrition security. In 2020, between 720 and 811 million people faced hunger, primarily in Africa and Asia [4]. Although the effects of climate change on the availability and production of food are extensively studied yet the effects on food safety have received little attention. The scientific method or discipline of food safety describes the handling, preparation, and storage of food to prevent foodborne illness [5].

Changes in climate have multiple effects on food safety. Temperature rise and increased precipitation are conducive to the occurrence, persistence, and virulence of several microorganisms associated with foodborne diseases. Additionally, it promotes the growth of plant parasites and weeds. This leads to an increase in the use of hazardous compounds in the form of pesticides, which endangers food safety. Parasites related to livestock diseases are also affected by climate change [6]. Temperature extremes and increased precipitation may result in decreased fodder, crowded livestock lodging, an increase in morbidity due to heat stress, and an increase in the use of drugs, particularly antibiotics, leading to drug and antibiotic resistance among consumers. Water and soil are contaminated by pathogens from effluent and heavy metals because of flooding. Increased heavy metal absorption in fish is correlated with ocean warming, hypoxia, and increased salinity. Bioaccumulation of heavy metals up the food chain poses a larger threat to human health. The various pathways through which climate change affects food safety, adaptation, and mitigation are discussed in detail herewith [7, 8].

2. Causes and impact of climate change on food systems

Climate change is a complicated phenomenon involving long-term alterations in temperature and weather patterns. The changes may be natural or caused by human activities. Since the 1800s, these changes have been largely caused by human activities, such as the burning of fossil fuels, rapid industrialization, modern transportation methods, and extensive food supply chains, to mention a few. These human activities have increased the production and presence of greenhouse gases (GHGs), such as carbon dioxide, methane, hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), nitrous oxide, and ozone, in the lower atmosphere layers. These gases capture the sun's energy, resulting in higher global temperatures than would otherwise be the case, or the greenhouse effect. Carbon dioxide (79.4%) is the most significant contributor to GHGs, followed by methane (11.5%), nitrous oxide (6.2%), and chlorofluorocarbons (3.0%) [9]. In 1990, the first Intergovernmental Panel on Climate Change (IPCC) report stressed the need to control climate change, which was emerging as the greatest problem of the twenty-first century. The challenge is to limit global warming to 1.5°C above preindustrial era. The presence of GHGs has affected the food system, i.e., life on land and water through various pathways [10].

Increased atmospheric carbon dioxide levels have caused the acidification of water bodies. Ocean acidification diminishes its capacity to retain oxygen, resulting in hypoxia. It is estimated that over the past 50 years, the open oceans have lost 77 billion tons (2%) of their dissolved oxygen stock, which has grave consequences for the survival of marine life. Numerous marine species, such as the commercially valuable Atlantic Cod, become extinct, or species, such as krill, migrate to the Polar Regions. The rising ocean temperature is conducive to the development and proliferation of algal species that cause ciguatera [11].

As temperatures and CO_2 levels rise, glaciers are melting. Between 1961 and 2016, a period of over four and a half decades 19,000 glaciers across the globe lost about 9000 billion tons of ice, with losses accelerating over the past three decades [12]. The risk of flooding is increasing as sea levels rise due to melting glaciers, warming oceans, and increased unseasonal precipitation with insufficient snowfall. The melting of glaciers and permafrost (frozen water in the subsoil layers) is releasing into the environment once-buried chemicals such as pesticides, heavy metals such as mercury, dormant ancient strains of harmful bacteria and viruses, and micro-plastics [13]. Algae are found in both salt and fresh water. Algae can rapidly develop and multiply under ideal conditions such as enough light availability, warm seas, and high nutrition levels, resulting in "blooms." Algae blooms can harm aquatic environments by blocking sunlight and depleting oxygen, limiting the growth and survival of other aquatic creatures. Certain algae species, such as golden and red algae and certain forms of cyanobacteria, can create strong toxins that can harm wildlife and humans by causing liver and nervous system damage. Harmful algal blooms (HABs) are those that damage aquatic ecosystems or have the potential to impact human health. Climate change may promote the growth and dominance of harmful algal blooms through a variety of mechanisms including:

- Warmer water temperatures
- Increased salinity
- Increases in atmospheric carbon dioxide concentrations
- Changes in rainfall patterns
- Intensifying of coastal upwelling
- Sea level rise

Ocean acidification may increase phytoplankton methyl mercury (MeHg) assimilation by promoting the growth of a small species that accumulates MeHg efficiently. Human activities, namely, waste disposal through incineration and industrial processes, are predicted to raise atmospheric mercury levels over the coming centuries. The ability of deeper waters to sequester mercury may be overwhelmed as a result of these human activities and ocean warming, resulting in higher concentrations of the neurotoxin in surface waters and, thereby, in the food chain [14, 15].

Animals produce greenhouse gases and are therefore both contributors to and victims of climate change. In some regions, increased temperatures will lengthen the grass-growing season, allowing for more extensive livestock grazing and greater exposure to vectors and wildlife [16]. It has been hypothesized that high temperatures caused by climate change could contribute to heat stress in livestock, resulting in an increase in the release of enteric pathogens that could overwhelm food control systems and enter the food supply [17, 18]. To avoid excessive exposure and stress, more animals may be brought indoors in some regions, thereby increasing the likelihood of disease transmission.

Climate change has had significant effects on both biotic and abiotic factors that contribute to agriculture. Climate change influences the prevalence of microorganisms such as fungi and viruses, as well as the populations of insects, parasites, and other vectors. Abiotic factors, such as air pollution, nutrient deficiencies, and extreme temperature, have an impact on soil quality, plant health, and crop yield [19].

Thus, climate change poses a threat to food safety via both biotic and abiotic routes or sources. These factors operate through the food system both plant and animal-based foods and feeds. The biotic sources include algal blooms, mycotoxins, insects, and pathogens, while the abiotic sources include increased exposure to heavy metals, pesticide residues, and drug residues. The impact of human activities on climate change and methods for mitigating their negative effects to promote food safety are discussed.

2.1 Climate change agriculture and food safety

By 2050, the global population is projected to reach 9.3 billion, necessitating a 50–60% increase in food production to sustain it. (FAO) The increased food demand necessitates intensifying agriculture by increasing the use of fertilizers and pesticides to prevent food loss due to the increased presence of parasites caused by climate change [20].

Agricultural production has witnessed a ninefold increase in the use of synthetic nitrogen fertilizers and a threefold increase in the use of phosphorus fertilizers over the last four and a half decades, and this usage is estimated to increase by 40–50% over the next four decades [21]. Only 42–47% of nitrogenous fertilizers are assimilated by plant vegetation, while the remainder escapes into the atmosphere or enters water bodies, where it promotes the initiation and persistence of harmful algal blooms (HAB). Algal blooms are associated with phosphorus accumulation in freshwater sources. Blooms of *Prorocentrum* spp., *Karenia mikimotoi*, and others are not only spread over a larger area but are present longer because of China's increased fertilizer use. Between 2008 and 2012, the total economic cost of HABs in China was approximately USD 364 million [22]. Increased frequency and intensity of extreme events, such as hurricanes, can cause enormous release of nutrients and organic matter from watersheds into coastal waters, thereby fostering algal blooms. The Chesapeake Bay region of the United States experienced a massive bloom in 2003 as a result of conditions caused by Hurricane Isabel. Deep-water upwelling, which brings nutrients from deeper waters to the surface and causes algal blooms days after the passing of a hurricane, also contributes to a phytoplankton bloom caused by a hurricane. In 2007, a phytoplankton bloom was caused by Hurricane Gonu in the Arabian Sea [23]. Several HAB-forming species have expanded their geographic distributions over time. In the 1970s, *Alexandrium tamarense* and *A. catenella*, the organisms responsible for paralytic shellfish poisoning (PSP), were found in temperate coastal regions of Europe, Japan, and North America. They have since migrated to the Southern Hemisphere, where they have caused toxic blooms along the coastlines of Australia, New Zealand, Papua New Guinea, and South Africa. In addition, new PSP-causing species (*A. fundyense*, *A. minutum*, and *A. cohorticula*) have been identified off the coasts of Brunei, India, Thailand, and the Philippines [24]. In 2012, PSP-causing Alexandrium species were discovered in subpolar regions off the coast of Greenland for the first time. Globally, approximately 2000 cases of PSP are reported annually, with a mortality rate between 15% and 50% [25]. Consequently, the inhabitants of these regions are either exposed to mycotoxins or face food insecurity due to restrictions on fishing.

Mycotoxins, which are metabolites of fungi that thrive on starch and oil seed crops, pose an important threat to food safety [26]. *Aspergillus*, *Fusarium*, *Penicillium*, and *Claviceps* contain the vast majority of toxigenic food and forage species. Agriculture is concerned with five mycotoxins: aflatoxins, ochratoxin A, fumonisins, deoxynivalenol, and zearalenone. According to data collected between 2006 and 2016, these mycotoxins accounted for 55, 29, 61, 58, and 46% of occurrences in cereal grains. Similar outcomes emerged from the analysis of submitted feed samples [27]. There is an insignificant reduction in the mycotoxin content on processing of food, except through dilution; hence they pose a major challenge to food safety. As reported by the Foodborne Diseases Burden Epidemiology Reference Group of WHO, aflatoxins are associated with the highest number of global DALYs (636889) attributable to liver cancer [28]. Concomitant exposure to aflatoxins and hepatitis B virus infection is responsible for about 5–28% of all cases of hepatocellular carcinoma in the world. Other mycotoxins have harmful effects on the kidneys, reproductive system, immune system, and gastrointestinal system [29]. Animal feed is frequently contaminated with multiple toxins, in addition to human food. Recent reports indicate that 64% of the feed samples submitted for analysis, primarily from sub-Saharan Africa, Southeast Asia, and South Asia, contained two or more mycotoxins. When mycotoxin concentrations exceed the regulated or recommended levels, animal protein losses and contamination of animal products such as milk occur leading to a negative impact on human health and nutrition [27]. Alterations in the prevalence patterns of various mycotoxins have also been caused by the introduction of novel feed sources, such as food refuse. Due to a shift toward more plant-based feed, mycotoxins are also becoming a developing concern for the global aquaculture industry [29].

Mycotoxin mitigation calls for good agricultural practices, Pre- and postharvest measures, such as biological and chemical procedures and the choice of suitable packaging materials for storage such as Purdue Improved Crop Storage (PICs) bags. Biological control agents can be used as one of the mitigating strategies. Commercial crops like groundnuts, maize, pistachios, and cottonseed are sprayed with nontoxigenic *Aspergillus flavus* fungal strains that out compete toxic strains during preharvest. Enzymes have fewer safety concerns, are easier to use, and are more specific than bacteria when it comes to biocontrol [30].

2.2 Climate change human behavior and food safety

Indirect threats to food safety occur due to climate change. Prolonged warmer seasons influence consumers' behavior and practices associated with food. Climate change presents indirect dangers to food safety. Prolonged milder seasons influence consumer behavior and food handling and storage practices, which can increase the risk of human exposure to foodborne pathogens [24]. During the summer, outdoor cooking and picnics can pose difficulties in terms of temperature-safe food storage and cross-contamination of cooked and uncooked foods. There is a correlation between environmental stressors and an increase in food safety violations due to a decrease in food safety inspections [31]. Water scarcity can affect the transmission of foodborne pathogens such as Listeria monocytogenes by compromising hygienic conditions in food processing facilities, hand hygiene of food handlers, and equipment sanitation. A lack of water may compel farmers to irrigate their crops with surface water containing pathogens that cause foodborne illness [32]. A rise in ambient temperatures affects the entire food cold chain, from the initial refrigeration or freezing of food to its transportation, storage, and retail display. Increasing ambient temperatures and elevated food storage temperatures will increase the probability that humans will consume unsafe food [33].

According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the average increase in global surface temperature will range between 1.7 and 4.8 degrees Celsius by the end of the twenty-first century [34]. This projected increase in temperature as a result of climate change could impact the microbiological stability of nonrefrigerated food products by increasing the growth potential of spoilage microorganisms during transportation and storage (on retail and domestic levels), thereby increasing the risk of spoilage and resulting in significant economic and material losses. Increased temperature, humidity, and precipitation promote the proliferation of fungi. *Aspergillus* and *Fusarium* species are the predominant fungi responsible for contaminating cereal grains. Maize is the most susceptible crop to *Fusarium* spp. contamination, while maize is the most susceptible crop to Aspergillus spp. Temperature and water activity (aw) have been found to affect the growth of both fungi, with the latter being the most significant growth factor [35].

2.3 Climate change livestock and food safety

There is substantial evidence that climate change will impact the entire livestock food supply chain, from farm production to processing operations, storage, transportation, retailing, and human consumption. As has been stated previously, pests and pathogens are expanding their geographic presence due to climate change, resulting in an increase in antimicrobial use. Natural selection has led to the emergence of antimicrobial-resistant pathogens due to the rampant and indiscriminate use of antimicrobials in humans and the extensive use of medically important antimicrobials in terrestrial livestock production, aquaculture, and crop production. Approximately 73% of global antimicrobial use is in meat production, and antimicrobial resistance in food-producing animals is growing. According to research, 40% of chickens and 30% of pigs raised for human consumption in LMIC failed to respond to antibiotics used to treat disease more than 50% of the time [36]. Antimicrobial resistance has grave consequences for public health, with an estimated 700,000 people dying annually from drug-resistant diseases (including nonfoodborne diseases). Extreme weather that causes flooding, such as hurricanes, increases the likelihood that areas containing animal farm waste containing antibiotics will be flooded. This increases the spread of antibiotic-resistant bacteria in the surrounding environment [37].

Climate change and the lengthening of food chains increase the likelihood of contamination issues arising from foodborne pathogens and parasites, so it is crucial to raise awareness of this in order to mitigate public health risks. When national and regional health authorities in different sectors, medical and scientific research communities, and the agri-food industry collaborate, more effective regulations and guidelines can be developed to improve public health.

Heavy metal contamination of animal feeds is yet another major food safety concern. The two most common routes for entry of heavy metals in animal feeds are the natural route through metal corrosion and atmospheric deposition in soil and water, and through the anthropogenic activities such as the application of fertilizer, pesticides, and mining. The animal feeds grown in the contaminated soil and/or by application of contaminated water lead to entry of heavy metals into feeds and animal foods. Not only do heavy metals in animal feed endanger animal health and reduce animal productivity, but they also contaminate animal products, posing risks to humans [38].

The heavy metals of concern are cadmium, chromium, arsenic, lead, and mercury. Based on the morbidity and mortality of humans, mercury is regarded as one of the most toxic materials. Heavy metals are nonbiodegradable (they are excreted at much slower rates than they are absorbed), and as a result, their concentration within an organism builds over time (bioaccumulation). Bio-magnification causes their concentration to increase as we ascend the food chain. Cadmium and mercury are two examples. Once heavy metals enter living organisms, they undergo transformation and are converted into more reactive or toxic forms, such as mercury being converted in vivo to methyl mercury [39]. Once they enter the human system, all the heavy metals get stored in the liver and are excreted through the kidneys. Cadmium overexposure has been linked to renal dysfunction, lung insufficiency, and osteomalacia. The primary target of mercury is the kidney. Necrosis of the tubular epithelium following acute poisoning can lead to renal failure within 24 hours. After prolonged exposure, tubular necrosis in the kidney and glomerulonephritis are the most prominent toxic effects of mercury. Chromium is required for the normal metabolism of carbohydrates, lipids, and proteins in animals and humans. However, elevated chromium levels can lead to a variety of diseases, including liver cancer. Chromium enters the food system from soil or metal contact during harvesting and processing. Arsenic is a metalloid element and carcinogen associated with increased risks of numerous noncancer endpoints, such as diabetes, cardiovascular disease, and neuropathy. Reviews on the presence of heavy metals in animal feeds, vitamins, minerals, or supplements for livestock revealed that cadmium, chromium, arsenic, lead, and mercury are among the heavy metals present. However, because heavy metals have a propensity to bioaccumulate, they present a risk to both livestock and people even though the levels were below the tolerance limits set by the regulatory body. Although it is challenging to completely eradicate them, monitoring the presence of heavy metals in feeds and feed ingredients and implementing feed management and bioremediation strategies to lessen exposure can help reduce the risk of heavy metal toxicity throughout the food system [40].

2.4 Climate change adaptation and mitigation

Dealing with the threat of climate change can be done in one of two ways:

i. Mitigation, which involves reducing GHG emissions, and

ii. Adaptation, which entails changing human behavior to account for the unavoidable changes in the climate.

In order to track greenhouse global warming, the level of CO_2 emissions should be reduced by 50% over the next 50 years, according to documented scientific evidence. As a result, taking quick action is crucial to avoiding the worst-case scenarios. Major climate change adaptation measures include, among other things, the development of rainwater storage systems and the strengthening of protective levees along coastlines. Major climate change mitigation actions include increased energy efficiency, expanded use of renewable energy, and slower deforestation. One of the biggest consumers of energy worldwide is transportation. Therefore, it is necessary to address fuel efficiency. Good agricultural practices should be taught in schools. For instance, methods to extract CH_4 from animal waste or landfills and convert it into electricity can be developed. Alternative energy sources include geothermal energy from rocks for the production of electricity, biofuels, and nuclear power, as well as solar energy, which can be used in photovoltaic cells, hydropower to create hydroelectricity, wind energy, which is captured by wind turbines and wind farms, and hydropower. Other approaches are carbon sequestration in natural systems, such as the soil, through large-scale reforestation, the increase of organic matter in the soil, and farming techniques, such as no-till farming and crop rotation and research [41]. Other approaches include the promotion of minimally processed foods, short food supply chains through the promotion of local and indigenous food systems. Empowerment of the different actors in the food chain to implement food safety management programs in the production systems is also key. In addition to law enforcement, a critical review of existing food laws and standards is also needed in order to adapt to emerging risks and threats. Hence, developing food safety preparedness plans in the event of natural disasters should also be a national priority for every country. Finally, education and awareness campaigns on food safety, sustainable production, and consumption of foods with due emphasis on curbing food loss and waste, a major source of GHGs [42].

Transport is one of the most significant energy consumers in the world. Consequently, fuel efficiency must be addressed. Good agricultural practices must be inculcated in the field of agriculture. For instance, techniques can be developed to capture CH_4 from landfills or animal waste for the production of electricity. Alternative energy sources include solar energy, which can be utilized in photovoltaic cells, hydropower to produce hydroelectricity; wind energy captured by wind turbines and wind farms, geothermal energy from rocks for the production of electricity, biofuels, and nuclear energy [43]. Other strategies include carbon sequestration in natural systems, such as the soil, via large-scale reforestation, the increase of organic matter in the soil, and farming techniques, such as no-till farming and crop rotation, as well as research. Other strategies include promoting minimally processed foods and short food supply chains by promoting local and indigenous food systems. Key is also the empowerment of the various food chain actors to implement food safety management programs in production systems. In addition to law enforcement, a critical review of existing food laws and standards is necessary to adapt to new risks and threats. Consequently, the development of food safety preparedness plans in the event of natural disasters should be a national priority across the globe. Education and awareness campaigns on food safety, sustainable food production, and consumption, with an emphasis on reducing food loss and waste, can help in reducing greenhouse gas emissions [44].

