Review

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# Bacteriophage Therapy as an Alternative Strategy for Controlling Biofilm-Associated Infections in Food Processing Environments

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Posted Date: 31 March 2025

doi: 10.20944/preprints202503.2417.v1

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*Review*

# Bacteriophage Therapy as an Alternative Strategy for Controlling Biofilm-Associated Infections in Food Processing Environments

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**Abstract:** Biofilms in food processing environments pose a significant challenge due to their resilience and resistance to conventional sanitation and antimicrobial strategies. These biofilm-associated infections increase the risk of contamination and spoilage in food products. Bacteriophage therapy has emerged as a promising alternative to combat these resilient microbial communities. This review explores the mechanisms by which bacteriophages target biofilms, evaluates current applications in food environments, discusses advantages over traditional methods, and highlights the limitations and prospects of phage-based interventions. A comprehensive analysis of literature from 2010 to 2024 with emphasis on the most recent advancements (2020–2024) is presented to support the feasibility of this approach in modern food safety systems.

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## 1. Introduction

Biofilms are complex microbial communities embedded in a self-produced extracellular polymeric substance (EPS) matrix that adheres to various surfaces, including those in food processing environments (Flemming et al., 2016). These biofilms protect pathogens such as Listeria monocytogenes, Salmonella enterica, and Escherichia coli O157:H7 from environmental stresses, disinfectants, and antibiotics (Azeredo et al., 2017). The persistent nature of biofilms poses a major threat to food safety and sanitation protocols.

Conventional cleaning and chemical disinfectants are often insufficient to eradicate biofilms completely, especially on rough or inaccessible surfaces within food processing equipment (Galié et al., 2018). This has prompted exploration of alternative strategies such as enzymatic treatments, nanoparticles, and bacteriophage (phage) therapy. Phages are viruses that infect and lyse specific bacterial hosts, and their ability to disrupt biofilms has made them promising agents for biofilm control (Abedon, 2020).

## 2. Mechanisms of Bacteriophage Action Against Biofilms

Bacteriophages interact with bacterial biofilms through several key mechanisms:

- Bacterial Lysis: Upon binding to specific receptors on bacterial surfaces, phages inject their genetic material and hijack the host's cellular machinery, resulting in lysis and release of progeny phages (Harper et al., 2014).
- Depolymerase Activity: Many phages produce polysaccharide depolymerases that degrade the EPS matrix, facilitating deeper penetration into biofilms and increased access to embedded bacteria (Pires et al., 2016).
- Self-Replication and Amplification: Phages replicate exponentially within susceptible bacteria, allowing sustained infection throughout the biofilm over time (Gutiérrez et al., 2016).

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- Synergy with Antimicrobials: Phages can act synergistically with sanitizers or antibiotics, increasing the efficacy of traditional treatments and overcoming resistance barriers (Torres-Barceló & Hochberg, 2016).

Studies have shown that phages specific to Listeria, Salmonella, or Pseudomonas can reduce biofilm biomass significantly on surfaces common in food processing environments (Wittebole et al., 2014; Kim et al., 2023).

## 3. Applications of Phage Therapy in Food Processing Environments

Bacteriophages have been applied in various ways to control biofilms in the food industry:

- Surface Sanitation: Phage-based disinfectants have been used to treat stainless steel, plastic, and rubber surfaces in processing equipment (Sillankorva et al., 2012; Endersen & Coffey, 2020).
- Food Contact and Packaging: Phages have been incorporated into edible films and packaging materials to reduce bacterial loads on meat, dairy, and produce surfaces (Mangieri et al., 2021).
- Water Systems and Drainage Control: Application of phages in water lines and drainage systems helps target persistent biofilms in hard-to-reach locations (Zhang et al., 2020).

Commercial phage products like Listex P100 (targeting Listeria monocytogenes) and SalmoFresh (targeting Salmonella) are already approved in some countries for use in food safety applications (EFSA, 2016; FDA, 2021).

## 4. Advantages over Conventional Methods

Phage therapy offers several distinct advantages:

- Host Specificity: Phages target specific pathogens without disturbing beneficial microbiota or causing chemical residue concerns (Abedon, 2020).
- Eco-Friendly: Unlike harsh chemical sanitizers, phages are biodegradable and safe for workers and consumers (O'Flaherty et al., 2021).
- Low Resistance Risk: While resistance can occur, phage cocktails and engineered phages reduce this risk significantly (Moye et al., 2018).
- Adaptability: Phages can evolve with bacterial hosts, maintaining efficacy over time (Burrowes et al., 2019).

## 5. Limitations and Challenges

Despite their promise, several challenges remain:

- Regulatory Uncertainty: Approval processes vary globally, limiting large-scale deployment in food systems (Nobrega et al., 2015).
- Environmental Stability: Phage stability can be affected by temperature, pH, and surface materials (Yin et al., 2019).
- Narrow Host Range: Phage specificity necessitates accurate bacterial identification before application (Chan et al., 2013).
- Production and Storage: Large-scale production, purification, and formulation into stable products require further optimization (Hesse & Adhya, 2019).

## 6. Prospects

Advances in synthetic biology and nanotechnology may improve phage stability and expand host ranges through engineered phages. Phage cocktails designed to target multi-species biofilms and co-application with enzymes or mild sanitizers could provide comprehensive disinfection solutions (Luong et al., 2020). Furthermore, improved regulatory frameworks and public awareness will facilitate broader adoption in food industry practices.

 doi:10.20944/preprints202503.2417.v1



## 7. Conclusion

Bacteriophage therapy represents a promising, environmentally sustainable alternative for controlling biofilm-associated infections in food processing environments. With growing concerns over antimicrobial resistance and biofilm persistence, phage-based strategies offer targeted, safe, and effective interventions. Continued research, regulatory support, and industrial collaboration are essential to translate these promising findings into mainstream sanitation protocols.

**Conflict of Interest Statement:** The author declares no conflict of interest.

**Author Affiliation:** This research was conducted independently. The author is not affiliated with any institution.

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