

## PLANT-BASED NON-ALCOHOLIC FERMENTED BEVERAGES: MICROBIOTA OVERVIEW AND BIOTECHNOLOGICAL PRODUCTION PERSPECTIVES

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**Review**



**ABSTRACT**

The article is devoted to the food industry topical issue – the production of fermented beverages of plant origin. Based on the literature analysis, the main types of fermented non-dairy products and raw materials for their production have been described. The distribution of the traditional fermented alcohol-free drinks has been shown and the connection with the typical raw materials of production has been established. The review introduces the inherent microbiota of such well-known drinks as kombucha, kvass, and boza. The symbiotic interactions between bacteria and yeast, which are typical microbial representatives of these beverages, have been described. The impact of microbial interactions on the quality and functional product characteristics, as well as their importance, have been analyzed. Probiotic properties of lactic acid bacteria isolated from fermented drinks have been presented. The presence of functional properties of raw materials used in beverages production, as well as the importance of fermentation processes, have been established. The typical biologically active metabolites inherent in many fermented beverages have been described. The main probiotic properties of lactic acid bacteria isolated from traditional fermented drinks have been highlighted. The issue of technological aspects of the common fermented drinks production has been considered. The importance of highlighting the typical microbiota representatives of beverages for further industrial use in food or therapeutic practice has been emphasized. The importance of the use of lactic acid bacteria in the fermented beverages production has been highlighted. The introduction of new methods and technologies, which will allow the production of functional fermented beverages with increased biological value, has been highlighted.

**Keywords:** fermentation, beverage, kombucha, kvass, lactic acid bacteria, yeast, biotechnology

**INTRODUCTION**

Based on the concept of functional nutrition developed in 1991 – "Foods for Specified Health Uses" (FOSHU), Japanese nutritionists suggested that the functional focus of food products should meet certain requirements, namely: food ingredients should be of natural origin; "functionally oriented" food products should be included in the daily diet; products consumed as a part of the daily diet should be regulators of the biological defense mechanisms of the human body, have preventive properties for certain nosological forms, as well as control the physical condition of the body and slow down the aging process (Shimizu, 2019). This concept significantly influenced and qualitatively changed the world market of food products having expanded the range of products that meet the conditions listed in the concept. Also, the spread and active production of functional food products has increased due to the perception of this concept from the point of view of convenience and relative cheapness of solving some health problems, as well as the improvement of the consumer's life quality (Birch & Bonwick, 2019; Llamas-Arriba et al., 2019). Today, many groups of functional food products are known, a separate category of which consists of beverages, which have their own characteristics related to the ease of enriching them with useful components (macroelements, vitamins, probiotics, etc.), as well as the ease of storage (Llamas-Arriba et al., 2019; Tolun & Altintas, 2019). Currently, a functional beverage is one of the most developed areas of the food industry and is highly valued in the world market mainly due to the above-mentioned health effects and nutritional properties (Chavan et al., 2018).

In the processes of food and beverage fermentation, the main role belongs to microorganisms, mainly representatives of the kingdoms of bacteria (anaerobic fermentation) and fungi (aerobic fermentation) (Marsh et al., 2014). The fermentation process, depending on the producer involved, is divided into yeast, lactic (hetero- and homofermentative), butyric, propionic and acetic acid. Such a variety of technological approaches makes it possible to obtain a wide range of end products of the process, and therefore their content in the end (functional) product. Typical end products of the fermentation process are ethanol, acetic, lactic, propionic, butyric, succinic, formic acids, and in some cases butanol, isopropanol, and acetone (Bernalier et al., 1999; Voidarou et al., 2020). The most common

microorganisms in fermentation processes among fungi are representatives of the genera: *Aspergillus*, *Brettanomyces*, *Candida*, *Rhizopus*, *Lachancea*, *Saccharomyces*, *Yarrowia*, *Zygosaccharomyces*, etc.; among bacteria there are representatives of the following families: *Acetobacteraceae*, *Brevibacteriaceae*, *Propionibacteriaceae*, *Bifidobacteriaceae*, *Enterococcaceae*, *Leuconostocaceae*, *Lactobacillaceae* and others (Tamang et al., 2016; Voidarou et al., 2020).

Fermentation based on microorganisms is a purely biotechnological process. Today, such a "biotechnological tool" is used all over the world for the production of various vitamins (Polishchuk & Dugan, 2020; Y. Wang, Liu, et al., 2021), amino acids (Wendisch, 2020), biopolymers of various origin (Jose et al., 2022; Siroid et al., 2022), enzymes (Liu & Kokare, 2023), various probiotics (Abedin et al., 2023; Khablenko et al., 2023), as well as food products and beverages, in particular of functional purposes (Baschali et al., 2017; Khablenko et al., 2022). Currently, a significant number of fermented beverages occupy an important place in human nutrition (or diet), and are also a special part of the cultural heritage of many people (Makwana & Hati, 2019).

Fermented beverages are distinguished depending on the type of raw materials, the duration of the fermentation process and the use of microorganisms. Thus, alcoholic and non-alcoholic beverages are distinguished, which in turn can be divided into fermented milk (for example, kefir, yogurt, ayran, acidophilic milk), plant-based beverages, or non-fermented milk (Baschali et al., 2017; Makwana & Hati, 2019).

