Applications of bioremediation using lactic acid bacteria for the removal of heavy metals in wastewater

Literature Review

Abstract

Topic: Applications of bioremediation using lactic acid bacteria (LAB) for heavy metals in wastewater

Background: Bioremediation, the use of microorganisms as a detoxifying process, is becoming a better understood, eco-friendly, alternative solution to environmental, agricultural and health problems. While significant research is being done in the field, the use of bioremediation to treat polluted water remains in early development. The aim of this literature review was to investigate the biosorption abilities of lactic acid bacteria for heavy metals in wastewater, specifically whether or not LAB could consistently decrease the heavy-metal concentration in effluents. The goal of this research is to develop feasible, sustainable and inexpensive methods for water detoxification on an industrial scale. This review will not explore the biosorption abilities of other species of bacteria.

Method: The area of bioremediation using lactic acid bacteria has been previously studied. However, the use of microbes for detoxifying wastewater is still being investigated. The current studies expressed three main topics associated with LAB bioremediation. These topics are:

1. Microbial mechanisms
2. Efficiency and effectiveness
3. Potential benefits for humans

Findings: The literature review indicates that there are two main mechanisms by which lactic acid bacteria remove heavy metals from their environment: biosorption and bioaccumulation. Although other studies suggest alternate methods for microbial binding of heavy metals, these are the two most well-known and investigated. Data showed efficient and effective binding of metals to the cell wall of the bacteria proving the biosorption ability of microorganism. However, different strains of LAB produced varying results based on the concentration of metals and the environmental conditions. This review also showed that the use of microorganisms for the removal of heavy metals in contaminated environments has potential future health benefits for humans.

Key Words: Lactic acid bacteria, bioremediation, heavy metals, wastewater, microorganisms

Introduction

Water pollution is a serious worldwide problem. It is the contamination of bodies of water by toxic substances that degrade its quality (WWF). The availability of safe, clean water is a basic human right as recognized by the World Health Organization. Yet, according to National Geographic (2020), less than one percent of the world's water is accessible. For low-income cities within developing countries, potable water is extremely rare. This is because a large proportion of wastewater is discharged directly into the environment. Environmental contamination by heavy metals from sources such as mining, battery manufacturers and other anthropogenic activities has caused considerable, irreparable damage to aqueous ecosystems (Coelho et al., 2015). In large industries, as well as these under-developed countries, the accumulation of heavy metal ions in water has become a significant issue (Monachese et al. 2012). This is because, apart from being hazardous to human health, the metals that contaminate water and food, such as lead, cadmium, arsenic, chromium, and mercury, have adverse effects on fauna and flora and are not naturally biodegradable (Coelho et al., 2015).

Although there are established technologies available to properly treat heavy metal wastewater, many of these impoverished cities do not have the resources to develop these water-treatment systems. In recent years, the expansion of new technologies has led to research in bioremediation as an alternative solution. Lactic acid bacteria (LAB), a probiotic microorganism, has been looked at as a potential biosorbent for the removal of heavy metals in wastewater. The mechanisms of extraction have been established. The effectiveness of certain strains against heavy metals is a subject of ongoing investigation. While further research is needed for industrial scale applications, bioremediation is a promising heavy metal waste solution with benefits to human health.

Microbial mechanisms

Bioremediation can be defined as "the ability of certain biomolecules or types of biomass to bind and concentrate selected ions or other molecules present in aqueous solutions" (Coelho et al., 2015). The use of microorganisms for treating environmental toxins is a complex process as the interaction of bacteria species with each metal is unique.

Heavy metals are naturally present and are used as micronutrients for environmental processes, however, some are considered highly toxic (Coelho et al., 2015). These metals, such as chromium, lead, mercury and nickel, can accumulate over time as degradation and metabolism are not possible (Monachese et al., 2012). Microorganisms have evolved mechanisms that can survive in these hazardous and contaminated habitats as they are capable of converting these contaminants into energy, transforming them into less harmful substrates or degrading them to nontoxic products (Coelho et al., 2015).

Certain species of LAB have the ability to concentrate and bind contaminants, such as metal ions, onto their cellular walls or transport them into their cells for storage. As the cell wall of the bacteria contains functional groups, such as ketones and aldehydes, the metal ions are bound to these groups and removed from the environment. Jasna Mrvčić and colleagues (2012) described two primary binding mechanisms. Biosorption is the natural passive binding process of metal ions to the bacteria, while bioaccumulation is the metabolically mediated intake of ions through the cell membrane and accumulation within the cell itself. Similarly, Coelho (2015) found that the metals were either retained via an ion exchange and other physicochemical interactions or by the passive uptake of intra and extra-cellular processes.

