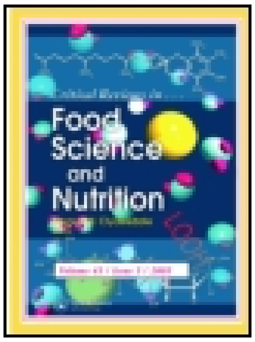


Taylor & Francis
Taylor & Francis Group

Critical Reviews in Food Science and Nutrition

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

Barley-based probiotic food mixture: health effects and future prospects

Ruchi Sharma, Samira Mokhtari, Seid Mahdi Jafari & Somesh Sharma

To cite this article: Ruchi Sharma, Samira Mokhtari, Seid Mahdi Jafari & Somesh Sharma (2021): Barley-based probiotic food mixture: health effects and future prospects, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2021.1921692

To link to this article: https://doi.org/10.1080/10408398.2021.1921692

Published online: 17 May 2021.

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2021.1921692

REVIEW

Barley-based probiotic food mixture: health effects and future prospects

Ruchi Sharma[a], Samira Mokhtari[b], Seid Mahdi Jafari[c], and Somesh Sharma[a]

[a]School of Bioengineering and Food Technology, Shoolini University of Biotechnology and Management Sciences, Solan, Himachal Pradesh, India; [b]Department of Microbiology, Faculty of Agriculture and Forestry, University of Helsinki, Helsinki, Finland; [c]Department of Food Materials and Process Design Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

ABSTRACT

Consumers around the globe are increasingly aware of the relation between nutrition and health. In this sense, food products that can improve gastrointestinal health such as probiotics, prebiotics and synbiotics are the most important segment within functional foods. Cereals are the potential substrates for probiotic products as they contain nutrients easily assimilated by probiotics and serve as the transporters of Lactobacilli through the severe conditions of gastrointestinal tract. Barley is one of the important substrates for the probiotic formulation because of its high phenolic compounds, β-glucans and tocols. The purpose of this review is to examine recent information regarding barley-based probiotic foods with a specific focus on the potential benefits of barley as a substrate for probiotic microorganisms in the development of dairy and nondairy based food products, and to study the effects of food matrices containing barley β-glucans on the growth and features of Lactobacillus strains after fermentation.

KEYWORDS
Probiotics; lactic acid bacteria; barley; functional foods

1. Introduction

The word “probiotic” comes from the Greek word “πρo-βίoς” that means “for life.” Probiotics are defined as “live microorganisms which when administered in adequate amounts confer a health benefit on the host” (Fenster et al. 2019). Normally, the intestinal flora is in a constant state of flux but the balance between them is disturbed by junk food, alcohol, antibiotics, stress, aging and digestive disorders (Amara and Shibl 2015). Based on the amount of ingested food along with the effect of storage on probiotic viability, it was suggested that a daily intake of 10^8–10^9CFU/g probiotic bacteria could survive the upper gastrointestinal tract (GIT) to exert their positive physiological functions in the human body (Turkmen, Akal, and Özer 2019).

Probiotics are an important concept for healthcare in the 21st century. The global probiotics market should reach $69.1 billion by 2024 from $48.4 billion in 2019 at a compound annual growth rate (CAGR) of 7.4% (BCC, 2020). In the global probiotic market, the European market is the largest and fastest growing with an average annual growth rate of around 20% with more use of probiotics in food and medicine. The health benefits of probiotics and rising awareness among consumers are expected to drive the industry growth over the next few years (Zelinska et al., 2018). Microorganisms recognized as probiotics, mainly members of the Lactobacillus and Bifidobacterium genera, are increasingly being used in food preparations and for the development of novel functional foods (Nakkarach and Withayagiat 2018).

The label “functional food” was introduced in 1980 in Japan, which was the first country that stated a specific regulatory approval process for functional foods, known as Foods for Specified Health Use (FOSHU). Several critical factors have been recognized as the key factors leading to the emergence of functional foods: health deterioration due to busy lifestyles, consumption of convenience foods and insufficient exercise, increased incidence of self-medication, increased awareness of the link between diet and health, and a crowded and competitive food market (Begum et al. 2017). In recent years, consumers have become more aware toward the relationship between food and health, which has led to an explosion of interest in functional foods (Periconne et al. 2015). Well-known examples of functional foods are those containing or prepared with bioactive compounds, such as dietary fibers, oligosaccharides, and active and friendly bacteria that promote the equilibrium of intestinal bacterial strains. In addition to the well-established functional ingredients, such as vitamins, minerals, and micronutrients, probiotics belong to an emerging generation of active ingredients, which includes prebiotics, phytonutrients and lipids (Adefegha 2018). The market of functional foods is characterized by an increasing trend, and some researchers reported that probiotic foods represent 60–70% of functional foods (Perricone et al. 2015). Probiotic foods are classically confined to traditionally dairy-based, comprising milk and its fermented products containing live

CONTACT Seid Mahdi Jafari smjafari@gau.ac.ir Department of Food Materials and Process Design Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran; Somesh Sharma sharmawine@gmail.com School of Bioengineering and Food Technology, Shoolini University of Biotechnology and Management Sciences, Solan, 173229, Himachal Pradesh, India.

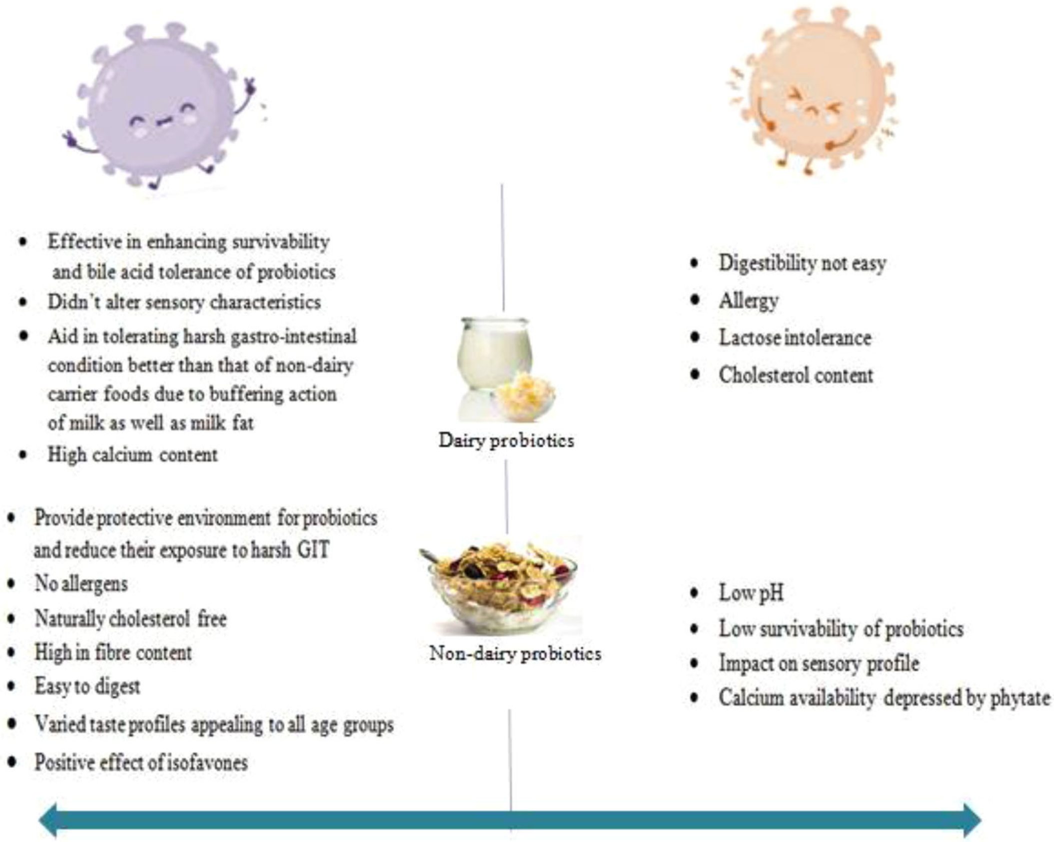


Figure 1. Comparative advantages and disadvantages of dairy and nondairy probiotic foods.