The category of functional fermented milk beverages is the most popular now, mainly due to the thorough investigation and scientific validation of their positive attributes through multiple studies. One of the most widely used fermented milk beverages with functional properties is yogurt, the benefits of which were proven back in the 19th century (Rashwan et al., 2023). It should be noted that one of the first functional beverages was the fermented milk product Yakult, which was used and continues to have significant demand in various countries of the world (S. Sharma et al., 2021). The functionality and beneficial properties of fermented milk beverages are due mainly to microorganisms that carry out milk fermentation, i.e. lactic acid bacteria (LAB) (Makwana & Hati, 2019; S. Sharma et al., 2021). Today, LAB are known for their therapeutic properties, and a large number of them are known as probiotic microorganisms, including strains of *Lactobacillus*

*acidophilus* NCFM (Ramos et al., 2021), *Lactocaseibacillus casei* Shirota (Hill et al., 2018) and *Lactocaseibacillus rhamnosus* GG (Capurso, 2019). However, the rapid synthesis of lactic acid and other valuable metabolites, growth on various relatively cheap substrates, and the relative ease of genetic manipulation with their genomes also make LAB to be important industrial super synthetic microorganisms, the metabolic products of which can be used in many industries (Johansen, 2017; Y. Wang, Wu, et al., 2021).

Although fermented milk products are very popular, such a common problem as lactose intolerance, a change in the diet of many consumers, and an increase in awareness of various food products prompts the search for opportunities to create variants of traditional non-fermented milk beverages, improve their recipes, start mass production, or even create new plant-based beverages. Such advantages of plant-based fermented beverages as high nutritional value, functional properties and the presence of probiotic microorganisms make them quite attractive for various categories of consumers (Ziarno & Cichońska, 2021). However, the lack of standardized fermentation compositions of microorganisms or biopreparations for the production of beverages with specific functional properties, as well as the complexity of the microbiota of natural fermented beverages is the main problem for modern studies in this area. Since LAB is one of the main parts of the microbiota of many well-known fermented beverages, and also has unconditional special useful properties, the research and introduction of these microorganisms and their compositions into the industrial practice of the production of fermented non-dairy beverages is currently relevant, undoubtedly useful and timely.

The purpose of the article is analysis of variety of plant-based fermented beverages and their microbiota and biochemical features of the fermentation process with an overview of the technological aspects of the production of plant-based fermented beverages.

**GEOGRAPHICAL DISTRIBUTION OF NON-ALCOHOLIC FERMENTED BEVERAGES**

Traditional fermented beverages have been known for a long time, the first evidence of the use of fermented beverages and products comes from the countries of Mesopotamia about 8 thousand years BC (Cuamatzin-García et al., 2022). Such evidence was obtained from archaeologists using the examples of finds of appropriate kitchen utensils and recipes for the production of about 20 types of beer (McGovern et al., 2004). Historical evidence indicates that fermented beverages in different eras of human development were widespread, practically, on all continents of the world. Religion, race and ethnicity, and lifestyle have long had an impact on the quality and variety of food, including fermented beverages (Tamang et al., 2020). Different plants are the main raw materials for fermented non-sour milk beverages. The following vegetable raw materials are mainly distinguished: legumes (soy, peas, tung beans), cereals (rice, wheat, barley, rye, oats, millet, sorghum, corn), pseudo cereals (buckwheat, amaranth, quinoa), seeds or nuts (almonds, coconut, walnuts), oil plants (flax, sesame, sunflower) and vegetables (potatoes) (Ziarno & Cichońska, 2021). Therefore, it can be concluded that the production of a certain fermented beverage depends on the place of distribution of raw materials and on the climatic zone. For example, common raw materials for European countries are wheat and barley (Giraldo et al., 2019), and for Asia – rice and soybeans (Baniwal et al., 2021; Zohary et al., 2012). Many countries of the world have their own traditional fermented beverages of non-sour milk origin, which is shown in Table 1.

**Table 1** Traditional fermented drinks of the countries of the world

Drink	Country of origin	Raw materials	References
Kanji	India	Black carrot, crushed mustard, red pepper powder	(Lamba et al., 2019)
Soy sauce	Indonesia, Malaysia, Cambodia	Millet, soybeans	(D. Kumar et al., 2022)
Kombucha	China (country of origin), consumption all over the world	Tea	(Marsh et al., 2014)
Shalgam, shalgam juice or turnip water	Turkey	Flour bulgur, turnip, black carrot	(Şanlier et al., 2019)
Hardaliye		Red grapes or ground mustard seeds	
Amazake	Japan	Rice	(Patra et al., 2023)
Borde	Ethiopia	Cereals	(Cuamatzin-García et al., 2022)
Shamita			
Oshikundu	Namibia	Millet, sorghum	(Misihairabgwi & Cheikhyoussef, 2017)
Maxau		Corn, corn flour	
Kununuzaki or kunu	Nigeria	Millet, sorghum	
Ogi or akamu	Nigeria, Benin	Corn, sorghum or millet	(Soni & Dey, 2014)
Mageu	South Africa		
Hulu-mur	Sudan	Sorghum, rice, millet	(Eltayeb et al., 2020)
Togwa	Tanzania	Cassava, sorghum, corn or commmeal	(Basinskiene & Cizeikiene, 2020; Cuamatzin-García et al., 2022)
Andamahewu		Cornmeal	
Obushera	Uganda	Sorghum flour, millet, corn	(Ignat et al., 2020)
Boza or bosa	Bulgaria, Serbia, Romania, Albania, Macedonia, Turkey	Wheat, millet, rye, corn, barley, semolina	(Basinskiene & Cizeikiene, 2020)
Taar	Estonia	Rye, barley, rarely oats	(Baschali et al., 2017)
Bors	Romania, Eastern Europe	Wheat bran, corn flour	(Ignat et al., 2020)
Beet kvass	Ukraine	Beet	(Karpyk et al., 2021)
Kvass	Ukraine, Poland, Baltic countries	Rye bread, rye, barley malt, flour, stale rye bread, extruded whole grain rye flour	(Basinskiene & Cizeikiene, 2020)
Chicha	Argentina	Corn	
Masato	Colombia, Peru, Venezuela and other South American countries	Cassava, rice, pineapple or corn	
Tepache		Pineapple	(Cuamatzin-García et al., 2022)
Pozol	Mexico	Corn and flour	
Tesgüino		Corn	
Atole		Cornflour	

Despite the variety of fermented drinks, most of them are produced at home or "artisanal" and have only local consumers. This is especially true for most beverages from Africa and South America. Only some fermented drinks have established industrial production, namely: kombucha, kvass, boza and the Turkish drinks listed in the table.