Existing greenhouse gases will continue to contribute to global warming; accordingly, parallel adaptive measures are required. Building of rainwater storage systems to alleviate damage caused by floods, with the water being reused during drier periods, development of crop strains that require less water and soil moisture, precision agriculture to manage resources, namely water, and use of fertilizers and pesticides can reduce GHG emissions considerably. Precision application of fertilizer decreased methane and nitrous oxide emissions by 1% and 16%, respectively, over conventional methods. Direct-seeded rice (DSR) produces fewer GHG emissions than transplanted rice. Dry DSR and wet DSR have 76.2% and 60.4% less global warming potential than transplanted rice, respectively. In addition, wet DSR produced a 10.8% greater yield than transplanted rice. Aerobic rice has enormous potential for mitigating future climate change, as it conserves 73% of irrigation water used in land preparation and 56% of irrigation water used during crop growth. Utilizing micro-irrigation technologies to cultivate aerobic rice is an appropriate method for sustainable rice production. It also aids in reducing rice field methane emissions [45].

3. Conclusions

Climate change has impacted food safety through multiple pathways, which could lead to an increase in the risk of foodborne illness and impact millions of people's access to safe, nutritious food around the world. The food contamination issues also threaten the Sustainable Development Goals (SDGs), particularly SDG 2 (zero hunger), SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 8 (decent work and economic growth), SDG 10 (reduced inequalities), SDG 12 (responsible consumption and production), and SDG 13 (reduced inequalities) (climate change). Timely measures to adapt and mitigate the effects of climate change are required to promote human and planet health.

Conflict of interest

None.

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Section 4

Food Safety and Restaurants

Chapter 5

Hospitality Restaurant Operations: Safety and Hygiene Practices

Were Simon O.

Abstract

Hotel Restaurants contributes immensely to the economic well-being of many Countries worldwide. Apart from solving patrons' dining needs, restaurants employ many people across the world and thus contributes to the global economic growth. Notwithstanding, restaurant operations provides an avenue for customer attraction, service, and retention! Globally, hotels and/or restaurants invest heavily in restaurant operations processes with a view of staying competitive within the highly volatile field. However, investors within this lucrative business are facing a myriad of challenge pertaining safety and hygiene, which is a threat to the goodwill, and in many cases results in legal proceeding which may be very costly to hospitality organizations. This book chapter will therefore focus on safety and hygiene practices within independent and dependent restaurants, in order to equip hotel practitioners with up-to date and relevant skills, knowledge and information on how to provide hazard-free environment, in consideration of sound restaurant operations that incorporates sound hygiene practices, critical control points and organizational safety principles.

Keywords: foodborne illness, food intoxication, hazard, safety, critical control points

1. Introduction

Food safety initiatives are critical to both independent and dependent restaurants, whose main aim is to develop an all-inclusive farm-to-fork strategies [1, 2]. It is therefore important for these organizations to develop and implement food safety and hygiene procedures and practices in order to ensure a free microworld and thus eliminating the occurrence of related foodborne illnesses among their clientele, both internal and external. These processes must commence right from the level at which food leaves the farm all the way to the fork. However, this procedural approach depends on many factors among which food type remains the major factor [3, 4]. Whereas meats and meat products may require more critical handling processes at various stages of transition, dry cereals on the other hand might not be such technical [5]. Moreover, the slightest lapse in any of the processes and/or conditions required for successful transition of meats and meat products might lead to huge disasters.

Even so, catering outlets constitutes key social points for leisure, relaxation, and business transactions [1, 6]. Thus, restaurants have of late become a 'home' for the global community, not only to meet their physiological needs but also social needs. Thus today, hotels and hotel restaurants host people from all walks of life, but on the other hand a source of income to many hospitality practitioners worldwide. Further, the larger hospitality industry has emerged as one of the highest foreign exchange earners for many countries in the world [2, 7, 8]. However, increased activity as a result of mobility is speculated as being the probable cause of vulnerable diseases, including foodborne illnesses as well as food intoxication across the world [3, 5, 9–11]. Hotels offer accommodation as well as a place to have food and drink to clientele from around the globe, both healthy and sick [3, 6, 12–15]. In essence, it is possible for hotels to accommodate patrons already infected with an amalgam of ailments including infections which are known to spread rapidly among hospitality staff or client. This could be explained on the basis of the social role that hotels play, bringing together people from all walks of life across the world, but again involving many personalities in order to act as the link between restaurant menus and hospitality organizations. Therefore, catering outlets have attracted attention from hospitality, public health as well as other professionals including medical personnel and government agencies in an attempt to minimize and/or eliminate the spread of food related illnesses and intoxications that are the greatest threat to humanity and thus the world economy.

Indeed, it is true that 'cleanliness is closer to Godliness' and therefore all restaurant personnel have an obligation to ensure proper levels of sanitation as well as safety. Human health is currently treated with priority as many Countries of the world struggle to keep their citizens healthy, including huge capital investments in both preventive and curative approaches. Factual pride in operational professionalism demands hospitality brigade to observe high standards of workplace hygiene and safety [5, 16]. This will not only minimize and/or control foodborne illnesses and food intoxications, but also minimize costs that would arise from legal battles, compensation awarded by the courts for the affected as well as business goodwill from the market segments served. Furthermore, the inconveniences and humiliation faced by restaurant owners as well as staff from the public health sector and the police is incredible. But above all, many business associates and customers alike may no longer have the trust to engage in any meaningful business transaction with any catering business associated with foodborne related illnesses and food intoxication.

Nonetheless, the containment in the spread of these diseases must be spearheaded by hospitality practitioners, and particularly the food and beverage production and service staff [1, 17, 18]. This is on the basis of the problem being more prevalent within the food and beverage sections of hotels as compared to other operational departments, although all front-of-the-house staffs have a role to play in the process of not only eliminating but also minimizing the spread of foodborne illnesses and food intoxications. In general, disease transmission in the global hospitality's restaurant business remains a significant universal economic problem, public health issue, and restaurant management challenge that needs concerted efforts in order to solve [2]. This is for the reason that hotels have an active role and thus considered to be the hot bed in the spread of diseases from a social point of view. Because the geographic distribution of diseases is dynamic and influenced by ecologic, genetic, and human factors, travel allows humans to interact with micro-organisms and introduce them into new locations and populations [19, 20]. The global spatial mobility therefore has reduced geographic barriers for disease causing micro-organisms as well and heightened the potential for the spread of diseases that can negatively affect the not only the tourism and hospitality's restaurant industry, but also many other industries across the globe.

Thus, the fear of foodborne illnesses and food intoxication outbreaks require that hotel practitioners must be constantly on the alert not only to detect but also contain any possible outbreaks [5, 21, 22]. They should also be capable of monitoring the trends and initiate preventive mitigations on a day-to-day basis so that they can make the necessary positive adjustments to their operations. This includes being prepared for unforeseen circumstances and changes in their operating environment by practicing and ensuring compliance to food safety and sanitation practices in order to not only mitigate but also prevent the occurrence and spread of these ailments [16, 23]. One way of doing this is by constantly practicing hygiene related control measures, some of which is captured in the occupational safety and public health act, [22, 24]. Thus, it is possible to customize these OSHA requirements within hospitality's food and beverage operations in order to curb the ever-increasing threat of foodborne illnesses. According to Motarjemi and Lelieved [2] the most common foods that caused food poisoning in 2010 are presented in **Figure 1.**

The study results show that many restaurant food items are agents of food poisoning, with eggs and egg products being responsible for 22.1%. This is a clear indication that eggs and egg products are the most hazardous among all the food items prepared and offered for customer consumption in restaurants. Nonetheless, mixed or buffet meals came in second (13.9%), followed by other foods (8.9%), vegetables and juices (8.7%), Crustaceans, shellfish, mollusks and other products (8.5%), bakery products (7.9%), fish and fish products (6.3%), broiler meat and other products (6.0%), Mixed meat and products (6.0%), pork and products (4.9%), bovine meat and products (3.3%), cheese (2.3%), fruit, berries and other products (1.3%). The data results signify that almost all food items served in restaurants have the potential to cause foodborne illnesses if maximum care is not practiced in the process of receiving, storing, preparing and service.

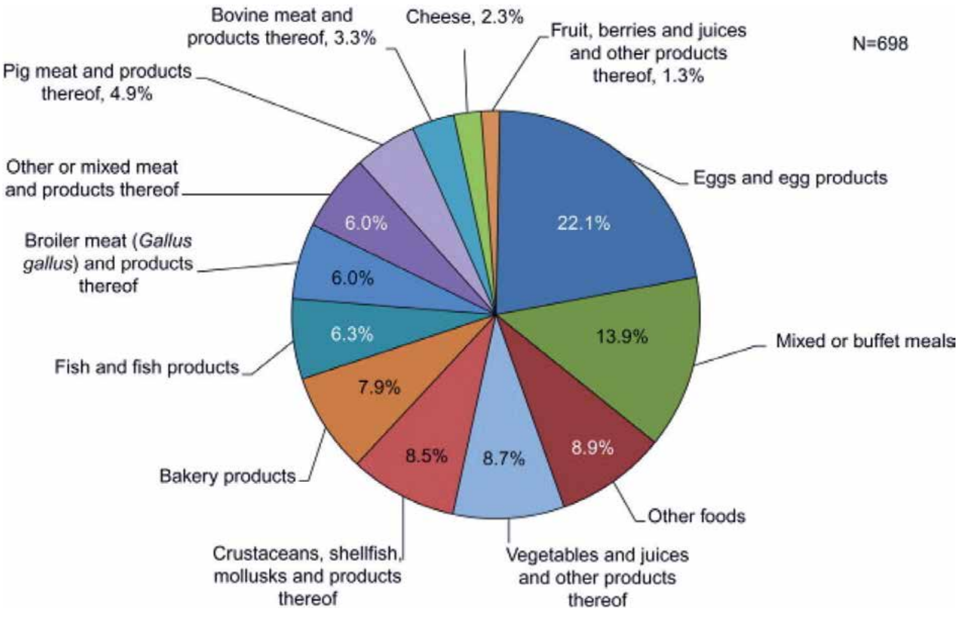

Figure 1.
Food poisoning 2010 from restaurant foods. (Adopted from Motarjemi and Lelieved [2]).

Moreover, the global burden of food intoxication and foodborne illnesses to public health and to economies has often been underestimated by the various state authorities due to underreporting across many countries of the world and therefore the difficulty to establish causal relationships between food contamination and resulting illness or death. Further, the 2019 World Bank report on the global economic burden of the food intoxication and foodborne illnesses indicates that the total productivity loss associated with these diseases in low- and middle-income countries such as Kenya and many African and Asian Countries, was at US$ 95.2 billion per year, and the annual cost of incurred in preventive and curative approaches to these illnesses is estimated at US$ 15 billion [4]. This calls for concerted efforts not only among hospitality practitioners, but across all global industries to help putting in place preventive measures with the aim of minimizing and/or eliminating these diseases for a global economic gain.

1.1 Categories of food contamination

Food poisoning may be categorized in three depending on the contaminant type [25]. These three categories of food poisoning include;

Chemical poisoning: Chemical food poisoning may occur when food is contaminated with chemicals substances. It is accidental contamination of food caused by cleaning solvents, pest control sprays, or other chemicals used in entire food production chain [4, 22]. This food may contamination occur when utensils or other tableware are not wiped dry after washing them using cleaning liquids [5, 25, 26]. This may occur either during growth of the food by pesticides, storage especially if storage of food is not separated from chemical substances such as cleaning detergents, or during food preparation and service in a restaurant set-up as a result of negligence food handling by hospitality personnel.

Physical: This is accidental in nature and is caused by employee carelessness [4, 22, 26]. The major culprits are air, dust, smoke, and dirt. To prevent this, food must be properly covered and stored.

Biological: This is a contamination type resulting from micro-organisms such as bacteria, molds, parasites, and fungi [4, 22]. However, of the most effect are bacteria which are known to cause foodborne illnesses as well as food intoxication if infected food is ingested.

Even though the public health act was meant to protect both clientele as well as hospitality practitioners by enhancing surveillance and building an early warning system; improving responses to foodborne outbreaks; improving risk assessment; developing new research methods for identification, prevention, and control of pathogens; improving inspections and compliance; broaden food hygiene and safety education; and continuation of the long-range planning process, very little has so far been achieved [15]. Food born illnesses as well as food intoxications are so commonly reported not only in Kenya but many countries of the world. Food contamination in many cases has been as a result of poor food handling practices and/or improper food handling by both catering personnel within these outlets [26]. According to Walczak [26], five coping strategies, if applied properly may effectively eliminate the food contamination and menace within hospitality's catering outlets. These strategies include proper maintenance and control of temperature, efficient management and control of the time factor, proper, safe and hygienic food handling procedures, proper and up-to-date restaurant as well as employee hygiene, adequate, proper and standardized cleaning and sanitizing techniques, and the plan of hazard analysis and critical control points applicable within the restaurant operations cycle.

2. Coping strategies

Foodborne illnesses as well as food intoxication related ailments cause a lot of harm not only to the hospitality industry but also clienteles at large. These diseases are widely spread through restaurant foodservice within hotels [26]. The global hospitality industry registers massive losses annually, which results to global economic shrinkage. According to WHO [4], 600 million cases of foodborne illnesses and 420,000 deaths occur annually all over the world, with 30% of foodborne deaths occurring among children under 5 years of age. This is such a huge loss of life and income that calls for urgent and effective intervention in order to curb the trend. For purposes of this chapter, restaurant mitigation strategies against foodborne illnesses will be discussed, as it contributes a huge percentage of food related contamination and therefore foodborne illnesses and intoxication cases.

In relation to the transmission and spread of this disease, restaurant personnel are the most responsible and vulnerable as they are always in close contact with both clients as well as food supplies. This does not only risk the employees but also the hospitality clients who may either contract the disease from infected hotel employees and contaminated foods alike. However, food contamination in restaurants remains the most common explanation of foodborne illnesses and food intoxication in addition to many other factors. This constitutes the basis upon which these infectious ailments are spread and hence risking thousands of lives, both staff and clientele [26]. The industry therefore needs to provide long lasting solutions with the aim of combating the growth and spread of concerned micro-organisms against future outbreaks. The hotel and hospitality organizations have to change their way of operation by adopting strategies that would ensure minimal growth and spread of pathogens.

In an attempt to address the global effects of foodborne illnesses and food intoxications, various food-safety related coping strategies have been effectively proposed for application within the restaurant sector with the main aim being to minimize the multiplication and spread of foodborne infections via hospitality's restaurant operation related services. Basing on various studies on foodborne infections, hospitality's' restaurant management needs to focus more on the coping strategies in order to break microbial cycle and therefore effectively address these infections. Thus, in view of the restaurants' food service systems, five basic strategies were tested, approved and proposed for adoption, in which food service personnel may try to prevent customers as well as restaurant service providers from getting sick. These strategies include; time and temperature control, safe food handling procedures, good employee hygiene, cleaning and sanitizing techniques, and a Hazard Analysis and Critical Control Points (HACCP) plan. These are critical control measures that front-of-the house hotel personnel must embrace in order to suppress the spread of these diseases.

2.1 Time and temperature control

Micro-organisms generally thrive well under favorable temperatures, preferably the temperature danger zone [25]. Nonetheless, time is also needed for the micro-organisms to grow and thus increase in numbers, capable enough to cause diseases. Time and temperature are therefore fundamental factors for the growth, multiplication and survival of micro-organisms. When considering growth rates of microbial pathogens, in addition to temperature, time is a critical consideration [25]. At optimal temperatures over moderately long-time duration, micro-organisms can multiply very quickly and this normally happens at satisfactory temperature, mainly within the temperature danger zone. By holding at temperatures below 4°C or above 60°C, the growth of micro-organisms is slowed down or stopped.

In essence, lower temperatures below 4°C makes micro-organisms inactive and therefore reduce their multiplication. This limits further reproduction and therefore multiplication of the microbes and thus minimizing their pathogenic effect in food. On the other hand, temperatures above 60°C denatures micro-organisms. This would lead to their depletion with time and therefore eliminated from food substances which as well eliminates their pathogenic effect. Thus bacteria, fungi and viruses have a defined temperature range in which they flourish, with a minimum, maximum, and optimum temperature levels. Nonetheless, temperature danger zone, at which the reproduction and growth of microbes is at its optimal level, is the cornerstone of any restaurant food safety program. Thus, a clear comprehension of the interaction between time, temperature, and other inherent and extrinsic aspects is crucial for the successful manipulation and therefore, control, destruction and elimination of infection of any diseases that may arise out of these microbes. **Figure 2** below illustrates the reproduction and/or multiplication of micro-organisms with time.

At the very initial stages of infestation, the microbes are fewer in number (Lag phase). With the right conditions, they exponentially reproduce and therefore increase rapidly in numbers with time (exponential phase) until at the level when they are so many that they begin to compete for the available nutrients and thus reproduction and growth stops (Stationary phase). Since the microbes are so many in numbers, the available nutrients start getting depleted with time as competition for

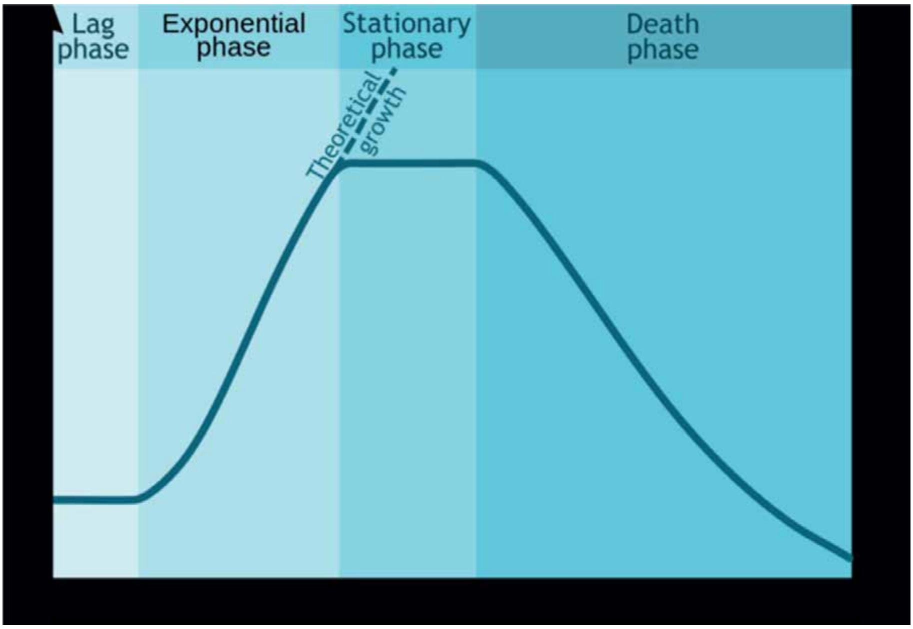

Figure 2.
Bacterial growth curve. (Adopted from Motarjemi and Lelieved [2]).

