Type of Resistant Microbes Responsible for Food Spoilage

Trisha Paul[1], Dr. Sibashish Baksi[2], Alipe Saha[3], Rounak Mandal[4]

[1]Department of Microbiology, School of Life Sciences, Swami Vivekananda University, Barrackpore, India.
Corresponding author: *tpaul5995[at]gmail.com*

[2]Department of Biotechnology, School of Life Sciences, Swami Vivekananda University, Barrackpore, India.

[3]Department of Microbiology, School of Life Sciences, Swami Vivekananda University, Barrackpore, India.

[4]Department of Microbiology, School of Life Sciences, Swami Vivekananda University, Barrackpore, India.

Abstract: ***In recent years, the persistence of resistant microbes in food has posed major challenges to food security around the world. Bacteria, ubiquitous in the environment, show remarkable resistance to the harsh conditions of food processing and storage. The most common types of bacteria associated with food spoilage include Pseudomonas, Bacillus and Clostridium. These organisms have inherent mechanisms that allow them to survive and thrive in various environments, including extreme temperatures, pH fluctuations, and high salt concentrations. Their ability to form biofilms further increases their resistance to sanitation measures and makes them persistent contaminants in food processing plants. Likewise, yeasts, particularly those of the genera Saccharomyces and Candida, contribute to food spoilage through fermentation processes by lowering pH and give foods undesirable flavors, odors and textures. These yeasts thrive in high - sugar, low - oxygen environments, making them common contaminants in sweetened beverages, baked items, and fermented foods. Molds pose another major challenge in food preservation, species such as Aspergillus, Penicillium and Fusarium are known for their ability to produce resistant spores, mycotoxin and hydrolytic enzyme. These spores can withstand harsh environmental conditions such as dehydration, high osmotic pressure and extreme temperatures. Therefore, mold contamination poses a significant risk to various food products, including grains, fruits and baked items, resulting in economic losses and potential health risks. The aim of this comprehensive review is to provide a detailed understanding of the various types of resistant microorganisms that play a critical role in food spoilage, with particular emphasis on bacterial, fungal and yeast contaminants.***

Keywords: Resistant microbes, Spore forming bacteria, Antibiotic resistant bacteria, Spoilage.

1. Introduction

The presence of resistant microbes responsible for food spoilage represents an ongoing challenge to food safety and preservation efforts worldwide. Microorganisms have variety mechanisms to adapt and survive the adverse conditions of food processing, storage and distribution. Understanding the complexity of microbial resistance is critical to developing effective strategies to mitigate its impact on food quality and safety. This comprehensive review aims to examine the diverse spectrum of resistant microbes involved in food spoilage and to examine their impact on food industry practices.

Microbial resistance to food spoilage is illustrated by spore - forming bacteria such as *Bacillus* and *Clostridium* species. These microorganisms have evolved robust protective structures, including endospores, that allow them to withstand extreme temperatures, desiccation, and chemical agents. Its ability to survive in various environments poses significant challenges to food processing plants and requires strict hygiene protocols to prevent contamination [1].

Furthermore, the emergence of antibiotic - resistant strains of foodborne pathogens exacerbates the problem of microbial resistance to food spoilage. Bacteria such as *Salmonella* and *Escherichia coli* have developed resistance to antimicrobials through genetic mutations or horizontal gene transfer, limiting the effectiveness of traditional treatment methods. This resistance not only affects publics health, but also raises concerns about the possible spread of resistant strains through the food chain [2].

A comprehensive understanding of microbial resistance mechanisms is essential to address the challenges posed by resistant microbes in food spoilage. By elucidating the genetic and physiological factors underlying microbial resistance, reseachers can develop new approaches to improve food safety and preservation. This review summarize and provides information about their distrubution, diversity, and impact on food industry practices.

Food spoilage - Food spoilage during storage is a major environmental problem and a major concern for the food industry. Food spoilage can be defined as a process or change that causes a product to become undesirable or unacceptable for consumption. Food spoilage, “an detrimental change in food, ” can occur at any stage of the food chain. The main culprit for this deterioration are insects, physical damage and indigenous enzymatic activity or microorganisms (bacteria and fungi). In addition to perishable foods with a limited shelf life, there are also foods that generally have a much longer shelf life but spoil overtime. The microbial decomposition of food produces substrates such as organic acids, esters. carbonyls, diamine alcohols, sulfur compounds, hydrocarbons and fluorescent pigments as byproducts. Although chemical and physical variables are key factors in the detection of spoilage - causing microorganisms, contamination of food by toxins or microbial spores often goes unnoticed until foodborne infections break out [3].