**MICROBIOTA OF COMMON FERMENTED BEVERAGES**

Analysis of the scientific literature indicates that the production of both world-famous and widely consumed beverages and "homemade" fermented beverages are associated with the presence of a unique microbiota in them. Identification, selection and research of the properties of unique, from our point of view, microorganisms from various fermented beverages and fermentation products

(vegetables, fruits) is a critically important stage for setting up the industrial production of a certain type of beverage (Franco-Duarte et al., 2019). Sometimes such research allows to identify new probiotic cultures that can be used not only for the production of fermented beverages, but also, in the future, for the development of therapeutic preparations (Patra et al., 2023).

**Kombucha**

Kombucha is a popular fermented beverage that is consumed all over the world. The word "kombucha" comes from the Japanese word "kombu" – "seaweed" and "cha" – "tea" (Ivanišová et al., 2019). The drink is also known by such names as kombucha, tea kvass, kocha kinoko, etc (Watawana et al., 2015). The country of origin is believed to be China, although certain historical studies point to the

Middle East and Germany. The drink became most popular after the Second World War (Kapp & Sumner, 2019).

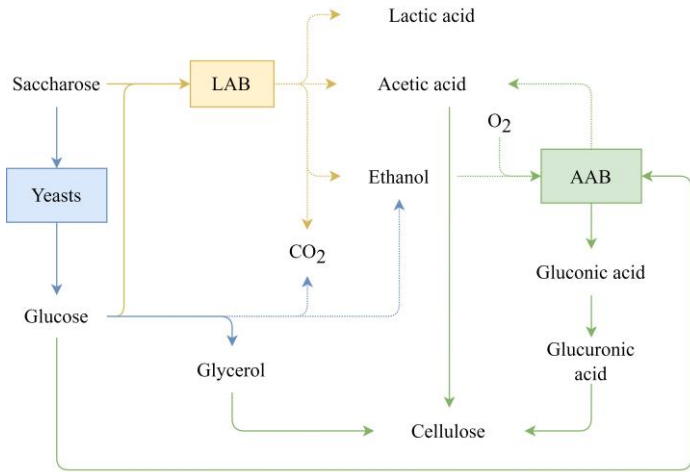


Figure 1 Metabolic interactions of tea fungus microorganisms

Black, white, blue (oolong) (Laureys et al., 2020) and most often green tea (Yang et al., 2022) are the main raw materials or substrate for fermentation and beverage production. An additional source of carbohydrates is sugar (Diez-Ozaeta & Astiazaran, 2022). From a microbiological point of view, kombucha is a rather complex beverage, since fermentation takes place after the addition of a complex association of microorganisms – a symbiotic culture of bacteria and yeast (symbiotic culture of bacteria and yeast (SCOBY), or kombucha (Diez-Ozaeta & Astiazaran, 2022; Kapp & Sumner, 2019). Microbial composition kombucha is quite complex and can vary depending on the raw material (substrate), geographical location, climate, local species of microorganisms and the fermentation matrix (Barbosa et al., 2021; Bishop et al., 2022). In addition, depending on the microbial composition of the leaven, the properties of kombucha itself can change. The main components the microbiota of kombucha is considered to be three groups of microorganisms: yeast, acetic acid bacteria (AAB) and LAB (Bishop et al., 2022; Kapp & Sumner, 2019). As can be seen from the English name, SCOBY is a symbiotic matrix of microorganisms, so all the microorganisms are closely related to each other by metabolic ties, the scheme of which is presented in Fig. 1.

The composition of SCOBY microbiota can vary depending on its position during the fermentation process, whilst AAB and yeast are more characteristic for the surface biofilm (İçen et al., 2023; Sanwal et al., 2023; B. Wang et al., 2022b). As the consortium contains three major groups of microorganisms, the species composition is quite diverse, which are presented in Table 2.