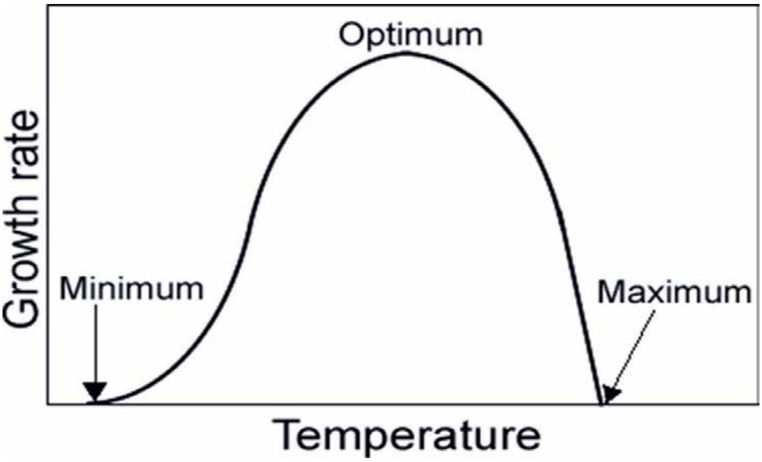

Figure 3.
Bacterial growth curve (number-temperature effect). (Adopted from Motarjemi and Lelieved [2]).

the same intensifies and therefore the same microbes declining in numbers (Decline/Death phase).

On the other hand, studies into the effect of temperature on the multiplication and/or reproduction of microbes have shown almost similar results for the bacterial growth curve as in **Figure 2** above. Thus, in consideration of temperature, the results have yielded outputs as illustrated in **Figure 3** above.

At lower temperatures (below 5°C), the microbes are at their minimal reproduction and/or growth rate is at its minimal. This could be explained by the inactivating effect of lower temperatures on microbes. As the temperatures increases, the growth rate of the microbes increases exponentially as well until the temperatures hits 40°C (optimal temperature) which do not yield any significant increase in the microbial load. Further increase in temperature above 40°C will see the microbes reduce in number. Further increase in temperature up to 60°C will see the microbial load drop to zero in number (maximum temperature). This is because from 40°C and above, the micro-organisms are denatured and completely eliminated at60^0C.

Previous studies on many foodborne illnesses and food intoxications suggest that warm temperature increases the intensity of transmission [11]. Thus, these study results confirms that temperature and time are important factors in the spread of many foodborne illnesses and food intoxications, hence higher infection rates translate into a greater number of individuals who experienced multiple infections and thereby may have an elevated risk for not only developing serious illnesses but also spreading the infections. Thus, increasing temperature to a certain level would lead to diminishing survival of the microbes and therefore an important factor which may be adopted by hospitality's restaurant operators for not only minimizing the spread but also eliminate these illnesses. From the study findings therefore it's apparent that increases in temperatures leads to destruction of microbes causing foodborne illnesses and food intoxications.

It is therefore imperative for hospitality practitioners to apply the effects of temperature in minimizing the spread of foodborne illnesses. This could be achieved through proper handling of food service equipment and the food service processes. Before handling any food service equipment, food service employees must first ensure high personal hygiene. Cutlery should be well taken care of by first soaking in hot soapy water in addition to vinegar and/or lemon juice for purposes of disinfecting [5, 24, 27]. They should be well rinsed and drip-dried after which they should be wiped clean using a sanitized piece of linen. Linen should be washed properly using disinfectants and pressed before use. Hand towels must be pre-heated well before being used by clients. Crockery should as well be correctly cleaned using warm soapy water, dried and wiped with a sanitized piece of linen too. Further, service of hot food must be carried out on hot crockery while cold food must be on cold crockery. This implies that dinner plates, soup and/or consommé' cups, tea/coffee cups etc. must be pre-heated before being used to serve food for the client. On the other hand, glasses must be chilled before service of cold drinks to the client. All these will ensure alteration of temperature which perhaps is one of the most effective applicable strategies in minimizing and may be eliminating microbial contamination which results in foodborne illness and food intoxications.

2.2 Safe food handling procedures

For all food businesses including restaurants, retail foodservice, fast-food, hospital, cafeterias, cafes, messes etc., food safety policies and procedures must be seriously adhered to in order to minimize, if not, eliminate contamination and thus foodborne disease outbreaks. The origin of microbial contaminants in food includes the food itself or its source, the environment, cross-contamination or an infected food handler. Contamination from microorganisms can be responsible for foodborne disease outbreaks passed from food workers to consumers via food. It is therefore important for hospitality personnel to understand the theory and practicalities of safe food handling procedures, and apply the same in the food production-service cycle within both commercial and non-commercial food outlets. Thus, a critical review of purchasing, receiving, storage, issuance, preparation and service of food is an important approach in order to ensure safe and healthy food production and service.

Many countries have statutory regulations in relation to safe food handling requirements and procedures. In Kenya for example, the public health Act 2012 stipulates guidelines as far as safe handling of food is concerned [5, 15]. It is this act that provides important guidelines for animal slaughter, transportation of the carcass, preparation and cooking of meat and allied products. Thus, the act provides well-structured procedures and practices related to safe handling of food, over and above the carcasses that are fit for human consumption. It is therefore a legal requirement that all food-related businesses conform to the requirements of this act, and ensure that food is free from contamination and minimize food poisoning incidents. Thus, the act provides guidelines to ensure sound food safety practices, identify food safety hazards, and reduce the likelihood of foodborne illnesses and food intoxications. Thus, in accordance with the Public Health Act, various issues must be reinforced including personal hygiene for the food handlers, reporting the presence of any suspected illness, continuous education as well as regular medical certification, which applies to all food handlers within the larger restaurant operations business [5, 15].

Nonetheless, food source is as important and safe as the food itself. This implies that proper due diligence is important at the very initial stages of sourcing for supplies. This requires a critical review of the environment in which the food source is nurtured, the feeding and care process as well as the pathological history of the breed and/or species from which the food id harvested. Food should therefore be sourced and supplied from approved, reliable and reputable sources. Thereafter, food supplies must be promptly identified and moved to proper and appropriate storage areas within the food outlet upon receipt. This is important in facilitating the process of tracing the affected products in the event of a recall or food incident. Sourcing, purchasing, storage, issuing and consumption of food from un-approved food suppliers and distributors is a threat to the safety of food held and offered by the food service organization. Therefore, only reputable suppliers should be engaged for the supply of food after due diligence by the relevant authorities for approval. Additionally, food and raw materials should be stored off the floor and first-in-first-out (FIFO) or Last in First Out (LIFO) principle applied appropriately to minimize the growth of microorganisms and to prevent food from becoming unsafe or unsuitable during their expected shelf-lives. Further, food outlets should develop systems in order to effectively and efficiently manage stocks appropriately from receiving, storage, production and service. Foods that have been received and/or issued from storage should take the minimal time on work surfaces before being prepared and presented for service. Nonetheless, food should be held at proper temperature during the sale and service time.

Temperature control has yielded fruits as evidenced from previous studies. Thus, food must be kept at proper temperature during delivery, storage, display, sale and consumption to suppress bacteria, viruses and fungi from multiplying to an unsafe level [2, 22]. The temperature inside the refrigerator should be kept at or below 4°C and the freezer at or below −18°C. The temperature inside the refrigerator should be controlled and monitored regularly by the stipulated staff within the organization [5, 22, 26]. Further, frozen food should be thawed properly and completely to minimize the growth of food poisoning microbes and toxin production. Prevention of cross-contamination between raw and cooked or ready-to-eat food should be by separate handling (e.g., using separate knives and chopping boards) and storage [2, 22].

Food should also be properly protected during storage, preparation, display, service and transportation to prevent contamination by equipment, utensils and personnel as the transfer of micro-organisms from one food (usually raw) to another is one of the major causes of foodborne illnesses [3, 14]. Further, food should be cooked thoroughly and/or appropriately marinaded before consumption in order to ensure food safety [2–5, 22]. The center or the thickest part of the food needs to reach 75°C for 15 seconds to destroy any micro-organism causing foodborne diseases, although heating food to a lower temperature for longer periods of time may be equally effective. Food that previously cooked and cooled should be reheated thoroughly before service or consumption to minimize the time that cooked food is exposed to the temperature danger zone (between 4°C and 60°C) which allows not only pathogenic bacteria but also viruses and fungi to grow during the reheating process [14, 19].

However, vegetables should only be sautéed to ensure that nutrients and especially vitamins are not lost through the process of cooking. This calls for proper hygiene practices, by washing vegetables properly and several times, and blanching them before finishing for presentation and service. Vegetable salads and fruits must be handled with caution, right away from sourcing, transportation, storage, preparation and service. Ensure that vegetables and fruits to be used in the preparation of vegetable and/or fruit salads and allied menu items are properly washed, several times before cutting. The food handler must wear gloves while preparing vegetable and/or fruit salads and allied products, and minimize handling of the salads with hands, but instead use a folk and table spoon for mixing. Ensure that your vegetable salad is well dressed with vinegar, lime or lemon juice, and should be kept frozen before service. All dressings for vegetable salads must be from reputable and approved sources.

2.3 Good employee-clientele hygiene

Infected workers and personal hygiene account for about twenty-five per- cent of foodborne illness out-break. Employees cannot work with food unless they have a clean bill of health. According to Calcador as well as Knowles [14, 19], good personal hygiene means employees must learn how and when to wash their hands properly. Their uniforms and aprons must be kept clean and should be worn only in designated areas [19]. Uniforms should not be worn to and from work, and aprons should not be worn to the bathroom. Employees must ensure they take a bath before service and every time they are engaged in heavy tasks leading to sweating and may be cross contamination [5, 11, 25].

The existing legal responsibilities of food handlers in connection with the prevention of transmission of micro-organisms encompass personal hygiene, illness reporting and not working if a possible source of infection relevant to food safety is suspected. Food handler obligations relating to personal hygiene must be included in the food service staff training schedules that should be well planned and administered by the restaurant food service managers of every hospitality's catering organization. They should cover personal hygiene, in particular proper hand washing, clean and hygienic clothing, hygienic maintenance of equipment and general hygiene measures encompassing the facility, restaurant food service staff as well as the food service clientele. Thus, in an effort to combat the ever-rising foodborne illnesses within the hospitality's restaurant set-up, every person working in a food service area must maintain a high degree of personal cleanliness and should wear suitable, clean and, where appropriate, protective clothing. Food handlers whose work involves touching unwrapped foods to be consumed raw or without further cooking or other forms of treatment have been identified as a particular risk group and this explains the concern on personal hygiene of the kitchen brigade. Other requirements like washing hands properly after visiting the washrooms, smoking as well as handling refuse must be adhered to strictly.

In summary, Lillicrap and Cousins [25] among many other authors postulates that food service staff must portray proper professional and hygienic appearance. Thus, all food service staff MUST put into consideration the following factors;

a. Staff should be clean and use deodorants, NOT strong-smelling perfumes

b. Aftershaves and perfumes should be avoided, and if NOT, then should not be too strong

c. Hands should always be clean, free from nicotine stains and with clean well-trimmed nails

d. Men should normally be clean shaven

e. Women should only wear light make-up

f. Uniform should be clean, starched and neatly pressed

g. Hair MUST be clean and well groomed

h. Shoes MUST be comfortable and clean, and of a plain neat design

i. Staff must brush their teeth after every meal

j. Any cuts and/or burns should be covered with waterproof dressings

k. Any colds and/or other infections among staff should be reported immediately

l. Staff should wash hand immediately after using the toilet, smoking or dealing with refuse

m. Staff must avoid any mannerisms such as running fingers through hair, chewing gum, or scratching the face

2.4 Cleaning and sanitizing techniques

Proper cleaning and sanitizing techniques can also be effectively used to combat the spread of contagious illness within the global hospitality operations. Food personnel should be sensitized not to use side towels or sponges to clean or sanitize knives, cutting boards, and work stations as this could be a vehicle for further spread of contagious illnesses within hospitality's restaurant operations. Instead, proper cleaning and sanitization mechanisms should be put in to consideration, with the aim of not only minimizing but also bringing to a halt the spontaneous spread of foodborne ailments. Time and temperature considerations are necessary factors in the cleaning and sanitization process of crockery, silverware, cutlery, linen and other food service equipment, either manually or by use of relevant equipment, water and detergents. This should also be made common among food and beverage production and service staff in order to address cross contamination of microbes. Food service equipment washed by hand must be air-dried and given ample time before they are utilized in the food production-service cycle.

Hand wash products including un-medicated (plain) soaps, medicated soaps and alcohol hand disinfectants should be provided and used by both the food service staff as well as patrons. A number of studies have been carried out to evaluate the effectiveness of a variety of such hand wash products. According to the National Disease Surveillance Centre [5], there has been no standardized approach to evaluating the effectiveness of these hand wash products, and therefore making comparisons between studies on these products is difficult. According to Larson, Mayur and Laughon [24, 28], plain soaps are detergent-based cleansers that have no bactericidal activity and, by mechanical action, are used for the physical removal of dirt. However, studies have shown that washing with plain soap and water has been shown to be effective in mechanically removing transient microorganisms from the hands [2, 5, 24, 28]. Nonetheless, plain soaps are considered to be sufficient to remove transient microorganisms from the hands of food employees as well as patrons and thus eliminating the spread of foodborne diseases [4, 26]. In addition, plain soaps are gentle on skin, are non-allergenic and are cosmetically acceptable –important factors in promoting hand washing compliance.

On the other hand, medicated soaps contain ingredients active against microorganisms and are used for the mechanical removal and killing or inhibition of both transient and resident micro-organisms [16, 28]. Thus, according to studies by Fendler, Dolan & Williams [16], antimicrobial hand washing agents were found to yield considerable effectiveness in not only suppressing the growth and development cycle of micro-organisms, but also destroying (killing) them. Therefore, these agents have shown a great potential, basing on the outcome of previous studies in providing outstanding antimicrobial activity for over a period of several days and/ or hours [4, 14, 16, 28]. Nonetheless, the antimicrobial effectiveness of medicated soaps has been proven to increase with multiple applications over a number of days. This is mainly of particular relevance when a long-term reduction and/or elimination of the colonizing micro flora is needed. However, the impacts of repeated hand washing with chemical substances, which might be harsh to the human skin and body. This is in view of the sustainability of these products as well as their irritant effect not only to food workers hands but also to restaurant clientele, and therefore require intensive fact-finding, evaluation, as well as investigation prior to consideration. Larson carried out a study review on the effects of hygiene by skin products found that the integrity of the skin could be damaged by excessive washing with antiseptic preparations [28]. The explanation could be pegged on the common chemicals used in the manufacture of these chemical products, which has a broad spectrum of activity and a relatively low skin-irritation, but which may magnify on continual use. The use of plain soap by food handlers as well as restaurant patrons for hand washing should be adequate for removing transient micro-organisms. Further, soap may also be beneficial as it avoids the risks of excessive drying and irritation leading to dermatitis [28].

Conversely, alcohol-based sanitizers may also be applied instead of hand washing, although it is only effective when used on physically clean hands. These sanitizers are known for providing a rapid reduction in skin micro-organisms [5]. Larson [28] contents that alcohol-based formulations have been recommended in preference to detergent based products for health care workers. However, the literature available is minimal on the use of these products in the food service organizations by both food handlers as well as patrons. But still, as a measure to save on the cost of water bills, this could be the better option instead of hand washing. Nonetheless, alcohol solutions have been shown to have a very drying effect on the skin causing skin irritation, although many commercially produced products now contain emollients to solve the problem of drying effect of these products, [28]. While alcohol formulations containing 70% alcohols have been found to be effective in reducing the numbers, recent research has shown that washing hands with a mild soap was more effective than applying a 70% alcohol hand sanitizer [11, 12].

2.5 Hazard analysis critical control point plan

Hazard Analysis and Critical Control Points (HACCP) is the name of a wide-ranging hazard analysis methodology in combination of critical point prevention-based food safety system that is commonly, effectively and efficiently applied by food handlers in any food related organization, including hospitality's restaurant business. This program was developed by the Pillsbury Company in the 1960s for the U. S. space program but currently utilized in almost all global food related production and service organizations including hospitality's restaurant sector [22]. This is because of the effectiveness of the program in containing foodborne illnesses and food intoxication if properly applied and adhered to. HACCP is a seven principles plan aimed at achieving the stated goal. These seven principles are;

i. Hazard analysis

ii. Critical control point identification

iii. Establishing critical limits

iv. Monitoring procedures

v. Corrective action

vi. Verification procedures

vii. Record keeping and documentation

Thus, HACCPs seven principles provides guidelines for effectively dealing and eliminating biological hazards and therefore foodborne illnesses. A good application of this system may be traced in the United States where federal law requires that all meat and poultry producers including food service businesses must adopt a HACCP system. Nonetheless, similar legislative frameworks have trickled to other countries of the world. Loken [22] further argues that HACCP is the cornerstone of a paradigm shift that is occurring at the retail level, indeed an indication of HACCP application at the lowest level of food distribution cycle. The original ancient food safety paradigm was based on a sanitation program according to a 44-point inspection system which included issues ranging from covering and refrigerating all foods, requiring hair restraints for all food preparation and service employees, cleaning and sanitizing the physical environment, and monitoring hot and cold temperatures [3, 19]. All these was aimed at minimizing and further checking off microbial activity as well as cross contamination.

The proposal in the new food safety model however focuses on HACCP as a food safety system designed to prevent foodborne as well food intoxication associated diseases and therefore a perfect tool in containing the current scourge of foodborne related illnesses [2, 4, 5, 14, 26]. Proper utilization of HACCP within hospitality's restaurant operations may yield an amalgam of positive results, especially in an attempt to contain the spread of foodborne illnesses and intoxications. In this system, all foods are cooled rapidly, covered, and then refrigerated thus making use of temperature control in eliminating micro-organisms. A combination of safe food handling practices and hand washing are critical and therefore must be observed and adhered to the latter for the achievement of effective results. Consequently, according to the HACCP principle, food safety is a continuous and thus ongoing process, yielding the HACCP cycle. In accordance to the seven steps in the HACCP system, food service managers must identify the potential food safety hazard and critical control points (CCPs), establish control and monitoring procedures, take corrective actions, keep accurate records, and verify the system is working properly. Thus, by applying the seven steps, food service business would be able to effectively combat any threat from the micro-world that would cause foodborne illnesses and intoxication.

