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Bioprocessing of Lentil Hulls for the Development of Functional Ice Cream Cones

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Abstract

The industrial dehulling of lentils generates a substantial volume of by-products, primarily lentil hulls (LH), which account for approximately 20-30% of the total grain weight. Despite being currently relegated to low-value animal feed, LH represent a promising and underutilized reservoir of proteins, lipids, essential vitamins, and minerals. Most notably, they are an extraordinary source of dietary fibre and phenolic compounds with potential health-promoting effects. However, their integration into human diets is severely hindered by the presence of antinutritional factors, such as phytic acid, saponins, condensed tannins, and inhibitors of digestive enzymes, which significantly reduce nutrient bioavailability and protein digestibility. Within the framework of the OnFoods project, this research aimed to develop an innovative bioprocessing strategy to valorise LH through controlled fermentation. A comprehensive screening was performed using lactic acid bacteria (LAB), yeasts, and filamentous fungi. Specifically, commercial (Lactiplantibacillus plantarum CATBA, Lactococcus lactis V MO 01, Lacticaseibacillus casei BGP 93, Lacticaseibacillus rhamnosus LR 4PD), and autochthonous (five Pediococcus acidilactici isolates and Furfurilactobacillus rossiae LV-S) strains were inoculated at 6-7 log CFU/g in a standardized LH-water mixture (1:4 ratio, ground to 500 µm). In parallel, solid-state fermentation was evaluated using yeasts (Debaryomyces hansenii DSM 70238, Geotrichum candidum DSM 13629) and filamentous fungi (Penicillium roqueforti D1) to assess their proteolytic and metabolic impact over a 120-hour incubation period. The experimental results highlighted significant microbial adaptations. Fungal strains successfully adapted to the substrate, demonstrating robust growth, distinct growth kinetics, and active metabolic utilization of organic acids during the 5 days of solid-state fermentation. LAB populations increased by 1-2 log cycles, successfully lowering the matrix pH to values between 4.0 and 5.4. Among the candidates, L. plantarum CATBA stood out for its robust growth kinetics and superior acidification performance. Crucially, this bioprocess led to a significant reduction in raffinose and phytic acid levels, while simultaneously enhancing the antioxidant activity and the concentration of soluble phenols within the matrix. In addition, LH fermented with LAB exhibited anti-inflammatory effects on an in vitro model represented by Caco-2 intestinal cell line. Based on these positive outcomes and its QPS/GRAS safety status, CATBA was selected as the primary starter for the production of a functional fermented flour.

This ingredient was subsequently incorporated at a concentration of 90% into the formulation of ice cream wafers. The optimization of the technological and baking parameters resulted in a final product characterized by good texture and an optimized nutritional profile. This study confirms that microbial bioprocessing is a powerful tool for the upcycling of food side-streams, transforming industrial waste into sustainable, high-value ingredients that meet modern consumer demands for health, functionality, and environmental responsibility.

Keywords: lentil hull, by-product, lactic acid bacteria, yeast and fungi, fermentation

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