organisms of the Lactic Acid Bacteria (LAB) family. Dairy based products are the main segment of this sector, and it is estimated that they account for 74% of the probiotic products market share (Periconne et al. 2015). However, lactose intolerance, milk protein allergy, high levels of saturated fatty acids and cholesterol content associated with dairy products, tend to enforce the recent shift to the nondairy probiotic foods (Enujiugha and Badejo 2017). Furthermore, cultural (strict vegans) as well as specific religious believes among certain communities may also limit the consumption of dairy foods. In such situations, nondairy probiotic carrier foods are convenient mode of probiotic deliveries (e.g., in tablet forms) (Ranadheera et al. 2017).

Nondairy matrices (legumes, cereals, pseudocereals, fruits, and vegetables) represent potential carriers of probiotics, prebiotics, and bioactive compounds (Salmerón, Thomas, and Pandiella 2015; Valero-Cases et al. 2020) owing to the growing trend on the market for vegetarian foods, together with the high percentage of lactose intolerant people and the presence of cholesterol in dairy products. Hence, there are nutritional reasons for testing lactic acid fermentation as a potential process for production of fermented juices from fruits and vegetables. During storage of fermented drinks, the low pH, nutrient depletion and accumulation of lactic acid is a challenge for the survival of probiotic bacteria being difficult to keep the right microbial doses at the time of consumption. In addition, the studies have reported a viability count greater than minimum recommended (10^6 − a CFU/mL) during the storage making these matrices as an alternative source to dairy probiotics, that can also be consumed by people who are intolerant or allergic to milk proteins, those who are hypercholesterolemic, or those who are vegetarian, among others (Valero-Cases and Frutos 2017; Valero-Cases et al. 2020; Mantzourani et al. 2020). The studies also proved that the fermentation of these matrices can improve the shelf life and their safety due to the organic acids generated during the fermentation period, which further improve digestibility, nutritional and functional composition. In addition, dairy products are generally stored at temperatures close to 5 °C, so probiotic cell viability is probably guaranteed during product shelf life. Storage at room temperature, which is common for many types of nondairy products can create a great challenge for probiotic viability (Vinderola, Burns, and Reinheimer 2017). A schematic illustration on the advantages and disadvantages of dairy and nondairy probiotic foods are given in Figure 1.

Cereals are the potential viable substrates as they hold nutrients easily assimilated by probiotics. Formulation of beverages with cereals is the promising next class of food matrices to serve as the carriers of probiotic bacteria (Salmerón, Thomas, and Pandiella 2015). They have the capability to transport Lactobacilli through the severe conditions of GIT; also, they stimulate the growth of single and mixed-culture fermentations of probiotic microorganisms (Markowiak and Slizewska 2017). Cereal grains can be used as suitable fermentable substrates/carriers for probiotics to produce new functional products in foods and nutraceuticals in the food industry. They contribute over half of the global food produced, and they are grown in over 73% of the world population (Di Stefano et al. 2017). Cereals are comprised of carbohydrates (60–70%), proteins (7–11%), fat (1.5–5%), crude fiber (2–7%), minerals (1.0–2.5%), and vitamins (B-vitamins and tocopherols) (Koehler, Wieser, and Konitzer 2014; Gull, Prasad, and Kumar 2016). Barley (*Hordeum vulgare* L.) represents 12% of the cereal grains and ranks fourth after wheat, rice, and maize (Schulte et al. 2009). Approximately, 65% of cultivated barley is used for animal feed and 33% for malting, whereas only 2% is used directly for human consumption (Idehen, Tang, and Sang 2017). Recently, interest in barley as a food grain is reviving due to heightened consumer awareness of good nutrition and increased interest in foods and food ingredients rich in dietary fiber (Izydorczyk and Dexter 2008). It has also gained popularity due to the functional properties of its bioactive compounds.

The purpose of this review article is to examine recent information regarding barley-based probiotics foods with specific focus on the potential benefits of barley as a substrate for probiotics microorganisms in the development of functional food products. The review will also highlight the great nutritional value and health benefits of barley supporting probiotics beverages.

2. An overview of the composition of barley

Barley grain is clean, bright yellow-white, plump, thin hulled, medium-hard, uniform in size, and is generally suitable for food uses and preferred for pearling (Sharma and Kotari, 2017). Grain hardness is an important characteristic of barley because it determines the pearling and subsequent end-use quality of barley. Whole barley grain consists of about 65–68% starch, 10–17% protein, 4–9% β-glucan, 2–3% free lipids, and 1.5–2.5% minerals (Gupta, Abu-Ghannam, and &Gallaghar 2010). Total dietary fiber of barley ranges from 11% to 34% and soluble dietary fiber from 3% to 20% (Fastnaught 2001). Hordeins are the most abundant proteins (40% to 50%) found in a barley grain (Osman et al. 2002). In addition to hordeins, other proteins have been identified, including albumins, glutelins (globulins), friabilin, enzymes, and serpins (Osman et al. 2003; Borén et al., 2004). Figure 2 shows the main components of barley grain.

Barley presents many bioactive compounds and natural antioxidants. Barley is one of the best sources of tocols among cereals due to a high concentration and favorable distribution of all eight biologically active vitamers (Moreau, Flores, and Hicks 2007) that are known to reduce serum low density lipoproteins (LDLs) through their antioxidant action (Gupta, Abu-Ghannam, and &Gallaghar 2010). Many of the natural antioxidants present in barley exhibit a wide range of biological effects including antibacterial, antiviral, anti-inflammatory, anti-allergic and antithrombotic effects, and may also be involved in vasodilatory actions (Chandrasekara and Shahidi 2018). Compared to other grains, the amount of arabinoxylans, another antioxidant present in barley, is similar to that in wheat (5.8%), but higher than in oats (2.7% to 3.5%), sorghum (1.8%), or rice (2.6%) (Izydorczyk and Biliaderis 2007). Polyphenols comprise a prominent proportion of antioxidants in barley including anthocyanins, flavonols, phenolic acids, catechins and more than 50 types of proanthocyanidins (Friedrich, Eberhardt, and Galensa 2000). The major phytochemicals in barley includes phenolic acids, flavonoids, lignans, vitamin E (tocols), sterols, and folates (Idehen, Tang, and Sang 2017). β-glucan is also the predominant soluble fiber found in barley and has been shown to reduce serum cholesterol and improve post-prandial insulin and glucose responses in healthy and diabetic adults (Tosh 2013).