3. Conclusion

Foodborne related diseases are a threat not only to the hospitality's restaurant operations but to the entire foodservice industry. This is as a result of loss of life, increased production costs incurred in the control of the same illnesses, increased costs incurred in legal tussles, loss of goodwill from clients as a result of the bad reputation these organizations would have with the public. It is therefore important for organization to apply relevant coping strategies to combat these threats caused by foodborne illnesses and intoxications on a timely basis. Thus, in order to deal with the threat posed by these contagious diseases, hospitality's restaurant personnel can effectively apply five coping strategies in order to battle out this pandemic. These five coping strategies includes temperature and time monitoring which helps in eliminating the micro-organisms, Safe food handling which is key in the control of cross contamination, good employee-clientele hygiene for minimizing and/or eliminating cross contamination and transfer of micro-organisms, cleaning and sanitizing techniques for eliminating the micro-organisms, and lastly the Hazard Analysis Critical Control Points, which is a wide-ranging hazard analysis and critical point prevention-based food safety system that can effectively be applied in the food service cycle to prevent the occurrence of any foodborne diseases based on the identified critical control points. Accordingly, in order for a hospitality's restaurant organization to achieve safety, these five coping strategies must be fully adopted and applied appropriately within their operations. This implies that every foodservice organization has a responsibility while employees as well as clienteles within these organizations have an obligation, with the basic principle of care to minimize and/or eliminate the spread of foodborne illnesses and food intoxications. It is therefore a combined responsibility among restaurant employees, the management, clienteles as well as the government to ensure that these coping strategies are fully implemented for positive results.

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Section 5

Food Safety and Products

Chapter 6

Cultivation and Product Development Study of Commercially Important Seaweeds in South-Eastern Coast of Bangladesh

Mohammad Khairul Alam Sobuj, Md. Mohidul Islam, Shafiqur Rahman and Yahia Mahmud

Abstract

Seaweeds are predominantly macroscopic, multicellular, and photosynthetic marine algae that grow primarily in the ocean's rocky littoral zone. About 154 seaweed species are found in our coastal area, of which 34 belong to green (Chlorophyta), 38 brown (Phaeophyta), and 82 red (Rhodophyta). Among them, 26 species are considered economically important based on their availability, abundance, and use. Seaweeds are mainly available in St. Martin Island, Shaporir dip, Inani, Bakkhali, Kutubdia, Patowartek, Pecherdwip, Teknaf, Shaplapur, and Moheshkhali in Cox's Bazar region of Bangladesh. They are generally found on our Cox's Bazar coast from October to April, but the highest abundance occurs from January to March. However, in the case of mangrove forests, seaweeds are available throughout the year. Additionally, seven species are considered commercially cultivable species. Their culture techniques were developed in the long-line and net methods at different Cox's Bazar region sites. St. Martin Island had the highest biomass yield production of seaweed due to its favorable water quality parameters. Several value-added seaweed products were developed from dried seaweed powder. Industries based on seaweed can potentially contribute to the socioeconomic upliftment of the coastal inhabitants in Cox's Bazar.

Keywords: seaweed, inventory study, seaweed cultivation, value-added products, Bangladesh

1. Introduction

Seaweeds are an immense group of macroalgae, which refers to several macroscopic, multicellular, marine algae species. They are found in various habitats, from shallow rocky shores to deep oceanic waters [1]. Additionally, seaweed plays a vital role in marine ecosystems by providing food and habitat for many aquatic organisms. Seaweeds are the major thallophytic subdivided into three major classes: Chlorophyceae (green algae), Phaeophyceae (brown algae), and Rhodophyceae (red algae). Around 8000 different types of seaweed may be found throughout the world's coastlines [2]. Only 150 seaweed species are edible and commonly consumed as fresh, dried, or culinary components out of 250 economically used seaweeds [3]. Seaweed is not as widely consumed in Bangladesh as in Japan and China. Seaweed, which accounts for around 25% of all food consumed in Japan and is cooked and served in various ways, has become the primary source of income for the country's fishermen.

Natural abundances of seaweeds have been observed in Bangladesh from the south-eastern portion of the mainland and offshore islands, such as St. Martin Island, which has a stony substratum and is ideal for seaweed development. Although the seaweed floras of St. Martin's Island in Bangladesh are extensively found, they are relatively underutilized. Fishermen, women and their children are gathering seaweeds on the island of St. Martin. The collected seaweeds were dried in the sun spreading on the open beach, whereas the people of Bangladesh did not know that seaweeds can be used as human food. In Bangladesh, the diversity of seaweed is rich, and it reported that there are 193 seaweed species belonging to 88 red (Rhodophyta), 51 green (Chlorophyta), and 54 brown (Phaeophyta) groups occurring on the Bangladesh coast [4].

2. Nutritional and medicinal values of seaweeds

Food's nutritional value is primarily influenced by its protein content and carbohydrate reserve (or fats). Because they often include significant levels of proteins and carbohydrates, marine algae can be considered a potentially good source of nutrients. They also have a high iodine content, which explains why the population of the Asiatic Coast has a low prevalence of hypothyroidism and goiter. Additionally, some algae have high concentrations of vitamins A, B_1 (thiamin), B_2 (riboflavin), C, and B_{12}, making them a valuable source of nutrition for both humans and animals.

Seaweed consumption as a diet staple has a long history in Southeast Asia, China, Japan, and Korea. In fact, seaweed has been a mainstay of some cultures' diets for centuries. As a sustainable and healthy ingredient, seaweed is now frequently used in salads, soups, and sushi rolls in Western cuisine. However, the most notable application of seaweed is in the pharmaceutical industry for developing drugs for Alzheimer's disease, cancer, and gastric ulcer, phycocolloid or hydrocolloid industry, cosmetic industry, biofuel industry, wastewater treatment industry, and bioremediation [5, 6] (**Figure 1**). Seaweed is a versatile resource that has the potential to revolutionize various industries due to its unique properties, such as high water-holding capacity, gelling ability, and bioactive compounds. Seaweeds are also valuable sources of protein, fiber, fatty acids, vitamins, macro, and trace elements, and essential bioactive compounds. Traditionally seaweeds are rich in bioactive compounds with potent anti-inflammatory, antipain, antibacterial, antifungal, and high antioxidant properties [7]. In addition, seaweed contains different phytochemical compositions in varying concentrations, such as phlobatannins, saponins, terpenoids, phenols, and flavonoids [8, 9]. As the demand for sustainable and eco-friendly products increases, seaweed becomes an attractive alternative to traditional materials and ingredients.

Figure 1.
Diversified uses of seaweeds.

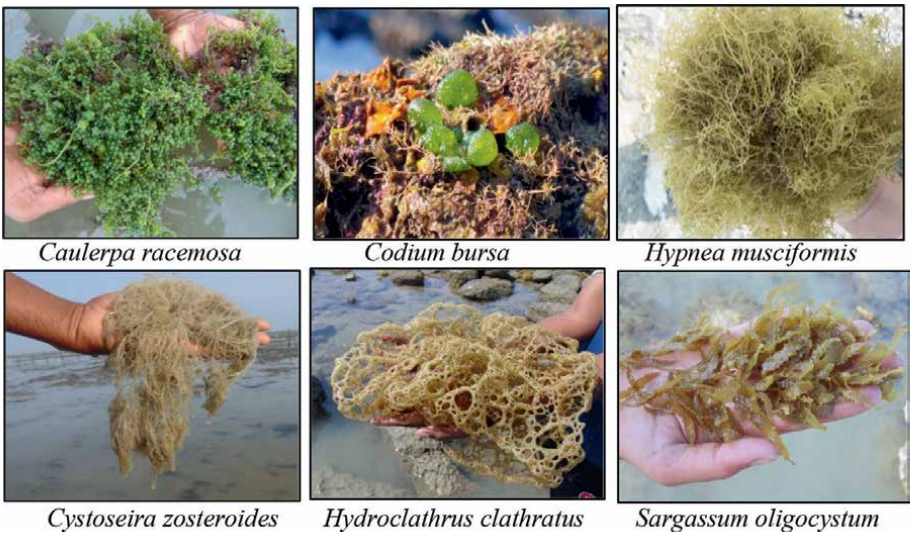
3. Inventory of available seaweed species on the Bangladesh coast

A detailed survey was conducted in and around Cox's Bazar (St. Martin Island, Shah Pori Dip, Teknaf, Moheshkhali, Kotubdia, Chokaria) and mangrove forest to find out the available seaweed species, their abundance, season, etc. The collection of seaweeds from the intertidal area was done during the low tide. This will give more time for collecting seaweed and observing seaweeds in their natural habitat. Description of the site location, associated flora and fauna, and other related parameters were also observed and recorded. A random sampling method was applied to assess the abundance of available seaweeds. Samples were selected at random as per requirement. This was done by selecting sampling points in the area and using a quadrant. Sampling points were chosen so that every species of the study area has a good chance of being selected. It was also employed for qualitative estimation of the seaweed.

3.1 Availability of seaweeds on the Bangladesh coast

The survey found that seaweeds are available in and around Cox's Bazar (St. Martin Island, Shaporir dip, Inani, Bakkhali, Kutubdia, Patowartek, Pecherdwip, Teknaf, Shaplapur, and Moheshkhali). Seaweeds are generally found attaching to the rocks or sandy bottom in mid-intertidal to subtidal zones along shorelines with calm to moderate wave activity and in tidal pools. Different species of seaweeds were collected randomly by hand-picking at the time of low tide (**Figure 2**). Fresh samples were taken into plastic jars and kept in an icebox for laboratory work. In the laboratory, samples were gently brushed under running seawater, rinsed with distilled water, dried with paper tissue, and finally preserved by open-air drying.

A survey was also conducted in different mangrove forests, i.e., Sundarbans mangrove, Sonadia mangrove, Nijhum dip mangrove, Fatrar chor mangrove, and Fakir hat mangrove area. The Sundarban mangrove forest is one of the renowned mangrove forests and a UNESCO heritage site in the Bay of Bengal. During our inventory, we observed that several seaweed species possess a decent association with mangrove species (**Figure 3**). Mangrove provides a substrate for the attachment of seaweed as



Caulerpa racemosa *Codium bursa* *Hypnea musciformis*

Cystoseira zosteroides *Hydroclathrus clathratus* *Sargassum oligocystum*

Figure 2.
Seaweed species collected from Saint Martin's island.

Caloglossa bengalensis *Chaetomorpha aerea* *Catenella nipae*

Figure 3.
Seaweed species collected from mangrove forests.

Figure 4.
Seaweed attachment in different mangrove areas.

they were found to be attached to the roots and barks of the mangrove trees (**Figure 4**). Some seaweed species were also found in the aerial root of mangrove trees and even in the muddy bottom of the mangrove (**Figure 4**). These epiphytic mangrove seaweeds are available throughout the year and can survive in adverse conditions (zero salinity).

3.2 Abundance and seasonality of identified seaweeds in Bangladesh

A total of 154 seaweed samples were identified during the study period. Among them, 34 are Chlorophyta group, 38 are Phaeophyta group, and 82 are Rhodophyta group (**Figure 5**). Some photographs are attached in **Figures 2** and **3**. Seaweeds

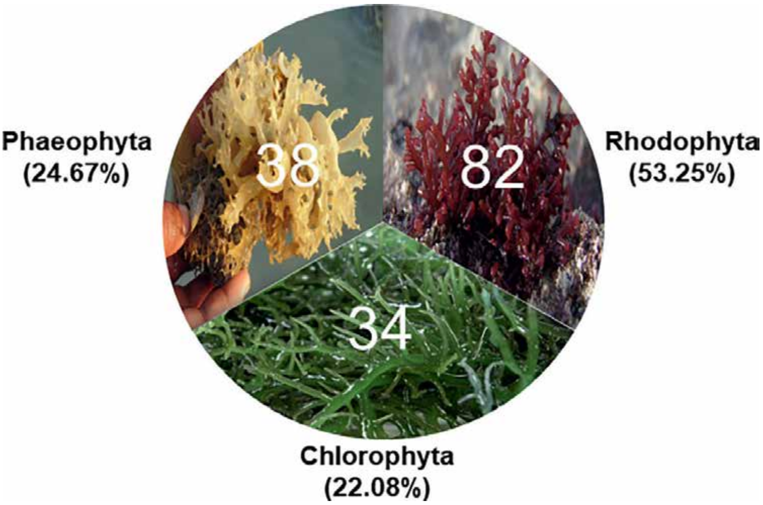
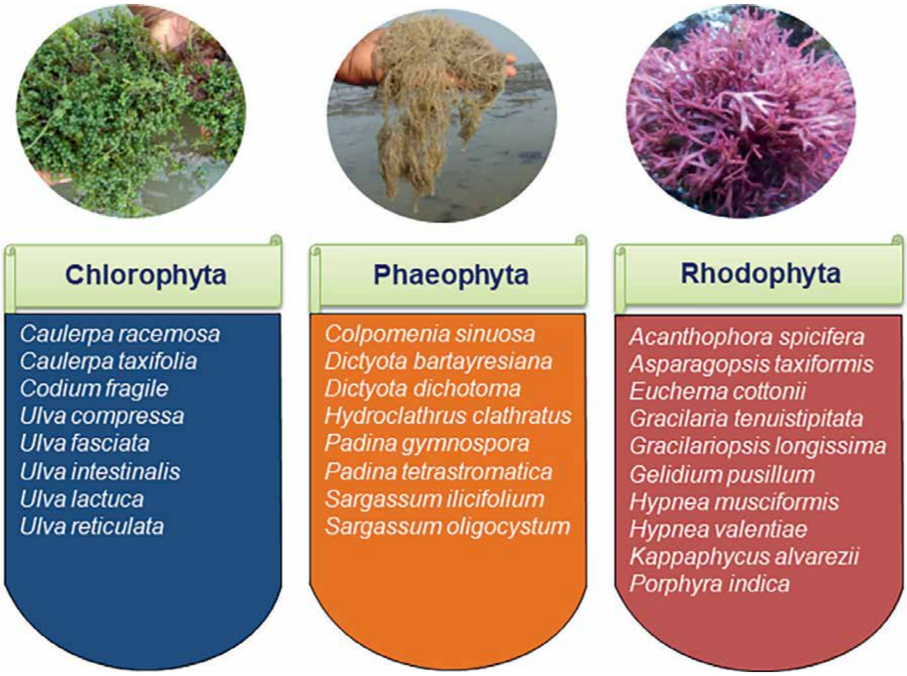


Figure 5.
Classwise distribution of seaweed biodiversity in Bangladesh.



Chlorophyta	Phaeophyta	Rhodophyta
Caulerpa racemosa	*Colpomenia sinuosa*	*Acanthophora spicifera*
Caulerpa taxifolia	*Dictyota bartayresiana*	*Asparagopsis taxiformis*
Codium fragile	*Dictyota dichotoma*	*Euchema cottonii*
Ulva compressa	*Hydroclathrus clathratus*	*Gracilaria tenuistipitata*
Ulva fasciata	*Padina gymnospora*	*Gracilariopsis longissima*
Ulva intestinalis	*Padina tetrastromatica*	*Gelidium pusillum*
Ulva lactuca	*Sargassum ilicifolium*	*Hypnea musciformis*
Ulva reticulata	*Sargassum oligocystum*	*Hypnea valentiae*
		Kappaphycus alvarezii
		Porphyra indica

Figure 6.
Commercially important seaweed species.

were abundant on St. Martin Island from October to April. However, from January to March, seaweeds were abundant in the St. Martin Island. Comparatively, more abundance of seaweeds was found on Saint Martin Island in the Western, Southern tip of Cheradip, and the Eastern part (surrounding the Coast-guard/Navy point). However, in the case of mangrove forests, seaweeds are available throughout the year, from January to December.

3.3 Commercially important seaweeds

Aside from the export potential, the development of seaweed cultivation in the country's coastal areas might provide an alternative source of income for the people. On the shore, there are a variety of edible seaweed species. Therefore, commercially important seaweed species were identified throughout the experimental period. Based on our country's abundance, availability, use, and culture potentiality, 26 seaweed species were identified as commercially important. Among them, 8 were Chlorophyta, 10 were Rhodophyta, and 8 were Phaeophyta group (**Figure 6**). These seaweeds have multiple uses, like fodder, fertilizer, human food, industrial, biofuel feedstock, heavy metal removal from wastewater, and pharmaceutical raw materials.

4. Seaweed culture practices

Seaweed farming can be described as strategically placing seaweed crops in water for growth. From there, farming ensures sustained photosynthesis at the optimal rate till harvest during the grow-out period. Though the availability of water, sunshine, and gases may typically be taken for granted when choosing a place for seaweed cultivation, appropriate nutrition supply may be a key factor. Furthermore, ropes and nets offer suitable substrates for seaweed growth; however, their performance in this capacity depends on the fabric type employed. Therefore, they are a modifiable component of farming infrastructure, allowing for altering plot lengths and widths in a range of conditions, both floating and submerged. Within collected and identified seaweed species, economically important *C. racemosa*, *H. musciformis*, *P. tetrastromatica*, *S. ilicifolium*, *S. oligocystum*, *U. intestinalis*, and *U. lactuca* were selected for culture experiments in Saint Martin Island and other suitable areas.

The younger pieces of seaweed were used for seeding with an average of 5 ± 0.4 grams of fresh weight in each knot and 5 cm in size in the rope twists. The density of seaweed seed was 25–28 seeds/m^2. The horizontal net (square net) and long-line methods were applied to cultivate seaweed when cultured between the intertidal zone. The floating raft method was applied when seaweed was cultured beyond the intertidal zone or open sea [10]. Bamboo poles anchored culture nets and kept afloat at the surface level with plastic floats. The frame was tied loosely to the poles and fixed in a submerged floating condition to facilitate it going vertically to the tide. The cultivation was attempted at slightly deeper water, i.e., 0.5–1.0 m depth on fish nets, to avoid the intensity of sedimentation and grazing by fish. No fertilizer, growth hormone, or other chemicals were used during the culture period. Partial harvesting was done after 15/20 days of seaweed reaching an average standard length. The culture period was 60/90 days. The partial harvesting took place by cutting off the algae hanging on the surface, allowing the base on the surface to expand further. Standard methods were also followed to measure different physicochemical parameters [11].

Seaweed biomass production was measured as the fresh weight of seaweed per unit culture area (kg m^{-2}) and was calculated using the following formula [12]:

$$Y = (Wn - W_0) / A \tag{1}$$

Here, Y = seaweed biomass production; Wn = raw weight on day n; W_0 = beginning raw weight; A = culture unit's area.

The daily growth rate (DGR %) was calculated using the following formula [13]:

$$DGR\% = \ln(W_f / Wo) / t \times 100 \tag{2}$$

Here, W_f = final raw weight (g) at t day; Wo = initial raw weight (g); t = cultivation period (days).

