Microbial Food Fermentation: Enhancing Nutritional Fitness**

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Summary
Lactic acid bacteria (LAB) are the most widely studied microorganisms for food biopreservation. LAB play a particularly critical role in the preservation and microbial safety of fermentable foods. As world population increases, the use of improved LAB strains as probiotic cultures in industrial food fermentation is expected to have a large economic impact that attracts increasing commercial interest in preserving fresh vegetables, fruits, and a broad variety of food items for feeding populations, especially in developing countries. Many fermented fruit and vegetable products co-evolved with human nutrition, and people have lived with high and continuous loads of LAB since ancient times. Genomic and metabolomic biotechnologies are now readily available and provide molecular footprints, mapping LAB mixed strains that have co-evolved with humans and developed intimate interrelationships with our bodies. Their genomes have sparked the discovery of how functional probiotic LAB strains may play a promising role in biofortification strategies and offer the potential for addressing key public health challenges, including over- and under-nutrition. The food sustainability realities confronting science and public health require that federal agencies consider improving proficiencies of diverse stakeholders in the public and private sectors to better inform research efforts on food fermentation, streamline processes, maximize safety, and ensure benefit to public health. Large-scale sustainable strategies in which qualified experts on agriculture and nutrition issues partner with key stakeholders in the molecular sciences and emerging biotechnologies will help to decipher the "Rosetta Stone" of metabolic footprints that are of key importance to enhancing health and longevity. Such partnerships require endorsement of core principles of mutual trust, cooperation, procedural transparency, performance criteria, and evaluation effectiveness.

Current realities

Reliably identifying functional health properties in the food chain and during biotechnological processes can be seen as common research priorities for food microbiologists and other interdisciplinary scientists and stakeholders. In the current food science and technology paradigms, biopreservation can be defined as the extension of shelf life and food safety by the use of natural or controlled microbiota and/or their antimicrobial compounds. One of the most common forms of food biopreservation is fermentation, which occurs when bacteria and enzymes convert carbohydrates into alcohol or organic acids, changing the flavor of food and preserving it. One important outcome of food fermentation is the enrichment of food with essential amino acids, vitamins, minerals, and bioactive compounds. Fermentation makes foods easier to digest and perhaps is more nutritious than raw fruit or vegetables. Notably, most fruits and vegetables contain some undesirable or toxic bioactive compounds that can be removed or detoxified by the action of microorganisms during the fermentation process.

A key result of gut digestion and fermentation is production of short-chain fatty acids, which cells need for energy. This process occurs naturally in many foods, and humans have made use of it for thousands of years by making yogurt out of milk or alcohol from fruit. Before refrigeration, humans routinely consumed fresh vegetables in season and fermented them for preservation for the winter. In fact, the earliest record of fermentation may date back as far as 6000 B.C. in Middle Eastern and Asian cultures and nearly every civilization since have included at least one fermented food in its culinary traditions. From yogurt and cheese to Korean kimchi and Indian chutneys to German sauerkraut, global cultures have crafted unique flavors and traditions around fermentation.

Although challenges remain, fermented foods, handed down for many generations, are experiencing a rapid resurgence in the global food industry. This growth is, spurred by innovative technologies that include biological antimicrobial systems, particularly LAB and their metabolites that have been combined with traditional preservation methods in food fermentation for the intended purpose of inhibiting spoilage and pathogenic bacteria. One growth market of these technologies is the exponential rise of LAB-containing food cultures being marketed as having enhanced functional (probiotic) characteristics and health benefits.

About 80% of traditional fermented foods are produced, in part, by natural fermentation and may contain functionally beneficial (probiotic) and pathogenic microorganisms. Clearer understanding of microbial ecosystems is critical, in light of the evidence of increasing pathogen resistance to established hygienic and biopreservation techniques. Consequently, thermal and nonthermal technological processes applied to the evolution of food fermentation require continuous innovation of food safety and microbiological risk assessment tools. Effective tools for metabolic profiling (e.g., metabolomics) in supporting safe and sustainable food systems that can reliably enhance nutritional value and human health are also essential.

Scientific opportunities and challenges

Until recently, fermentation technologies have played an overlooked yet vital role in ensuring the food security of millions of people around the world, particularly marginalized and vulnerable groups. Traditional fermented weaning foods, for example, may play a preventive role in infant malnutrition, lactose intolerance, and tropical diarrhea. With increases in world populations and arid land, food security can be better achieved with improved preservation processes, increasing the range of raw materials used to produce fermented food products, and removing antinutritional factors (e.g., toxic bioactive compounds) that make foods unsafe to eat.

As evidence of improved nutritional quality and food safety of fermented foods becomes more available, the consumption of fermented food is likely to reach new milestones. Biofortification and designer foods (foods with defined health benefits other than nutritional value) are among the promising strategies to reduce micronutrient deficiencies worldwide, and food fortification with LAB probiotic properties is rapidly gaining increasing interest. Although evidence indicates that fermented dairy products are the best matrices for delivering probiotics, there is consumer demand for probiotic foods obtained from nondairy matrices. Several food materials (e.g., cereals, fruits, and vegetables) are, therefore, being studied to determine their suitability for safe, sustainable, nondairy probiotic foods.

The challenge in developing health recommendations for probiotic consumption is not a lack of scientific literature, but rather a lack of consolidated research and consistency across studies with respect to validating the safety of bacterial strains, dosages, and the specificity of their functional benefits for selected populations. Conclusive substantiation of the efficacy of probiotics is still emerging, while at the same time a growing number of consumers are interested in trying probiotics as well as increasing the levels of live active cultures in their diets.

Once consumed, LAB from fermented fruits and vegetables have many potential benefits (e.g., increased absorption of nutrients). To market enriched probiotic fermented food sustainably, it is essential that key ecological principles, food safety measures, and health indicators are rigorously tested. Product integrity, harmonized standards, and hygienic preparation of the products are crucial to success.

Policy Issues

- Create a strong training and education strategy to raise awareness of the vital importance of microbial food fermentation in secure and sustainable food systems. Existing international and domestic organizations (e.g., the Food and Agricultural Organisation [FAO] of the United Nations, and the U.S. Department of Agriculture [USDA] Nutrition Centers) possess the leadership, interdisciplinary expertise, and substantial resources to advance training programs examining interactions between microbial cells and food system complexity, as well as integrating biotechnologies, ecology principles, and deciphering food impacts on host-microbial dynamical networks.
- Develop multiscaled biotechnology and harmonized international food standards and guidelines for food fermentation products aligned at the U.S. and international levels through the Codex Alimentarius Commission.
- Invest prudently following the principles outlined by published frameworks (e.g., reference below), technology transfer pathways and public-private partnerships among government and nongovernment organizations, academic, and industry environments that can maximize the capacities of cross-disciplinary expertise and financial resources.
- Build ecologic frameworks wherein food webs are integrated with host-microbial metabolic networks on different spatial and temporal scales. This will involve a multi-pronged approach including U.S. departments (e.g., Department of Energy [DOE]) and multigovernment agency efforts in habitat restoration, promotion of native species, and targeted removal of invasives. Metabolic profiling of microbial fermentation can further advance our knowledge about its role in bioactivity of extracts, energy balance, and functional impacts on health.
- Establish appropriate safety regulations in the market by the regulatory authorities of the country that inform consumer awareness about substantiated benefits/risks. Factors include evaluating the possible effects on biodiversity, the environment, and food safety; weighing the benefits of the product or process against its assessed risks; and tools that provide risk monitoring to ensure continued safety.

References

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