THE IMPACT OF COMPLEX ECOSYSTEMS IN THE FOOD INDUSTRY

Olha Chorna, PhD Student, Roman Baitsar, Dr.Sc., Prof.;
Lviv Polytechnic National University, Ukraine, e-mail: olha.r.chorna@lpnu.ua

https://doi.org/10.23939/istcmtm2024.03.042

Abstract. Today, in food safety, one of the most difficult to identify by visual methods, without accredited methodological practices, is microbiological contamination, which carries a risk of product quality reduction and a high risk of consumer poisoning by pathogenic microorganisms. This type of contamination can pose a significant threat to the health of the consumer and incur both reputational and financial losses for the manufacturer. In a highly competitive food manufacturing environment, manufacturers must pay attention to the risks that affect them.

Key words: Microbiology, food industry, sanitary treatment, threat to consumer health, prevention of the development of resistance of microorganisms.

1. Introduction

Biofilm formation can lead to problems in healthcare, water distribution systems, food processing and packaging, industrial manufacturing, marine industries, and sanitation. These microbial communities can proliferate on biotic or abiotic surfaces and are responsible for human disease and decreasing production efficiency and service equipment life in many industrial fields. Biofilms appear when the contacting of bacteria to the surface, is followed by bacterial proliferation and maturation of the microbial community. After molding biofilm, bacteria not resistant to antimicrobial agents in their planktonic forms can turn resistant. The antibiotic resistance of bacterial biofilm, and the association of biofilms in generating infectious diseases in humans, highlight the need for designing novel and successful antibacterial, anti-biofilm, or anti-infection materials [1].

2. Goal

To assess the risks and impact on food safety and quality by analyzing and developing measures that prevent contamination of microbiological products, namely the formation of biofilms on production surfaces.

3. Studies of complex communities in the food industry

Biofilms are complex communities of microorganisms that adhere to surfaces and can lead to serious contamination issues in the food industry. Several well-documented cases have shown how biofilms can cause widespread foodborne illness outbreaks, resulting in severe health consequences for consumers. Unfortunately, in the history of the food industry, fatal cases of impact on human health due to microbiological contamination of the product have been recorded.

In one of the largest listeriosis outbreaks in U.S. history, 1998-1999, a meat processing plant faced massive contamination. Biofilm containing Listeria monocytogenes has formed on the slicing and packaging equipment. Despite routine cleaning, the biofilm protected the bacteria, allowing them to survive and contaminate ready-to-eat meat products. This led to over 100 cases of illness, including 21 deaths, prompting a significant product recall and heightened awareness of biofilm risks in food production.

A dairy plant in Illinois in 1985, experienced a severe salmonella outbreak due to biofilm formation on its equipment. The biofilm harbored Salmonella typhimurium, which contaminated the milk, resulting in one of the largest salmonella outbreaks in the United States. Over 16,000 people were affected, leading to hospitalizations and a reevaluation of cleaning practices and regulations in the dairy industry.

In Spain in 2005, an outbreak of food poisoning was traced back to smoked fish products. Investigations revealed that biofilm on the smoking and packaging equipment contained Listeria monocytogenes. The bacteria survived despite standard cleaning procedures, leading to contamination of the fish and several cases of illness, including fatalities. This incident underscored the need for more rigorous sanitation controls in the fish processing industry [2].

A biofilm is a thin layer of microorganisms that forms on the surface of equipment, containers, or elements of production facilities that have the properties of forming resistance to disinfectants. It makes it impossible to completely neutralize the formed ecosystem [3]. These may be bacteria, fungi, or other microorganisms that are present in the environment of the production facility or may be present in raw materials, ingredients, or process equipment (through cross-contamination with raw materials or ingredients).

