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Popular Article

Nanoparticles as anti-biofilm agents in dairy industry

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Abstract

Biofilm formation is a persistent problem in the dairy industry, leading to contamination and spoilage of dairy products. Nanoparticles have emerged as promising agents to prevent and control biofilm formation. This review focuses on the role of nanoparticles as anti-biofilm agents in the dairy industry, their mode of action, advantages and challenges.

Introduction

Biofilm formation is a persistent problem in the dairy industry, leading to contamination and spoilage of dairy products. Traditional methods for controlling biofilm formation, such as chemical disinfectants and antibiotics, have limitations such as toxicity and the potential for bacterial resistance. Nanoparticles have emerged as promising agents to prevent and control biofilm formation due to their unique physicochemical properties and ability to interact with bacterial cells.

Nanoparticles have shown great potential as anti-biofilm agents in the dairy industry. AgNPs, CSNPs, ZnO NPs, and TiO2 NPs have been extensively studied for their anti-biofilm properties and have shown promising results in inhibiting biofilm formation of various bacterial pathogens. The use of nanoparticles as anti-biofilm agents has the potential to improve the safety and quality of dairy products while reducing the reliance on traditional disinfectants and antibiotics.

Zhang *et al.* (2017) investigated the effect of AgNPs on the biofilm formation of Staphylococcus aureus and Escherichia coli, two common pathogens in the dairy industry. The results showed that AgNPs significantly inhibited biofilm formation and disrupted preformed biofilms. In addition, the release of silver ions from AgNPs contributes to their antimicrobial activity (Wijnhoven *et al.,* 2009). Another promising nanoparticle is chitosan, a natural polymer derived from chitin. Chitosan nanoparticles (CSNPs) have been shown to inhibit biofilm formation of various bacteria, including Staphylococcus aureus and Listeria monocytogenes (Sun *et al.*, 2019). In a study by Chen *et al.* (2020), CSNPs were used to control biofilm formation and improve the quality of mozzarella cheese. The results showed that CSNPs significantly reduced biofilm formation and improved the sensory properties of the cheese.

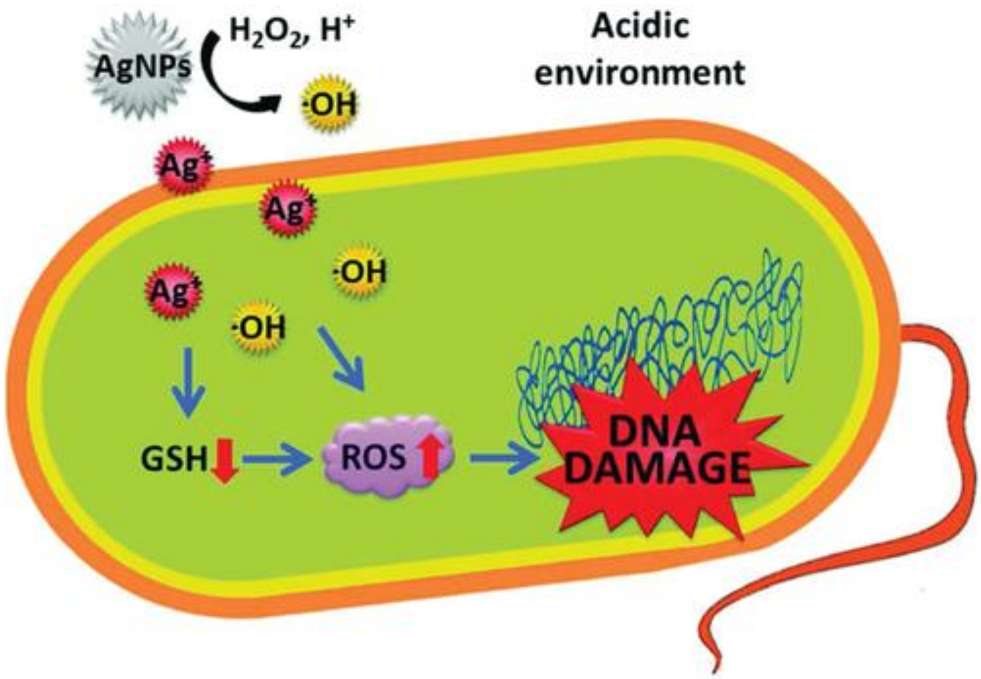

Fig 1: Routes of entry of nanoparticles into microorganisms adopted from Xin Tian *et al.* (2018)

Chitosan nanoparticles (CSNPs) have also been investigated as anti-biofilm agents in the dairy industry. Chitosan is a natural polymer derived from chitin and has been shown to have antimicrobial and anti-biofilm properties against various bacterial pathogens (Sun *et al.,* 2019). CSNPs have the advantage of being biodegradable and non-toxic, making them a promising alternative to traditional disinfectants and antibiotics.