4.1 Seaweeds biomass production

Experimental culture sites of seaweeds were set up in sheltered intertidal zones of the Bakkhali river estuary at Nuniarchora, Chowfoldondi, Kutubdia, Pecherdwip, S.M. Para, and Saint Martin Island. Harvesting at the end of 60/90 days of the culture period in Saint Martin sites resulted in the maximum biomass yields for all seaweed species (**Figure 7**). Saint Martin Island has favorable environmental conditions, resulting in higher growth and maximum biomass yields for all seaweed species. Among the seven seaweed species, the most increased biomass production (30.61 ± 0.23 kg m^{-2}) was observed in the case of *H. musciformis*, and the lowest biomass production (10.18 ± 0.45 kg m^{-2}) was observed in the case of *P. tetrastromatica* (**Figure 8**). Here,

Figure 7.
Biomass productions of different cultured seaweed species.

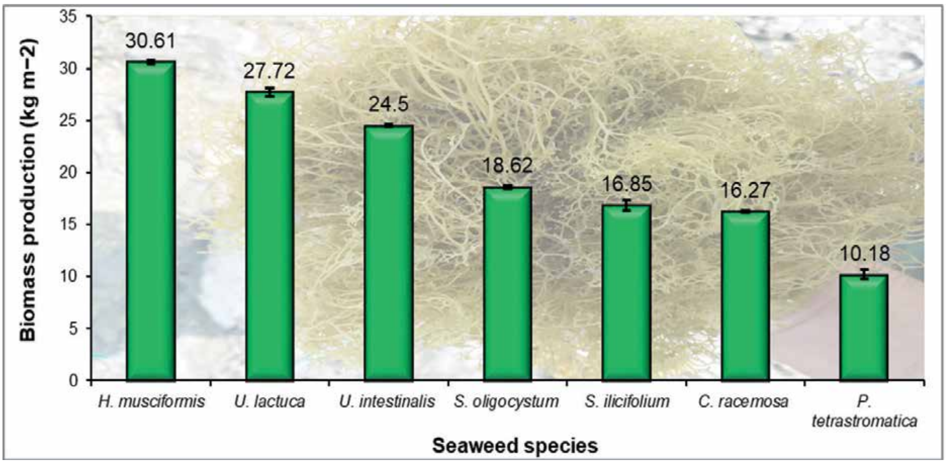


Figure 8.
Maximum biomass production (kg m^{-2}) of seaweed species at Saint Martin Island.

total biomass production of seaweed descending sequentially as *H. musciformis* > *U. lactuca* > *U. intestinalis* > *S. oligocystum* > *S. ilicifolium* > *C. racemosa* > *P. tetrastromatica*, with an evident variation among them. The observed biomass yield of seaweeds was significantly higher in Saint Martin than in Nuniarchora, Chowfoldondi, S.M. Para, Kutubdia, Pecherdwip, and Inani. Generally, Bakkhali, Chowfoldondi, Nuniarchora, and Inani are allocated upstream, where water quality parameters do not remain stable like Saint Martin and have not had extensive substratum facilities to form an enormous colony of seaweeds. Again, in S.M. Para, the site was on a polyculture farm. There the surrounding water quality parameters were not satisfactory for seaweed culture. Additionally, in Pecherdwip, the site was near the Raju Khal estuary, where upstream runoff carrying heavy silt causes lower seaweed growth.

4.2 Seaweed daily growth rate (% day^{-1})

Saint Martin Island possesses the highest daily growth rate for all seaweed species. Among the seven seaweed species, the highest daily growth rate (5.99 ± 0.22% day^{-1}) was observed in the case of *H. musciformis,* and the lowest daily growth rate (4.76 ± 0.19% day^{-1}) was observed in the case of *P. tetrastromatica*. Here, the daily growth rate of seaweed is descending sequentially as *H. musciformis* > *U. lactuca* > *U. intestinalis* > *S. oligocystum* > *S. ilicifolium* > *C. racemosa* > *P. tetrastromatica*, with an apparent variation among them (**Figure 9**).

4.3 Environmental parameters

The cultivation of seaweed requires appropriate physicochemical conditions. The range values of different water quality variables during the culture period at different experimental sites at Cox's Bazar are described in **Table 1**. All parameters were measured every 15 days during the partial harvest following standard protocols. In our experiment, different water quality variables showed higher fluctuations throughout the culture due to the high rainfall and surface runoff.

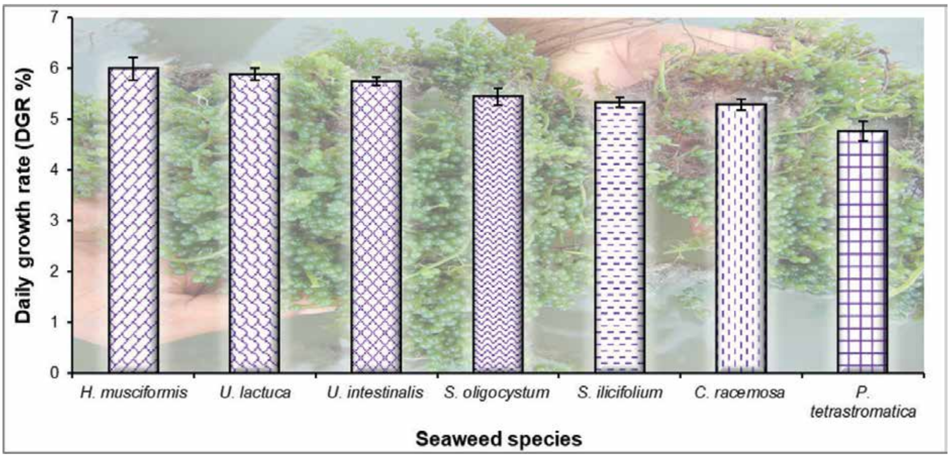


Figure 9.
Daily growth rate (% day^{-1}) of seaweed species at Saint Martin Island.

Experimental sites	Range values of hydrological data					
	Temperature (°C)	Salinity (ppt)	DO (mg/l)	pH	Alkanity (ppm)	Transparency (cm)
St. Martin	23.1–30.8	28–36	6.5–8.2	6.8–7.8	105–120	81.5–88
Nuniarchora	22.8–31.5	27–35	5.9–7.8	6.9–7.1	110–120	52.5–68
Inani	23.0–28.4	30–34	6.3–8.0	6.5–7.7	100–120	65–70.5
Chowfoldondi	24.1–32.5	28–35	6.1–7.9	6.8–7.5	100–120	54–70
Pecherdwip	24.2–30.1	25–32	6.6–7.7	7.0–7.4	110–120	62–67
Kutubdia	24.5–29.5	24–31	6.4–7.9	6.3–7.2	95–120	45–58.5
S.M. Para	24.8–30.5	22–32	5.7–6.8	6.3–7.0	95–110	47–59.5

Table 1.
Different water quality variables of the culture sites during the experimental period.

The salinity of seawater is a very prudent and potential factor in growing seaweeds, as it is the crucial determinator of osmotic balance. The present study recorded salinity ranged from 28 to 36 ppt in Saint Martin. So, stable and moderate salinity is the critical factor of the highest biomass yield in Saint Martin. Moreover, water salinity had a strong positive correlation with water pH, DO, and transparency; that means salinity plays a vital and influential role in these water quality parameters. Water pH is the primary factor for animals and biota in aquatic environments. pH value of the present study was found favorable at Saint Martin compared to other sites. Dissolved oxygen concentration was found in this study favorable at Saint Martin than in other culture sites. That may be the cause of higher seaweed production from Saint Martin. Water transparency is the dormant factor to govern the growth rate of seaweeds. Transparent water allows adequate light intensity to facilitate the growth of algae. This study recorded the highest average light intensity from Saint Martin compared to other sites. So, water transparency was vital in getting the highest biomass yield from Saint Martin's.

5. Seaweed product development study

To get raw seaweed in table form, repeated screening and washing were performed to isolate nontarget seaweed species and remove the sand and other undesirable particles. Harvested seaweeds were processed, dried, powdered, and preserved

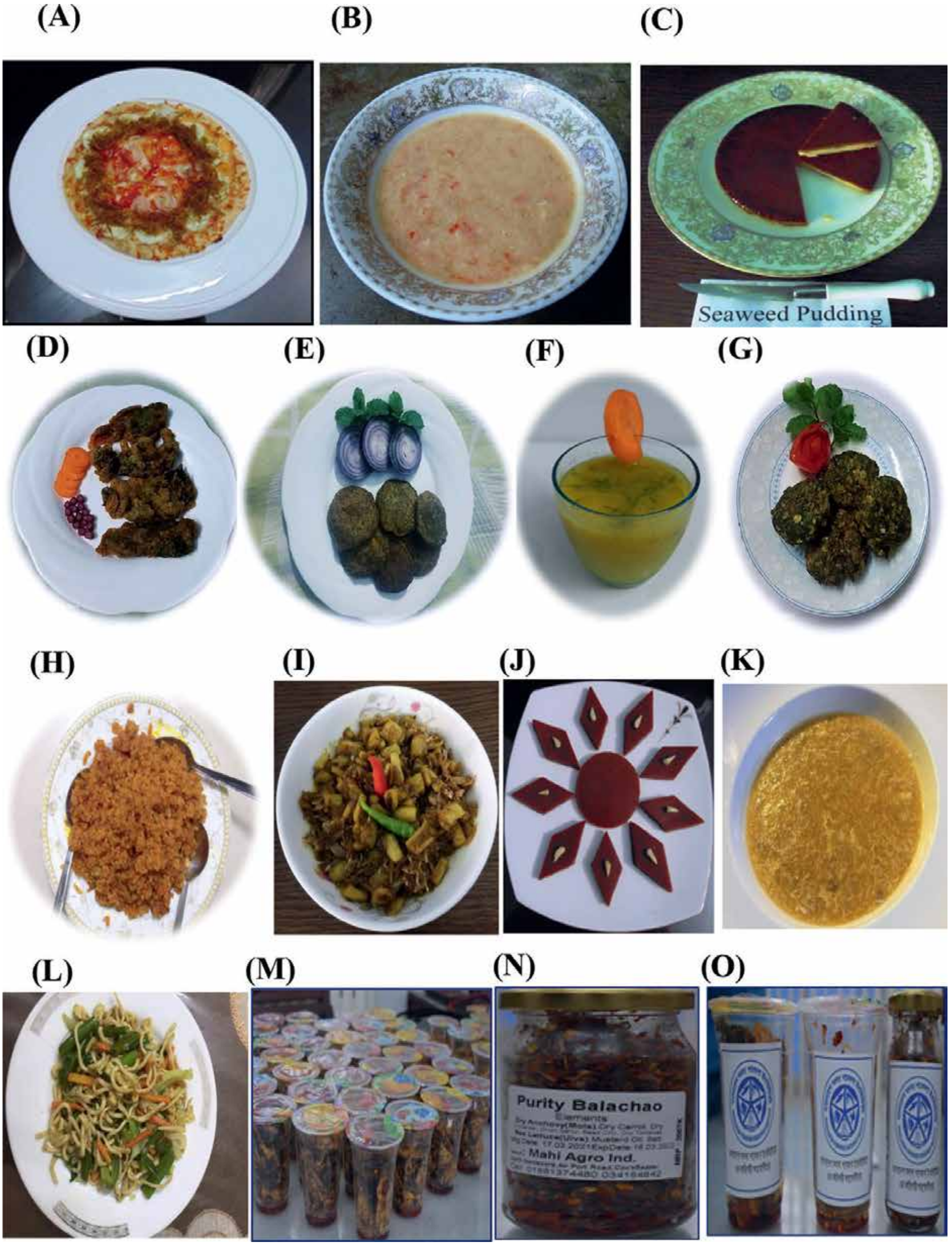


Figure 10.
Various food products are developed from seaweed powder. (A) Seaweed pizza, (B) seaweed soap, (C) seaweed pudding, (D) seaweed Papor, (E) seaweed Beguni, (F) seaweed mango juice, (G) seaweed Piyajo, (H) seaweed Jorda, (I) squid-seaweed masala, (J) seaweed barfi, (K) seaweed soap, (L) seaweed noodles, (M) seaweed value-added product, (N) seaweed value-added product (Balachao), and (O) seaweed value-added product.

for seaweed-based product development. Processed seaweeds were used to produce the products. Seaweed powder was used at different percentages to prepare Seaweed Papor (98% U. *lactuca*), Seaweed Piyajo (5% *U. lactuca*), Seaweed Beguni (5% *U. lactuca*), Seaweed Mango Juice (3% *U. intestinalis*), and Seaweed Jorda (5% *H. musciformis)* (**Figure 10**). Also seaweed soup, seaweed barfi, seaweed noodles, seaweed pizza, seaweed soap, seaweed pudding, and squid-seaweed masala were prepared. Several other value-added seaweed products were also prepared and marketed with the collaboration of local entrepreneurs Mahi Agro Industry and Jahanara Green Agro (**Figure 10**). The flavors and tests of these seaweed food products were good. The information about seaweed products' nutritional value was disseminated to different hotels, motels, restaurants, and local people to build awareness of seaweed utilization as a food item.

6. Conclusions

With nutritional and medicinal values, seaweeds have garnered attention for their rich content of vitamins, minerals, proteins, and fibers. These marine macroalgae also possess bioactive compounds that offer potential therapeutic benefits, such as antioxidant, antimicrobial, and anti-inflammatory properties. Along the coast of Bangladesh, about 154 seaweed species exist, varying in availability and abundance throughout the year. Notably, 26 seaweeds have been identified as commercially important due to their high demand and economic value. Cultivating seaweeds involves practices aimed at optimizing growth and productivity, resulting in the production of seaweed biomass. Environmental parameters, including temperature, light intensity, salinity, and nutrient availability, play pivotal roles in seaweed culture practices, influencing growth and development. Understanding and controlling these parameters are crucial for successful seaweed cultivation. Additionally, studies on seaweed product development aim to explore diverse applications and potential uses, incorporating seaweed extracts or biomass to create value-added products across various industries. These studies contribute to expanding their utilization beyond traditional consumption by capitalizing on seaweed's nutritional and medicinal properties.

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Conflict of interest

The authors declare no conflict of interest.

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Chapter 7

The Role of Electrolytic Acidified Minerals (Prehydrated Microparticles, PMPs) in Food Safety: A Field Trial and Case Study at Breeders and Packers Uruguay (BPU)

Donald J. Wagner II

Abstract

Electrolytic acidified minerals (as “Prehydrated microparticles, or PMPs”), such as silicates, aluminum, calcium, sodium, magnesium, and sulfur, have been explored for beef preservation. PMPs are produced by combining organic acids (organic reference USDA National List of Allowed and Prohibited Substances, not necessarily organic chemistry), and natural minerals under controlled manufacturing conditions using Generally Recognized As Safe (GRAS) food-grade materials that are listed with the US Food and Drug Administration. The resulting mixture is odorless, colorless, and tasteless when diluted to RTU concentrations. When applied to the surface of beef through spraying or immersion techniques, at various dilutions, PMPs significantly inhibit the growth of microorganisms during cold storage, resulting in a longer shelf life and maintained quality. The PMPs control of pH and oxidation on the surface of the meat is safer effective technique than using more toxic preservatives and antimicrobials that can lead to mutations, adaptation, and resistant superbugs. The acids are supported through integration into microparticle minerals, which stabilize and enhance the effectiveness and longevity of the preservative effect. Lab studies were done on PMPs at Microchem in Round Rock TX, USA. A real-world case study was conducted with acidified PMPs at Breeders and Packers Uruguay (BPU), located in Durazno Uruguay.

Keywords: meat preservation, GRAS, organic, microparticles, acidified minerals, antimicrobial, food safety, shelf life

1. Introduction

The cost of meat spoilage on a global scale is staggering, affecting not only the economy but also food security and environmental sustainability. According to the Food and Agriculture Organization (FAO) of the United Nations, approximately one-third of all food produced globally goes to waste, and meat products are a significant part of this wastage. Here are some of the ramifications of meat spoilage on a global scale:

1. **Economic losses**: Meat production is a resource-intensive process that involves substantial costs in terms of animal feed, water, energy, labor, and transportation. When meat spoils, all the resources invested in its production and distribution are wasted. The economic losses are borne by everyone in the supply chain, from the farmers to the retailers. For consumers, this often translates into higher prices for meat products. The global financial cost of food wastage, including meat spoilage, is estimated to be around $1 trillion annually.

2. **Food security**: With the global population continuing to rise, food security is a critical concern. Meat spoilage exacerbates the challenge of ensuring that there is enough food to meet the dietary needs of the global population. In countries where meat is a primary source of protein, spoilage can severely impact nutritional intake and food availability for the population, especially for those who already face economic challenges in accessing sufficient food.

3. **Environmental impact**: The production of meat has a substantial environmental footprint, particularly in terms of greenhouse gas emissions, land use, and water consumption. When meat is spoiled and discarded, it signifies that all the environmental resources expended in its production were used in vain. Moreover, the decomposition of spoiled meat in landfills generates methane, a potent greenhouse gas that contributes to climate change.

4. **Social costs**: Meat spoilage also has social implications. It represents a failure in the distribution of food, where surplus food, including meat, is wasted in some parts of the world while there are regions suffering from hunger and malnutrition. This unequal distribution and wastage highlight the inefficiencies in global food systems and the ethical concerns related to food wastage when others are in need.

5. **Contamination and recalls**: Mitigating meat spoilage requires a multi-faceted approach, including improving supply chain efficiencies, investing in preservation technologies, educating consumers, and establishing better food distribution networks to ensure that the meat reaches consumers before it spoils. The benefits of reducing meat spoilage are far-reaching, from bolstering economic stability to promoting food security and environmental sustainability. In meat processing plants, bacterial contamination is one of the most pressing challenges. Bacteria such as Escherichia coli (E. coli), Salmonella, and Listeria monocytogenes pose significant risks to food safety and public health. These bacteria can be introduced into the meat through various means including the animals themselves, the equipment used in processing, and the handling of meat by employees.

One of the primary problems caused by bacterial contamination in meat processing plants is the potential for widespread foodborne illness outbreaks. For instance, E. coli is known to cause severe gastroenteritis, which can be fatal in vulnerable populations such as the elderly, children, and immunocompromised individuals. Similarly, Salmonella infections can cause salmonellosis, characterized by diarrhea, fever, and abdominal cramps. Listeria, on the other hand, can lead to listeriosis, which is particularly hazardous for pregnant women, as it can cause miscarriages or life-threatening infections in newborns.

Over the past decade, there have been several instances of outbreaks and recalls due to bacterial contamination in meat products. For example, in 2018, JBS Tolleson, a major meat processor in the United States, recalled approximately 6.9 million pounds of beef products linked to a Salmonella Newport outbreak. The outbreak resulted in 246 people being infected across 25 states, with 59 hospitalizations [1].

In another instance, in 2020, a Listeria outbreak linked to deli meats caused illnesses across three states in the United States. Ten people were infected, all of whom were hospitalized, and one person died [2].