Environmental factors such as pH, water activity, temperature, and nutrient composition of the food soil can be important for the phenotypic transition of planktonic cells to sessile form. They may also affect the susceptibility of cells to disinfectants. When exposed to mild acid or osmotic stress conditions, such as pH 5.0 or NaCl 3–5%, bacteria have been found to develop resistance mechanisms to even more stressful conditions. Scientists studied the influence of the pH of the growth environment on the tolerance of suspended L. monocytogenes cells against disinfection and concluded that cells grown at pH 5.2 needed four times higher minimal bactericidal concentration (MBC) of a quaternary ammonium compound (QAC) and two times higher MBC of chlorine, than those grown at pH 7.2. tested a commercial hydrogen peroxide-based agent and found that it was ineffective in eliminating for example L. monocytogenes biofilms.

Under the layer of microorganism accumulation, it is possible to form microorganisms such as [4]:

- Bacteria: Many bacteria can form a biofilm on the surface of media, such as *Pseudomonas aeruginosa*, *Escherichia coli*, *Staphylococcus aureus*, and others.
- Fungi: Some fungi, such as smart mold (*Aspergillus niger*) and *Candida albicans*, can also form biofilms.
- Algae: Some types of algae, such as green algae, can form a biofilm on the surface of the water or underwater.
- Protists: Some protists, such as Amoeba proteus, can also form biofilms, especially in high-humidity environments.

1.1. Analysis of the risks of biofilm formation

Analysis of specifics of food production in our issue is conjugated with the risks of formation of biofilms on their surfaces (Fig.1).

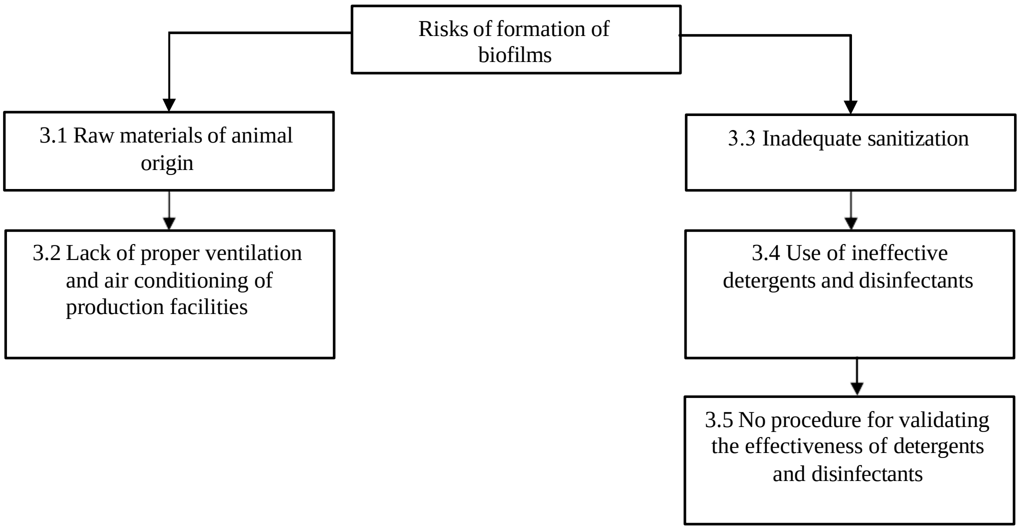

Figure 1. Risks of formation of biofilms

1.2. Raw materials of animal origin

Products of animal origin are potential carriers of pathogenic microorganisms, thanks to favorable conditions, namely the content of proteins, fats, and moisture, they can positively affect the contamination of unstable production surfaces.

The main microorganisms and pathogens that can contribute to the formation of complex ecosystems are *Pseudomonas aeruginosa, Escherichia coli, and Staphylococcus aureus*, the specificity and origin of these bacteria are fecal contaminants, which, if improperly processed (raw meat, eggs, fish), can contaminate raw materials or ingredients through cross-contamination [4].