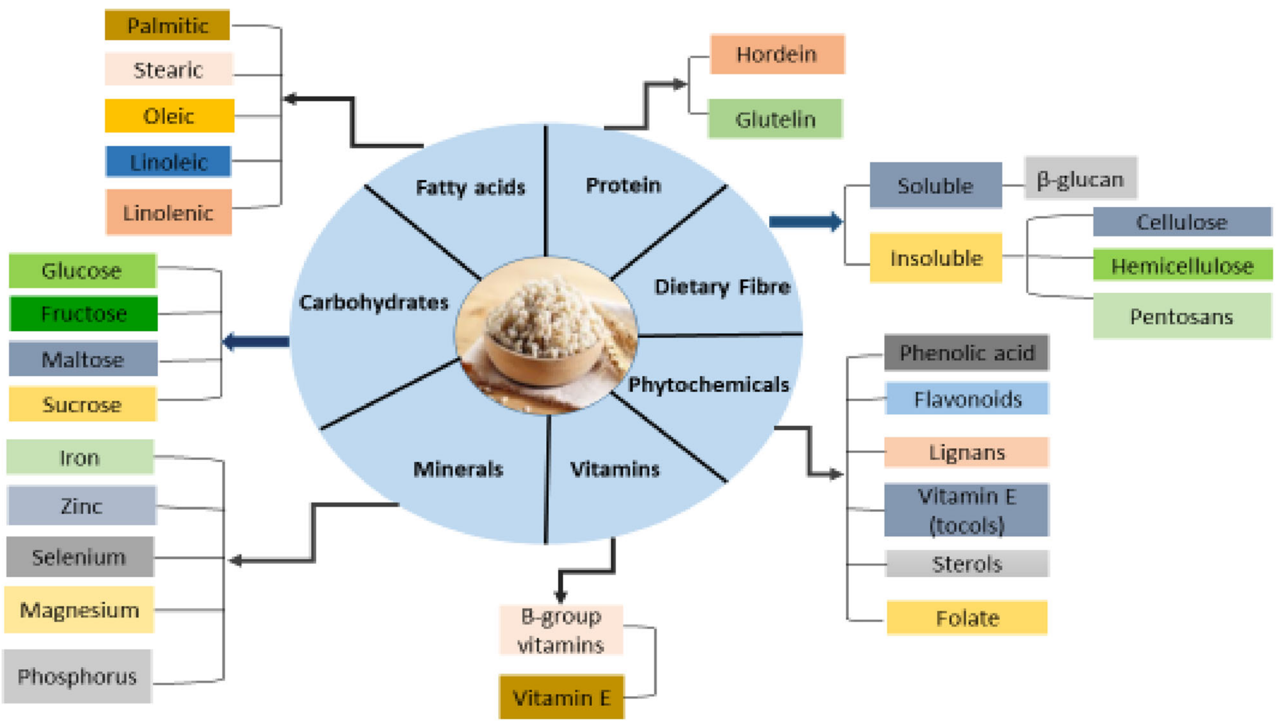
3. Uses of barley

Whole barley grain is mostly used for animal feed, whereas de-hulled barley grain items are mostly used for human consumption. Barley flakes, grits, and flour are all commercially available wholegrain products (OECD 2004). Cooked pearled barley is used in the production of miso, barley tea, and rice extender. Bread, flat breads (pitas, tortillas, and chapatis), cakes, muffins, cookies, noodles, and extruded snack foods can all be made with barley flour (Ullrich 2010). Barley starch is used in conjunction with barley malt to make beer and also has applications such as sweetening and binding agent in the food industry. Malt extract is a source of soluble sugars, protein, and amylase in the dough, and promotes yeast development, which is used to make breakfast cereals, fermented and non-fermented bakery products (e.g., crackers, cookies, and muffins) with improved texture and volume (Tricase et al. 2018).

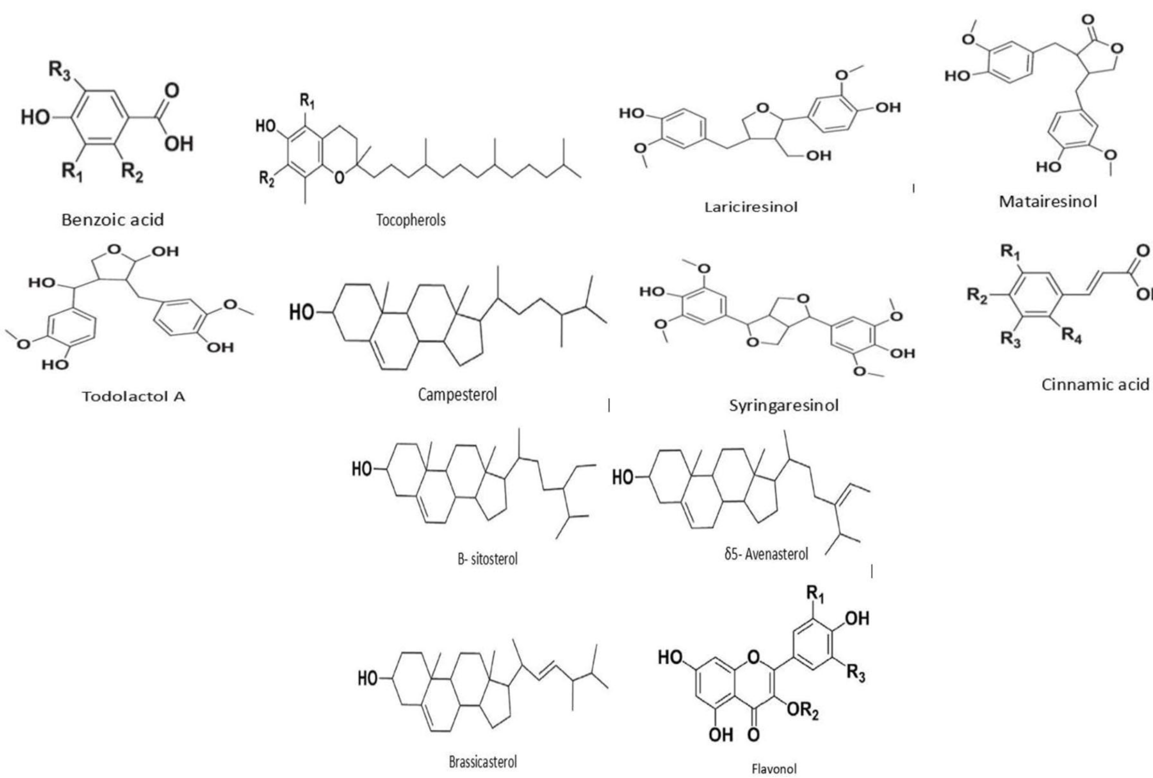
The current utilization of barley grain is for bioethanol production in the United States and the European Union when the cheapest starch sources, such as corn or wheat, are unavailable or there is a surplus of barley production (Nghiem et al. 2017). However, the use of barley residues or residual barley by-products as bio-energy sources is being investigated and as a result, hydrothermal liquefaction technology may be useful in obtaining bio-oil for use in transportation or the energy sector to generate heat and/or electricity (Zhu et al. 2015). Furthermore, the high concentration of phenolics, vitamin E and β-glucan, sterols, fatty acids, and bioactive peptides in barley grain and distillery and brewery by-products makes barley a possible source to be used in the pharmaceutical and cosmetic industries. Lactic acid, xylitol, and microbial enzyme are also barley products that are useful in a variety of industries (Nigam 2017).

4. Barley-based probiotic foods

Barley is rich in β-glucans, a functional bioactive ingredient which comprises a group of β-D-glucose polysaccharides found in the cell walls of cereals, yeasts, bacteria, and fungi, with different properties depending on the source (Gangopadhyay et al. 2015). Food and Drug Administration (FDA) has approved β-glucan (3 g/day) to qualify for the coronary heart disease (CHD) claims (FDA 2005). Fortification of foods with β-glucan is of great interest



(a)



(b)

Figure 2. Representation of (a) nutritional profile, and (b) bioactive compounds of barley.

including pasta, tea, muffins, bread, yogurt and beverages (Ahmed et al. 2017). Foods containing probiotics are frequent on the market, and it could be argued that co-ingestion of probiotic strains could affect health outcomes rising from gut fermentation of indigestible carbohydrate substrates (Nilsson et al. 2016). The dairy and nondairy probiotics food products with barley as a substrate are discussed in the following sections.