Factor influencing food spoilage - Foods are naturally rich in carbohydrates, protein and lipids, which are considered highly nutrious by both microbes and humans. Living plants and animals have structural and chemical defense mechanisms to prevent colonizations by microbes. However, once these system are die or become inactive, and its effectiveness deteriorate. Many different microbes maybe able to utilize the nutrients in a food, but some species have competitive advantage under certain conditions. Food processors must keep in mind that certain foods because some nutrients are missing. When the food product is reformulated, a new ingredient may enable the growth of a previously insignificant microbe [4].

Microbial behaviour in food -

Temperature - Bacteria grow fastest in the temperature range between 40º and 140º F, doubling in number in just 20 minutes. This temperature range is often referred to as the "threat zone. ''Many of the pathogens found in food belong to the group of psychotrophs. The best temperature range for psychrotrophs is 20 to 30º C [5]. However, psychrotrophs can be inhibited by internal and external methods [6]. The low temperature effect applied to the products prevents the development of mesophiles and thermophiles.

pH - Most microorganisms thrive best near neutral pH (pH 6.6 to 7.5). Few microorganisms grow in very acidic conditions below a pH of 4.0. Bacteria grow at a fairly specific pH for each species, but fungi grow in a wider range of pH values. For example, most meats naturally have a pH of around 5.6 or higher. At this pH level, meat is susceptible to spoilage from bacteria, mold and yeast.

Water activity - It determines the growth ability of microorganisms. As water activity decreases, the ability of microorganisms to grow also decreases. The higher the water activity, the faster microorganisms such as bacteria, yeast and mold can grow. The water activity of the food can be expressed as the ratio between the water vapor pressure of the food and pure water at the same temperature [7]. >0 to<1, as no food can have a water activity of 0 or 1. Most bacteria associated with food spoilage grow at rates above 0.91, while most filamentous fungi can grow at rates as low as 0.80 [8].

Resistant microbes involvement - Different type of resistant microbes present in food and these microbes responsible for food spoilage. Here some type of microbes are explained.

1. **Spore forming bacteria** -
Spore forming bacteria are a group of microorganisms capable of forming very resistant spores such as *Bacillus* and *Clostridium* species pose a significant risk to food safety due to their ability to form highly resistant spores [9]. These spores can survive adverse conditions, including heat and chemical treatments, which can lead to food contaminations and spoilage lead and pose a challenges in the preservations and storage of food. Some spore forming bacteria produce toxins (e. g. *Clostridium botulinium* produces botulinum toxin) that can cause foodborne illness or spoilage [10].

1.1. *Bacillus* species - *Bacillus* species are group of spore - forming bacteria that are often associated with food spoilage and foodborne illness. *Bacillus subtilis*, implicated in food spoilage, employs resistance mechanisms such as efflux pumps, target modification and enzymatic antibiotic inactivation. By secreting proteolytic and lipolytic enzyme, *Bacillus subtilis* and *Bacillus velezensis* implicating food spoilage in a extended shelf - life (ESL) milk [11]. *Bacillus cereus* in particular is known to produce enterotoxins that cause food poisoning, highlighting the importance of understanding its resistance mechanisms. The role of specific genes in conferring resistance to heat and oxidative stress in *Bacillus cereus* spores [12]. *Bacillus licheniformis* produces proteolytic enzymes and lipase that contribute to the decay of various food products. Also *Bacillus pumilus* is involved in food spoilage due to its enzymatic and metabolic activities. The study identified key genetic determinants involved in stress response pathways and provided valuable insights into spore resistance mechanisms in *Bacillus* species. The resilience of *Bacillus* spores poses challenges for food preservation as traditional methods such as heat treatment may not be sufficient to eliminate them.

1.2. *Clostridium* species

Clostridium species that are resistant to food preservation methods can cause food spoilage [13]. *Clostridium* species are known for their ability to form highly resistant endospores, allowing them to survive the extreme conditions of food processings and storage. The resistance mechanisms of *Clostridium* species, including *Clostridium botulinum* and *Clostridium perfringens*, have been extensively studied. These bacteria produce toxins such as botulinum and alpha toxin respectively, that can cause serious foodborne illnesses. Therefore, it is important to understand their resistance mechanisms and take appropriate control measures.