Table 2 Species composition of SCOBY microbiota

Group of microorganisms	Genus	Species	References	
AAB	Acetobacter	<i>A. aceti</i>	(Abd Soheir S. El-Salam, 2012)	
		<i>A. indonesiensis</i>	(Tran et al., 2022)	
		<i>A. musti</i>	(B. Wang et al., 2022a)	
		<i>A. nitrogenifigens</i>	(Dutta & Gachhui, 2006)	
		<i>A. okinawensis</i>	(Savary et al., 2021)	
		<i>A. papayae</i>	(Tran et al., 2022)	
		<i>A. pasteurianus</i>	(Al-Mohammadi et al., 2021; Sievers et al., 1995)	
		<i>A. pomorum</i>	(Landis et al., 2022)	
		<i>A. senegalensis</i>		
		<i>A. tropicalis</i>	(Coton et al., 2017; Landis et al., 2022)	
		Gluconacetobacter	<i>Gl. intermedius</i>	(Nguyen, Nguyen, et al., 2015)
			<i>Gl. kombuchae</i>	(Dutta & Gachhui, 2007)
		Gluconobacter	<i>Gl. saccharivorans</i>	(Angela et al., 2020)
			<i>G. oxydans</i>	(Hooi et al., 2023)
Komagataibacter	<i>G. potus</i>	(B. Wang et al., 2022a)		
	<i>K. rhaeticus</i>	(Dinh Thi et al., 2022; Hooi et al., 2023)		
	<i>K. xylinus</i>	(Angela et al., 2020; Hooi et al., 2023)		
	<i>K. saccharivorans</i>	(Angela et al., 2020; Dinh Thi et al., 2020; Dinh Thi et al., 2022; Hooi et al., 2023; Mukadam et al., 2016)		
LAB	<i>Bifidobacterium</i>	-	(Chakravorty et al., 2016)	
	<i>Heyndrickxia</i>	<i>H. coagulans</i>	(Hooi et al., 2023)	
	<i>Lactocaseibacillus</i>	<i>Lcb. casei</i>	(Nguyen, Dong, et al., 2015)	
	<i>Lactiplantibacillus</i>	<i>Lpb. plantarum</i>	(Nguyen, Nguyen, et al., 2015)	
	<i>Lactobacillus</i>	<i>Lb. acidophilus</i>	(Al-Mohammadi et al., 2021)	
	<i>Lactococcus</i>	-	(Watawana et al., 2017)	
	<i>Leuconostoc</i>	-		
	<i>Limosilactobacillus</i>	<i>Lmb. fermentum</i>	(Al-Mohammadi et al., 2021)	
	Liquorilactobacillus	<i>Lq. nagelii</i>	(Hooi et al., 2023; Savary et al., 2021)	
		<i>Lq. satsumensis</i>	(Coton et al., 2017)	
	Yeast	Oenococcus	<i>Lq. mali</i>	(Yang et al., 2022)
<i>O. oeni</i>			(Coton et al., 2017)	
Pediococcus		<i>Pc. acidilactici</i>	(Diguță et al., 2020)	
		<i>Pc. pentosaceus</i>		
<i>Sporolactobacillus</i>		<i>Slb.shoreae</i>	(LEE et al., 2022)	
<i>Weissella</i>		-	(Chakravorty et al., 2016)	
Brettanomyces		<i>B. anomalous</i>	(B. Wang et al., 2022a)	
		<i>B. bruxellensis</i>	(Angela et al., 2020)	
<i>Dekkera</i>		<i>D. bruxellensis</i>	(Nguyen, Nguyen, et al., 2015; B. Wang et al., 2022a)	
Hanseniaspora		<i>Hs. uvarum</i>	(Savary et al., 2021)	
		<i>Hs. valbyensis</i>	(B. Wang et al., 2022a)	
<i>Kluyveromyces</i>	<i>Kl. marxianus</i>	(Beloso-Morales & Hernández-Sánchez, 2003)		
<i>Lachancea</i>	<i>L. fermentati</i>	(Bellut et al., 2020; Chakravorty et al., 2016)		
<i>Pichia</i>	<i>P. kudriavzevii</i>	(B. Wang et al., 2022a)		
<i>Saccharomyces</i>	<i>S. cerevisiae</i>	(Hooi et al., 2023; B. Wang et al., 2022a)		
<i>Schizosaccharomyces</i>	<i>Sch. pombe</i>	(B. Wang et al., 2022a)		
<i>Starmerella</i>	<i>St. vitis</i>			
<i>Zygosaccharomyces</i>	<i>Z. bailii</i>	(Mukadam et al., 2016)		

**Boza**

Boza is a non-alcoholic or sometimes low-alcohol beverage common on the Balkan Peninsula and in Turkey (P. Petrova et al., 2010). The main raw materials for its production are cereals, for example, such as corn, barley, rice, oats, wheat and millet (Yildiz & Bayat, 2019). Although the beverage is not as world-famous as kombucha, it is still popular in its countries of origin. Bosa is a typical fermented beverage, and its microbiota can vary depending on the recipe, raw materials, fermentation time, process temperature, etc. (von Mollendorff et al., 2016). So far, it has been established that fermentation during the production of boza takes place in the process of the simultaneous growth of LAB and yeast (Bozdemir et al., 2022).

A significant number of scientific papers are devoted to the search for LAB from boza of various production means. Thus, in a scientific paper (Osimani et al., 2015) the authors indicate the presence of many types of LAB in various commercially available unpasteurized beverage. The following species were isolated: *Lcb. casei*, *Lcb. paracasei* subsp. *paracasei*, *Loigolactobacillus coryniformis*, *Lmb. fermentum*, *Lnb. buchneri*.

Less diversity is observed among yeasts: *Meyerozyma guilliermondii*, *P. fermentans*, *P. norvegensis* and *Torulaspora* spp (Osimani et al., 2015). A study of boza produced in China indicates the presence in it of such types of LAB as *Pc. pentosaceus*, *Lpb. plantarum* and *Lcb. rhamnosus*, as well as *S. cerevisiae* yeast (Reheman et al., 2020). *Lpb. plantarum*, *Enterococcus faecium* and *Leu. lactis* were isolated from Bulgarian traditional boza (Todorov, 2010). The research (P. Petrova et al., 2010) indicates the presence of strains *Lpb. plantarum* and *Lpb. pentosus* with amylolytic activity. Other studies also indicate the presence of a large diversity of LAB in boza of different origins. Thus, there were isolated and identified the following: *Lactococcus raffinolactis*, *Lb. acidophilus*, *Leu. mesenteroides*, *Lv. brevis*, *Weissella confusa*, *W. paramesenteroides* (Arici & Daglioglu, 2002; Gotcheva et al., 2000; Hancioğlu & Karapinar, 1997), *Lc. garvieae*, *Pc. parvulus* (Heperkan et al., 2014), *Lmb. fermentum* (Allaith et al., 2022; Rasheed et al., 2020), *Leu. mesenteroides* subsp. *dextranicum* (Moncheva et al., 2003), *Pc. acidilactici*, *Pc. pentosaceus* (Queiroz et al., 2022; Todorov & Dicks, 2005), *E. faecium* (Ucak et al., 2022; Valledor et al., 2020), *Lb. delbrueckii* subsp. *delbrueckii* (BORCAKLI et al., 2018). The most common among yeasts are *S. cerevisiae*, *S. uvarum* (Hancioğlu & Karapinar, 1997), *Candida tropicalis*, *C. glabrata*, *Geotrichum penicillatum*, *G. candidum* (Gotcheva et al., 2000; Tamer et al., 2019), *C. inconspicua*, *C. diversa*, *Rhodotorula mucilaginosa*, *P. fermentans*, *P. norvegensis* (Botes et al., 2007).