4.1. Dairy-based barley probiotics

Barley has been reported to be a great supplementation for dairy probiotic foods since it is naturally healthy, readily available and relatively inexpensive (Newman and Newman 2006). Ahuja (2015) developed a barley milk-based probiotic beverage with *Lactobacillus plantarum* culture for 12 h at 37 °C and reported an approximate 8.59 logCFU/mL of probiotic count and 0.14 g/100g of β-glucan. Gupta, Khetarpaul, and Chauhan (1992) attempted preparation of barley butter milk-based traditional beverage popularly using curd starter called as rabadi at different time-temperature combinations (30, 35 and 40 °C for 6, 12, 18, 24 and 48 h). The beverage was reported to have overall acceptability score in a range of 6.35–8.36 on the basis of 9-point hedonic scale and this also depends on time and temperature of incubation. Barley flour rabadi fermented at 35 °C for 18 h had the highest overall acceptability (Gupta, Khetarpaul, and Chauhan 1992). Ganguly and Sabikhi (2012) also developed a composite dairy-cereal substrate consisting of whey skim milk, germinated pearl millet flour and liquid barley extract which was fermented by *Lactobacillus acidophilus* NCDC 13, (National Collection of Dairy Cultures). A high count of 13.22 log CFU/mL was reported in the substrate with 4% inoculum level and 8 h incubation at 37 °C. In another study by Ganguli et al. (2014) the phytic acid, polyphenol contents and phytate phosphorous were reported to be reduced by 80, 47.2, 76.5% with concomitant increase by 69 and 64% in the bioavailability of Ca and Fe, respectively. The protein and starch digestibility of the mixture were reported to increase from 45.4 and 43.4% to 62.4 and 57.8% respectively. Table 1 summarizes the variety of dairy-based barley probiotics.

4.2. Nondairy-based barley probiotics

Nondairy based probiotic foods are finding their way into our routine life one by one. This group of probiotic beverages are not new, and many nondairy preparations of cereals such as wheat, maize and barley have been traditionally made for centuries in many parts of the world. Cereals have complex nutrient composition and are being consumed on a daily-basis all over the world as one of the staple foods. Many of cereals have been recognized as origin of some strains of probiotics, whereas microorganisms used as probiotics are mostly of human or animal origin (Kumar, Vijayendra, and Reddy 2015). Numerous fermented dairy products using probiotic microorganisms have been prepared so far, but much less work has been done on the development of probiotic fermented products based on cereals (Enujiugha and Badejo 2017). Table 2 summarizes the variety of nondairy based barley probiotic products worldwide.

A nondairy fermented probiotic drink based on germinated and non-germinated seeds of barley and legume (finger millet and moth bean) was developed by Chavan et al. (2018). The drink mixtures were added to distilled water and milks like soy, almond and coconut in different concentrations and inoculated with *Lactobacilli acidophilus.* According to them, fermentation improved the overall acceptability and functional properties of beverage during fermentation. Changes in the pH, acidity, bacterial count, 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay and polyphenol content were increased as the concentration of drink mixture increased in milk and distilled water. Mridula and Sharma (2015) developed a nondairy probiotic drink using a mixture of sprouted cereals including barley, wheat, pearl millet and green gram separately with oat, stabilizer portion. Acidity and pH in different probiotic samples ranged from 0.45 to 1.02% and 4.11 to 4.49, respectively. Probiotic count ranged from 10.36 to 11.17 log CFU/mL in barley-based probiotics, respectively with increasing level of grain flour (Mridula and Sharma 2015).

Single and mixed cereals (barley and malt) based probiotic beverages containing *Lactobacillus plantarum* and *Lactobacillus acidophilus* in the range of 7.9 and 8.5 log CFU/mL also have been developed by Rathore, Salmerón, and Pandiella and proved malt to be the best substrate (as single and mixed media) for LAB growth with significant amounts of lactic acid were produced (0.5–3.5 g/L). This development concludes that the functional and organoleptic properties of cereal-based probiotic drinks could be considerably modified by changing the substrate or inoculum concentration (Rathore, Salmerón, and Pandiell). Moreover, Helland, Wicklund, and Narvhus (2004) estimated the growth and metabolism of *Lactobacillus reuteri*, *Lactobacillus acidophilus* (LA5 and 1748) and *Lactobacillus rhamnosus* GG in maize porridge with added malted barley. The results showed most strains reached the maximum cell count of 7.2–8.2 log CFU/g after 12 h fermentation, with a pH below 4.0. High amounts of diacetyl and acetoin were detected in porridge when inoculated with *Lactobacillus rhamnosus* GG. The inoculated cell concentration was shown to be particularly important during the first hours of the fermentation period, showing a delayed production of most metabolites in porridge inoculated with approximately 6 log CFU/g (Helland, Wicklund, and Narvhus 2004).

5. Fermented barley as a probiotic functional food

Probiotic microorganisms are delivered into food or dairy products via supplementation and fermentation. Fermentation is an ancient and inexpensive food preservation method as it improves the nutritional value of raw products by enhancement of sensory characteristics, and improving functional qualities (Rakhmanova, Khan, and Shah 2018). Anti-nutrients such as phytic acid, tannins, and polyphenols when present in cereals can bind to proteins and lead to a reduction in digestibility. Fermentation by LAB showed a reduction in phytic acids and tannins content, therefore enhancing the protein availability and digestion (Salari, Razavi, and Gharibzahedi 2015). Fermentation also provides optimum pH for enzymatic degradation of phytate which may increase the amount of soluble iron, zinc and calcium (Blandino et al. 2003). The gut microbiota comprises mostly anaerobic bacteria that need fermentative substrates to obtain metabolic energy for their growth and

Table 1. Variety of dairy-based probiotic products containing barley.