In 2021, there was a recall of more than 2,000 lb of beef jerky products produced by Boyd Specialties, LLC, due to possible Listeria monocytogenes contamination [3].

These examples underscore the importance of rigorous food safety protocols and monitoring systems in meat processing plants to mitigate the risks posed by bacterial contamination. Ensuring the hygiene and sanitation of processing environments, proper handling of meat products, and timely testing for microbial contaminants are crucial steps in safeguarding public health.

2. Prehydrated microparticle lab results

A modified version of ASTM E1153 was performed at Microchem Laboratory in Round Rock, TX, USA. Microchem maintains ISO 17025 accreditation through ANSI National Accreditation Board (ANAB). Accreditation provides additional confidence in the laboratory's quality system and technical competence. In addition to ISO 17025 accreditation, Microchem maintains compliance with EPA and FDA Good Laboratory Practices (GLPs). In this study challenging PMPs, exemplary microorganisms were chosen, two bacteria (Gram-positive, Gram-negative) and a virus.

2.1 Staphylococcus 6538

This bacterium is a Gram-positive, spherical-shaped, facultative anaerobe. Staphylococcus species are known to demonstrate resistance to antibiotics such as methicillin. S. aureus pathogenicity can range from commensal skin colonization to more severe diseases such as pneumonia and toxic shock syndrome (TSS). S. aureus is commonly used in several test methods as a model for gram-positive bacteria. It can be difficult to disinfect but does demonstrate susceptibility to low-level disinfectants.

2.2 *Pseudomonas aeruginosa*

This bacterium is a Gram-negative, rod-shaped microorganism with a single flagellum. It grows optimally under aerobic conditions; however, it can use a host of electron receptors to respire anaerobically. P. aeruginosa can be found almost anywhere in nature and it is an opportunistic pathogen. Like many other bacterial-related diseases, the ability to form resilient biofilms within human tissues under anaerobic conditions is thought to be the primary cause of pathogenicity.

2.3 MS2 bacteriophage (MS2), ATCC 15597-Bl

This virus is a non-enveloped positive-stranded RNA virus of the bacteriophage family Leviviridae. Bacterial cells are the hosts for bacteriophages, and E coli 15597 serves this purpose for MS2 bacteriophage. Its small size, icosahedral structure, and environmental resistance have made MS2 ideal for use as a surrogate virus (particularly in place of picornaviruses such as poliovirus and human norovirus) in water quality and disinfectant studies. Permissive Host Cell System for MS2: Escherichia coli 15597.

2.4 Test material

Prehydrated Microparticles (PMPs) of siliceous minerals were studied for their ability to trap and sequester microbial contaminants. Some specifications of the test materials were as follows (**Table 1**).

2.5 Test method

Bacterial/Viral Removal Study Based on ASTM E1153.

To consider the study to be scientifically defensible, the following criteria were met:

1. The initial and final concentration of microorganisms must be significantly high enough to observe significant log/percent reduction.

2. The media used for testing must be sterile.

3. The target microorganism must be pure colony morphology (**Table 2**).

The test microorganisms were prepared, by growth in liquid culture medium. Sterilized carriers were inoculated with a volume of the test culture. Inoculated slides were dried. Only completely dried carriers were used in the test. Test carriers were treated with the test substance and incubated for the predetermined contact time.

Two types of tests were performed:

- **Dry microparticles** (not prehydrated, less than 10% moisture) microparticles were added to the inoculated carrier for 15 s. The test substance was then removed by irrigating the carrier with sterile PBS prior to harvesting in extraction media.

Pore Volume (ml/g)	1.25
BET Surface Area (m^2/g)	00
Total Volatile (% water)	~65%
Oil Absorption (ml/100 g)	200
Loose bulk density dry (mL/5 g)	45
Average Particle Size (micron)	8.5

Table 1.
Physical properties of select porous microparticle minerals.

Cultures Initiated	12/16/2020
Carriers Inoculated	12/17/2020
Carriers Tested	12/17/2020
Enumeration Plates Evaluated	12/18/2020
Culture Growth Media:	Tryptic Soy Broth
Culture Growth Time:	18–24 h
Carrier Type:	1″ × 3″ Glass Slides
Inoculum Volume	0.030 ml
Carrier Dry Time	15–20 min
Carrier Dry Temp. and Humidity:	Ambient
Contact Time:	15 s
Contact Temperature:	Ambient
Harvest Media (Volume):	D/E Broth (20.0 ml)
Incubation Temperature:	36 ± 1°C
Enumeration Media:	Nutrient Agar (SA)
	Tryptic Soy Agar (PA)
Incubation Time:	~24 h

Table 2.
Procedural details of test method ASTM E1153.

- **65% prehydrated microparticles** were added to the inoculated carrier for 15 s. The test substance was then removed by irrigating the carrier with sterile PBS prior to harvesting in extraction media.

Control carriers were harvested at appropriate intervals to accurately represent any reduction during the contact time. Numbers control carriers were inoculated and allowed to dry. The control carriers were directly harvested in extraction media (i.e. no irrigation with PBS performed). At the conclusion of the contact time, test and control carriers were chemically neutralized (despite there being no chemicals used in this test, only siliceous minerals, this is standard practice). Dilutions of the neutralized test substance were evaluated using appropriate growth media to determine the remaining microorganisms at the respective contact time.

The effect of test substance A and test substance B was compared with carriers exposed to no test substance to determine percent or log reduction of microorganism (**Table 3**).

The results of our lab study, conducted at Microchem Laboratory, Round Rock, TX, demonstrate the efficiency of Prehydrated Microparticles (PMPs) in trapping and sequestering bacterial and viral contaminants. The test microorganisms chosen, Staphylococcus aureus (Gram-positive bacteria), Pseudomonas aeruginosa (Gram-negative bacteria), and MS2 Bacteriophage (virus), were exemplary representatives to assess the efficacy of PMPs.

These results indicate that the PMPs were consistently far more effective than dry microparticles in reducing the microbial load across all tested microorganisms. The

Test microorganism	Test substance	Test substance quantity	Remaining CFU's	Percent reduction	Log reduction
Virus (MS2 Phage)	Control	n/a	160,000,000	—	—
	Dry microparticles	0.5 g	124,000,000	22.50%	0.11
	65% prehydrated microparticles	0.5 g	1,400,000	99.13%	2.06
P. aeruginosa	Control	n/a	179,000,000	—	—
	Dry microparticles	0.5 g	11,100,000	93.79%	1.21
	65% prehydrated microparticles	0.5 g	19,000	99.99%	3.97
S. aureus	Control	n/a	33,000,000	—	—
	Dry microparticles	0.5 g	8,100,000	75.45%	0.61
	65% prehydrated microparticles	0.5 g	51,000	99.85%	2.81

Table 3.
Results of ASTM E1153.

65% Prehydrated Microparticles exhibited significant log reductions, indicating their exceptional ability to trap and sequester the pathogens effectively.

Notably, the 65% Prehydrated Microparticles demonstrated an impressive 99.13% reduction in MS2 Phage, a 99.99% reduction in Pseudomonas aeruginosa, and a 99.85% reduction in Staphylococcus aureus. These findings underscore the performance of PMPs in combatting a wide range of microbial contaminants.

The results can be attributed to the unique properties of PMPs, including their high pore volume, pore size, shape, and distribution, extensive BET surface area, and significant absorption capacity. These features, coupled with their prehydrated state for enhanced capillary action, make them highly effective in attracting and retaining microorganisms.

3. 150-day case study and field trial of acidified prehydrated mineral microparticles (PMPs) at breeders and packers Uruguay (BPU)

Studying aerobic bacteria, Enterobacteria, and lactic acid bacteria is crucial for assessing the freshness of meat because these three groups of bacteria are significant indicators of the microbial population and shelf life of meat products.

1. **Aerobic bacteria**: Aerobic bacteria are microorganisms that thrive in the presence of oxygen. Meat, being rich in nutrients and water, provides an ideal environment for the growth of these bacteria when exposed to air. The total aerobic bacterial count, often referred to as the Total Viable Count (TVC), is a standard indicator of meat's microbial quality. As the meat begins to spoil, the number of aerobic bacteria increases significantly. Monitoring the TVC is a way to assess the freshness of meat; high counts indicate that the meat is no longer fresh and may be unfit for consumption.

2. **Enterobacteria**: This group includes various bacteria such as Escherichia coli and Salmonella, which are facultative anaerobes (they can thrive in both oxygen-rich and oxygen-poor environments). Enterobacteria are often associated with fecal contamination and can be pathogenic. An increase in Enterobacteria is usually an indication of poor hygiene during the or processing of the meat. By monitoring the levels of Enterobacteria, one can not only assess the freshness of the meat but also determine potential risks to food safety.

3. **Lactic acid bacteria**: Lactic acid bacteria are a group of Gram-positive bacteria that generate lactic acid as a byproduct of carbohydrate fermentation. These bacteria play a dual role in meat. On the one hand, they are used beneficially in the fermentation of some meat products, such as salami. On the other hand, their growth on fresh meat can contribute to spoilage. As lactic acid bacteria proliferate on the meat surface, they produce lactic acid, which can result in a sour smell and slime formation, signs of spoilage.

The methodology used in research for swabbing and plating meat samples to test for aerobic bacteria, enterobacteria, and lactic acid bacteria is systematic and requires attention to detail to ensure the accuracy and reliability of the results. Below is an overview of the general steps involved:

1. **Sample collection**: Select representative samples of meat, ensuring that they are handled with sterile gloves or instruments to prevent contamination.

2. **Preparation of media**: Before starting the swabbing process, prepare the media plates for bacterial growth. For aerobic bacteria, you might use Tryptic Soy Agar (TSA); for enterobacteria, Violet Red Bile Glucose Agar (VRBGA) can be used; and for lactic acid bacteria, De Man, Rogosa and Sharpe (MRS) agar is commonly used.

3. **Swabbing**:

    a. Use sterile swabs for collecting samples. Pre-moisten the swab in a sterile diluent (such as sterile peptone water) to ensure efficient pickup of bacteria.

    b. Carefully swab a defined area of the meat surface. It's essential to cover the area systematically to ensure that a representative sample is obtained.

    c. Place the swab into a tube containing a known volume of sterile diluent and agitate to release the bacteria into the solution.

4. **Serial dilutions**: To ensure that you get countable plates, perform serial dilutions of the sample.

    a. Take 1 mL from the swab tube and add it to 9 mL of sterile diluent. This is a 1:10 dilution.

    b. Perform additional serial dilutions as needed (1:100, 1:1000, etc.).

5. **Plating**:

    a. Take 1 mL from the desired dilution tube and spread it onto the surface of the appropriate agar plate (TSA for aerobic bacteria, VRBGA for enterobacteria, and MRS for lactic acid bacteria).

    b. Use a sterile bent glass rod or spreader to spread the liquid evenly over the surface of the agar.

    c. This process should be repeated for each type of media and bacteria being tested.

6. **Incubation**: Incubate the plates at appropriate temperatures for the bacteria being tested. For example, aerobic bacteria are generally incubated at 35–37°C, enterobacteria at 37°C, and lactic acid bacteria at 30°C. Plates are usually incubated for 24–48 h.

7. **Counting colonies**: After incubation, count the colonies on the plates. Choose plates that have between 30 and 300 colonies for accurate counting. Use this data and the dilution factor to calculate the number of colony-forming units (CFUs) per square centimeter or gram of the sample.

8. **Documentation and analysis**: Document the data collected including the number of colonies and the corresponding CFUs. Perform statistical analysis as needed.

9. **Interpretation**: Based on the CFU counts and the scientific literature, make interpretations regarding the microbial load and its implications for the quality and safety of the meat samples tested.

It is important to note that adherence to aseptic techniques is crucial throughout this process to avoid contamination and ensure the reliability of the results. Additionally, the methodology might vary slightly based on specific protocols or standards followed by different laboratories or regulatory bodies.

Studying aerobic bacteria provides an overview of the microbial load on the meat. Enterobacteria serve as indicators of hygiene and potential pathogenic contamination, and lactic acid bacteria are specific indicators of spoilage due to fermentation processes. Together, the analysis of these bacterial groups offers an indication of the meat's freshness and safety for consumption.

In this study, Acidified Prehydrated MicroParticles (PMPs) were used to not only trap and sequester microbes, but also to cause cell lysis of the microbes through pH and oxidative stress. Organic acids kill microorganisms by disrupting their internal pH balance, creating an acidic environment that impairs cellular functions and destabilizes the cell membrane. Additionally, organic acids induce oxidative stress by generating reactive oxygen species (ROS), which damage cellular components such as lipids, proteins, and nucleic acids, leading to cell death. This dual mode of action makes organic acids potent antimicrobial agents, finding applications in various industries for food preservation and sanitation purposes. As the pre-storage treatment at Breeders and Packers Uruguay (BPU), a modern beef slaughterhouse facility in Durazno, Uruguay, acidified PMPs were applied to beef and studied from November

23, 2021, and April 22, 2022. The trial explored the benefits of using acidified PMPs as a GRAS (Generally Recognized As Safe) preservative for beef, expanding our understanding of food preservation and safety. Researchers have published papers on the use of organic acids in meat preservation, but do not explore the use of mineral prehydrated microparticles as a stabilized delivery method, and studies typically run for hundreds of hours, not 150 days [4–6].

4. The role of acidified prehydrated microparticles (PMP's)

PMPs can be composed of various minerals, including silicates of aluminum, calcium, sodium, and sulfur, combined with other acids under controlled conditions. Organic acids are chosen from those that are FDA Generally Recognized as Safe (GRAS) for food preservation, with consideration of their differences and attributes:

1. **Citric acid**:
    - Source: Naturally found in citrus fruits like lemons and oranges
    - Function: It acts as an acidulant, preserving freshness in various food products
    - Attributes: Non-toxic, non-corrosive, and has a pleasant, sour taste
    - Uses: Used in beverages, canned fruits, salad dressings, and other processed foods
2. **Lactic acid**:
    - Source: Naturally produced during fermentation processes, especially in dairy products
    - Function: Acts as an acidifier, flavor enhancer, and antimicrobial agent
    - Attributes: Mild flavor, safe, and effective against bacteria
    - Uses: Used in dairy products, meat processing, and as a preservative in various foods
3. **Acetic acid:**
    - Source: Derived from the fermentation of ethanol by acetic acid bacteria
    - Function: Widely used as a preservative and flavor enhancer
    - Attributes: Effective against a wide range of microorganisms, bacteria and molds
    - Uses: Used in pickling, condiments, salad dressings, and various processed foods

4. **Sorbic acid**:
    - Source: Naturally occurring in some fruits like mountain ash berries
    - Function: Effective against molds, yeast, and some bacteria
    - Attributes: Stable, tasteless, and odorless
    - Uses: Commonly used in baked goods, cheese, and other processed foods
5. **Benzoic acid:**
    - Source: Found naturally in some fruits, such as cranberries
    - Function: Exhibits antimicrobial properties against yeasts and bacteria
    - Attributes: Stable and effective at low concentrations
    - Uses: Used in carbonated beverages, fruit juices, and other food products
6. **Hypochlorous acid:**
    - Source: Naturally produced by white blood cells and the electrolysis of saltwater
    - Function: A powerful oxidizing agent with strong antimicrobial properties
    - Attributes: Effective against a broad spectrum of microorganisms
    - Uses: Disinfection in food processing, surface cleaning, and water treatment applications

It is important to note that while these organic acids are considered safe for food preservation when used within established regulatory guidelines, the concentration and application must comply with FDA regulations to ensure food safety and consumer health. All acids used are listed as GRAS materials by the US Food and Drug Administration. This results in an odorless, colorless, and tasteless mixture when diluted to RTU (ready-to-use) concentrations.

What are the proposed uses of acidified PMPs?

- FDA GRAS Food-grade antimicrobial preservative
- Food shelf-life extender
- Formulated for use on beef, poultry, pork, and other ready-to-eat products.
- Unique blend of minerals and acids
- pH adjustable solutions available as a concentrate dilutable 100-1

Benefits of the technology:

- Kills bacteria on contact and/or prevents further proliferation
- Extends the shelf life of the treated food
- Minimal organoleptic effect
- Application methods include spray or dip
- 100-1 dilution is economically viable

5. Experimental procedure and variables

During the trial, we analyzed two different beef cuts: Striploin and Oyster Blade.

1. **Striploin**: The term "Striploin" typically refers to a lean cut of beef that comes from the loin area of the cow, close to the backbone. It is a cut that is known for being tender, and it is often used for steaks. This cut is usually referred to as "New York strip." Because of its tenderness and relatively low-fat content, Striploin is often cooked quickly over high heat, such as grilling or pan-searing. It's a popular cut for making steaks, and it's prized for its flavor and tenderness.

2. **Oyster blade**: Oyster Blade, on the other hand, refers to a cut of beef that is taken from the shoulder area of the cow, specifically from the section known as the blade. In the US, this cut is often referred to as "blade steak" or "shoulder steak." Oyster Blade has a higher content of connective tissue and can be a bit tougher compared to cuts like Striploin. However, it is also more flavorful due to the marbling and connective tissues. Oyster Blade is often used in slow cooking methods like braising, which helps break down the connective tissues and results in a tender and flavorful dish. It can also be marinated and grilled, but it benefits from not being overcooked to retain tenderness.

We applied acidified PMPs at dilution ratios of 1/100, 1/50, 1/30, and 1/10 through electrostatic spraying and dipping (quick submersion). We then took swab samples for colony-forming unit (CFU) counts at intervals of 0, 30, 60, 90, 120, and 150 days. Upon analyzing the data, it was found that the two application methods, electrostatic spraying and immersion (dipping), had no statistically significant difference in terms of their efficacy in reducing microbial growth on the meat. This suggests that both methods were equally effective in distributing the PMPs across the surface of the meat, ensuring that the low pH environment and oxidative stress necessary for microbial inhibition were achieved, regardless of the application technique employed.

- Beef cuts
- Striploin Steak
- Oyster Blade Steak

- Dilution ratios
- 100:1
- 50:1
- 30:1
- 10:1
- Application technique:
- Electrostatic spray
- Dip (quick submersion)
- Swabbing and plate counts for CFU's on:
- Day 0
- 30 days
- 60 days
- 90 days
- 120 days
- 150 days
- Bacteria studied (CFU counts):
- Aerobic
- Enterobacteria
- Lactic Acid

We focused on three bacterial classes for CFU counts: aerobic bacteria, enterobacteria, and lactic acid bacteria. Of the 238 samples taken, 13 data points were identified as outliers, attributed to random contamination from handling or equipment. The purpose of this study was to focus on the typical meat flora when in the standard cold storage environment, and not testing the active disinfection of the meat when contamination is introduced from an outside source.