1.3. Lack of proper ventilation and air conditioning in production facilities.

Following the factors that influence the formation and growth of microbiological biofilms is crucial for maintaining high standards of hygiene, safety, and efficiency in environments like meat processing plants. Here's why each factor is important:

– Moist Environment

Importance: Moisture is essential for microbial life. When surfaces are consistently wet, they provide a fertile environment for microorganisms to attach and thrive. In meat processing facilities, where water is frequently used for cleaning and processing, controlling moisture levels is key to preventing biofilm formation. If biofilms form, they can harbor pathogens, leading to contamination of food products, which can cause foodborne illnesses.

– Availability of Nutrients. Nutrients such as organic residues (e.g., fats, proteins) from meat processing provide the energy sources that microorganisms need to grow. If these residues are not thoroughly cleaned, they become a breeding ground for bacteria, leading to biofilm formation. This can result in persistent contamination issues that are difficult to eliminate, potentially compromising product safety and quality.

– Temperature. Different microorganisms have optimal temperature ranges for growth. In meat processing, certain bacteria thrive in the temperature range commonly used, which increases the risk of biofilm formation if conditions are not properly managed. Controlling temperature helps in reducing the growth rate of harmful microorganisms and maintaining product safety.

− Surface Characteristics. The nature of the surfaces in processing plants (smooth vs. rough) plays a significant role in biofilm formation. Rough or damaged surfaces provide more niches where microorganisms can attach and evade cleaning efforts. Regular maintenance and the use of appropriate materials for surfaces can reduce the likelihood of biofilm development, making cleaning more effective and reducing the risk of contamination.

− Time. The longer microorganisms remain on a surface, the more likely they are to develop into a biofilm. Over time, biofilms become more resistant to cleaning and disinfection. Monitoring and reducing the time between cleaning cycles is essential to prevent biofilms from becoming established, thus ensuring a consistently high level of hygiene.

− pH of the Environment. The pH of the environment affects the growth of different types of microorganisms. A neutral to slightly acidic pH is often ideal for many bacteria involved in biofilm formation. By controlling the pH levels during cleaning and processing, it is possible to create less favorable conditions for biofilm development, thus contributing to better control over microbial contamination [5].

1.4. Inadequate sanitization

Food sanitation is the exercise of subsequent measures to avoid microbial contamination of food processing. The attachment of food pathogenic bacteria to food contact or food processing surfaces can lead to possible hygienic complications because these food biofilms deliver a basin of contamination to the food chain. Microbial species attached to the food surfaces increase the hazard of microbial contamination in food processing and plants. Different cell surface appendages and structures have been involved in biofilm establishment. Cleaning and sanitization in food processing surfaces are significant measures, but disinfectants and other cleaning materials alone are not competent to eradicate the anchored biofilm and do not prevent the microbial populations from colonizing the surfaces.

Failure to comply with the requirements for sanitization can lead to the residue of pathogenic microorganisms on equipment or surfaces, residual organisms can also accumulate under the influence of external factors and form a protective layer, i.e. biofilm [6].

1.5. Use of ineffective detergents and disinfectants

The use of effective detergents and disinfectants in the food industry is a strategically necessary method of managing the microbiology of the production environment. When using household chemicals, there is a high probability of ineffective neutralization of contaminants, which can also affect residual microorganisms on surfaces. Today, the Ukrainian market for professional chemicals is diverse, with a large selection of products for cleaning and disinfecting production surfaces, but even the chemicals selected are not always following the manufacturer's recommendations.

1.6. No procedure for validating the effectiveness of detergents and disinfectants

Let’s consider the specifics and risk analysis in the manufacture of products, chemicals should be used according to the specifics of contamination [7].

Detergent validation involves testing detergents to ensure that the detergent meets the established safety performance. This should include checking their ability to remove dirt (visual method), kill microorganisms (laboratory method), ensure safety for application, and other parameters that determine their effectiveness. Therefore, when testing chemicals, it is necessary to validate the effectiveness of the product by conducting a laboratory study [8].

Validation of detergents is an important part of the quality control system and helps ensure that they perform their functions properly, reducing the risk of food contamination by pathogens.