Product	Microorganism	Microbial cell count in the product	Temperature/ incubation time	Obtained results	Country	Reference
Fermented milk	*Lactobacillus helveticus*	6.586 CFU/mL	42 °C/-ND	The fermented milk improved the nutrient value, shelf life and decreased the production cost for the end products	Egypt	El-Aidie et al. (2017)
Yogurt	*Bifidobacteriumbifidum*Bb-12	9.42 CFU/g	37 °C/23 h, 42 °C/3 h	The survival of *Bifidobacteriumbifidum*was within biotherapeutic level (>7 log CFU/g) as a result of the prebiotic effect of barley	Turkey	Ozcan and Kurtuldu (2014)
Milk	*Lactobacillus rhamnosus* GR-1	16.9×10^8 CFU/mL	37.5 °C/24 h.	The probiotic milk supported the growth of *Lactobacillusrhamnosus*GR-1 at viable levels (10^8 CFU/mL) during the first 14 days of storage	Canada	Maselli and Hekmat (2016)
Yogurt	*Lactobacillus acidophilus*	7.42–7.77 $\log_{10}$ CFU/mL	42 °C/4 h	Incorporation of barley bran in low-fat yogurt containing *Lactobacillus acidophilus* significantly affected viable probiotic bacteria in comparison with control group	Iran	Hasani et al. (2017)
Yoghurt	*Lactobacillus rhamnosus* GR-1	10.4×10^8 CFU/mL	38 °C/24 h.	Yoghurt did not have any negative effect on the growth and survival probiotics and had the potential as a vehicle to deliver *Lactobacillusrhamnosus* GR-1 to consumers	Canada	Soltani, Hekmat, and Ahmadi (2018)
Yoghurt	*Bifidobacteriumanimalis* ssp. lactis (Bb-12TM)	ND	42 °C/48 h	Supplementation of yogurt with selected prebiotics improved viability and stability of *probiotics* in yogurt during 4-wk cold storage. The barley β-glucan addition suppressed proteolytic activity	Australia	Vasiljevic, Kealy, and Mishra (2007)
Milk	*Lactobacillusplantarum* NCDC344 (Lp344)	8.59 log CFU/mL	37 °C/ND	The optimized drink rated 7.80 on a 9-point hedonic scale, and 0.144 g/ 100 g of β-glucan	India	Ahuja et al. (2017)
Milk	*Lactobacillusparacasei subsp. paracasei B117*	7.93–8.92 log CFU/mL	40 °C/ND	*Lactobacillus paracasei* showed good compatibility with the yogurt starter culture and the addition of β -glucan enhanced the viability of the probiotic strain in the fermented products throughout cold storage (4 °C)	Greece	Lazaridou et al. (2014)
Low-fat yoghurt	*Bifidobacteriumlactis Bb-12; Lactobacillus acidophilus LA-5*	9×10^7 CFU/mL	37 °C/24 h.	Addition of barley β-glucans improved the formation of flavors in yoghurt. The substitution of fat with β-glucans enhanced sensory attributes of yoghurt, wherein β-glucans -enriched samples recorded high score and acceptability	Egypt	Elsanhoty and Ramadan (2018)
Yoghurt	*Lactobacillus acidophilus, Bifidobacteriumlactis* Bb12	10^7 CFU/g	40 °C/ND	Values of carbohydrate, volatile fatty acids, unsaturated fatty acids, antioxidant activity were higher in milk supplemented with barley flour; addition of vanilla (0.1%) or cocoa powder (0.5%) improved the sensory properties	Egypt	Ismail, Hamad, and Elraghy (2018)

ND: Not defined.

activity (Jalili-Firoozinezhad et al., 2019; Arena et al. 2014). Numerous fermented dairy products using probiotic microorganisms have been prepared so far, much less work has been done on the development of probiotic fermented products based on cereals (Enujiugha and Badejo 2017).

Fermentation of cereals increase the shelf-life, digestibility and bioavailability of many nutrients such as B-group vitamins, minerals such as phosphorous, iron and zinc due to the action of microbial enzymes such as phytases and/or organic acids produced during fermentation of cereals (Kumar, Vijayendra, and Reddy 2015; Keşkekoğlu and Üren 2013). During fermentation, the grain constituents are modified by the action of both endogenous and bacterial enzymes, including esterases, xylanases and phenoloxidases, thereby affecting their structure, bioactivity and bioavailability. Cereal-based LAB fermentation has been shown to increase the levels of nutrients including folates, soluble dietary fiber and total content of phenolic compounds in cereals, and to improve the protein digestibility and short chain fatty acid production in vitro (Anson et al. 2009). It has also

Table 2. Nondairy probiotic products containing barley.

Product	Microorganism	Microbial cell count/	Temperature/ incubation time	Obtained results	Country	Reference
Beverage	*Lactobacillus rhamnosus*GG	6.68–7.58 log CFU/g	37 °C/10 h	Barley flour fermented in water produced the highest probiotic culture density for *Lactobacillus rhamnosus*GG when compared to other cereal-grain flours	Slovakia	Kockova and Valík (2014)
Beverage	*Lactobacillus plantarum* NCIMB8826, *Lactobacillus acidophilus* NCIMB 8821	7.9–8.5 Log_{10} CFU/mL	30 °C/28 h	LAB growth was enhanced in media containing malt and (0.5–3.5 g/L) of lactic acid were produced	UK	Rathore, Salmerón, and Pandiella
Beverage	*Bifidobacteriumadolescentis NCIMB 702204, B. infantis NCIMB 702205,B. breve NCIMB 702257, B. longum NCIMB 702259*	8.73–9 log_{10} CFU/mL	37˚C/24–36 h	The results showed an increase in bacterial population between 1.5 and 2.0 log10 cycles with a maximum growth rate of approximately 0.2 per hour	UK	Rozada-Sánchez et al. (2008)
Beverage	*Lactobacillus paracasei, Lactobacillus delbrueckii*	1.2×10^6 CFU/mL	37 °C/24 h	Significant decrease in pH value to 4.25 and a considerable increase in titratable acidity level to 2.96 g/100 g lactic acid were obtained by initial 6 h fermentation of *Lactobacillus paracasei* on malt medium	Iran	Salari, Razavi, and Gharibzahedi (2015)
Probiotic drink	*Lactobacillus acidophilus Bifidobacteriumlactis* Bb12; *Bifidobacteriumlactis* Bb12	8.1–8.60 log CFU/mL	37 °C/48 h	Acidity, pH, probiotic count, level of antioxidants and polyphenols increased as the concentration of drink mixture increased. Germinated probiotic drink had higher values of Total phenolic content	India	Chavan et al. (2018)
Beverage	*Lactobacillus acidophilus* NCIMB 8821;*Lactobacillus plantarum* NCIMB 8826; *Lactobacillus reuteri* NCIMB 11951	7.73 ± 0.08–8.20 ± 0.07 CFU/mL	37 °C/20 h	The beverage formulated with *Lactobacillus plantarum* and malt substrate exhibited greater acceptance and it encompassed the highest concentration of acetaldehyde	UK	Salmerón, Thomas, and Pandiella (2015)
Porridge	*Lactobacillus reuteri* SD 2112; *Lactobacillus acidophilus* LA5; *Lactobacillus acidophilus* NCDO 1748; *Lactobacillus rhamnosus* GG (ATCC 53103)	7.2–8.2 log CFU/g	37 °C/24 h	Small amounts of diacetyl, were detected in porridge inoculated with *Lactobacillus acidophilus* 1748 and *Lactobacillus acidophilus* LA5	Norway	Helland, Wicklund, and Narvhus (2004)
Food Mixture	*Lactobacillus acidophilus*	8.88 CFU/g	37 °C/12 h	Improvement in reducing sugar, thiamin, niacin, lysine and soluble dietary fiber contents of barley based food mixtures	India	Arora, Jood, and Khetarpaul (2010)
Probiotic drink	*Lactobacillus acidophilus*	9.10–11.32 log CFU/mL	37 °C/8 h	Acidity (in terms of lactic acid) and pH in probiotic drink samples ranged from 0.45 to 1.02% and 4.11 to 4.49	India	Mridula and Sharma (2015)

been reported that the antioxidants in buckwheat, wheat germ, barley and rye increased after the fermentation with *Lactobacillus rhamnosus* and *Saccharomyces cerevisiae* (Đorđević, Šiler-Marinković, and Dimitrijević-Branković 2010). Improvement in cell growth of probiotic bacteria in fermented barley beverage was reported by Salari, Razavi, and Gharibzahedi (2015) where they study characteristics of synbiotic beverages based on barley and malt flours fermented by *Lactobacillus delbrueckii* and *Lactobacillus paracasei* strains. They found the highest microbial growth (9.7 log CFU/mL) in malt medium after 15 h of fermentation. Many studies on probiotics formulated with barley cereal as a substrate is showing that the LAB count is increasing after the addition of barley extract or any form of it. Coda et al. (2012) used cereal (rice, barley, emmer and oat), "concentrated red grape must" and soy flours for making vegetable yogurt-like beverages. Two selected strains of *Lactobacillus plantarum* were used for lactic acid fermentation and were inoculated at a cell density of approximately 7 log CFU/g. The starters remained viable at 8.4 log CFU/g throughout storage (Coda et al. 2012).