**Kvass**

Kvass is a traditional beverage based on cereal crops, which is most often made from fermented barley and rye malt, rye flour, and at home from stale rye bread (Basinskiene & Cizeikiene, 2020). Kvass is most widespread in the countries of Eastern Europe (Poland, Ukraine, Slovenia, Czech Republic) and the Baltic countries (Lithuania, Latvia) (Basinskiene et al., 2016). Kvass is a non-alcoholic beverage, which is noted to contain insignificant amount of ethanol; when this indicator increases, the drink is considered spoiled (Basinskiene & Cizeikiene, 2020). As with the previous beverages, the microbiota of the end product varies depending on the raw materials and fermentation conditions. Although kvass is currently produced on an industrial scale, there are variations that are produced at home, namely: beet kvass (Karpuk et al., 2021), mint kvass, with the addition of different types of bread or flour, with the addition of raisins, etc. (Basinskiene & Cizeikiene, 2020). The yeast *S. cerevisiae* (Lidums & Karklina, 2014) and various types of LAB are considered to be the main microorganisms that ferment raw materials in the production of kvass. Usually, kvass differs by representatives of the LAB, among which the following species are common: *Lb. delbrueckii*, *Lpb. plantarum*, *Lcb. casei* (Bati & Boyko, 2016) and *Leu. mesenteroides* (Basinskiene & Cizeikiene, 2020; Dlusskaya et al., 2008). Microorganisms that are characteristic for fermented wort are *Leu. dextranicum*, *Lpb. plantarum*, *Lcb. casei*, *Str. thermophilus*, *E. faecalis* and *Lv. brevis* (Kosogolova et al., 2012).

**Other fermented beverages**

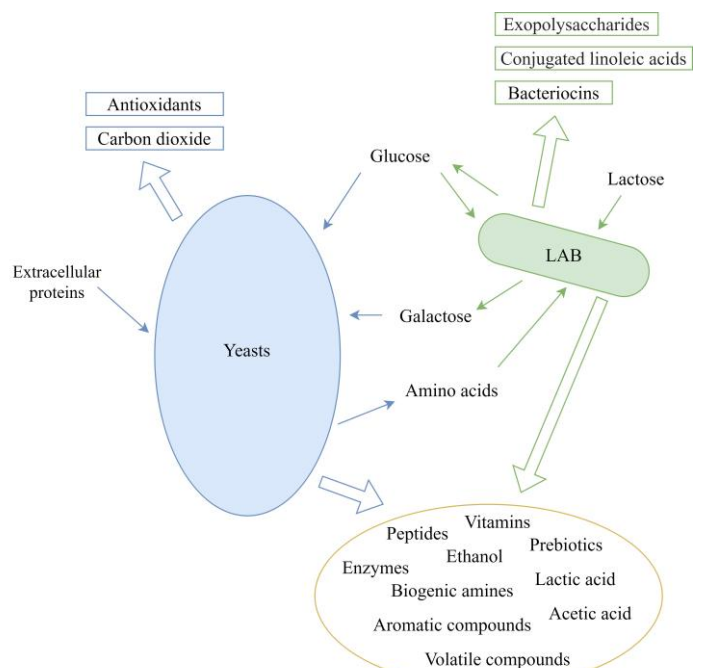
The microbiota of other less common fermented beverages is also of interest to many scientists. For example, the scientific paper (Gizachew et al., 2023) investigated the Ethiopian beverages naake and cheka, prepared on the basis of corn and sorghum flour. Various LAB were isolated and identified from the prepared beverages, including *Lmb. fermentum*, *Pc. pentosaceus* and *W. confusa*. A significant diversity of microorganisms was found in many other traditional beverages of African countries, the most typical species among the LAB are *A. pasteurianus*, *Furfurilactobacillus rossiae*, *Lb. delbrueckii*, *Lc. lactis*, *Lmb. fermentum*, *Lpb. plantarum*, *Lv. brevis*, *W. paramesenteroides* (Afolayan et al., 2017; Agarry et al., 2010; Carole Sanya et al., 2023; Ilango & Antony, 2021; Pswarayi & Gänzle, 2019), *Bacillus subtilis*, *Leu. mesenteroides* (Mokoena et al., 2016). Among yeasts, the species *S. cerevisiae* (Mugula et al., 2003), *C. glabrata* (Pswarayi & Gänzle, 2019), as well as the representatives of the genera *Diutina*, *Kluyveromyces*, *Lachancea*, *Pichia* (Carole Sanya et al., 2023).

A study of the traditional Indian fermented beverage kanji revealed the presence of *Lpb. plantarum* species in it (Lamba et al., 2019). The study (Sagdic et al., 2014) indicates the rich microbiological diversity of the traditional fermented Turkish beverage made from the fruits of the plant *Viburnum opulus* L. (guelder rose) or from Turkish gilaburu (fermented viburnum juice). The following types of LAB have been isolated and identified: *Lcb. casei*, *Lcb. pantheris*, *Leu. pseudomesenteroides*, *Lnb. buchneri*, *Lnb. parabuchneri*, *Lpb. plantarum*, *Lv. brevis* and *Schleiferilactobacillus harbinensis*. Species *Lcb. pentosus*, *Lmb. fermentum*, *Lpb. plantarum* were also isolated from traditional Turkish beverages shalgam and gilaburu juice (Akman et al., 2021). Another Turkish beverage is hardaliye, typical representatives of the microbiota of which are *Fructilactobacillus sanfranciscensis*, *Lb. acetotolerans*, *Lcb. paracasei* subsp. *paracasei*, *Lmb. pontis*, *Lv. brevis*, *Paucilactobacillus vaccinostercus* (Altay et al., 2013). The Japanese fermented rice beverage amazake, made from rice, is characterized by the LAB species *Latilactobacillus sakei* (Sakurai et al., 2019) and micromycetes of the species *Aspergillus oryzae* (Ignat et al., 2020). In paper (GROSU-TUDOR et al., 2019) the microbiota of the Romanian traditional beverage bors was studied and based on the results it was established that different types of LAB are specific, namely: *Lb. amylolyticus*, *Lcb. casei*, *Lmb. fermentum*, *Lnb. buchneri*, *Lpb. plantarum*. Traditional Mexican beverages are also characterized by the presence of LAB, AAB and yeast of the species already listed above (Pérez-Armendáriz & Cardoso-Ugarte, 2020).