6. Trial results and discussion

The 150-day investigation demonstrated a substantial mean reduction in bacterial colonization on both Striploin and Oyster Blade cuts. The data presented in this chapter pertain to the acidified PMPs at a dilution ratio of 100:1. As hypothesized, an improvement in bacterial reduction was observed with escalating concentrations of the acidified PMPs. Nonetheless, the economic feasibility achieved by the 100:1 dilution ratio renders this concentration pragmatically viable for large-scale integration within the food processing industry.

Oyster Blade steak showed an impressive average reduction of 98.21% in aerobes, 99.51% in Enterobacteria, and 99.99% in lactic acid bacteria at the 100:1 dilution ratio (**Table 4**).

For Striploin steak, an 88.06% reduction was observed in aerobes, 97.82% in Enterobacteria, and 99.92% in lactic acid bacteria at the same dilution ratio (**Table 5** and **Figure 1**).

Acidified PMPs, rather than simple aqueous acids, are an emerging innovation in the meat processing industry that represents a promising alternative for controlling microbial growth on raw meat. These minerals are typically inorganic substances, such as silicates of aluminum, calcium, sodium, or sulfur, which have been treated with organic acids to create acidified prehydrated microparticles (PMPs). The utilization of these acidified minerals can serve as a crucial advancement in ensuring food safety.

The mode of action of acidified PMPs is somewhat similar to that of simple aqueous acids, but with certain advantages. Acidified PMPs work primarily by lowering the pH and delivering oxidative stress on the surface of the meat, creating an environment that is unfavorable for microbial growth. The microparticles, when applied to the meat, release the acids slowly, ensuring a sustained low pH environment and oxidative stress. This controlled release is often more efficient compared to simple aqueous acids, which can be neutralized more quickly. Furthermore, the mineral component in the PMPs can also have an adsorbent effect, binding to microbial cells and further enhancing the antimicrobial action.

A significant advantage of using acidified PMPs is their safety and compatibility with food-grade requirements. The minerals are combined with organic acids that are Generally Recognized as Safe (GRAS) for use in food products. When applied at appropriate concentrations, acidified PMPs are odorless, colorless, and tasteless,

150 day averages CFU's	Control average	100:1 Spray average	Percent reduction (%)
Oyster Blade Stake Aerobes	18,702,005	334,000	98.21
Oyster Blade Stake Enterobacteria	101,851	500	99.51
Oyster Blade Stake Lactic Acid	18,451,668	1,333	99.99

Table 4.
Reduction of CFU Counts in Oyster Blade.

150 day averages CFU's	Control average	100:1 Spray average	Percent reduction (%)
Striploin Stake Aerobes	730,267	87,200	88.06
Striploin Stake Enterobacteria	121,500	2,650	97.82
Striploin Stake Lactic Acid	372,500	300	99.92

Table 5.
Reduction of CFU Counts in Striploin.

Figure 1.
Images of Acidified Prehydrated MicroParticle (PMPs) trial in progress (2021).

ensuring that there is no alteration in the sensory properties of the meat. This is essential for consumer acceptance.

The methods of application for acidified PMPs can include dipping or spraying. In dipping, the meat is immersed in the solution, ensuring complete coverage. Spraying involves applying a fine mist of the solution onto the meat surface. Both methods can effectively distribute the acidified PMPs on the meat, but the choice between them might be influenced by factors such as the scale of operation, existing manufacturing infrastructure, processing speed, and specific antimicrobial targets.

Acidified PMPs offer a novel and effective approach for microbial control on raw meat. Through the controlled release of acids and the adsorbent properties of the minerals, these microparticles create a sustained low pH and oxidative environment that is inhospitable to bacteria. Being formulated with food-grade ingredients, they ensure safety and leave the organoleptic properties of the meat intact. This makes acidified PMPs an exciting prospect for enhancing food safety and quality in the meat processing industry.

The utilization of low pH and oxidation technology for meat preservation, when applied judiciously above the minimum inhibitory concentration, ensures the effective control of microbial growth without any sensory alterations to the meat. This delicate balance is crucial for maintaining the product's appeal to consumers.

Aromatics, which are essential for the perception of flavor, remain unaltered, ensuring that the meat retains its characteristic smell. Feeling factors, such as the sensation of juiciness or tenderness, remain intact, providing the same mouthfeel as untreated meat. Basic tastes, including saltiness, sourness, bitterness, and sweetness, are unaffected, which is critical as these are fundamental attributes that consumers expect in meat products. There is no imparting of aftertastes, which could be off-putting to consumers and indicative of chemical preservatives. Texturally, the meat remains consistent with untreated counterparts, retaining its firmness or tenderness as is characteristic of the specific cut. In essence, by applying acidic PMPs above the minimum inhibitory concentration, the preservation is achieved with a stealth-like approach, where the invisible hand of preservation effectively curbs microbial growth while leaving the sensory tapestry of the meat untouched.

7. Conclusion

The BPU trial with acidified PMPs illuminates a path toward safer and more sustainable food preservation strategies. These results suggest that acidified PMPs can be a reliable and sustainable preservative technique, preventing spoilage and enhancing the shelf life of beef without the use of antibiotics or potentially toxic preservatives. The study lends credence to the hypothesis that controlling the pH and oxidative stress on meat surfaces via a non-toxic, safe, and effective technique, like our acidified minerals in the form of PMPs, could revolutionize meat preservation strategies, reducing food waste and enhancing global food safety. In conclusion, the demonstrated effectiveness of PMPs, supported by laboratory studies and real-world testing, underscores their safety and efficacy; this assurance is further solidified by their FDA recognition as Generally Recognized as Safe (GRAS) and USDA organic status, which establishes a strong foundation in both science and regulatory approval. We aim for a healthier future for both our food systems and the consumers they nourish.

8. Broader agricultural implications

Echo Scientific has formed partnerships with experts in the agriculture industry to develop siliceous mineral and zeolite-based products, which incorporate stabilized organic acids derived from natural sources. These innovative combinations have demonstrated remarkable efficacy in laboratory studies and real-world environments. Targets for deploying the technology include additives for feed, and soil and plant adjuvants, improving animal health, soil health, and addressing methane and ammonia waste.

By incorporating mineral/acid formulations into animal feed and supplements, significant improvements in animal health have been observed. The synergistic combination of natural minerals, zeolites, and naturally derived organic acid enhances digestion, nutrient absorption, and fortifies the immune system in livestock. This results in accelerated growth rates, increased milk production, cleaner and healthier barn environments, and reduced reliance on antibiotics. Our products foster healthier and more productive animals, leading to improved profitability for farmers.

We are also targeting soil health. The inclusion of natural minerals, zeolites, and naturally derived organic acid in soil amendments has transformative effects. These combinations improve soil structure, water retention, and nutrient availability, leading to increased crop yields and enhanced resilience against environmental stressors. Additionally, our products aid in pH balance, nutrient retention, and stimulate the growth of beneficial soil microorganisms. These benefits contribute to sustainable and regenerative farming practices, ensuring long-term soil fertility and productivity.

Addressing methane and ammonia waste is a critical challenge in agriculture. Our innovative formulations effectively mitigate these emissions from livestock waste by greater than 50%, and in most cases greater than 80%. The combination of natural minerals, zeolites, and naturally derived organic acid enables the binding and neutralization of ammonia, reducing its volatilization into the atmosphere. Furthermore, our products have demonstrated exceptional efficacy in capturing and mitigating methane emissions from livestock manure, minimizing their environmental impact.

By integrating our natural mineral and zeolite-based products, enriched with organic acid derived from natural minerals, farmers can unlock a range of benefits. These include improved animal health and feed conversion rates, reduced morbidity and mortality, reduced reliance on antibiotics, enhanced soil fertility, and the reduction of methane and ammonia, and increased fertilizer value from animal waste. Recent attention on these issues is leading to data acquisition from real-time sensors tracking the mitigation of ammonia, methane, and other noxious gas emissions in farming operations, which leads to the generation of valuable carbon credits, contributing to sustainable practices and environmental stewardship.

The net result is to optimize productivity, increase profitability, and contribute to a more sustainable future.

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Chapter 8

Magnesium Intake in the Mediterranean Diet

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Abstract

The Mediterranean Diet (MedDiet) is a nutritional pattern native to many cultures within the Mediterranean Basin. The diet is composed of fruits, vegetables, fish, eggs, fermented dairy, grains, poultry, and minimal consumption of red meats such as lamb and beef. The diet encourages the consumption of extra virgin olive oil and moderate red wine for those who consume alcohol. The diet does not incorporate processed foods and sugary beverages. The MedDiet is rich in many micronutrients and has a healthful fatty acid profile (primarily mono- and polyunsaturated fats, with low amounts of saturated fats). The diet is rich in foods with high magnesium content, such as leafy green vegetables, nuts, seeds, and some lesser magnesium-rich foods (e.g., fish). The MedDiet is associated with reduced incidence of several diseases such as cardiovascular disease, cerebrovascular disease, neurodegenerative disease, metabolic syndrome, and type 2 diabetes mellitus. Magnesium intake has been shown to play a prominent role in the prevention and management of many of these diseases, with some of the disease-preventing capacity of the MedDiet likely caused by its high magnesium content. Those making nutritional recommendations in line with the concepts of MedDiet should particularly encourage the consumption of foods high in magnesium.

Keywords: Mediterranean diet, magnesium, cardiovascular disease, type 2 diabetes mellitus, neurodegenerative disease

1. Introduction

The Mediterranean diet (MedDiet) was a term coined by Dr. Ancel Keys following his "Seven Countries Study" in the 1960s [1]. The MedDiet is an eating pattern classically associated with the populations habituating the region of the Mediterranean Basin in the 1950s and 1960s, but less so in the present day [2, 3]. The MedDiet is the result of several millennia of cultural and culinary developments, nutritionally founded on the food cultivated in Mediterranean agriculture [4]. Unfortunately, due to the increased urbanization of the region and increasingly globalized food production, the consumption of foods traditionally associated with the MedDiet has significantly decreased [4].

The MedDiet emphasizes consumption of traditional foods and local seasonal produce, helping ensure a solid variety of fruits and vegetables [5]. Cultural vitality, vivacious and amicable culinary settings, adequate physical activity, and appropriate periods of rest are several lifestyle elements related to the MedDiet [4, 6]. Nutritionally, the diet incorporates seasonal fruits and vegetables, fresh seafood, bread, some dairy products, monounsaturated fats from olives (the fruit and the oil) and nuts, and moderate wine intake [4]. The consumption of red and processed meats, as well as sugary and fatty foods, is discouraged [4].

One of the potential benefits of MedDiet is its magnesium content. Magnesium is one of the most productive minerals in the body (second most prominent intracellular cation), implicated as a cofactor in more than 300 enzymatic processes in the body [7–9]. The most prominent sources of magnesium in the MedDiet are generally nuts, seeds, and leafy green vegetables (e.g., spinach). Magnesium consumption is implicated in the prevention of several chronic conditions. The MedDiet provides adequate amounts of magnesium, resulting in more favorable health outcomes. In the following chapter, we will explore the benefits of the MedDiet, potentially explained by its magnesium content.

2. The composition of the Mediterranean Diet

The MedDiet encourages significant consumption of locally grown and minimally processed fruits and vegetables, with sustainability and seasonality highly emphasized [6]. Furthermore, significant consumption of nuts, legumes, and unrefined grains (e.g., unprocessed cereals) is emphasized in the MedDiet [10]. The MedDiet is also characterized by minimal consumption of red and processed meats [2, 3]. This dietary pattern also excludes some dairy products, such as butter and ice cream, while including the consumption of fermented dairy products (e.g., yogurt and cheese) [2, 3, 10]. The primary sources of protein in the diet come from fish and shellfish, moderate poultry consumption, and occasional inclusion of beef, pork, and lamb (in traditional Mediterranean settings these meats are saved for celebrations) [2, 10]. Inconsistencies exist with egg consumption; some regard moderate egg consumption as a reasonable inclusion in the diet, while others do not include them in the MedDiet [4, 11]. Desserts consist of fresh fruit consumption, and not sugary cakes, pies, etc. [11]. Furthermore, beverage consumption is usually limited to water and red wine for those of age, avoiding sugar-sweetened beverages [11].

The MedDiet is extremely abundant in the consumption of extra virgin olive oil (EVOO), the recommended primary culinary oil and source of dietary fat (besides nuts and fish) [4]. Extra virgin olive oil is the oil produced from the first pressing of olives, which contains several antioxidants and bioactive polyphenols that do not present in more processed olive oil [2, 12, 13]. It has been postulated that EVOO may have antiatherogenic properties due to high concentrations of monounsaturated fatty acid and oleic acid [2, 14]. However, EVOO's high concentration of bioactive polyphenols is likely important in EVOO's cardioprotective and anti-inflammatory effects [2, 12, 15]. One specific polyphenol, oleocanthal, has been shown to have mechanistic effects similar to the non-steroidal anti-inflammatory medication ibuprofen, inhibiting the same cyclooxygenase enzymes in the prostaglandin-biosynthesis pathway [12]. Oleocanthal has been reported to stimulate a tingling sensation in the throat [13], thus it may be possible that this sensation could be a simple method to confirm the polyphenol content of EVOO.

The MedDiet is known to traditionally include moderate consumption of red wine with meals [10]. Red wine also contains bioactive polyphenols that may have antiatherogenic and cardioprotective properties [2, 12]. There are several polyphenols present in red wine including resveratrol, catechin, epicatechin, and anthocyanin, with resveratrol considered the most prominent polyphenol in red wine [16]. Resveratrol may be the main reason for many of the potential benefits of red wine, potentially leading to improved blood lipid concentrations, reduced insulin resistance, and attenuated oxidative stress of low-density lipoprotein cholesterol (LDL-C) [16]. Furthermore, red wine consumption has been associated with increased concentrations of high-density lipoprotein cholesterol (HDL-C) [16]. Thus, moderate red wine consumption may provide some health benefits when consumed in moderation. However, it is not recommended that individuals who do not drink, or those who are not of proper age, begin drinking red wine or other alcoholic beverages, despite its prevalence in the traditional MedDiet [2].

The MedDiet boasts an impressive nutritional profile with a higher monounsaturated fatty acid to saturated fatty acid ratio than other diets [6, 17, 18]. The MedDiet provides foods with high amounts of fiber, antioxidants, and anti-inflammatory compounds [6, 19–22]. Castiglione et al. evaluated the dietary habits and nutritional adequacy of a Sicilian cohort and reported that their dietary pattern allowed for adequate thiamine and biotin intake in the entire sample. Furthermore, greater than 50% of the participants consumed adequate iron, magnesium, selenium, zinc, and vitamins A, B_2, B_6, B_9, B_{12}, and C [23]. With respect to magnesium specifically, 66.9% and 90.4% of the study population met the European and Italian recommendations for magnesium of 363 mg/day and 240 mg/day, respectively [23–25].

A number of researchers have demonstrated the capacity of the MedDiet to reduce the incidence of cardiovascular disease, type 2 diabetes mellitus (T2DM), peripheral artery disease, atrial fibrillation, breast cancer, neurodegenerative disease, cerebrovascular disease, and cognitive decline [2, 6, 26–29]. Furthermore, the MedDiet has been implicated in reducing the risk of metabolic syndrome by targeting risk factors and aspects of the syndrome such as reducing waist circumference, blood pressure, and glucose concentrations, while subsequently increasing HDL-C concentrations [30]. Andreoli et al. implemented the MedDiet with a moderate energy deficit and exercise, which resulted in significant reductions in body weight, body mass index (BMI), fat mass, diastolic blood pressure, and total serum cholesterol, LDL-C, triglyceride, and fasting blood glucose concentrations, while simultaneously increasing HDL-C concentrations in women who were obese [31]. The MedDiet has also been found to reduce all-cause mortality [6, 28, 29, 32]. Thus, significant evidence demonstrates the potential for MedDiet to be a reasonable lifestyle intervention for disease prevention and management.

The MedDiet has potential for adoption in non-Mediterranean settings, providing that some flexibility is allotted and that the foods that are the central elements of the MedDiet are maintained [11]. The MedDiet has historically been a nutritional pattern shared among various cultural, religious, and ethnic groups, indicating a reasonable capacity for adoption among differing populations [11]. However, education regarding the many aspects of the MedDiet likely would be required [11]. This could be a potential barrier to the widespread adaptation of the diet.

As previously mentioned, some of the health benefits of the MedDiet may be due to the high prevalence of EVOO and red wine consumption, because the bioactive polyphenols present in these foods may have anti-inflammatory properties [12]. Furthermore, the potential benefits of MedDiet may be explained by the micronutrient density of the foods. Specifically, the MedDiet provides substantial magnesium, a crucial mineral (the fourth most abundant in the body), functioning in a large variety of metabolic processes [9]. Some foods in the MedDiet that may provide the greatest quantity of magnesium are nuts, seeds, chickpeas, and spinach [33].

3. Magnesium and health outcomes

The vast majority of magnesium in the human body is located within the mineral structures of the osseous tissues, with some residing intracellularly [23]. An extreme deficiency in magnesium can manifest as hypomagnesemia, defined as when the concentration of serum magnesium is less than 0.75 mmol/L. Symptoms associated with hypomagnesemia include tremors, spasms, muscle cramps, or general weakness [34]. Chronic low concentrations of magnesium have been implicated in the development of diseases with an inflammatory element such as Alzheimer's disease, asthma, attention deficit hyperactivity disorder, insulin resistance, T2DM, hypertension, cardiovascular disease, cerebrovascular disease, migraine headaches, and osteoporosis [8, 34, 35].

Magnesium functions primarily as a structural or enzymatic cofactor, helping to maintain protein structure and/or enzyme function. The presence of this mineral in the diet is crucial for normal biological functions because magnesium is required for adenosine triphosphate (ATP) metabolism, overall cellular energy production and storage, reproductive functions, stabilization of mitochondrial membranes, and the synthesis of deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and proteins [8, 34, 36–39]. Magnesium is implicated in protein, nucleotide, and mitochondrial structure [34]. Via maintenance of this protein structure and function, magnesium aids in the formation of enzyme complexes, mitochondria, nucleic acids, bone, and polyribosomes [34]. Approximately 50% to 60% of magnesium in the body serves a structural role as hydroxyapatite within bone [34].

Magnesium also plays an integral role in oxidative phosphorylation and glycolysis, either via its role in the ATP complex (the principal form of biochemical energy in the body) or as a fundamental cofactor of key enzymes [34]. Magnesium is also involved in normal membrane functioning, assisting in the active processes required for potassium and calcium ion transport across the membrane. Proper ion transport is imperative for muscle contraction, nerve impulse transmission, normal cardiac rhythm, and vasomotor tone [34].