Moreover, malt-based beverages fermented with *Lactobacillus delbrueckii* were reported to be the best sample due to the highest cell viability (1.2×10^6 CFU/mL) after 4 weeks under cold-storage (Salari, Razavi, and Gharibzahedi 2015). Apart from the contribution of fermentation to improving survival of probiotics in cereal foods, cereal extracts also showed a capacity to increase the tolerance of probiotic bacteria to harsh conditions. For instance; cereal extracts from malt, barley and wheat significantly improved the acid tolerance of three Lactobacilli (*Lactobacillus plantarum, Lactobacillus acidophilus* and *Lactobacillus reuteri*) to gastric acid (Charalampopoulos, Pandiella, and Webb 2003). This could be due to the total sugar, reducing sugar, soluble sugars, and free amino nitrogen content of cereal extracts, which all contribute to the breakdown of starch and proteins resulting in higher cell viability. Since food formulations with pH ranging from 3.5 to 4.5 and high buffering capacity will increase the pH of the gastric tract, the buffering capacity and pH of the carrier medium are important factors that improve the probiotic strain's stability. In this analysis, however, the effect of buffering power on cell viability was minimized. Michida et al. (2006) also compared the influence of malt and barley extracts on the survival of *Lactobacillus plantarum* in gastric and bile acids, and found the higher content of sugars in the malt extract enabled these bacteria to tolerate the acid conditions better than the barley extract (Michida et al. 2006).

Improvement of bioavailability in barley beverages by fermentation has also been reported. Hole et al. (2012), conducted a study to enhance the bioavailability of the dietary phenolic acids in flours from whole grain barley following fermentation with LAB strains, *Lactobacillus johnsonii* LA1, *Lactobacillus reuteri* SD2112 and *Lactobacillus acidophilus* LA-5. Their results exhibited high feruloyl esterase activity with an increase of free phenolic acids from 2.55 to 69.91 $\mu g\ g^{-1}$ Dry Matter (DM) in whole grain barley. In particular, they observed that ferulic acid content in barley was 81.9% higher than in non-fermented substrates after fermentation (Hole et al. 2012). Arora, Jood, and Khetarpaul (2010) also examined the effect of germination and probiotic fermentation on nutrient composition of barley-based food mixtures and observed that when germinated autoclaved barley mixture was fermented with probiotic (*Lactobacillus acidophilus*) it caused an enhancement of thiamin (14%), niacin (11%) and lysine (34%). The cell count also was found to be significantly higher in the fermented food mixture formulated from germinated flour (8.88 log CFU/g) as compared to the non-germinated barley-based food mixture (7.75 log CFU/g) (Arora, Jood, and Khetarpaul 2010). Similarly, the production of sixty volatile compounds were identified by Salmerón et al. (2009) using the probiotic strain, *Lactobacillus plantarum* NCIMB 8826 (National Collection of Industrial and Marine Bacteria), in cereal-based media (oat, wheat, barley and malt). The aroma profile was significantly changed by *Lactobacillus plantarum* and the most abundant volatiles detected in barley was acetic acid (Salmerón et al. 2009). Moreover, the β-glucans present in cereals including barley have been reported to be highly fermentable by the intestinal microbiota in the cecum and colon; consequently, enhancing both growth rate and lactic acid production of microbes isolated from the human intestine (Kedia, Vázquez, and Pandiella 2008).

Fermentation of barley has been also shown to reduce anti-nutrients. In the study of Sindhu and Khetarpaul (2001), single culture fermentation or sequential culture fermentation (by Lactobacilli and yeast) of an indigenously developed mixture containing barley flour, milk co-precipitate, sprouted green gram paste and tomato pulp was reported to drastically decrease the levels of anti-nutrients such as phytic acid, polyphenols, trypsin inhibitor activity, while improved the in vitro digestibilities of starch and protein (Sindhu and Khetarpaul 2001). An increase in gamma aminobutyric acid content was also reported when germination and sourdough fermentation of barley flours by strains of *Lactobacillus plantarum*, *Lactobacillus rossiae* and *Lactobacillus sanfranciscensis* were used (Montemurro et al., 2019). Đorđević, Šiler-Marinković, and Dimitrijević-Branković (2010) showed that fermentation of several cereals including barley by *Lactobacillus rhamnosus* for 24 h increased total phenolic content and antioxidant activities measured by diphenyl-2-picryl-hydrazyl radical scavenging activity, ferric ion-reducing antioxidant power and lipid peroxidation inhibition ability (Đorđević, Šiler-Marinković, and Dimitrijević-Branković 2010).

6. Physiological effects of barley probiotics

The pivotal role of nutrition for maintaining a good state of health is a well-accepted notion. A correct diet can have preventive and curative effects on the diseases and disorders of various origins, including obesity, phlogosis, immune dysfunctions, cancer and the detrimental consequences of aging (Johnston et al. 2017). Cereals (wheat, barley, corn, rice) and pseudocereals (buckwheat, amaranth) are known to be important sources of bioactive peptides with anticancer, anti-inflammatory, antioxidant and cardiovascular protective properties (Laurent-Babot and Guyot 2017). Fermentation of cereal and pseudo-cereal flours with sourdough LAB was shown to successfully increase the concentration of the anticancer peptide lunasin known for its anticancer activities (Hernandez-Ledesma, C Hsieh, and O De Lumen 2013; Rizzello et al. 2012). There are two types of dietary fibers: soluble fiber including pectin, fructo-oligosaccharides and oat β-glucan; and insoluble fiber including cellulose (Sima, Vannucci, and Vetvicka 2018). After soluble fiber consumption, a delay occurs in the intestinal absorption of glucose and lipids and inhibition of absorption and reabsorption of cholesterol and bile acids accompanied by increased excretion of bile acids. The reduced absorption may be caused by the high viscosity of β-glucan solutions, which increases the viscosity of the intestinal contents (Ames and Rhymer 2008).

According to the FDA (2006), the recommended level of β-glucan in functional drinks should be 0.75 g, which results in 3 g per day in four servings. Barley is a great source of β-glucan; functional drinks made from barley also present β-glucan in substantial quantities. Use of barley as a suitable substrate for the growth of probiotic microorganisms improves functionality of colonic strains due to presence of non-digestible components such as β-glucan, arabinoxylan, galacto- and fructo-oligosaccharides, and soluble dietary fiber of barley grain, as well as enhancing the bioavailability of LAB (Charalampopoulos et al. 2002; Elsanhoty, Zaghlol, and Hassanein 2009). Barley also contributes to decrease cholesterol absorption, lowering blood glucose levels and improved gut microbial balance (Wang et al. 2016). Daily intake levels of 0.75 g barley β-glucan for 30 days has demonstrated a bifidogenic effect in older healthy volunteers (Mitsou et al. 2010). β-glucan may affect the colonic mucosa as well as mucosal and systemic immunity, including mucosal repair in chronic inflammation and the reduction of pro-inflammatory cytokines (Hung and Suzuki 2016). Supplementation with isolated barley β-glucans of different molecular weights had small effects on cardiovascular

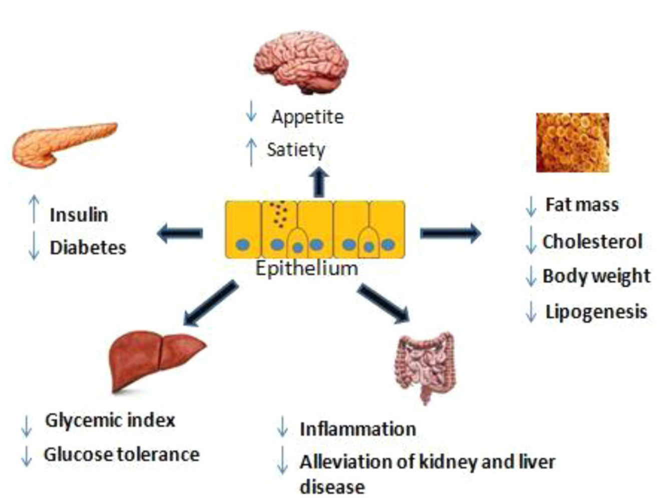


Figure 3. Modulation of intestinal microbiota and physiological effects upon consumption of barley-based probiotic food mixture.

disease markers. Molecular weight of the barley fiber altered the body weight with the high-MW fiber significantly decreasing body weight (Smith et al. 2008). Figure 3 summarizes the physiological effects upon consumption of barley probiotics.

