Valorization of Agro-Industrial By-Products and Food Waste for Sustainable Biomass and Functional Ingredient Production

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Introduction

The growing need for sustainable and low-cost biotechnological processes has increased interest in the use of agro-industrial by-products and food waste. These materials are often discarded but can be used as alternative substrates for microbial biomass production, supporting circular economy principles [1]. At the same time, maintaining the stability and viability of beneficial microoganisms remains a major challenge for their use in food and feed products [2]. In this study, agro-industrial by-products and food waste were evaluated for *Lacticaseibacillus rhamnosus* OLXAL-1 cell biomass production and functional ingredient development, aligned with a sustainable production approach.

Materials and Methods

The wild-type strain *L. rhamnosus* OLXAL-1 was selected based on its documented *in vitro* functional properties, antagonistic activity against pathogens/spoilage microorganisms, resistance to simulated gastrointestinal conditions, and compliance with EFSA safety requirements [3, 4]. A range of agro-industrial by-products and food residues, including expired fruit juices, dairy by-products, and formulated mixtures, were evaluated as alternative growth media. Biomass production, maximum specific growth rate (μmax), and viable cell counts were determined and compared with conventional laboratory growth media.

For the development of functional ingredients, cell immobilization on natural supports derived from agro-industrial by-products and fiber-rich food matrices was tested as a stabilization strategy. Immobilization efficiency was assessed by determining the viable immobilized cell load. The effect of freeze-drying on the viability of free and immobilized cells was subsequently examined.

Results and Discussion

High viable cell concentrations (> 9.0 log CFU/mL) were achieved when expired pineapple juice, pineapple juice–whey mixtures, as well as pineapple juice–milk mixtures were used as growth media (Figure 1). Among them, expired pineapple juice–milk mixture exhibited the highest μmax values (0.258 h^{-1}) and biomass production (> 1.45 g/ dry mass / L), reaching levels comparable to those obtained in standard laboratory growth media. In contrast, single by-products, such as whey and molasses resulted in reduced biomass yields, underlining the importance of substrate formulation and nutrient balance.

Immobilization experiments demonstrated high efficiencies (> 8.9 log CFU / g) on oat and wheat flakes, brewer's spent grain, whey protein, and fruit-based matrices. The optimal carrier-to-culture ratio was carrier-dependent, enabling high immobilized cell loads within short processing times.

Freeze-drying ensured high viability for both free and immobilized cultures (80.9–96.6%), although the protective effect varied depending on the support.

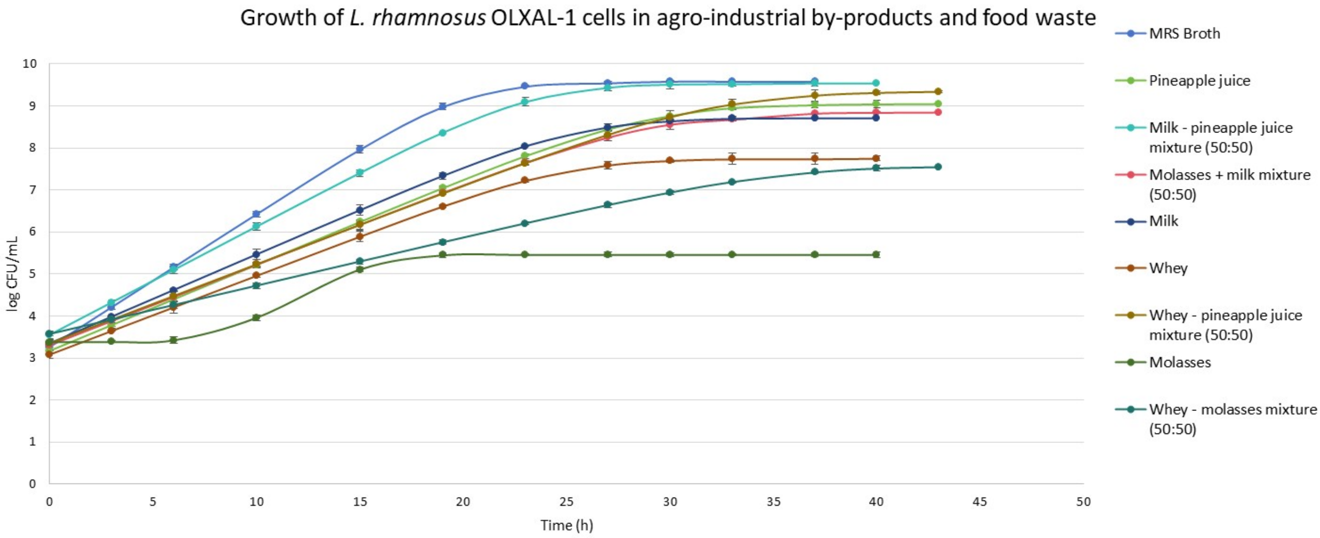

Figure 1. Cell concentration (logCFU/mL) of *L. rhamnosus* OLXAL-1 during growth in agro-industrial residues and food waste compared with synthetic food grade media.

Conclusions

The results demonstrated that properly formulated agro-industrial by-products and food waste can effectively support both biomass and stable functional immobilized *L. rhamnosus* OLXAL-1 culture production. The combined approach of valorizing these materials provides a sustainable and technically robust strategy for developing functional ingredients for food and feed applications, fully aligned with circular economy principles.

References

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