Chapter 10

Microbial Architects of Environmental Restoration:
Exploring the Frontiers of Genetically Engineered Bacteria in Remediation Strategies

Anjali Rajpoot
Banasthali Vidyapith, India

Veena Sharma
Banasthali Vidyapith, India

Tanya Aggarwal
Banasthali Vidyapith, India

ABSTRACT

Environmental pollution poses a significant threat to ecosystems and human health worldwide. Traditional methods of environmental remediation often fall short in addressing the complexities of contemporary pollutants. The emergence of genetic engineering technologies has opened new avenues for innovative solutions to environmental challenges. This chapter aims to explore the potential of genetically engineered bacteria as a cutting-edge tool for environmental remediation. By delving into the principles, applications, and concerns surrounding this technology, the chapter seeks to contribute to the understanding of its feasibility and sustainability. However, as we navigate the frontiers of this innovative approach, it is imperative to acknowledge and address the environmental concerns and conduct thorough risk assessments associated with the deployment of genetically engineered bacteria. Ecological impact, potential risks to human health, and ethical considerations necessitate careful consideration and mitigation strategies to ensure responsible and sustainable implementation.

DOI: 10.4018/979-8-3693-1618-4.ch010

INTRODUCTION

In recent years, the field of environmental science has witnessed a paradigm shift with the advent of genetically engineered bacteria as innovative tools for addressing pollution and contamination challenges. This book chapter explores the transformative potential of genetically modified bacteria in environmental remediation, drawing insights from influential review papers that have significantly shaped our understanding of this evolving field. The initial section provides a comprehensive overview of the current state of environmental degradation, setting the stage for an in-depth exploration of the intricate details of genetic engineering applied to bacteria. This includes an elucidation of key mechanisms and molecular tools employed to enhance the environmental detoxification capabilities of these genetically modified organisms. Through a meticulous examination of leading review papers, the chapter navigates the diverse applications of genetically engineered bacteria across various environmental matrices. Furthermore, the chapter critically analyzes the ecological implications, ethical considerations, and regulatory frameworks surrounding the deployment of genetically modified bacteria, offering a balanced perspective on the socio-scientific landscape. It delves into existing regulatory frameworks and advocates for international collaboration to enhance guidelines governing the use of genetically engineered organisms in environmental applications. The chapter underscores the need for robust risk management strategies and emphasizes the importance of public engagement, highlighting the necessity of a comprehensive and adaptive regulatory framework.

Although microbial communities in the environment possess the ability to degrade various pollutants, the degradation of many pollutants occurs slowly, leading to their accumulation and posing severe hazards. Microorganisms often lack the necessary pathways to degrade novel pollutants due to their complex chemical structures, which inhibits complete transformation. This limitation may stem from the novelty of these pollutants, hindering microbial evolution to develop appropriate catabolic pathways. Additionally, populations of microorganisms responsible for degradation might not be sufficiently large or active, or complex mixtures of pollutants may resist degradation.

To address these challenges, one strategy involves bioaugmentation, where exogenous microorganisms are introduced to enhance indigenous populations' degradation capabilities. This can include naturally occurring microorganisms with the required genes or genetically engineered microorganisms (GEMs). However, concerns arise regarding the stability of inserted genetic material in GEMs and the potential negative perception of genetic material transfer to indigenous organisms.

Advancements in molecular biology have facilitated the development of novel microbial strains tailored for bioremediation. These advancements encompass various aspects such as constructing and regulating pathways, expanding substrate ranges, and improving metabolic efficiency. For instance, genetic engineering techniques can introduce genes encoding bacterial hemoglobin (VHb) to enable microbial growth and catabolic activities under hypoxic conditions.

This chapter focuses on the transformative landscape of environmental bioremediation facilitated by genetically engineered bacteria, with a specific emphasis on the remediation of heavy metal pollutants. It accentuates the ecological and health advantages over conventional physico-chemical strategies, advocating for a synergy of microbiological, ecological, and biochemical insights coupled with innovative field engineering designs. The chapter delves into the intricate realm of microbial metal bioremediation, highlighting its significance as a cost-effective and eco-friendly strategy for addressing heavy metal pollutants. This approach represents a paradigm shift from conventional physico-chemical methods, offering unique advantages in terms of sustainability and environmental compatibility.