Animals and human models have been used to evaluate the effects of probiotics on serum cholesterol levels over the years. Many studies have used rats, mice, hamsters, guinea pigs and pigs as models due to their similarities with humans in terms of cholesterol and bile acid metabolism, plasma lipoprotein distribution, and regulation of hepatic cholesterol enzymes. These animals also share an almost similar digestive anatomy and physiology, nutrient requirements, bioavailability and absorption and metabolic processes with humans, making them useful experimental models for research applications (Ooi and Liong 2010). Table 3 represents the *in-vivo* and *in-vitro* studies on physiological effects of barley probiotics.

Ganguly, Sabikhi, and Singh (2019) studied the effect of whey-pearl millet-barley based probiotic beverage on *Shigella* induced pathogenicity in murine model. Probiotic beverage prepared from whey-skim milk (60:40, v/v), germinated pearl millet flour (4.73%, w/v) and liquid barley malt extract (3.27%, w/v) with *Lactobacillus acidophilus* NCDC 13 was found effective in controlling *Shigella*-induced pathogenicity in mice model by reducing translocation of pathogen in various organs and increased secretion of IgA level in intestinal fluid (Ganguly, Sabikhi, and Singh 2019). Similarly, Hypocholesterolaemic effect of probiotic yogurt enriched with barley β-glucan in rats fed on a high-cholesterol diet was examined. Four treatments of yogurt were formulated, where the first and second treatments were produced from skim milk and without the addition of β-glucan and fermented by yogurts starter. The third and fourth treatments were produced from skim milk with and without the addition of 0.75% β-glucan and fermented by *Bifidobacterium lactis* plus *Lactobacillus acidophilus*. The results indicated that yogurt containing probiotic bacteria and β-glucan was more effective in lowering of plasma and liver cholesterol levels than other treatments (Ahmed et al. 2017).

Oro-gastrointestinal (OGI) tract is the tract from the mouth to the anus and includes all the organs of the digestive system; tolerance of probiotics to this tract is essential for cell survival, intestinal passage, and further colonization of the colon (Damodharan et al. 2019). The ability of a probiotic to survive through the GIT system depends mainly on their acid and bile tolerance. During GIT passage, the strains are required to tolerate the presence of pepsin and the low pH of the stomach, the presence of enzymes in the duodenum, and the antimicrobial activity of bile salts (Millette et al. 2013). Arena et al. (2014) reported the effects of food matrices containing barley β-glucans on growth and probiotic features of four Lactobacillus strains. They observed that the food matrices, containing β-glucans, enhanced the OGI stress tolerance by probiotic strains. Although survival in the OGI transit was substantially unaffected by the presence of β-glucans in the carrier matrix, the effect of β-glucans-containing food on bacterial adhesion onto enterocyte-like cells was analyzed and a positive influence on probiotic-enterocyte interaction was observed. The matrices also improved the growth rate of the tested bacteria in unstressed conditions (Arena et al. 2014).

Zhang et al. (2019) investigated the effect of fermented barley extracts with *Lactobacillus plantarum* dy-1 for modulating glucose consumption in HepG2 cells (a human liver cancer cell line) via miR-212 regulation. Moreover, the contribution of miR-212 to the occurrence of palmitate-reduced glucose consumption (insulin resistance) was studied. They reported that fermented barley extract and phenolic acids with significant effects on glucose consumption may have a potential role in the prevention of obesity (Zhang et al. 2019). Zhang et al. (2016) investigated the effect of supplementary *Lactobacillus plantarum* dy-1 fermented barley on obesity in high-fat diet (HFD) induced obese rats. They reported a lower rate of increase in body weight and percentage of body fat and a reversal of HFD-induced glucose intolerance, with ameliorated hyperinsulinemia, decreased levels of triglycerides and total cholesterol, and inhibited concentration of interleukin (IL)-1β, IL-6 and tumor necrosis factor-α (Zhang et al. 2016). Same group also reported in their next study that oral administration of an aqueous extract of fermented barley with *Lactobacillus plantarum* dy-1 significantly prevented body weight gain and fat mass increase, and improved lipid profiles and glucose tolerance in high fat diet-induced obese male rats. In contrast, an aqueous extract of fermented barley with *Saccharomyces cerevisiae* had no significant anti-obesity effects. This report indicates the role of probiotic strain in the final functional properties of the food. They also reported that phenolic acids (mainly vanillic acid and ferulic acid) and β-glucan in fermented barley with *Lactobacillus plantarum* dy-1 were responsible for the lipid accumulating actions and may be considered primary anti-obesity mediators. The data indicated the potential of fermented barley in future strategies for functional supplements against obesity and obesity-related diseases (Zhang et al. 2017).

7. Challenges with barley probiotic food products

The presence of a husk that is difficult to remove and the lack of gluten protein in barley limits its use in leavened bakery products. Barley grain contains considerable amounts

Table 3. In vivo and in vitro studies on the physiological effects of barley-based probiotics.

Types of disease or disorder	Product	Probiotic strains	Probiotic outcome/results	Subject	Country	Dose level	References
Coronary heart disease	Indigenous food mixture	*Saccharomyces boulardii*; *Lactobacillus casei*	Serum cholesterol and LDL cholesterol concentrations	Mice	India	NA	Sindhu and Khetarpaul (2003)
		Hypocholesterolemic impact	Yoghurt			*Streptococcus salivarius* subsp. *Thermophiles*;	
		Lactobacilliusdulbrueekii sub sp. *Bulgaricus*	Lowering of plasma and liver cholesterol levels	Rats	Egypt	NA	Ahmed et al. (2017)
Metabolic syndrome (MetS) related diseases (obesity and type 2 diabetes)	Probiotic yoghurt (Activia); Probiotic tablet: (Probiomax) ; Probiotic tablet: (Probimage)	*Bifidobacteriumanimalis* DN-173 010; *Lactobacillus reuteri* DSM 17938; *Lactobacillus plantarum* 299v	Postprandial glycemic regulation and increased plasma concentration of gut hormones important to metabolic regulation and appetite control	Mice	Sweden	200 ml/day; 20×10^9 CFU/day 10×10^9 CFU/day 0.1×10^9 CFU/day	Nilsson et al. (2016)
Gastrointestinal diseases	ND	*Lactobacillus reuteri*	Strain showed great resistance to GIT conditions, including strong adherence to HT-29 cells and inhibitory activity against *E. coli*, *Shigellaflexneri*, *Salmonella paratyphi* β, and *S. aureus*.	Mice	China	_	Chen et al. (2018)
Inflammatory bowel disease, ulcerative colitis and Crohn disease	ND	*Clostridium butyricum*	Suppresses the Dextran Sulfate Sodium-induced Experimental Colitis	Rats	Japan	NA	Araki et al. (2000)
Shigelosis and infectious diarrhea	Beverage	*Lactobacillus acidophilus* NCDC 13	Reduction in *Shigella* induced pathogenicity	Murine	India	5g/animal/day	Ganguly, Sabikhi, and Singh (2019)
Intestinal diseases	ND	*Lactobacillus rhamnosus* MA27/6B; *L. acidophilus* MA27/6R	Ability to survive feed processing and intestinal tract conditions; they have no antibiotic resistance-linked plasmids, adhere to Caco-2 cells and have a wide anti-microbial spectrum	Swiss mice	France	NA	Bernardeau, Vernoux, and Gueguen (2002)
Intestinal diseases	Food mixture	*Lactobacillus acidophilus*	Alleviation of kidney and liver lesions caused by *E. coli* infection	Mice	India	NA	Jood, Khetarpaul, and Goyal (2012)
Inflammation of the colon	ND	*Lactobacillus rhamnosus* 271; *Lactobacillus paracasei* 87002; *Lactobacillus plantarum* HEAL 9 and 19; *Bifidobacterium infantis* CURE 21	Decrease in the cecal and portal levels of acetic acid, amino acids (glycine, proline, asparagine and phenylalanine) in the portal blood of rats also increased	Rats	Sweden	0.82 g/day	Zhong and Nyman (2014)