Thus, for all fermented foods and beverages, the main representatives of the microbiota are various LAB and to a lesser extent AAB and yeast. The great variety of LAB types is due, mainly, to the raw material (or substrate) and the production parameters of the fermented beverage (temperature, pH, time). Thanks to the diversity of microorganisms, it is possible to isolate unique strains with the potential for use in medicine and the food industry. This can contribute not only to the development of therapeutic drugs for various fields of medicine and the food industry, but also to the creation of new biological preparations for fermented beverages.

**FUNCTIONAL PROPERTIES OF FERMENTED BEVERAGES**

The presence of LAB in fermented beverages indicates the existence of a certain functionality, since these microorganisms belong to the category of probiotics (Ljungh & Wadström, 2006; S. Sharma et al., 2021). However, in case of fermented beverages, LAB are considered more like cell factories, that is, factories for the synthesis of many biologically active substances, as well as probiotics and metabiotics (Pihurov et al., 2021; Waters et al., 2015). In addition to LAB, for most fermented beverages, a characteristic part of the microbiota is yeast, which usually forms a symbiosis with LAB. Such a symbiosis is quite favorable for both groups of microorganisms and in many cases determines the functional properties of the end product (Maicas, 2020). Figure 2 presents the mechanisms of interaction between yeast and LAB, as well as their biosynthetic activity, which gives functional properties to the fermented beverage.



**Figure 2** Metabolic activity of yeast and LAB during beverage fermentation (Ellis et al., 2022; Maicas, 2020; Pei et al., 2020; Ruta & Farcasanu, 2019)

The most characteristic properties of LAB isolated from various fermented beverages are bacteriocinogenicity (the ability to synthesize bacteriocins), which is reported for various types of LAB to be isolated from various fermented beverages,

for example, for *E. faecium* (Valledor et al., 2020), *Pc. pentosaceus* (Queiroz et al., 2022), *Lmb. fermentum* (Rasheed et al., 2020) isolated from boza and *Lpb. plantarum* isolated from kombucha (Pei et al., 2020).

Micromycetes and yeasts, as well as non-lactic acid bacteria, produce a number of exoenzymes, for example, amylases, proteases, catalases,  $\beta$ -glucanases, glucose oxidases (R. Sharma et al., 2020). The proteolytic properties are also reported to be typical of many LAB, in particular, the ability to synthesize biologically active peptides and amines, as reported by studies of boza and shalgam (Tamer et al., 2019). Also, of great interest is the ability to synthesize polysaccharides, which is reported to be typical of the following species: *Lmb. fermentum*, *Leu. mesenteroides* (Allaith et al., 2022) and *Lg. coryniformis*, *Lcb. paracasei*, *Pc. parvulus* (Heperkan et al., 2014) isolated from boza. Other important compounds produced by LAB in the fermentation process are antioxidants. The synthesis of phenolic compounds,  $\gamma$ -aminobutyrate, conjugated linoleic acids and folate has also been reported (Melini et al., 2019). Of a great interest is the ability of non-saccharomyces yeast to synthesize atypical metabolites that affect the organoleptic properties and functional properties of the beverage, for example, acetoin, lactic acid, glycerol (Bellut et al., 2020; Zdaniewicz et al., 2020), acetaldehyde, cadaverine, etc (Aidoo & Nout, 2010; Ellis et al., 2022).

Thus, the given data indicate that during the fermentation process, the beverage is enriched with biologically active metabolites, which differ depending on the beverage, the raw materials of production, and, in fact, the types of microorganisms. In particular, many studies have been devoted to the valuable metabolites, probiotic properties and functional properties of kombucha, boza and kvass.

Kombucha is considered to be a functional beverage due to its rich nutraceutical and microbiological composition, as well as the studied beneficial properties (Selvaraj & Gurusurthy, 2023). The fermented beverage contains a number of enzymes (tannase,  $\alpha$ -glycosidase), organic acids (lactic, acetic, gluconic, citric, glucuronic) (Villarreal-Soto et al., 2018), vitamins (B<sub>1</sub>, B<sub>2</sub>, B<sub>6</sub>, B<sub>12</sub>) and minerals (copper, zinc, iron, manganese) (Jakubczyk et al., 2022), as well as polyphenols (Diez-Ozaeta & Astiazaran, 2022; Içen et al., 2023; Kaewkod et al., 2019; Sanwal et al., 2023). It is the presence of enzymes and their activity that increases the bioavailability of polyphenols inherent in tea (Içen et al., 2023). Quite a lot of studies confirm the functional properties of kombucha, in particular: antioxidant (Amarasinghe et al., 2018; Nurikasari et al., 2017; Silva et al., 2021), antimicrobial (Battikh et al., 2012; Nyiew et al., 2022; Sreeramulu et al., 2000), anti-inflammatory (Lee et al., 2022) and anticancer (Kaewkod et al., 2019; Khazi et al., 2023; Motafeghi et al., 2023). It is reported that such a range of properties is associated, to a greater extent, with the biological activity of phenolic compounds and organic acids (Diez-Ozaeta & Astiazaran, 2022).