Other nanoparticles, such as zinc oxide nanoparticles (ZnO NPs) and titanium dioxide nanoparticles (TiO2 NPs), have also been studied for their anti-biofilm properties in the dairy industry (Goudarzi *et al.,* 2021; Li *et al.,* 2017). ZnO NPs have been shown to inhibit biofilm

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formation of Lactobacillus plantarum, while TiO2 NPs have shown promising results in inhibiting biofilm formation of Escherichia coli and Listeria monocytogenes.

Mode of action

The mode of action of nanoparticles as anti-biofilm agents in the dairy industry can vary depending on the type of nanoparticle and the specific bacterial strain involved. However, some of the general mechanisms of action include:

Physical disruption: Nanoparticles can physically disrupt the extracellular polymeric substances (EPS) matrix that holds the biofilm together, leading to the detachment and dispersal of bacterial cells. This can be achieved through the use of positively charged nanoparticles that can bind to the negatively charged EPS matrix and destabilize it (Li *et al.*, 2019).

Antimicrobial activity: Nanoparticles can also act as antimicrobial agents by releasing biocidal agents that can kill the bacteria within the biofilm. This can be achieved through the use of silver nanoparticles, which have been shown to be effective against a wide range of bacteria commonly found in dairy products (Muthukrishnan *et al.*, 2019).

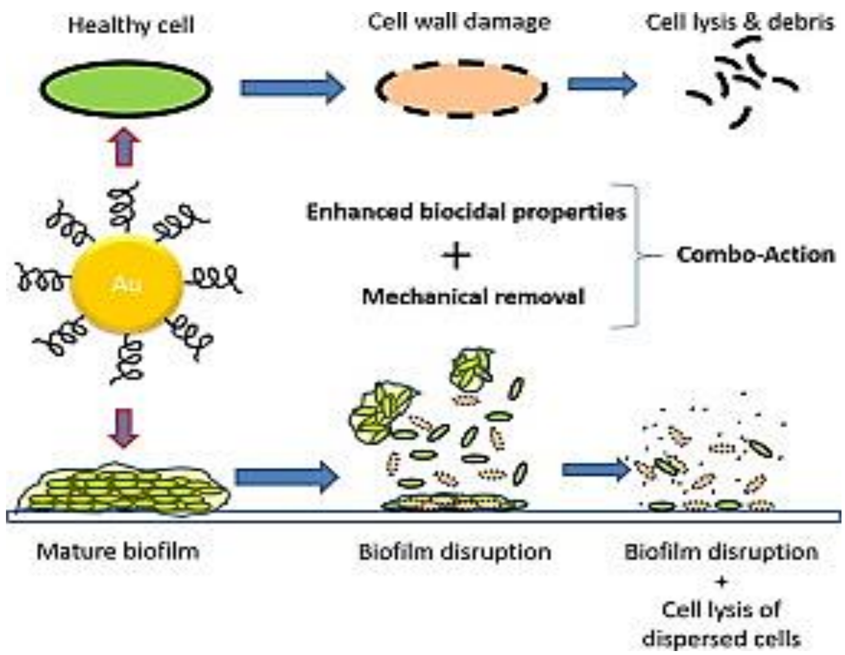

Fig 2: different modes of actions of nanoparticles on biofilms (Habimana *et al.*, 2018).

Quorum sensing inhibition: Nanoparticles can interfere with bacterial communication by mimicking natural quorum sensing molecules or by interfering with the signaling pathways used by bacteria to communicate. This can prevent the formation of biofilms by disrupting the communication between bacterial cells (Li *et al.*, 2019).

Reactive oxygen species (ROS) production: Some nanoparticles can produce ROS, such as hydrogen peroxide, which can damage bacterial cells and disrupt the biofilm structure.

