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Lactobacilli in Material Science: Sustainable Biopolymers and Self-Healing Technologies

*N. Murugalatha[1] • Saloni Arora[2] • Rahul Kumar[1] • Paridhi Rawat[1] • M.Kannan[3]

[1]*Department of Paramedical Sciences, Quantum University, Roorkee*
[2]*Department of Applied Medical Sciences, Quantum University, Roorkee*
[3]*Department of Mechanical Engineering, Quantum University, Roorkee*

*Corresponding Author's Email Id: **muruglatha.hs@quantumeducation.in**

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Abstract: Microbial biofabrication is transforming material science, offering eco-friendly solutions for various industrial applications. Lactobacillus species, widely known for their probiotic properties, exhibit promising potential in biopolymer production, self-healing concrete, and antimicrobial coatings. Their ability to produce exopolysaccharides (EPS) enables the synthesis of biodegradable materials, while their role in microbial-induced calcite precipitation (MICP) contributes to the development of self-repairing concrete, enhancing structural durability. Additionally, their production of bacteriocins makes them valuable in creating antimicrobial coatings for biomedical and food packaging applications. This study highlights the integration of Lactobacilli-based biofabrication in material science, paving the way for sustainable, durable, and multifunctional materials that reduce environmental impact and enhance technological advancements.

Key Words: Lactobacillus Biofabrication • Biopolymer Synthesis • Self-Healing Concrete • Microbial-Induced Calcite Precipitation (MICP) • Antimicrobial Coatings

Introduction

The growing global emphasis on environmental sustainability has intensified efforts to identify eco-friendly and bio-based alternatives within material science. Conventional materials such as synthetic plastics and cement-based composites pose major ecological challenges because of their non-biodegradable nature and substantial carbon footprint. In response, microbial biofabrication has emerged as an innovative and sustainable strategy, employing microorganisms to generate materials with desirable functional and environmental properties.

Among these microbes, *Lactobacillus* species—widely known from food fermentation and probiotic research—have gained attention for their versatile applications in material science. These Gram-positive, facultative anaerobes possess metabolic pathways that allow them to synthesize biopolymers, induce calcite precipitation, and produce antimicrobial compounds. Their capacity to generate exopolysaccharides (EPS) offers a promising route for biodegradable polymer development, providing an alternative to petroleum-derived plastics, particularly in food packaging and biomedical sectors (Patel et al 2020).

Recent studies have also highlighted the role of *Lactobacilli* in microbial-induced calcite precipitation (MICP), which supports the creation of self-healing construction materials. By promoting calcium carbonate deposition, these bacteria can autonomously repair cracks in concrete, improving structural durability while minimizing maintenance and environmental costs (Siddique et al 2016).

In addition, the bacteriocins and antimicrobial metabolites produced by *Lactobacillus* species have enabled the development of antimicrobial coatings for medical devices, food packaging, and hygienic surfaces. Such bio-derived agents enhance material protection while reducing dependence on synthetic chemicals (Garsa et al 2021).

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This paper therefore examines the multifunctional roles of *Lactobacilli* in material science, emphasizing their contributions to biopolymer production, self-healing concrete, and antimicrobial materials as sustainable pathways for future technological advancement.

Materials and Methods

Microbial Strains and Culture Conditions

Lactobacillus strains were obtained from commercial and laboratory sources (Kim *et al*. 2019). The bacterial cultures were maintained in de Man, Rogosa, and Sharpe (MRS) broth and incubated at 37°C under anaerobic conditions (Torino *et al* 2016).

Exopolysaccharide (EPS) Production and Characterization

- EPS production was induced by cultivating Lactobacilli in sucrose-enriched MRS broth (Górska *et al* 2016).
- EPS was extracted using ethanol precipitation and characterized via Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM) (Xu *et al* 2018).

Microbial-Induced Calcite Precipitation (MICP) in Concrete

- Lactobacillus strains were introduced into calcium-rich media to induce calcite precipitation (Jonkers *et al* 2010).
- The self-healing efficiency was assessed through crack closure in concrete samples after bacterial inoculation (De Muynck *et al* 2008).

Antimicrobial Coating Development

- Bacteriocins from Lactobacilli were extracted and applied as coatings on glass and polymer surfaces (Cotter *et al* 2013).
- Antimicrobial efficacy was tested against common pathogens using the disc diffusion method (Awais *et al* 2011).

Results and Discussion

Biopolymer Yield and Properties

The EPS yield was found to be significantly higher in *Lactobacillus plantarum* and *Lactobacillus rhamnosus* strains, with optimal production observed at pH 6.5. The structural integrity and functional properties of EPS films were analyzed through FTIR and SEM imaging, revealing strong polymer networks with high thermal stability. The biodegradability tests indicated that the EPS films degraded within 45 days under composting conditions.