The genetic determinants of spore resistance in *Clostridium difficile*, an important nosocomial pathogen and an emerging foodborne pathogen. The study identified several genes involved in spore resistance and shed light on the molecular mechanisms underlying Clostridium spore resistance [14].

Several psychrophilic and psychrotolerant species, including *Clostridium algadicarnis*, *Clostridium algidixilanolyticum*, *Clostridium estertheticum*, *Clostridium frigidicarnis* and *Clostridium gasigenes*, have been linked to red meat spoilage (meat becoming soft, dripping profusely, unpleasent odor). Of these species, *C. estertheticum* and *C. gasigenes* also produce gas and have been recognized as pathogens that damage the " inflated packaging" of refrigerated meats packaged under vacuume at normal storage temperature (- 1.5 to 2 º C) [15]. In addition, the acid tolerent species *Clostridium barati* and *Clostridium butyricum* have been reported to be the spoilers of canned pasteurized mung bean sprouts stored under acidic conditions [16]. *Clostridium tyrobutyricum* spores can spoil semi - hard cheeses with a long maturation period, such as: Gouda and Emmentaler [15].

2. Antibiotic - resistant bacteria

Antibiotic - resistant foodborne pathogens pose a significant threat to public health and complicate the treatment and control of foodborne illnesses. The emergence of multidrug - resistant bacterial strains such as *Salmonella*, *Escherichia coli* and *Salmonella* species highlights theurgent need to improve surveillance and intervention strategies.

2.1. *Salmonella* species

Salmonella sp. are among the most common causes of foodborne illnesses worldwide and antibiotic resistance is a growing concern. The global burden of antimicrobial resistant *Salmonella* infections and highlights the significant impact in public health and health systems [17].

The presence of an active efflux pump in *Salmonella typhimurium* has been described as a mechanism of antibiotic resistance. Overproduction of AcrAB (inner membrane transpoerter) and TolC (outer membrane protein) type efflux pump and associate changes in outer membrane proteins and lipopolysaccharides synergistically resulted in lower ciprofloxacin accumulation in *Salmonella typhymurium* and showed higher resistance in *Salmonella* [18]. Genomic analyses to elucidate the diverse mechanisms underlying antibiotic resistance in *Salmonella typhymurium* strains isolated from food samples (meat). Through whole genome sequencing and bioinformatics approaches, the researchers identify genes associated with resistance mechanisms such as efflux pumps, target site mutations, and horizontal gene transfer of resistance determinants [19]. Genetic determinants and mechanisms contributing to antibiotic resistance in *Salmonella enteritidis* strains of poultry and provide important information for the control of antibiotic - resistant foodborne pathogens [20].

2.2 *Escherichia coli*

Dietary *Escherichia coli*s trains may contain extended spectrum β - lactamase (ESBL) genes located on mobile genetic elements. Therefore, it is possible that resistance to cephalosporins may be transmitted to pathogens in the human digestive system [21]. In addition to antibiotic resistance, *Escherichia coli* may also exhibit resistance to environmental stresses that occur during food processing and storage. Understanding stress resistance mechanisms in *Escherichia coli* is crucial for developing effective control strategies thar ensure food safety [22].

2.3 *Pseudomonas* species

Antibiotic resistance pattern and genetic diversity of *Pseudomonas* sp. isolated from fresh products and raw milk samples. The researchers found a high prevalence of antibiotic resistance among *Pseudomonas* isolates, highlighting the potential risk these bacteria pose to food safety and public health [23]. Different mechanisms of antibiotic resistance in *Pseudomonas aeruginosa*, a common species involved in food spoilage. It analyzes mechanisms such as antibiotic modifying enzymes and biofilm formation that contribute to the resistance of bacteria to antibiotics [24]. The study provides valuable information about the complicated mechanisms that *Pseudomonas* species use to resist antibiotic treatments and emphasizes the importance of understanding these mechanisms in order to develop effective strategies to combat antibiotic resistance in both clinical and analytic settings to develop in the food sector. Genetic determinants and adaptive mechanisms contributing to antibiotic resistance in *Pseudomonas putida* strains from food samples and provide salient information for food safety practices [25].

3. Bacteriocin - resistant bacteria

Bacteriocins are ribosomally secreted antimicrobial peptides (AMPs), 20 to 60 amino acids long, cationic and hydrophobic, capable of inhibiting pathogenic or food - contaminating bacteria of both the gram - negative and gram - positive groups [26, 27].