The well-known Turkish drink boza is considered to be a natural probiotic, as evidenced by the above-described typical microbiota and isolated bacteriocinogenic cultures of the LAB, so it can be concluded that the beverage has antimicrobial properties (Gok, 2023; Queiroz et al., 2021). The paper (E. Petrova & Petrov, 2017) also reports on the presence of vitamins A, C, E and B. The presence of flavonoids and phenolic compounds indicates potential antioxidant properties (Gok, 2023; Marjanović et al., 2015). Furthermore, there is existing knowledge regarding the existence of biogenic amines within the beverage (Tamer et al., 2019). In other Turkish beverages, hardaliye, fermented viburnum juice, and shalgam have also been found to have similar functional properties, including probiotic and antioxidant properties (Aladeboyeje et al., 2022; Gok, 2023; Tamer et al., 2019).

Although there is little information about the functional properties of kvass, it is known that the beverage is rich in vitamins of B group (B<sub>1</sub>, B<sub>2</sub>, B<sub>5</sub>), as well as folic acid, which is due to the production of these compounds by yeasts typical for kvass of such species as *S. cerevisiae*, *C. milleri* and *T. delbrueckii*. It is also known that the drink has a positive effect on metabolism and can eliminate digestive disorders (CZERWIŃSKA, 2008; Gambuś et al., 2015). Research (Gambuś et al., 2015) indicates the presence of antioxidant activity of a beverage made from coarsely ground rye bread. The study (Amarowicz et al., 2019) also highlights the presence of a certain antioxidant activity of commercial kvass. In addition, a correlation between the content of phenolic compounds and the actual antioxidant activity was established. In the study (Shao et al., 2022) it was established that the produced fermented beverage can significantly improve the work of the gastrointestinal tract of rats by increasing the hormones ghrelin, motilin, and gastrin.

One of the main features of most fermented non-dairy beverages is plant-based raw materials, the most popular of which are cereals (corn, rye, millet, sorghum, oats) and pseudocereals (buckwheat, amaranth, quinoa) (Patra et al., 2023). An exception is kombucha, since the main raw material for it is tea (Bortolomedi et al., 2022). The popularity of cereal crops is determined by their prevalence and the presence in them of the most important sources of food nutrients, for example, carbohydrates, proteins, vitamins, minerals and fiber (Waters et al., 2015). In addition, they contain various functional compounds, for example, such as: polyphenols, fibers,  $\beta$ -glucans, carotenoids, tocopherols, fatty acids, flavones, aminophenolic compounds (Bangar & Kaushik, 2022; Baniwal et al., 2021). Compounds such as  $\beta$ -glucan, arabinoxylan, fructan, and fructooligosaccharides are considered to be prebiotics, i.e. substances that contribute to the growth of probiotic microorganisms (K. Sharma et al., 2022). Thus, due to the availability of nutritional and functional properties, plant-based raw materials are actively used

in the development and production of various fermented beverages and other food products (Ziarno & Cichońska, 2021). However, it is the fermentation process using the microorganisms inherent in the beverage that can increase biological activity, nutritional value and make the beverage functional (Zhang et al., 2022).

### ASPECTS OF INDUSTRIAL PRODUCTION OF FERMENTED BEVERAGES

Taking into account the presence of various functional properties and the growing interest of consumers in fermented beverages of plant origin, the creation of the production of such products is quite relevant (Melini et al., 2019). Most of the described fermented beverages are produced on an industrial scale and have their own technological patterns, which is shown in Figure 3. However, even today, research is being conducted to improve the technological process, create new starters for fermentation, provide or increase the functionality of the beverage, improve organoleptic properties, or even the creation of new fermented beverages (Basinskiene & Cizeikiene, 2020; Ziarno & Cichońska, 2021).

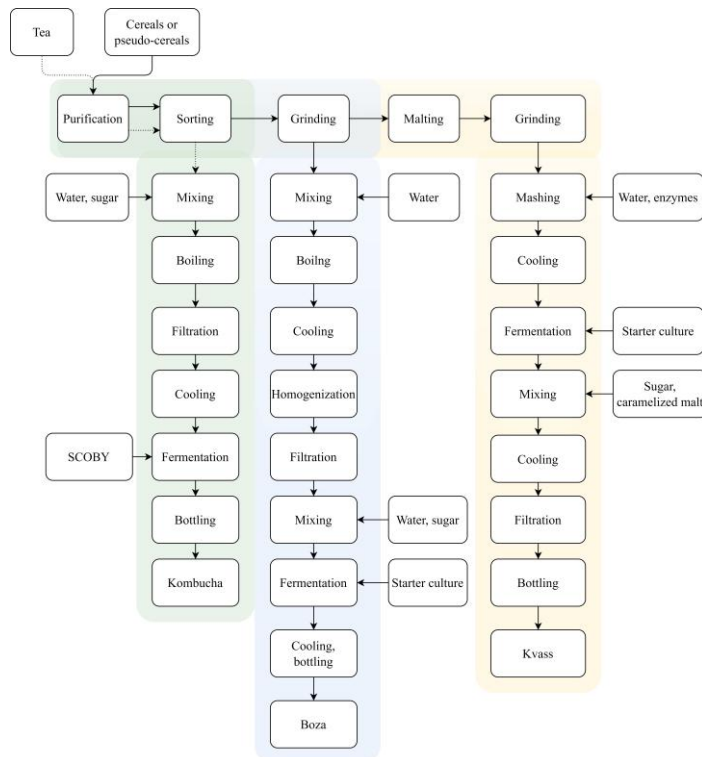


Figure 3 Generalized pattern of the stages of fermented beverages production (Basinskiene & Cizeikiene, 2020; Ignat et al., 2020; V. Kumar & Joshi, 2016; Ziarno & Cichońska, 2021)