Magnesium is crucial for the proper absorption and utilization of certain vitamins such as cholecalciferol (vitamin D) and thiamine [34]. Magnesium is necessary for the binding of vitamin D to its binding protein, which is essential for proper transport of the vitamin throughout the body [34]. In addition, magnesium is necessary for the proper functioning of hepatic 25-hydroxylase and renal 1-alpha hydroxylase, the enzymes necessary for the conversion of cholecalciferol to 25-hydroxyvitamin D (calcidiol) in the liver, and then to 1,25-dihydroxyvitamin D_3 (1,25-$(OH)_2$ vitamin D_3 or calcitriol) in the kidneys, respectively [34]. Calcitriol or 1,25-$(OH)_2$ vitamin D_3 is the most active form of vitamin D, necessary for the proper exertion of vitamin D's effects on gene expression [34]. A magnesium deficiency could result in reduced calcitriol and parathyroid hormone response, implicating it in the development of osteomalacia (magnesium-dependent vitamin-D-resistant rickets) [34].

In addition, magnesium may have an important function in blocking calcium binding to the N-methyl D-aspartate (NMDA) receptor [34]. The NMDA receptor binds glutamate primarily (an excitatory neurotransmitter) and is ubiquitous throughout the central nervous system (CNS), with approximately 80% of cortical neurons having NMDA receptors [40]. The NMDA receptor plays an important role in neural plasticity and memory formation and may be implicated in a process called excitotoxicity, a potential element of pathologies in epilepsy and Alzheimer's disease [40]. Specifically, during states of epilepsy, stroke, or traumatic brain injury, damage to the brain may occur via calcium-mediated excitotoxicity [40]. In fact, magnesium's ability to prevent migraines, preeclamptic seizures, and protect against premature neonatal neural injury is mediated via the ability of magnesium to bind to the NMDA receptor and block calcium's entry into the neuron and cause depolarization [40, 41]. Thus, it is possible that by blocking calcium binding, magnesium reduces the excitability of the NMDA receptor, indicating a role of magnesium in altering CNS function, and perhaps even reducing disease risk.

Magnesium supplementation has the potential to be an effective and affordable therapy for migraine headaches, demonstrating a high safety profile [42]. In addition to its possible role in mitigating migraine headaches, magnesium may play a role in individuals with Alzheimer's disease. Barbagallo et al. compared older individuals with Alzheimer's disease to age-matched controls and reported that those with Alzheimer's disease had reduced serum magnesium concentrations [43]. Furthermore, the researchers reported a significant relationship between serum magnesium concentrations and cognitive function, demonstrating that magnesium intake may play a role in supporting cognitive performance. Ozawa et al. found higher self-reported intakes of calcium, magnesium, and potassium in a Japanese population; however, no associations between these minerals and Alzheimer's disease risk were found [44].

Furthermore, magnesium is an essential cofactor for the synthesis of glutathione due to its importance in ATP function [45]. Glutathione is one of the primary antioxidants in the body, and it is important for nutrient metabolism, as well as the regulation of many cellular processes such as gene expression, DNA and protein synthesis, cellular proliferation and apoptosis, signal transduction, cytokine production, immune response, and protein glutathionylation [46]. Inadequate production of glutathione results in increased oxidative stress, and the development of several pathologies such as kwashiorkor, seizures, Alzheimer's disease, Parkinson's disease, liver dysfunction, cystic fibrosis, sickle cell anemia, human immunodeficiency virus (HIV), acquired immunodeficiency syndrome (AIDS), cancer, myocardial infarction, cerebrovascular disease, and T2DM [46]. Magnesium deficiency could reduce the body's capacity for endogenous glutathione synthesis and lead to the development of disease states associated with excessive oxidative stress.

Magnesium is instrumental in attenuating chronic inflammation. Song et al. investigated the relationship between magnesium intake, C-Reactive Protein (CRP) (a standard marker of systemic inflammation), and the incidence of metabolic syndrome in a cohort of middle-aged and older American women. The researchers presented evidence demonstrating an inverse relationship between magnesium intake and CRP concentrations [35]. This relationship was especially prominent in women with a BMI exceeding 25 kg/m^2 and those who had ever smoked in their lifetime [35], indicating the potential role of magnesium status in the development of systemic inflammation. Because metabolic syndrome is known to have a chronic inflammatory component, it is not surprising that magnesium intake was inversely associated with the risk of metabolic syndrome [35, 47].

Magnesium is particularly important as an electrolyte functioning in the cardiovascular system, contributing to normal potassium transport in the myocardium, vasodilation of coronary and peripheral arteries, and reducing the aggregation of platelets [34]. Magnesium assists in the maintenance of normal cardiac function via electrophysiological processes such as nerve transmission, muscle contraction, and gland secretions [23]. Magnesium may also be protective against cardiovascular disease due to its capacity to aid in endothelium-mediated vasodilation [23, 34]. Thus, ensuring adequate magnesium consumption could contribute to a lowered risk of developing cardiovascular disease due to the relationship between abnormal vasoconstriction and the platelet production implicated in blood clotting in the development of myocardial infarction and other cardiovascular events [34].

Magnesium is also essential to proper blood pressure regulation because it decreases the excitability of smooth muscle cells in response to depolarizing stimuli by activating calcium-dependent potassium channels [48]. Thus, via the promotion of vasodilation in vessels and reducing blood pressure, magnesium may be cardioprotective. This may be the mechanism by which magnesium may help prevent cerebrovascular diseases such as strokes, a disease commonly associated with chronic hypertension. Hypertension can lead to vasoconstriction of arteries adjacent to the cerebrum, potentially leading to an aneurysm or other endothelial damage that may lead to ischemic stroke. Larsson et al. conducted a meta-analysis where they examined the relationship between magnesium status and stroke risk. The researchers reported that magnesium intake of greater than 100 mg/day was correlated with an 8% reduced risk of total stroke incidence [49].

Magnesium is implicated in the prevention of T2DM, likely due to its importance in glucose metabolism and insulin function. Magnesium is important for transferring phosphates from ATP to protein, via tyrosine kinases [8]. Tyrosine kinases are involved in the transfer of phosphate of ATP to tyrosine residues on receptors or downstream proteins, which result in the altered activity of various enzymes and the creation of binding sites of various signaling proteins (such as insulin) [50]. Magnesium is implicated in the breakdown of glycogen and the release of glucose-1-phosphate, resulting in altered phosphorylase b kinase activity [8]. Phosphorylase b kinase is important for the activation of glycogen phosphorylase, the primary enzyme responsible for glycogenolysis [51]. Magnesium may also be involved in the translocation of the glucose transporter type 4 (GLUT4), essential for the uptake of blood glucose into cells [8], a process implicated in the prevention and management of diabetes mellitus. Guerrero-Romero et al. reported that magnesium supplementation and higher magnesium intakes improved insulin sensitivity in individuals without diabetes mellitus, but with insulin resistance [52].

4. The Mediterranean Diet as a source of magnesium

As previously mentioned, the MedDiet is characterized by the consumption of foods high in mono- and polyunsaturated fats, seafood, vegetables, fruits, grains, nuts, legumes, EVOO, and fermented dairy products [4]. Some specific fruits that may be incorporated include apples, bananas, oranges, pears, berries, and tomatoes [4].

Vegetables such as broccoli, kale, and spinach are likely to be included, as well [4]. Many of these foods vary in their magnesium content and are listed in **Tables 1**–**3**.

We chose to define the United States Recommended Dietary Allowance (RDA) for magnesium as 355 mg/day because it represents the mean RDA for women and men, 19 to 51 years of age. **Tables 1**–**3** list foods with high, medium, or low amounts of magnesium, considered to be 20%, 10% to 20%, or less than 10% of the mean RDA, respectively. Standard serving size of 100 grams was used as a realistic portion for the

Sunflower seeds	358 mg
Cashews	292 mg
Almond butter	279 mg
Pumpkin seeds	262 mg
Almonds	258 mg
Peanut butter	169 mg
Peanuts	168 mg
Hazelnuts	163 mg
Walnuts	158 mg
Barley	133 mg
Macadamia Nuts	130 mg
Chickpeas	115 mg
Baby Spinach	93 mg
Whole wheat bread	77 mg

Adapted from: FoodData Central. Accessed April 16, 2022. nal.usda.gov/fdc-app.html#/

Table 1.
Common Foods in the Mediterranean Diet with High Magnesium Concentrations per 100 Grams (defined as being greater than 20% of the average United States Recommended Dietary Allowance for women and men, 19 to 51 years of age [355 mg]).

Dried Figs	68 mg
Mackerel	60 mg
Oysters	58 mg
Cooked Brown Rice	43 mg
Dates	43 mg
Canned Sardines	39 mg
Shrimp	39 mg
Mussels	37 mg
Crab	36 mg
Lentils	36 mg

Adapted from: FoodData Central. Accessed April 16, 2022. nal.usda.gov/fdc-app.html#/nal.usda.gov/fdc-app.html#/

Table 2.
Common Foods in the Mediterranean Diet with Moderate Magnesium Concentrations per 100 Grams (defined as 10% to 20% of the average United States Recommended Dietary Allowance for women and men, 19 to 51 years of age [355 mg]).

Peas	33 mg
Pulses	33 mg
Raw Kale	33 mg
Chicken	32 mg
Ground Turkey	29 mg
Bananas	28 mg
Salmon	27 mg
Cheese	27 mg
Sweet Potatoes	25 mg
Trout	25 mg
Brussels Sprouts	23 mg
White Potatoes	23 mg
Raw Broccoli	21 mg
Duck	16 mg
Cauliflower	15 mg
Cantaloupe Melons	13 mg
Turnips	13 mg
Quail Eggs	13 mg
Red Wine	12 mg
Whole Milk	12 mg
Strawberries	12 mg
Chicken Eggs	11 mg
Frozen Carrots	11 mg
Greek Yogurt	11 mg
Oranges	11 mg
Canned Tomatoes	10 mg
Yellow Onions	9 mg
Peaches	8 mg
Pears	6 mg
Grapes	5 mg
Honeycrisp Apples	4 mg

Adapted from: FoodData Central. Accessed April 16, 2022. nal.usda.gov/fdc-app.html#/nal.usda.gov/fdc-app.html#/

Table 3.
Common Foods in the Mediterranean Diet with Low Magnesium Concentrations per 100 Grams (defined as being less than 10% of the average United States Recommended Dietary Allowance for women and men, 19 to 51 years of age [355 mg]).

vast majority of foods; however, for some foods, this may not be the case. Although the tables represent foods with varying amounts of magnesium, some factors that may potentially inhibit the absorption of magnesium are the presence of phytates, oxalates, and to a lesser extent, potassium and zinc [53].

5. Potential health outcomes of the Mediterranean Diet mediated by magnesium intake

Several benefits of the MedDiet may be partially explained by the physiological benefits of magnesium. As previously discussed, the MedDiet has been shown to reduce the incidence of cardiovascular disease, T2DM, peripheral artery disease, atrial fibrillation, certain cancers, cerebrovascular disease, neurodegenerative disease, metabolic syndrome, and improve blood lipid concentrations and glucose metabolism [2, 6, 26–30]. Magnesium, via its several prominent roles in the body, may be implicated in most, if not all of these positive changes.

Several of the aforementioned pathologies are associated with excessive inflammation and oxidative stress, which can be attenuated by processes associated with magnesium. Magnesium intake has been negatively associated with CRP concentrations [35]. Magnesium is also implicated in the production of glutathione (via its importance as an ATP/adenosine diphosphate [ADP] bridge) [45]. Glutathione is the primary antioxidant in human physiology and serves many other functions in cellular processes [46]. Low concentrations of this endogenous antioxidant are associated with many disease states such as neurodegenerative diseases, liver disease, cancer, and T2DM [46].

Magnesium may also contribute to MedDiet's prominent reductions in cardiovascular disease. Magnesium serves an important role as an electrolyte, necessary for potassium transport within the myocardium [34]. Magnesium is also essential in proper cardiac function via its role in electrophysiological processes [23]. Magnesium may also be beneficial in preventing and protecting against hypertension and other cardiovascular diseases via its ability to increase vasodilation of blood vessels, by reducing the excitability of smooth muscle cells, and regulating the endothelium [23, 34, 48]. Estruch et al. compared a MedDiet supplemented with mixed nuts or EVOO to a standard low-fat diet. The group who consumed mixed nuts demonstrated a small reduction in cardiac events compared to the group who consumed EVOO (3.8% vs. 3.4%, respectively) [54]. Nuts are a good source of magnesium, providing some potential evidence that increased magnesium intake within the context of the MedDiet may further enhance its cardioprotective potential.

Magnesium content of the MedDiet may also help partially explain the benefits of the diet on risk of T2DM. Adequate magnesium status may reduce the risk of T2DM, due to its role in glucose and insulin metabolism. As mentioned, magnesium is important as an ATP/ADP bridge, which influences tyrosine kinase activity [8]. Magnesium is important for glycogenolysis and the subsequent release of glucose-1-phosphate, causing changes in phosphorylase b kinase activity. Magnesium is also implicated in GLUT4 translocation, a process essential for glucose uptake into the cell [8]. Magnesium supplementation has also been shown to improve insulin sensitivity [52]. Furthermore, it is possible that MedDiet's potential to reduce neurodegenerative disease may be partly due to magnesium's capacity to bind to the NMDA receptor and block calcium from entering and triggering depolarization [34]. This is important for neurological health because overexcitability of the NMDA receptor is damaging to the brain and implicated in several cerebral pathologies [40].

There is reasonable evidence to support the notion that magnesium intake in the MedDiet may be one of the vectors by which many of the physiological and disease-preventing benefits of the MedDiet are enacted. Therefore, it is important to promote the consumption of foods within the context of MedDiet that are high in magnesium. Magnesium is present in water, consisting of approximately 10% of daily magnesium intake in some estimations [34, 55]. Magnesium is essential for the structure of chlorophyll, the green pigment in plants, which is why leafy green vegetables such as spinach and kale have high magnesium content [23]. However, it is important to keep in mind that some of these sources, such as spinach, also contain some phytochemicals, namely oxalates, that may impair magnesium absorption [53]. Considering the aforementioned information, it is likely beneficial to obtain magnesium from other sources, as well.

6. Comparing magnesium intake with different nutritional strategies

Because many of the benefits of the MedDiet may be attributable to its magnesium content, it is relevant to examine the magnesium intake in the MedDiet compared to other dietary strategies. The standard American diet is lacking in many micronutrients, with magnesium being prominent among these. The United States RDA for magnesium ranges from 310 to 420 mg per day for adults, 19 to 51 years of age, with most of the population failing to meet this recommendation [56]. It is estimated that 60% of the United States population does not meet the RDA for magnesium intake [8]. Castiglione et al. reported that, in a Sicilian cohort, 66.9% of the population met the European recommendations for magnesium intake of around 363 mg of magnesium per day, and 90.4% met the Italian recommendation of approximately 240 mg per day [23–25]. These data indicate that MedDiet is a superior source of magnesium-rich foods compared to the standard American diet.

Other dietary approaches may contain similar amounts of magnesium. The Dietary Approaches to Stop Hypertension (DASH) diet, which is composed predominantly of vegetables, nuts, and fish [57, 58], has been shown to reduce the incidence of T2DM similarly to the MedDiet [59]. Magnesium intake has been shown to be a relevant micronutrient for T2DM prevention in the Mediterranean and DASH diets [59]. One nutritional intervention that attempts to incorporate principles of both the Mediterranean and DASH diets is called the Mediterranean-DASH Intervention for Neurodegenerative Delay, or the MIND Diet [60]. Because the MIND Diet is somewhat of a fusion of the two dietary interventions, the nutritional adequacy of the intervention is comparable to the Mediterranean and DASH diets.

Morris et al. reported that adherence to the MIND diet resulted in significant reductions in the temporal progression of neurodegeneration in 960 participants, about 81 years of age, resulting in a difference equivalent to a reduction of 7.5 years in mental age [61]. Berendsen et al. reported that, in a cohort of 16,000 women, 70 years of age and greater, the MIND Diet attenuated declines in verbal memory, but not overall cognitive decline, over a period of six years [62]. Thus, the MIND Diet may be potentially protective against neurodegenerative disease, but more research comparing it to the Mediterranean and DASH diets separately is needed. This is especially the case for other facets of health such as cardiovascular and cerebrovascular disease risk, insulin sensitivity, quality of life, etc.

7. Conclusion and future perspectives

Overall, the Mediterranean Diet demonstrates incredible potential as a nutritional and lifestyle intervention to help reduce disease risk. The Mediterranean Diet is associated with reduced incidence of several diseases such as cardiovascular disease, type 2 diabetes mellitus, peripheral artery disease, atrial fibrillation, certain cancers, cerebrovascular disease, neurodegenerative disease, metabolic syndrome, improved blood lipid concentrations, and glucose metabolism [2, 6, 26–30]. Due to the Mediterranean Diet's inclusion of foods such as leafy green vegetables, nuts, fish, etc., provides a magnesium-rich nutritional pattern. This high magnesium content may be related to the disease-preventing health effects of the Mediterranean Diet. This is potentially due to the role of magnesium in glucose and insulin metabolism, vasomotor tone regulation, glutathione synthesis, its activity as a calcium blocker on the N-methyl D-aspartate receptor, and its importance in nutrient metabolism [8, 34, 45]. Thus, the consumption of magnesium-rich foods should be highly encouraged in Mediterranean Diet nutritional recommendations.

However, some considerations do exist in widespread adoption of the Mediterranean Diet, such as the required culinary education necessary to work with the foods comprising the diet. Furthermore, some of the qualitative lifestyle factors associated with Mediterranean culture might be more difficult to transfer to non-Mediterranean regions (such as longer meal duration, rest, etc.). However, many of the foods of the Mediterranean Diet fall within the nutritional considerations of many cultures, religions, ethnicities, etc. Thus, overall, the Mediterranean Diet is a promising nutritional intervention for widespread disease prevention, possibly mediated by its magnesium content.

This chapter provides a unique insight into the currently established health effects of the Mediterranean Diet by emphasizing the relevance of magnesium as mediator of these effects. The vast majority of research emphasizes the role of the favorable fatty acid profile and antioxidant content of the Mediterranean Diet as the primary mechanisms by which it exerts its beneficial health outcomes. While this avenue of research is certainly relevant, it is also important to examine the micronutrient density of the Mediterranean Diet as a potential vector for its positive role in the prevention of chronic disease. Due to magnesium's importance in a plethora of physiological activities, many of the widespread health effects of the Mediterranean Diet are likely mediated via the metabolic effects of this micronutrient. Further research is necessary to elucidate the micronutrient density of the Mediterranean Diet. In addition, it would be highly relevant to examine whether some of the health effects of the Mediterranean Diet may be attributable to specific micronutrient concentrations or ratios present in the diet. While significant research exists affirming the benefits of the Mediterranean Diet, some of the mechanisms by which it may exert its effects still remain somewhat unknown. This emphasizes the need for further understanding of the relative importance of differing factors such as fatty acid profile, antioxidant content, micronutrient density, and the macronutrient breakdown of the diet in contributing to the varied health effects of the Mediterranean Diet. This information would also help contribute to designing other nutritional interventions for targeted health outcomes.

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