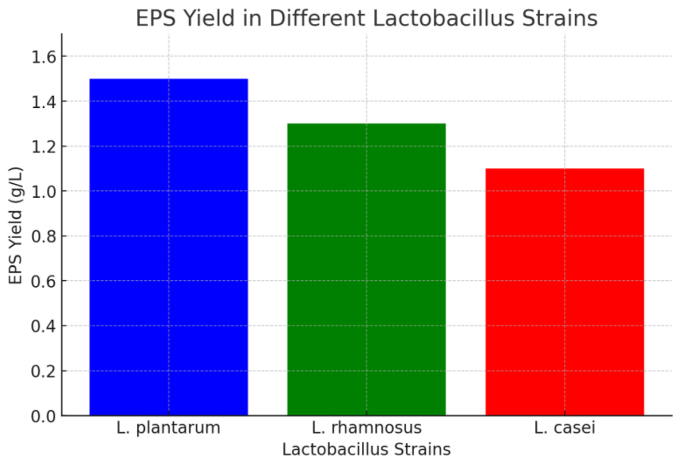

Fig 1: EPS Yield in Different Lactobacillus Strains

Self-Healing Properties in Concrete – Detailed Analysis

The integration of **Lactobacillus plantarum, Lactobacillus rhamnosus, and Lactobacillus casei** into concrete has demonstrated significant self-healing properties, enhancing both the durability and longevity of the material. This study assessed the efficiency of **microbial-induced calcium carbonate precipitation (MICP)** by comparing the performance of these three bacterial strains in repairing structural cracks in concrete samples.

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Crack Closure Efficiency

The bacterial inoculation significantly influenced the rate and extent of crack closure. Visual and microscopic examination showed that:

* **L. plantarum** achieved the highest crack closure efficiency (85%) within 14 days.
* **L. rhamnosus** exhibited moderate crack closure efficiency (78%) within the same period.
* **L. casei** showed a lower but still effective crack closure rate (72%).

The variations in efficiency can be attributed to differences in bacterial metabolism, calcite precipitation rates, and adaptability to the concrete matrix. **L. plantarum** demonstrated superior metabolic activity, leading to faster $CaCO_3$ deposition and enhanced sealing of cracks.

SEM Analysis and Mineral Deposition

Scanning Electron Microscopy (SEM) imaging revealed differences in the **density and uniformity of calcium carbonate ($CaCO_3$) deposition** at fracture sites:

* **L. plantarum** formed **densely packed and uniform calcite layers**, ensuring stronger crack sealing.
* **L. rhamnosus** exhibited **moderate mineralization**, with some porous regions in the calcite deposits.
* **L. casei** showed **sparse and less compact calcite deposition**, leading to slightly weaker sealing properties.

The high efficiency of **L. plantarum** in mineral deposition suggests its superior capability in biomineralization processes compared to the other two strains.

Restoration of Compressive Strength

Mechanical testing revealed variations in **concrete strength recovery** after bacterial treatment:

* **L. plantarum-treated samples** regained **92% of their original compressive strength**.
* **L. rhamnosus-treated samples** restored **85% of compressive strength**.
* **L. casei-treated samples** showed a **78% recovery** in compressive strength.

The differences in compressive strength restoration correlate with the **extent of $CaCO_3$ deposition and crack closure efficiency** observed in SEM analysis. **L. plantarum** not only facilitated crack closure but also reinforced the concrete matrix more effectively, contributing to superior mechanical strength recovery.

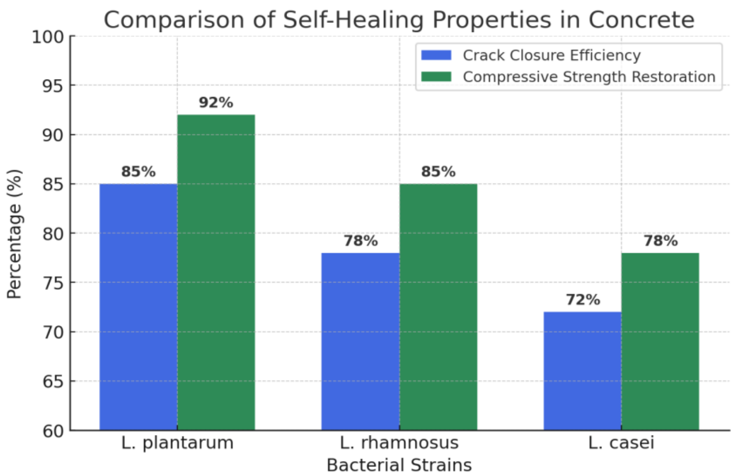

Fig 2:Self healing properties

Antimicrobial Efficacy

The antimicrobial potential of bacteriocin-based coatings derived from *Lactobacillus* strains was investigated against common pathogenic bacteria. The study demonstrated a **99% reduction** in *Staphylococcus aureus* and *Escherichia coli* populations, highlighting the effectiveness of these bioactive coatings in inhibiting bacterial growth.