All organisms have an inherent tendency to adapt to the changing environment. Therefore, target bacteria also evolve components to resist these bacteriocins upon sustained expoxure, resulting in bacteriocin resistance [28]. Resistance bacteria become resistant to bacteriocins through this type of modification in their cells:

i) Changes in membrane receptors that serve as docking molecules for bacteriocins - Depending on the type, bacteriocins bind to lipid II, the permease system mannose phosphotransferase, undecaprenyl pyrophosphate phosphatase (UppP), the maltose ABC transporter, the permease or zinc - dependent membrane - bound proteases. The bacteriocin Garvicin ML requires the maltose - ABC transporter complex as receptors, the absence of which leads to resistance in the Enterococcaceae family [29].

ii) D - alanylation of cell wall teichoic acids - Normally, teichoic acid imparts a negative charge to the cell wall, but when D - alanylated, it imparts a positive charge to the cell wall, resulting in neutralization of the anionic polymer [30]. The dlt operon of *Clostridium difficile* is expressed as a result of cAMP exposure and that this operon is directly involved in the addition of D - alanine residues to teichoic acids as well as in resistance to antimicrobial peptides such as nisin [31].

iii) L - lysinylation of cell membrane phospholipids - Some bacteria, such as *Staphylococcus aureus*, modify anionic phospholipids with L - lysine to form lysylphosphatidylglycerol, a basic phospholipid. It imparts a net positive charge to the cytoplasmic membrane, which can protect against bacteriocins, including the lipopeptide daptomycin [32].

iv) Changes in the fatty acid composition of the cell membrane - The higher proportion of saturated fatty acids and branched - chain fatty acids in the bacteriocin - resistant variants is explained as an adaptation towards greater membrane stiffness and lower fludity, which prevents the penetration of bacteriocins into the cell [33]. *Leuconostoc* and *Weisella* become resistant to mesenteriocin 52A through changes in membrane fatty acid composition, resulting in a more catanoic membrane [34].

4. Other microbial agents

In addition to spore - forming bacteria, antibiotic - resistant foodborne pathogens and bacteriocin resistant bacteria other microbial pathogens can also contribute to food spoilage. Fungi, yeasts and molds are common contaminants of various food products and cause spoilage through enzymatic degradation and toxin production.

Food spoilage caused by yeast occurs through several mechanisms, which are primarily controlled by the metabolic activities of the yeast cells. Here are detailed description [35, 36, 37]:

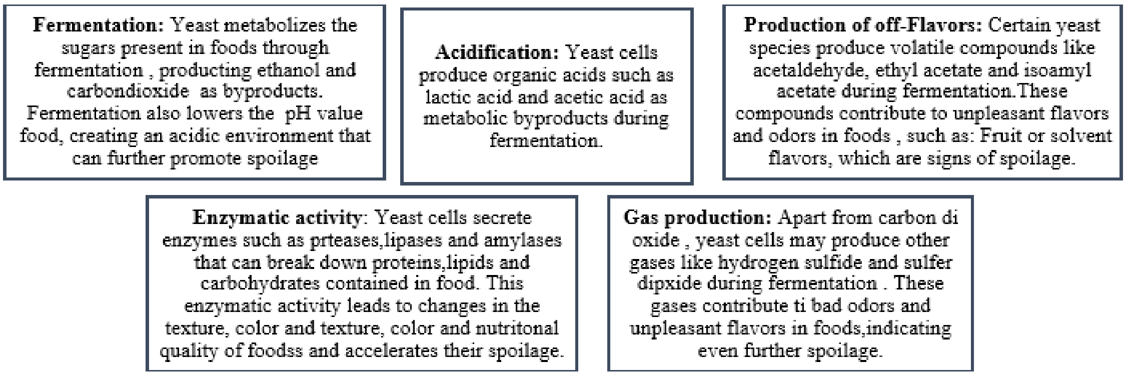

Figure: Schematic representation of mechanism of spoilage by yeast.

The yeast species *Zygosaccharomyces bisporus* has been reported to spoil food by producing off - flavours and carbon dioxide, which can cause bloating and even bursting of food containers. In addition, *Saccharomyces cerevisiae* and *Schizosaccharomyces pombe* can spoil fruit juice and soft drinks [38]. The *Candida* mechanism responsible for food spoilage can be described as follows*:* *Candida* species, commonly found in various foods, use their enzymatic activities to metabolize sugars and produce organic acids, ethanol and other metabolites. This fermentation process changes the taste, texture and appearance of food and causes it to spoil. In addition, *Candida* species can also produce mycotoxins, further threatening food safety [39]. Deterioration of the bread surface, mainly caused by *Pichia burtonii* (" chalk mold"). Contamination of products by osmophile yeast *(Pichia burtoni*) is usually due to dirty utensils and equipment. Therefore, following good manufacturing practices will minimize contamination by osmophilic yeasts [40].