Compared to fermented cereal beverages, the kombucha production technology is simpler, due to raw materials that do not require additional processing stages (Bortolomedi et al., 2022; V. Kumar & Joshi, 2016). Kombucha starter is also quite specific and "naturally engineered"/natural. However, in order to increase the diversity of the organoleptic properties of the beverage and its functional properties, the use of not only tea, but also other raw materials is being investigated. For example, grape juice (Ayed et al., 2017), apple juice (Zubaidah et al., 2018), soy milk (Xia et al., 2019), pineapple juice (WARANGKANA & SRICHAMNONG, 2020) etc. It is also reported about the possibility of changing fermentation parameters, temperature, and time. However, the raw material and the SCOBY itself have a greater influence on the end product [162]. Therefore, research is being conducted on "enrichment" or additional introduction of LAB into the SCOBY culture (Oliveira et al., 2022). The study (Lee et al., 2022) describes an increase in the antibacterial and anti-inflammatory properties of a drink with the addition of *Lcb. paracasei*. The authors (Cvetković et al., 2019) point to the presence of high adaptation potential to the kombucha environment of LAB species like *Lnb. hilgardii*, *Lmb. fermentum* and *Lpb. plantarum*. Such results indicate the possibility of introducing various probiotic types of LAB at the fermentation stage, or into the end product in order to increase functionality. In study (Bueno et al., 2021), kombucha was produced based on coffee with the addition of *Lcb. casei* and *Lcb. rhamnosus*. A high survival rate and a change in the proportion of microorganisms from the genus *Acetobacteraceae* to *Lactobacillaceae* were established, which increases the probiotic properties of the beverage. The study of the effect of *P. kluyveri* yeast on the fermentation of tea fungus is of a high interest; the acceleration of the accumulation of acetic acid and the increase of the fruity taste of kombucha were found. Thus, the potential to control both the functional and flavor characteristics of the beverage has been ascertained (van Wyk et al., 2023).

For cereal beverages, the quality of raw materials is quite important, in particular for kvass (Lidums et al., 2016). The study (Basinskiene et al., 2016) reports on the production of kvass with an increased content of arabino-oligo- and xylo-oligosaccharides by using extruded rye, xylanolytic enzymes and culture of LAB *Ltb. sakei*. Thus, a beverage with greater biological value and acceptable commercial quality was obtained. The paper (Treciokiene & Simoneliene, 2009) indicates the possibility of enriching kvass with vitamin C and improving the taste of the enriched beverage. Authors of (Hrek et al., 2012) proposed a method of producing kvass using milk whey as an additional source of proteins and carbohydrates, as well as dietary fibers, which increases the biological value of the end product. Other works are devoted to the improvement of technological solutions and the selection of fermentation cultures of microorganisms for the industrial kvass production. In particular, the study (Sagaidak, Blishch, & Prybylsky, 2016) is devoted to the selection of yeast races in the production of kvass; the technological advantages of using *S. cerevisiae* MP-10 yeast in combination with LAB *L. plantarum* AH 11/16 and *E. faecium* K-77D were established. The same results are presented by the authors of the study (Sagaidak, Blishch, Prybylsky, et al., 2016). Conducted studies using various bacterial preparations also indicate a positive effect of LAB on yeast growth and organoleptic properties of the end product (Sagaidak et al., 2014, 2018). Unconventional kvass has also been produced, in particular fruit kvass (Krapivnytska et al., 2021). Other technological improvements in the production of kvass are the staged method of grinding rye (Müller-Aufermann, 2010). It is known about the development of a dry combined starter for the production of kvass, which contains yeast and LAB, which is presented in (Dubkovetskiy et al., 2003).

Certain studies of Boza are also aimed at the selection of raw materials for the production of the beverage. The study (Göncü et al., 2023) was aimed at developing a gluten-free recipe for boza made from atypical raw materials - chia and quinoa, as well as their mixture. Thus, the content of soluble and insoluble dietary fibers in the end product was increased. A rather interesting approach is drying boza in order to obtain a powder, which will make the beverage more accessible to consumers at any time of the year (Gül et al., 2023).

A promising direction in the development of fermented non-dairy beverages is the creation of new beverages with functional characteristics, for example, juices, as reported in (Garcia et al., 2020). An interesting solution is the use or addition of non-traditional raw materials, as in the study (Scieszka et al., 2021), where the microalgae *Chlorella vulgaris* was used to create a soy lactose-free beverage with the LAB culture *Lvb. brevis*.

Since the fermented beverages, and especially those considered by us, are functional, the introduction and use of certain technological methods should be aimed at preserving all functional properties (Ziarno & Cichońska, 2021). One of the main problems in setting up the production of fermented beverages is the selection and creation of functional leavening compositions.

## CONCLUSION

Fermented food products (beverages made from various raw materials, fermented milk products) are a national heritage for most countries of the world. Interest in non-dairy (plant-based) fermented soft beverages is also growing among consumers. Beverages of this category are traditional for many countries of the world due to the prevalence of raw materials for their production.

Raw materials for non-dairy beverages depend on the country of origin. Usually these are cereal crops - corn, millet, rice, rye, sorghum, as well as tea, as a raw material for the kombucha beverage. Other common fermented beverages are boza, kvass, hardaliye, shalgam, ogi, etc.

The process of fermentation is provided by bacteria (genera *Lacticaseibacillus*, *Lactiplantibacillus*, *Lactobacillus*, *Pediococcus*) and yeast (*Saccharomyces*, *Candida*), as well as molds. The above-mentioned microorganisms, in particular, LAB belong to the group of probiotics, that is, microorganisms that can positively affect the health of the consumer, in connection with which fermented beverages attract attention as potential sources of probiotic LAB.

A significant part of LAB isolated from traditional fermented beverages have certain probiotic properties, in particular, antagonistic, bacteriocinogenic, exopolysaccharides and enzymes synthesis. The combination of raw materials rich in biologically active substances and potentially probiotic LAB makes most of the fermented beverages functional, which actualizes their industrial production.

For some beverages, the problem of the lack of standardized biological preparations for production on an industrial scale remains relevant. Given the scientific interest in fermented plant-based beverages, this problem can be solved by creating fermentation compositions created on the basis of LAB with certain useful properties.

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