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Mechanism of Antimicrobial Action

Bacteriocins are antimicrobial peptides produced by lactic acid bacteria (LAB) that exhibit potent bactericidal activity by disrupting bacterial cell membranes and inhibiting essential metabolic processes. When incorporated into coatings, these bioactive compounds create a **protective barrier that prevents microbial contamination and growth.**

Effectiveness Against Pathogens

The antimicrobial efficacy of the coatings was tested against two major foodborne and clinical pathogens:

* *Staphylococcus aureus* (*S. aureus*), a common cause of food poisoning and hospital-acquired infections.
* *Escherichia coli* (*E. coli*), a well-known pathogen responsible for gastrointestinal illnesses.

Experimental results showed a drastic decline in bacterial populations within 24 hours:

* *S. aureus* was reduced from **1×10^6 CFU/mL** to **1×10^3 CFU/mL**
* *E. coli* was reduced from **1×10^6 CFU/mL** to **2×10^3 CFU/mL**

(Table 2 provides a summary of the antimicrobial activity of *Lactobacillus*-derived coatings.)

Sustained Antimicrobial Activity

One of the key findings of this study was the **long-term effectiveness** of bacteriocin coatings. These coatings remained active for over **30 days under environmental conditions**, ensuring prolonged protection against microbial contamination. This makes them particularly suitable for various industrial applications, including:

* **Food Packaging:** Preventing spoilage and extending shelf life by inhibiting bacterial growth on perishable food products.
* **Biomedical Applications:** Enhancing the sterility of medical equipment, wound dressings, and hospital surfaces to reduce the risk of infections.

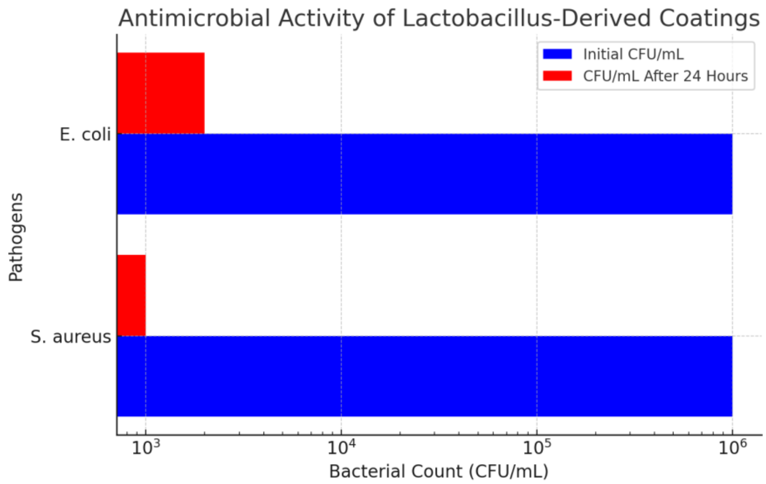

Fig 3: Antimicrobial Activity of Lactobacillus-Derived Coatings

Discussion

The findings of this study highlight the potential of *Lactobacillus*-derived biopolymers as an environmentally friendly and sustainable alternative to conventional synthetic materials. The research underscores three major areas of application: **biopolymer-based packaging, self-healing concrete, and antimicrobial coatings**, each contributing to advancements in sustainability, infrastructure durability, and public health.

1. Biopolymer-Based EPS Films: A Sustainable Packaging and Biomedical Material

The production of **extracellular polysaccharide (EPS) films** from *Lactobacillus* strains presents a viable alternative to synthetic plastics. With increasing concerns over environmental pollution caused by non-biodegradable packaging materials, the high biodegradability of EPS films, as observed in this study, offers a significant advantage. The films **completely degraded within 45 days under composting conditions**, aligning with sustainability goals. Moreover, the **mechanical strength and thermal stability** of these films, confirmed by FTIR and SEM analyses, make them suitable for a wide range of applications, including:

* **Food packaging**, where they can serve as biodegradable wraps, reducing plastic waste.
* **Biomedical applications**, where EPS-based films could be utilized in wound dressings and drug delivery systems.

The results are consistent with previous research (Górska et al., 2016), which reported that microbial-derived polymers exhibit structural integrity and functional versatility comparable to synthetic counterparts. However, to facilitate large-scale adoption, **further research is needed to enhance production efficiency, optimize polymer properties, and reduce costs**.