Food spoilage caused by mold involves several mechanisms, mainly controlled by the growth and metabolic activities of mold spores. Here is a detailed explanation [41, 42, 43, 44]:

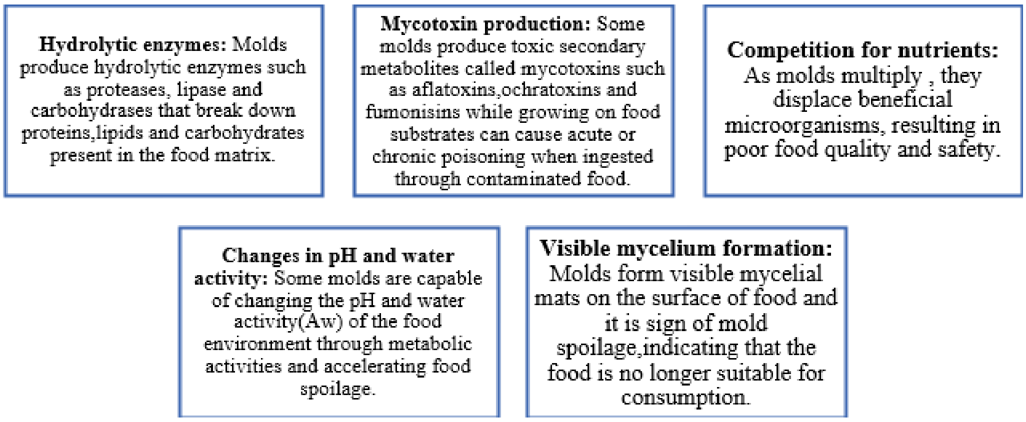

Figure: Schematic representation of mechanism of spoilage by mould

Aspergillus species are ubiquitous fungi that play an important role in food spoilage and foodborne illness. *Aspergillus* contamination can occur at various stages of food production, from cultivation and harvesting to processing, storage and distribution. Aflatoxins, ochratixins and fumonisins are among the most common mycotoxins associated with *Aspergillus* contamination of food. [44]. Volatile organic compounds (VOCs) produced by *Aspergillus* species contribute to the characteristic odors and tastes associated with fungal contamination of foods. These compounds include alcohols, aldeydes, ketones, esters ans sulfer - containing compounds [45]. *Penicillium* produces enzymes such as cellulases and pectinases that facilitate the breakdown of plant cell walls and cause soft rot in fruits and vegetables [41]. In addition, *Penicillium* species are known to produce mycotoxins, including patulin and ochratoxin A, which contaminate food and pose a health risk to consumers. *Fusarium* species produce mycotoxins such as fumonisins, trichothecenes and zearalenone, which contaminate grains, fruits and vegetables and pose health risks to consumers [46]. In addition, *Fusarium* species can break down food components by secreting celluolytic and pectinolytic enzymes, contributing to spoilage.

Impact on Food industry practices - The presence of resistant microbes in spoiled foods poses major challenges to the food industry and requires the implementation of robust control measures and quality assurance protocols. Effective hygiene practices, including cleaning and disinfection of food processing equipment and facilities, are essential to prevent microbial contamination and minimize the risk of foodborne illness.

In addition, the use of new antimicrobial agents and preservation techniques can help mitigate the impact of resistant microbes on food quality and safety. Research into natural antimicrobial compounds such as plant obtain essential oils and bacteriocin synergistically holds promise for inhibiting the growth of harmful microorganisms [47] while preserving the sensory properties of foods. For example - Thyme essential oil (0.6%) in combination with nisin (500 - 1000 IU/g) suppressed the growth of *Listeria monocytogenes* [48].

Furthermore, improved surveillance and monitoring of microbial resistance patterns is critical to detect emerging threats and guide intervention strategies. Collaborative efforts between food manufacturers, regulators and researchers are necessary to address the complex challenges posed by resistant microbes in food spoilage and to ensure the continued safety and integrity of food supply chain.

