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Health benefits of fermented foods: microbiota and beyond

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Fermented foods and beverages were among the first processed food products consumed by humans. The production of foods such as yogurt and cultured milk, wine and beer, sauerkraut and kimchi, and fermented sausage were initially valued because of their improved shelf life, safety, and organoleptic properties. It is increasingly understood that fermented foods can also have enhanced nutritional and functional properties due to transformation of substrates and formation of bioactive or bioavailable end-products. Many fermented foods also contain living microorganisms of which some are genetically similar to strains used as probiotics. Although only a limited number of clinical studies on fermented foods have been performed, there is evidence that these foods provide health benefits well-beyond the starting food materials.

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Introduction

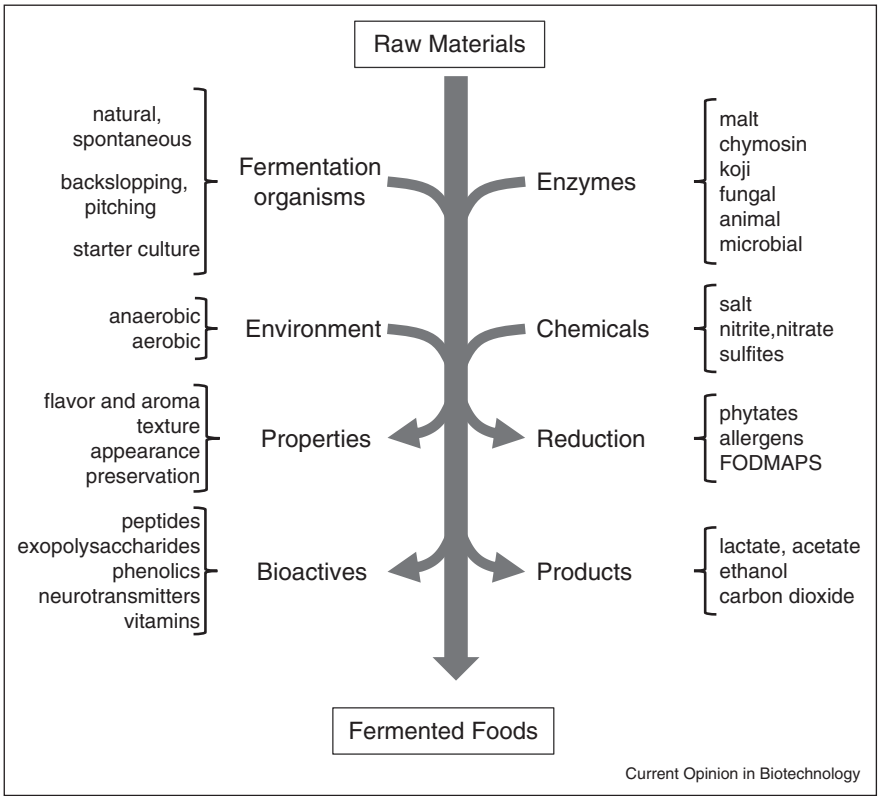
Fermented foods and beverages are staples of the human diet and have been produced and consumed since the development of human civilizations [1]. Fermented foods are generally defined as those foods or beverages made through controlled microbial growth and enzymatic conversions of major and minor food components (Figure 1). Food fermentation processes can be categorized by the primary metabolites and microorganisms involved: alcohol and carbon dioxide (yeast), acetic acid (*Acetobacter*), lactic acid (lactic acid bacteria (LAB) belonging to genera such as *Leuconostoc*, *Lactobacillus*, and *Streptococcus*), propionic acid (*Propionibacterium freudenreichii*), and ammonia and fatty acids (*Bacillus*, molds). Fermentations can also be described based on the food substrates, which include meats and fish, dairy, vegetables, soy beans and other legumes, cereals, starchy roots, and grapes and other fruits. Raw materials that contain high concentrations of monosaccharides and disaccharides, or in some cases starch, are fermented by yeasts or lactic acid bacteria. Molds and *Bacillus* are generally employed for starch saccharification or proteolysis or as secondary ripening microbiota after a primary fermentation.

As a result of the multitude of food-microbe combinations, there are thousands of different types of fermented foods and beverages. At least some form of these products is consumed by nearly every culture world-wide. Despite their long history, popularity, and culinary importance, the acceleration and industrialization of food production over the past century has reduced the diversity of fermented foods, particularly in the West. Recently, however, fermented foods have regained popularity as part of Western diets that emphasize artisanal processes. One reason for this surge in interest is their health-promoting potential. Recently, several groups have suggested that fermented foods should be included as part of national dietary recommendations [2,3]. This review will address what is currently known about how some of those foods support human health and the potential mechanisms underlying those effects.

Traditional fermented foods are diverse but stable microbial ecosystems

Traditional food fermentations are elegantly simple in that they generally require very few ingredients and minimal

Figure 1



Overview of the transformative nature of fermented foods. Raw materials are fermented in specific conditions to create interesting and desirable foods. Fermentation then creates novel and potentially health promoting compounds in foods, while removing those with negative health potential.

preparation and processing. Although some fermentations contain only a few dominant taxa (Table 1), strain differences and population dynamics during processing can be remarkably complex. In some foods, even minor alterations to species diversity or numbers can result in significantly different food products and variations in quality and organoleptic properties. Therefore, a microbial composition with temporal and spatial stability and resilience results in consistent fermentations and process conditions that are necessary to produce high quality food. Recent studies have explored the microbial diversity of numerous fermented food types and their associations with

Table 1

Primary source of fermentative organisms for common fermented foods and beverages. Microbial associations shown in the table are stable over time and show remarkable similarity in different regions or countries

Food	Source of organisms	Organisms
Yogurt	Starter culture	*St. thermophilus*, *L. delbrueckii* ssp. *bulgaricus*
Cheese, sour cream	Starter culture, backslopping	*Lc. lactis*, *Lu. mesenteroides*
Sausage	Backslopping, starter culture, spontaneous	*L. sake*, *L. plantarum*, *S. carnosus*, *S. xylosus*, *P. acidlactici*
Wine	Spontaneous, starter culture	*Sa. cerevisiae*, *O. oeni*
Beer	Backslopping, starter culture	*Sa. cerevisiae* (*L. brevis*)
Bread	Starter culture	*Sa. cerevisiae*
Sourdough bread	Backslopping	*L. sanfranciscensis*, *C. humilis*
Sauerkraut or kimchi	Spontaneous	*Lu. mesenteroides*, *L. plantarum*, *L. brevis*
Olives	Spontaneous	*L. plantarum*
Soy sauce, miso	Starter culture, spontaneous	*A. soyae*, *Z. rouxii*, *T. halophilus*
Tempeh	Starter culture, backslopping	*R. oligosporus*
Natto	Starter culture, backslopping	*B. subtilis* var. *natto*

St., *Streptococcus*; *L.*, *Lactobacillus*; *Lc*, *Lactococcus*; *Lu.*, *Leuconostoc*; *S.*, *Staphylococcus*; *P.*, *Pediococcus*; *Sa.*, *Saccharomyces*; *O.*, *Oenococcus*; *C.*, *Candida*; *A.*, *Aspergillus*; *Z.*, *Zygosaccharomyces*; *T.*, *Tetragenococcus*; *R.*, *Rhizopus*; *B.*, *Bacillus*.