Abstract

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Bacteriophages, viruses that specifically infect bacteria, play a crucial role in natural ecosystems but pose major threats to industrial biotechnology, pharmaceutical production, and food safety. Phage infections can devastate bacterial cultures, leading to process failures and significant economic losses. Effective management of bacteriophages, therefore, requires strategies that selectively eliminate phages without harming beneficial bacteria.

This thesis addresses the challenge of phage control by progressively developing materials capable of selective bacteriophage inactivation. The first approach explored novel antimicrobial nanomaterials, such as green-synthesized silver nanoparticles (TeaNPs). TeaNPs exhibited potent antibacterial and antifungal activities but lacked selectivity, affecting a broad range of microorganisms and failing to inactivate bacteriophages effectively. Although they enhanced antibacterial action when combined with phages, they highlighted the limitation of general antimicrobial strategies. Additionally, other nanomaterials such as zero-valent iron (ZVI) nanoparticles and copper-based nanocoatings were evaluated for their antiviral potential. While these materials demonstrated measurable inactivation of some phages, their broad-spectrum activity and limited selectivity reinforced the need for more targeted antiphage solutions.

Seeking selective approaches, the study next identified compounds capable of targeting phages. Indigo carmine (IC), an FDA-approved food dye, was discovered to inactivate phages without compromising bacterial viability. Mechanistic studies revealed IC's selective binding to DNA, disrupting phage integrity while sparing the host bacteria. This milestone demonstrated that molecular specificity in phage control is achievable using naturally available, food-safe substances.

Building on this foundation, engineered nanomaterials were designed to optimize selectivity further. Mixed-ligand gold nanoparticles (MLNPs), combining positive, negative, and hydrophobic ligands, achieved efficient phage inactivation (99% reduction) while maintaining over 90% bacterial survival. Similarly, polypyrrole nanoparticles

(PPyNPs) functionalized with carboxyl groups selectively targeted bacteriophages while exhibiting minimal cytotoxicity to mammalian cells. These rationally designed nanoparticles offer scalable, biocompatible solutions for targeted phage management. Overall, this work advances the field of phage control by moving from broad-spectrum antimicrobials to naturally selective agents and finally to engineered nanomaterials with high specificity. The developed strategies offer innovative, environmentally sustainable, and effective approaches for safeguarding microbial processes in biotechnology and industrial microbiology.