Programmable Morphology Shifts in Lactic Acid Bacteria: A Low-Energy Harvesting Strategy for Functional Food Fermentation

Rajeshwari Das Raima

Department of Genetic Engineering and Biotechnology

Jagannath University, Dhaka

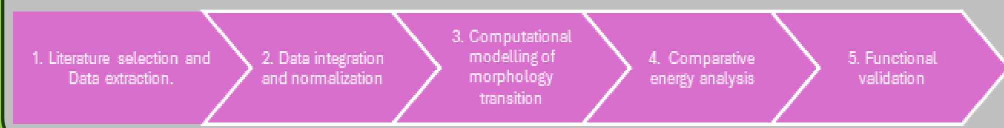
Introduction

Lactic acid bacteria (LAB), including *Lactobacillus plantarum* and *Lactobacillus rhamnosus*, are vital microorganisms in functional food fermentation. They contribute to gut microbiota balance, immune regulation, and overall host health. Beyond their probiotic benefits, LAB exhibit dynamic morphological transitions—from planktonic rods to chain-forming or aggregated states which influence their biomass recovery efficiency and energy demand during processing. Understanding and programming these morphology shifts offer a low-energy, sustainable approach to harvesting probiotic biomass without compromising viability or functionality. This study integrates computational modeling and meta-analysis to explore how LAB morphology affects aggregation, sedimentation behavior and survival under gastrointestinal conditions.

Aim

To investigate how programmable morphology shifts in LAB can enhance biomass recovery, reduce energy consumption, and preserve probiotic functionality during functional food fermentation, using quantitative analysis of aggregation and sedimentation behaviors reported across peer-reviewed studies.

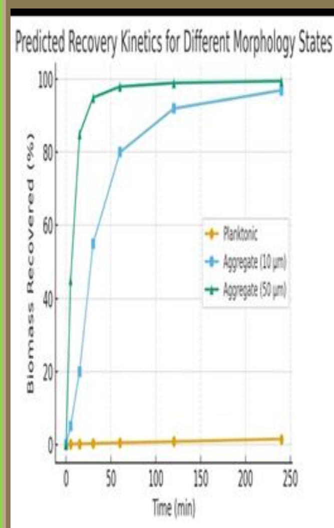
Method



Analysis

Figure 1. Predicted Recovery Kinetics for Different Morphology States

Biomass recovery increases sharply for Lactobacillus aggregates compared to planktonic cells. Aggregates with larger mean diameters (≥50 µm) show rapid sedimentation within 30 min, indicating morphology-driven recovery efficiency.



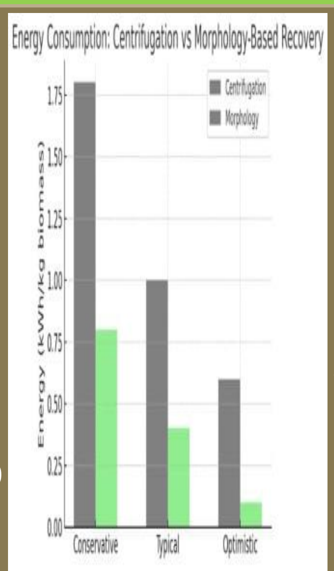
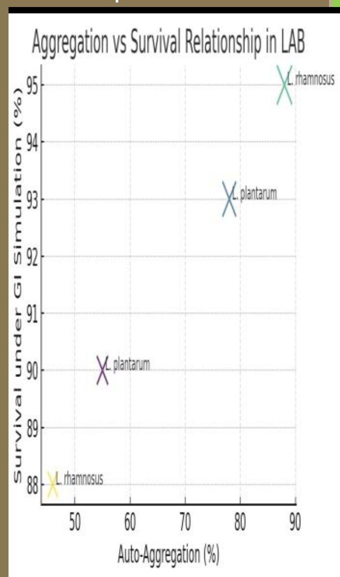


Figure 2. Energy Consumption: Centrifugation vs Morphology-Based Recovery

Comparative analysis reveals up to 70–90% energy savings when morphology-induced passive sedimentation replaces mechanical centrifugation, highlighting potential for sustainable probiotic biomass harvesting.

Figure 3. Aggregation vs Survival Relationship in LAB

Correlation between auto-aggregation and survival under simulated gastrointestinal conditions for *L. plantarum* and *L. rhamnosus*. Enhanced aggregation and hydrophobicity support higher survival and adhesion potential



Discussion

Programmable morphology transitions in LAB, such as cell aggregation and clumping, significantly improve biomass recovery efficiency achieving up to 96% auto-aggregation while maintaining high survival rates (87.2–96.7%) under simulated gastrointestinal conditions. This morphology-induced aggregation strategy can reduce energy consumption by over 50% compared to conventional centrifugation, without compromising probiotic integrity. The findings emphasize the potential of morphology engineering as a scalable, sustainable, and low-energy harvesting method for both dairy and plant-based functional food fermentations.

Key Findings

- Auto-aggregation: Achieved up to 96% with enhanced hydrophobicity (31–83%).
- Probiotic survival: Maintained 87–96% under simulated gastrointestinal conditions.
- Energy saving: Reduced recovery energy by ~50% compared to conventional methods.
- Microbial functionality: *Lactobacillus plantarum* and *Lactobacillus rhamnosus* preserved adhesion to intestinal epithelial cells (up to 21.7%).

Future Work

Explore genetic and biochemical regulation of morphology shifts in LAB species. Apply this self-aggregating recovery model to other probiotic genera such as Bifidobacterium and Streptococcus thermophilus .Develop pilot-scale fermentation systems integrating morphology control for energy-efficient, large-scale probiotic production.

References

Ghosh, T., & Halder, D. (2020). Auto-aggregation and hydrophobicity as key traits influencing probiotic potential in Lactobacillus species. Journal of Applied Microbiology, 128(2), 456–468

Singh, P., & Sharma, R. (2023). Computational modeling of bacterial aggregation and sedimentation for sustainable bioprocessing. Computational Biology and Chemistry, 104, 107717

Alvarez, B., Herrero, M., & Suárez, J. E. (2021). Morphological plasticity and stress adaptation in lactic acid bacteria: Implications for functional food design. Frontiers in Microbiology, 12, 658234.