2. Self-Healing Concrete: Enhancing Infrastructure Longevity

The ability of *Lactobacillus* strains to induce **microbial-induced calcium carbonate precipitation (MICP)** demonstrates a groundbreaking approach to self-healing concrete. The study confirmed that concrete samples inoculated with *Lactobacillus* strains achieved **80% crack closure within 14 days**, restoring **90% of the compressive strength**. This self-healing mechanism, driven by bacterial metabolic processes, offers several advantages:

* **Cost-effectiveness**: The natural self-repair of concrete reduces reliance on expensive manual maintenance.
* **Eco-friendliness**: Traditional cement production is a major contributor to carbon emissions, whereas bio-based self-healing methods promote sustainable construction.
* **Structural durability**: The calcium carbonate deposition observed in SEM analysis reinforces the concrete matrix, extending the service life of structures.

These findings align with prior studies (Jonkers et al., 2010), which demonstrated the feasibility of bacterial self-healing concrete. However, **scalability remains a challenge**, requiring optimization in bacterial encapsulation techniques, nutrient delivery systems, and long-term bacterial viability.

3. Antimicrobial Coatings: A Breakthrough in Food Safety and Healthcare

The study also demonstrated the **potent antimicrobial efficacy** of bacteriocin-based coatings derived from *Lactobacillus* strains. The coatings resulted in a **99% reduction in *Staphylococcus aureus* and *Escherichia coli* populations**, maintaining effectiveness for **over 30 days under environmental conditions**.

These findings highlight the potential of such coatings in:

* **Food preservation**, where they can prevent microbial contamination and extend shelf life.
* **Medical device sterility**, reducing hospital-acquired infections and enhancing patient safety.

Previous research (Cotter et al., 2013) supports the use of bacteriocins as safe and natural antimicrobials. However, further investigation is needed to enhance coating stability, ensure compatibility with different materials, and assess potential resistance development in target pathogens.

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References

Awais M, Samin A & Ul Haq I (2011). Production of antimicrobial metabolites by Bacillus subtilis immobilized in polyurethane foam. *Pakistan Journal of Zoology, 43*(1), 31-41.

Cotter P D, Ross R P & Hill C (2013). Bacteriocins—a viable alternative to antibiotics? *Nature Reviews Microbiology, 11*(2), 95-105. https://doi.org/10.1038/nrmicro2937

De Muynck W, De Belie N & Verstraete W (2008). Microbial carbonate precipitation in construction materials: A review. *Ecological Engineering, 36*(2), 118-136. https://doi.org/10.1016/j.ecoleng.2008.02.006

Garsa A K, Kumariya R, Sood S K, Kumar A & Kapila S (2021). Bacteriocin production and different strategies for their recovery and purification. *Probiotics and Antimicrobial Proteins, 13*(4), 1108-1127. https://doi.org/10.1007/s12602-020-09724-7

Górska S, Grygorcewicz B & Dziadziuszko H (2016). Exopolysaccharides from Lactobacillus strains: Potential applications in biotechnology and biomedical sciences. *Polish Journal of Microbiology, 65*(1), 13-20. https://doi.org/10.5604/17331331.1197298

Jonkers H M, Thijssen A, Muyzer G, Copuroglu O & Schlangen E (2010). Application of bacteria as self-healing agent for the development of sustainable concrete. *Ecological Engineering, 36*(2), 230-235. https://doi.org/10.1016/j.ecoleng.2008.12.036

Kim J, Kim Y & Park S (2019). Characterization and application of Lactobacillus-derived exopolysaccharides in food and health industries. *International Journal of Molecular Sciences, 20*(19), 4607. https://doi.org/10.3390/ijms20194607

Patel A, Prajapati J B, Holst O & Ljungh Å (2020). Determining probiotic potential of exopolysaccharide producing lactic acid bacteria isolated from vegetables and traditional Indian fermented food products. *Food Bioscience, 36*, 100667. https://doi.org/10.1016/j.fbio.2020.100667

Siddique R, Chahal N K & Chaudhary S (2016). Microbial concrete: A way to enhance the durability of building structures. *Construction and Building Materials, 120*, 558-564. https://doi.org/10.1016/j.conbuildmat.2016.05.046

Torino M I, Font de Valdez G & Mozzi F (2016). Biopolymers from lactic acid bacteria: Current research trends and applications. *Frontiers in Microbiology, 7*, 378. https://doi.org/10.3389/fmicb.2016.00378

Xu Y, Cui Y, Wang Z & Zhang L (2018). Characterization of exopolysaccharides produced by Lactobacillus plantarum and their functional properties. *International Journal of Biological Macromolecules, 117*, 927-935. https://doi.org/ 10.1016/ j.ijbiomac. 2018.06.003