5. Conclusion

In summary, the role of microbes in food spoilage highlights the critical importance of effective food safety measures. Microorganisms such as bacteria, yeast and mold contribute to taste, texture and odor changes and cause significant economic losses and health risks. Understanding the various mechanisms by which these microbes cause food spoilage, including enzymatic degradation, biofilm formation and antimicrobial resistance, is critical to developing targeted interventions.

Understanding the resilience of spore resistant microbes that contribute to food spoilage is critical to ensuring food safety. These microbes are equipped with robust microorganisms such as spore formation and exhibit remarkable resistance to adverse conditions and antimicrobial treatments. Addressing the challenge of spore - resistant microbes requires tailored measures, including strict hygiene practices, proper food storage and implementation of effective preservation techniques.

For effective food safety management, it is important to understand the various antibiotic resistance mechanisms used by microbes responsible for food spoilage. Efflux pumps, target site changes, enzymatic degradation, biofilm formation and horizontal gene transfer contribute to the persistance and spread of antibiotic resistance in spoilage - causing microbes. Addressing this challenges requires a multifaceted approach that includes the judicious use of antibiotics in agriculture, improved hygiene practices in food processing, and development of alternative antimicrobial strategies. By implementing these measures, we can reduce the risks associated with antibiotic - resistant spoilage microbes and protect public health. By implementing strict sanitation practices, proper storage techniques, and judicious use of antimicrobials, we can mitigate the effects of microbes that affect food quality and safety.

References

[1] ADAMS, M. M. MO (2008): Food microbiology Third Edition.
[2] Kadri, S. S. (2020). Key takeaways from the US CDC's 2019 antibiotic resistance threats report for frontline providers. Critical care medicine.
[3] Onyeaka, Helen & Nwabor, Ozioma Forstinus. (2022). Food ecology and microbial food spoilage.10.1016/B978 - 0 - 323 - 85700 - 0.00018 - 6.
[4] Pitt, J. I., & Hocking, A. D. (2009). Fungi and food spoilage (Vol.519, p.388). New York: Springer.
[5] Sevindik, M., & Uysal, I. (2021). Food spoilage and Microorganisms. Turkish Journal of Agriculture - Food Science and Technology, 9 (10), 1921 - 1924.
[6] Margesin, R., & Schinner, F. (1994). Properties of cold - adapted microorganisms and their potential role in biotechnology. Journal of Biotechnology, 33 (1), 1 - 14.
[7] Rahman, M. S., & Labuza, T. P. (2007). Water activity and food preservation. In Handbook of food preservation (pp.465 - 494). CRC Press.
[8] Tapia, M. S., Alzamora, S. M., & Chirife, J. (2020). Effects of water activity (aw) on microbial stability as a hurdle in food preservation. Water activity in foods: Fundamentals and applications, 323 - 355.
[9] Setlow, P. (2006). Spores of Bacillus subtilis: their resistance to and killing by radiation, heat and chemicals. Journal of applied microbiology, 101 (3), 514 - 525.
[10] Peck, M. W., Stringer, S. C., & Carter, A. T. (2011). Clostridium botulinum in the post - genomic era. Food microbiology, 28 (2), 183 - 191.
[11] Elegbeleye, J. A., & Buys, E. M. (2022). Potential spoilage of extended shelf - life (ESL) milk by Bacillus subtilis and Bacillus velezensis. LWT, 153, 112487.
[12] Hong, H. A., Huang, J. M., Khaneja, R., Hiep, L. V., Urdaci, M. C., & Cutting, S. M. (2008). The safety of Bacillus subtilis and Bacillus indicus as food probiotics. Journal of applied microbiology, 105 (2), 510 - 520.
[13] Bendary, M. M., Abd El - Hamid, M. I., El - Tarabili, R. M., Hefny, A. A., Algendy, R. M., Elzohairy, N. A.,. . . & Moustafa, W. H. (2022). Clostridium perfringens associated with foodborne infections of animal origins: Insights into prevalence, antimicrobial resistance, toxin genes profiles, and toxinotypes. Biology, 11 (4), 551.
[14] Smith, T. J., Cartman, S. T., Minton, N. P., & Kearns, D. B. (2017). A Conserved Regulatory System Governing Anaerobic Respiration in Clostridium difficile. Proceedings of the National Academy of Sciences of the United States of America, 117 (20), 10522–10528.
[15] Heyndrickx, M. (2011). The importance of endospore - forming bacteria originating from soil for contamination of industrial food processing. Applied and Environmental Soil Science, 2011.
[16] Remenant, B., Jaffrès, E., Dousset, X., Pilet, M. F., & Zagorec, M. (2015). Bacterial spoilers of food: behavior, fitness and functional properties. Food microbiology, 45, 45 - 53.
[17] Havelaar, A. H., Kirk, M. D., Torgerson, P. R., Gibb, H. J., Hald, T., Lake, R. J.,. . . & World Health Organization Foodborne Disease Burden