The mode of action of nanoparticles as anti-biofilm agents in the dairy industry is multifaceted and can involve physical, chemical, and biological mechanisms. The specific mode of action may depend on the type of nanoparticle, the bacterial strain involved, and the environmental conditions of the dairy production process (Muthukrishnan *et al.*, 2019).

Advantages

Nanoparticles offer several advantages as anti-biofilm agents in the dairy industry:

High efficacy: Nanoparticles have a high surface area to volume ratio, which allows them to penetrate the biofilm matrix and disrupt its structure (Li *et al.*, 2019). They can also be engineered to target specific bacterial strains or biofilm structures, making them highly effective at preventing and controlling biofilm formation (Muthukrishnan *et al.*, 2019).

Environmentally friendly: Nanoparticles can be synthesized from natural and biodegradable materials, making them environmentally friendly and sustainable (Muthukrishnan *et al.*, 2019).

Minimal impact on sensory properties: The use of nanoparticles has minimal impact on the taste, odor, and color of dairy products, making them an ideal solution for maintaining their sensory properties and consumer acceptability (Muthukrishnan *et al.*, 2019).

Reduced use of harsh chemicals and antibiotics: Nanoparticles offer an alternative to harsh chemicals and antibiotics, which can have negative impacts on human health and the environment (Li *et al.*, 2019).

Potential for targeted delivery: Nanoparticles can be engineered to target specific bacteria or biofilm structures, which reduces their impact on beneficial bacteria and minimizes the risk of developing antimicrobial resistance (Muthukrishnan *et al.*, 2019).

Cost-effective: The cost of nanoparticle synthesis has decreased in recent years, making their use more cost-effective and viable for industrial-scale dairy production (Li *et al.*, 2019).

Wide range of applications: Nanoparticles can be used to prevent and control biofilm formation in various dairy products, including milk, cheese, yogurt, and other fermented dairy products.

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Enhanced shelf life: The use of nanoparticles can enhance the shelf life of dairy products by reducing the risk of contamination and spoilage caused by biofilms.

Safe and non-toxic: Many nanoparticles are considered safe and non-toxic, and their use in dairy products has been approved by regulatory bodies such as the US Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA).

Compatibility with existing production methods: Nanoparticles can be incorporated into existing dairy production methods, making their adoption and implementation easier and much more cost-effective. The use of nanoparticles as anti-biofilm agents in the dairy industry offers numerous advantages that can improve the quality and safety of dairy products while reducing the environmental impact of traditional anti-biofilm agents.

Overall, the use of nanoparticles as anti-biofilm agents in the dairy industry offers numerous advantages that can improve the quality, safety, and sustainability of dairy products. However, it is important to continue researching and evaluating their safety and efficacy to ensure their optimal use and minimize potential risks.

Challenges

Despite their potential benefits, the use of nanoparticles as anti-biofilm agents in the dairy industry also poses several challenges. One of the main challenges is the potential toxicity of nanoparticles, especially when used in high concentrations or for extended periods. This requires the development of safe and effective dosing strategies that minimize their impact on human health and the environment.

Another challenge is the cost-effectiveness of nanoparticle synthesis and application. While the cost of nanoparticle synthesis has decreased in recent years, their use in industrial-scale dairy production requires cost-effective and scalable production methods.

In conclusion, nanoparticles have the potential to revolutionize the dairy industry by providing a safe, effective, and sustainable solution to biofilm formation. However, their use must be carefully evaluated and optimized to ensure their safety, efficacy, and regulatory compliance.

Summary

Nanoparticles can act as anti-biofilm agents in several ways. Firstly, they can physically disrupt biofilms by penetrating the extracellular polymeric substances (EPS) matrix that holds the biofilm together. This can be achieved through the use of positively charged nanoparticles that can bind to the negatively charged EPS matrix and destabilize it.

Secondly, nanoparticles can act as antimicrobial agents by releasing reactive oxygen species (ROS) or other biocidal agents that can kill the bacteria within the biofilm. This can be achieved through the use of silver nanoparticles, which have been shown to be effective against a wide range of bacteria commonly found in dairy products.

Finally, nanoparticles can also act as quorum sensing inhibitors, which can prevent the formation of biofilms by disrupting bacterial communication. This can be achieved through the use of nanoparticles that mimic natural quorum sensing molecules or by interfering with the signaling pathways used by bacteria to communicate.

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