2. Countermeasures against the formation of complex ecosystems

The formation of complex ecosystems raises some factors, that are considered below. They can be especially notable for the manufacturer (market operator), based on the analysis of hazardous factors and the establishment of control points and critical control points.

2.1. Establishing incoming control measures for raw materials and ingredients.

The control of incoming products should be carried out on an ongoing basis, and the responsible person at the enterprise should subject the raw materials to laboratory analysis for the control of microbiological factors, while the procedure for managing arbitration samples of incoming products should be carried out [9].

In the absence of a mobile laboratory at the manufactory, the manufacturer must control the manufacturer's declarations, as well as subject the results of laboratory tests for the batch of the product being supplied to control.

2.2. Proper design of the production hall

Inefficient ventilation of production facilities can lead to the accumulation of harmful particles in the air, such as bacteria, fungi, dust, smoke, vapors, etc. This can lead to food contamination with food poisons such as *Salmonella* or *Escherichia coli*.

Inadequate ventilation can lead to humidity, odors, and contamination in production facilities. This can create unpleasant conditions for workers and promote the development of bacteria and fungi that can negatively affect the hygiene of the room, and can also promote the development of microorganisms such as bacteria and fungi that can grow in a humid or warm environment.

2.3. Application of sanitary and hygienic practices

Sanitization of surfaces, work equipment, premises, etc. is a key tool for preventing microbiological contamination. To carry out the treatment, it is necessary to establish visual control (control of raw material residues, surface greasiness), control of detergent and disinfectant residues using litmus tests, as well as laboratory control of surface for bacterial smear by an accredited laboratory [10].

2.4. Usage of professional chemicals for sanitizing

Manufacturers should pay special attention to disinfectants (Fig.2). Today, the chemicals market is diverse. There is a wide range of disinfectants that are not only effective but also ergonomic to use. Disinfectants based on hydrogen peroxide, peracetic acid, etc., which after exposure decompose into water and oxygen, respectively, without the need to rinse with water. Also, detergents with antimicrobial effects are popular, which have a positive effect on the time of washing and disinfection, as well as the rational use of utilities.

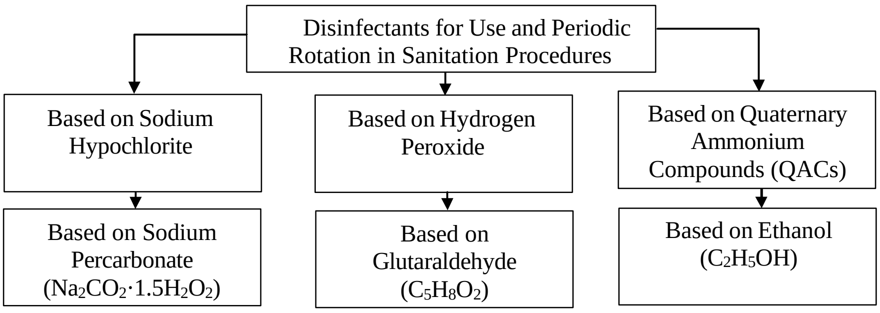

Figure 2. Disinfectants for Use and Periodic Circulation in Sanitation Procedures

2.5. Procedure for testing and validation of chemicals

Frequent and improper circulation of disinfectants can contribute to the development of resistance. For example, if a disinfectant is used in insufficient concentration or too often, microorganisms may have more time to develop resistance mechanisms, which can lead to the formation of complex ecosystems on surfaces – biofilms. To prevent the formation of contaminating ecosystems, it is necessary to rotate the chemicals with a minimum frequency of once every 6 months. Also, it is necessary to consider the effectiveness of the products by measuring them on different surfaces - stainless steel, polymer plastic, tiles, etc. If the results of laboratory measurements are positive, the products should be permittable.