Epidemiology Reference Group. (2015). World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. PLoS medicine, 12 (12), e1001923.
[18] VT Nair, D., Venkitanarayanan, K., & Kollanoor Johny, A. (2018). Antibiotic - resistant Salmonella in the food supply and the potential role of antibiotic alternatives for control. Foods, 7 (10), 167.
[19] Wang, X., Biswas, S., Paudyal, N., Pan, H., Li, X., Fang, W., & Yue, M. (2019). Antibiotic resistance in Salmonella Typhimurium isolates recovered from the food chain through national antimicrobial resistance monitoring system between 1996 and 2016. Frontiers in microbiology, 10, 985.
[20] Al - Zenki, S., Al - Nasser, A., Al - Safar, A., Alomirah, H., Al - Haddad, A., Hendriksen, R. S., & Aarestrup, F. M. (2007). Prevalence and antibiotic resistance of Salmonella isolated from a poultry farm and processing plant environment in the State of Kuwait. Foodborne pathogens and disease, 4 (3), 367 - 373.
[21] Thomson, K. S., & Moland, E. S. (2000). Version 2000: the new β - lactamases of Gram - negative bacteria at the dawn of the new millennium. Microbes and infection, 2 (10), 1225 - 1235.
[22] Wang, R., Van Dorp, L., Shaw, L. P., Bradley, P., Wang, Q., Wang, X.,. . . & Didelot, X. (2019). Mechanisms of Antibiotic Resistance in Escherichia coli: A Food Safety Perspective. Food Control, 101, 161 - 169. DOI: 10.1016/j. foodcont.2019.01.037.
[23] Moura, T. M., Perez - Chaparro, P. J., & Esposito, F. (2016). Antibiotic Resistance Profiles and Genetic Diversity in Pseudomonas spp. Isolated from Fresh Produce and Raw Milk. Journal of Food Protection, 79 (12), 2113–2120. DOI: 10.4315/0362 - 028X. JFP - 16 - 166
[24] Pang, Z., Raudonis, R., Glick, B. R., Lin, T. J., & Cheng, Z. (2019). Antibiotic resistance in Pseudomonas aeruginosa: mechanisms and alternative therapeutic strategies. Biotechnology advances, 37 (1), 177 - 192.
[25] Wong, M. H. Y., chi Chan, E. W., & Chen, S. (2015). Isolation of carbapenem - resistant Pseudomonas spp. from food. Journal of Global Antimicrobial Resistance, 3 (2), 109 - 114.
[26] Walsh, C. J., Guinane, C. M., Hill, C., Ross, R. P., O'Toole, P. W., & Cotter, P. D. (2015). In silico identification of bacteriocin gene clusters in the gastrointestinal tract, based on the Human Microbiome Project's reference genome database. BMC microbiology, 15, 1 - 11.
[27] Suganthi, V., & Mohanasrinivasan, V. (2015). Optimization studies for enhanced bacteriocin production by Pediococcus pentosaceus KC692718 using response surface methodology. Journal of food science and technology, 52, 3773 - 3783.
[28] Kumariya, R., Garsa, A. K., Rajput, Y. S., Sood, S. K., Akhtar, N., & Patel, S. (2019). Bacteriocins: Classification, synthesis, mechanism of action and resistance development in food spoilage causing bacteria. Microbial pathogenesis, 128, 171 - 177.
[29] Gabrielsen, C., Brede, D. A., Hernández, P. E., Nes, I. F., & Diep, D. B. (2012). The maltose ABC transporter in Lactococcus lactis facilitates high - level sensitivity to the circular bacteriocin garvicin ML. Antimicrobial agents and chemotherapy, 56 (6), 2908 - 2915.
[30] Bertsche, U., Weidenmaier, C., Kuehner, D., Yang, S. J., Baur, S., Wanner, S.,. . . & Bayer, A. S. (2011). Correlation of daptomycin resistance in a clinical Staphylococcus aureus strain with increased cell wall teichoic acid production and D - alanylation. Antimicrobial agents and chemotherapy, 55 (8), 3922 - 3928.
[31] McBride, S. M., & Sonenshein, A. L. (2011). The dlt operon confers resistance to cationic antimicrobial peptides in Clostridium difficile. Microbiology, 157 (Pt 5), 1457.