All studies suggest that these biological detoxification methods have been proven to work and to have an efficient uptake or binding capacity of heavy metals. Pakdel and colleagues (2019) emphasized that LAB strains are able to remove heavy metals in low concentration from aqueous media. However, the environmental conditions play a large role in the effectiveness and removal efficiency of heavy metals.

Efficiency and effectiveness

The applications of lactic acid bacteria as bioremediation agents are numerous, however, if the environmental conditions are not favorable for the specific type of bacteria, the efficiency and effectiveness of the heavy metal removal is variable.

Ammen (2020) examined the bacteria *Lactobacillus plantarum* MF042018, and showed that they have a high degree of tolerance to the presence of nickel and chromium. However, the study also revealed that the cadmium (Cd) and lead (Pb) removal efficiencies were concentration-dependent as higher uptake capacities were recorded at concentration of 50 ppm and 10 ppm, while nearly negligible fractions of the same metals were removed upon increasing metal concentration to 80 ppm (Ammen et al., 2020). Similarly, a study conducted by Pakdel and colleagues (2019) showed that the amount of Cd (II) and Pb (II) biosorption, by *Lactobacillus plantarum* PTCC 1896, was pH dependent.

Both studies revealed that environmental parameters, pH and temperature, could significantly influence microbial binding of heavy metals. The optimal conditions for the removal of heavy metals by the *Lactobacillus plantarum* MF042018 were at 22 °C and at a pH of 2 (Ammen et al., 2020). In contrast, Pakdel (2019) reported that most bacteria could only absorb heavy metals at a pH between 3.0 - 7.0.

Bioremediation is a complex process. The efficiency of heavy metal removal depends not only on the characteristics of the LAB strain, but also on the properties of the metal ions, the concentration of metals and the environmental conditions. Nonetheless, strides are being made in research to better our planet and human health. A strain of LAB, *Lactobacillus plantarum* MF042018, successfully removed 100 percent of the metal ions from battery-manufacturing effluent (Ammen et al., 2020). This shows great potential for lactic acid bacteria as a bioremediation agent in wastewater.

Potential benefits for humans

In recent years, there has been a new focus and need toward sustainable development and green processes. Poor water quality is a serious issue that warrants the full attention of the scientific community. Notably, bioremediation has great potential for future development as a result of its environmental compatibility and cost-effectiveness (Coelho et al., 2015).

In water scarce regions, in low to medium income countries, drinking water can contain heavy metals originating from a contamination source (Chowdhury et al., 2016). These pose a threat to human health as heavy metals can accumulate in the body and lead to serious health issues. In addition, many of these undeveloped countries are faced with the problem of reducing human exposure, but they are economically limited without the resources for water treatment. Bioremediation, using lactic acid bacteria, presents itself as an innovative, cost-effective approach to metal uptake in polluted waters (Coelho et al., 2015).

Not only can the biosorbent characteristics of LAB be applied to wastewater treatment, but also to food and pharmaceutical applications. Lactic acid bacteria are non-pathogenic – they don't cause illness or disease and are probiotic. People eat many LAB strains in food, especially fermented products such as yogurts and tempeh (Kinoshita et al., 2013). They are a part of the microbial population of the digestive tract and are involved in metabolism (Mrvčić et al., 2012). The use of lactic acid bacteria was shown to reduce metal ingestion by binding to the metals and preventing them from entering the body (Monachese et al., 2012). The applications of microbes for detoxification of anthropogenic activities, pharmaceuticals and even of the human body are well under way and the future benefits for not only the planet but people are promising.

Conclusion

The purpose of this literature review was to investigate the biosorption abilities of lactic acid bacteria for heavy metals and to determine whether they can effectively decrease their concentrations in wastewater. Among the studies, many identified two mechanisms associated with bioremediation. Both biosorption and bioaccumulation are processes by which microorganisms remove metals from aqueous solutions. Studies indicated that the effectiveness and removal efficiency of heavy metals was variable. While some research showed a high tolerance towards the metals and efficient binding capacity, others showed that at higher metal concentrations, the LAB were less efficient or unable to remove the heavy metal ions. The overall efficiency was dependent on the environmental conditions, such as pH and temperature, as well as other controlled factors. The potential use of lactic acid bacteria to remove heavy metals from wastewater provides an eco-friendly, cost-effective solution to treating contaminated water. In addition, this research provides a basis for future work using LAB for bioremediation not only for industrial purposes, but for pharmaceutical and health applications.

Recommendations

While there is an increasing number of studies being done using the applications of bioremediation for water treatment, future efforts should be focused on bioremediation on a global scale. Moreover, further studies should focus on the development of new environmentally acceptable technologies with commercial feasibility. It is also important to note that much of the data comes from in vitro studies. Studies that are done outside the organism's normal biological context rather than large-scale field trials on metal absorption in contaminated soil and water. Further studies are needed in order to determine how they behave in the natural world and how their heavy metal processes occur in their biological niche.

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