3. Conclusions

The implementation of robust management strategies, particularly the rotation of disinfectants and strict adherence to sanitation protocols, becomes crucial in mitigating the risk of bioterrorism in the food industry. By regularly rotating disinfectants, we can prevent the development of resistant microbial strains that might otherwise exploit vulnerabilities in sanitation processes. This approach ensures that the microbial population remains susceptible to monitor measures, thereby reducing the likelihood of biofilm formation – a key factor in the persistence and spread of harmful pathogens.

Moreover, stringent sanitation practices serve as a foundational defense mechanism against potential bioterrorist threats. Consistent and thorough cleaning routines disrupt the formation of biofilms and eliminate residual microbial contamination, which can serve as a vehicle for introducing bioterror agents into the food supply chain. The synergy between these two strategies not only safeguards public health but reinforces the integrity of the food production process, making it less susceptible to malicious interference.

So, the integration of disinfectant rotation and rigorous sanitation protocols is essential for minimizing the risk of bioterrorism. These measures not only control the microbial environment but also enhance the overall security of production systems, ensuring a safer food supply for consumers.

4. Gratitude

The authors are thankful to the staff of the Department of Information-measuring Technologies for assistance in publishing.

5. Mutual claims of authors

The authors declare the absence of any financial or other potential conflict related to the work.

References

[1] C.-E. A. Belessi, A. S. Gounadaki, A. N. Psomas та P. N. Skandamis, "Efficiency of different sanitation methods on Listeria monocytogenes biofilms formed under various environmental conditions", Int. J. Food Microbiol., т. 145, с. S46–S52 https://doi.org/10.1016/j.ijfoodmicro.2010.10.020

[2] "Food Recalls". foodsafetynews.com. [Online]. Evaliable: https://www.foodsafetynews.com/ 2021/11/research-expands-ability-to-detect-kill- harmful-biofilms/

[3] G. Shineh, M. Mobaraki, M. J. Perves Bappy та D. K. Mills, "Biofilm Formation, and Related Impacts on Healthcare, Food Processing and Packaging, Industrial Manufacturing, Marine Industries, and Sanitation–A Review", Appl. Microbiol., т. 3, № 3, с. 629–665 https://doi.org/10.3390/applmicrobiol3030044

[4] E. S. Vorobey, O. S. Voronkova, and A. I. Vin- nikov, "Bacterial Biofilms. QUORUM SENSING - "QUORUM SENSING" IN BACTERIA IN BIO- PLASMS," Vestnik Dnipropetrovs'k Univ. Biologiya. Ecology. Visnyk of Dnipropetrovsk University. Biology. Ecology. - 2012. - Vol. 20, N 1. - P. 13-22. https://doi.org/10.15421/011202

[5] Donlan R.M. Biofilms: Survival mechanisms of clinically relevant microorganisms / R.M.Donlan, J.W. Costerton // Clinical Microbiology. - 2002. - Vol. 15, N 2. - P. 167-193. 10.1128/CMR.15.2.167- 193.2002

[6] Liu Y. Role of Pseudomonas aeruginosa biofilm in the initial adhesion, growth and detachment of Escherichia coli in porous media / Y. Liu, J. Li // Environ. Scien. Technol. - 2008. - Vol. 42, N 2. - P. 443-449.

[7] WilliamsP. Quorum sensing, communication and cross-kingdom signaling in the bacterial world // Microbiology. - 2007. - Vol. 153. - P. 3923-3938. 10.1099/mic.0.2007/012856-0

[8] R. A. N. Chmielewski та J. F. Frank, "Biofilm Formation and Control in Food Processing Facilities", Comprehensive Rev. Food Sci. Food Saf., т. 2, № 1, с. 22–3 https://doi.org/10.1111/ j.1541-4337.2003.tb00012.x

[9] M. Sharma та S. K. Anand, "Biofilms evaluation as an essential component of HACCP for food/dairy processing industry – a case", Food Control, т. 13, № 6-7, с. 469–477, september 2002 https://doi.org/10.1016/s0956-7135(01)00068-8

[10] "A new technique for the performance evaluation of clean-in-place disinfection of biofilms". OUP Academic. https://www.google.com/search?client= firefox-b