[32] Khatib, T. O., Stevenson, H., Yeaman, M. R., Bayer, A. S., & Pokorny, A. (2016). Binding of daptomycin to anionic lipid vesicles is reduced in the presence of lysyl - phosphatidylglycerol. Antimicrobial agents and chemotherapy, 60 (8), 5051 - 5053.
[33] Naghmouchi, K., Kheadr, E., Lacroix, C., & Fliss, I. (2007). Class I/Class IIa bacteriocin cross - resistance phenomenon in Listeria monocytogenes. Food microbiology, 24 (7 - 8), 718 - 727.
[34] Limonet, M., Cailliez - Grimal, C., Linder, M., Revol - Junelles, A. M., & Millière, J. B. (2004). Cell envelope analysis of insensitive, susceptible or resistant strains of Leuconostoc and Weissella genus to Leuconostoc mesenteroides FR 52 bacteriocins. FEMS microbiology letters, 241 (1), 49 - 55.
[35] Fleet, G. H. (2003). Yeast interactions and wine flavour. International journal of food microbiology, 86 (1 - 2), 11 - 22.
[36] Steensels, J., & Verstrepen, K. J. (2014). Taming wild yeast: potential of conventional and nonconventional yeasts in industrial fermentations. Annual review of microbiology, 68, 61 - 80.
[37] Fleet, G. H. (2007). Yeasts in foods and beverages: impact on product quality and safety. Current opinion in biotechnology, 18 (2), 170 - 175.
[38] Stratford, M. (2006). Food and beverage spoilage yeasts. In Yeasts in food and beverages (pp.335 - 379). Berlin, Heidelberg: Springer Berlin Heidelberg.
[39] de Melo Pereira, G. V., Maske, B. L., de Carvalho Neto, D. P., Karp, S. G., De Dea Lindner, J., Martin, J. G. P.,. . . & Soccol, C. R. (2022). What is Candida doing in my food? A review and safety alert on its use as starter cultures in fermented foods. Microorganisms, 10 (9), 1855.
[40] Saranraj, P., & Geetha, M. (2012). Microbial spoilage of bakery products and its control by preservatives. International Journal of Pharmaceutical & biological archives, 3 (1), 38 - 48.
[41] Pitt, J. I., & Hocking, A. D. (2009). Fungi and food spoilage (Vol.519, p.388). New York: Springer.
[42] Heidtmann - Bemvenuti, R., Mendes, G. L., Scaglioni, P. T., Badiale - Furlong, E., & Souza - Soares, L. A. (2011). Biochemistry and metabolism of mycotoxins: A review. African Journal of Food Science, 5 (16), 861 - 869.
[43] Samson, R. A., Hoekstra, E. S., & Frisvad, J. C. (2004). Introduction to food - and airborne fungi (No. Ed.7). Centraalbureau voor Schimmelcultures (CBS).
[44] Beuchat, L. R. (1987). Spoilage of fruits and vegetables by microorganisms. In Microbiology of fruits and vegetables (pp.101 - 158). CRC Press.

[45] Jeleń, H. H., & Grabarkiewicz - Szczęsna, J. (2005). Volatile compounds of Aspergillus strains with different abilities to produce ochratoxin A. Journal of agricultural and food chemistry, 53 (5), 1678 - 1683.
[46] Petrucci, A., Khairullina, A., Sarrocco, S., Jensen, D. F., Jensen, B., Jørgensen, H. J. L., & Collinge, D. B. (2023). Understanding the mechanisms underlying biological control of Fusarium diseases in cereals. European Journal of Plant Pathology, 167 (4), 453 - 476.
[47] Rattanachaikunsopon, P., & Phumkhachorn, P. (2010). Synergistic antimicrobial effect of nisin and ρ - cymene on Salmonella enterica serovar typhi in vitro and on ready - to - eat food. Bioscience, biotechnology, and biochemistry, 74 (3), 520 - 524.
[48] Abdollahzadeh, E., Rezaei, M., & Hosseini, H. (2014). Antibacterial activity of plant essential oils and extracts: The role of thyme essential oil, nisin, and their combination to control Listeria monocytogenes inoculated in minced fish meat. Food control, 35 (1), 177 - 183.