NA: Not applicable; ND: Not defined.

of polyphenol oxidase (Sharma and Kotari 2017). Polyphenol oxidase reacts with phenolic compounds to produce *o*-quinones, which further react with other phenolic compounds or amino acids causing discoloration in various foods made from barley (Lagassé et al. 2006). On the other hand, probiotic bacteria experience several challenges during food processing and storage due to various factors such as acid-base changes, oxidative stress, temperature and molecular entrapments (Trujillo-de Santiago, Sáenz-Collins, and Rojas-de Gante 2012). There is also after-consumption stress of acid and bile in the upper GIT inhibiting the viability of probiotics. Probiotics, therefore, must exhibit high survivability in food products during storage and through the upper GIT. The packaging materials used and the storage conditions under which the products are kept are also important for the quality of products containing probiotic bacteria (Saarela et al. 2000). Survival of Lactobacillus strain at −18 °C was poor, showing a decrease of 1 log units in cell count. At −35 °C, however, its viability improved, with a decreased cell count to 0 to less than 1 log unit. They were fully stable at −45 °C with no losses.

Storage at room temperature, which is common for several types of nondairy products such as cereal products and drinks, can create an overwhelming challenge for probiotic stability (Saxelin et al. 1999). It is reported that the survival of *Lactobacillus helveticus* in barley-based fermented milk products decreased during storage at room for 120 days. The decrease in total LAB counts ranged from 6.586 log CFU/

mL on 0 days to 5.753 log CFU/mL on 120 days of storage (El-Aidie et al. 2017). Survivability problem in probiotic products can be solved by using encapsulation technology, which provides great potential to protect beneficial bacteria and compounds from undesirable effects of environmental conditions, thus retaining the structural integrity until the time of consumption or administration (Mokhtari et al. 2017a; Pourjafar et al. 2018; Abdolhosseinzadeh et al. 2018; Qi et al. 2020; Misra, Pandey, and Mishra 2021; Malmo, Giordano, and Mauriello 2021). Encapsulation of probiotic bacteria enhances their survival both in the food during the storage time and in the adverse conditions of the GIT (Mokhtari et al. 2017b; Oberoi et al. 2019; Pourjafar et al. 2020; Zhao et al. 2020; Yao et al. 2020; Zhang et al. 2021). There is a need for the controlled delivery of probiotics and/or bioactive compounds in barley based probiotic products, and few details are available on the performances of these systems in the GIT. Foods used for distribution of probiotics are usually fermented foods, which are produced by a microbial fermentation in which fermentable carbohydrates are transformed into ethanol and/or organic acids mainly acetic, lactic and propionic acids. In fermented probiotic products, it is important that the probiotic culture used contributes to good sensory properties during storage time. Therefore, it is quite common to use probiotic bacteria mixed together with other types of bacteria suited for the fermentation of the specific product (Enujiugha and Badejo 2017).

8. Conclusion and future aspects

The last decade has witnessed a considerable change in consumer demands for food product. The growing interest of developing healthy and natural foods drives consumer toward a healthy lifestyle and natural diet. Barley as a substrate have a great potential to develop novel probiotic foods that promote the gastrointestinal health, reduce the risk of chronic diseases such as obesity, cardiovascular disease, type 2 diabetes and some cancers. Barley fermentation with specific probiotic strains can lead to significant increase of bio available compounds, and the strain used determines the kind and quantity of the compound to be improved. Addition of barley into the other probiotic beverages also improves cell viability of the probiotic bacteria. Nonetheless, due to the sensitivity of probiotics to the environmental conditions such as those during food manufacture/processing as well as the condition in gastrointestinal, it is a challenge to develop barley probiotic products with desirable shelf life that can maintain both organoleptic properties of the food and viability of the probiotic cells. To formulate a successful barley-based probiotic foods, cell viability, survival and targeted release in the intestine is the important aspects to take into consideration for the bioavailability. Therefore, protection of probiotics using encapsulation technologies such as extrusion, spray drying, coacervation and internal gelation can be recommended in the future studies on barley functional foods.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Abdolhosseinzadeh, E., A. R. Dehnad, H. Pourjafar, A. Homayouni, and F. Ansari. 2018. The production of probiotic Scallion yogurt: Viability of Lactobacillus acidophilus freely and microencapsulated in the product. *Carpathian Journal of Food Science & Technology* 10 (3):72–80.

Adefegha, S. A. 2018. Functional foods and nutraceuticals as dietary intervention in chronic diseases; novel perspectives for health promotion and disease prevention. *Journal of Dietary Supplements* 15 (6):977–1009. doi: 10.1080/19390211.2017.1401573.

Ahmed, R. M., R. M. Elsanhoty, M. A. A. Al-Saman, and M. F. Ramadan. 2017. Hypocholesterolaemic effect of probiotic yogurt enriched with barley β-glucan in rats fed on a high-cholesterol diet. *Mediterranean Journal of Nutrition and Metabolism* 10 (1):1–12. doi: 10.3233/MNM-16114.

Ahuja, K. K. 2015. Development of Barley-Milk Based Fermented Probiotic Drink. Doctoral dissertation, NDRI, Karnal.

Ahuja, K. K., A. K. Singh, K. Bala, S. Arora, and L. Sabikhi. 2017. Optimisation of the formulation for barley–milk composite-based fermented drink. *International Journal of Dairy Technology* 70 (2): 237–44. doi: 10.1111/1471-0307.12328.

Amara, A. A., and A. Shibl. 2015. Role of Probiotics in health improvement, infection control and disease treatment and management. *Saudi Pharmaceutical Journal* 23 (2):107–14. doi: 10.1016/j.jsps.2013.07.001.

Ames, N. P., and C. R. Rhymer. 2008. Issues surrounding health claims for barley. *The Journal of Nutrition* 138 (6):1237S–43S. doi: 10.1093/jn/138.6.1237S.

Anson, N. M., E. Selinheimo, R. Havenaar, A.-M. Aura, I. Mattila, P. Lehtinen, A. Bast, K. Poutanen, and G. R. M. M. Haenen. 2009. Bioprocessing of wheat bran improves in vitro bioaccessibility and colonic metabolism of phenolic compounds. *Journal of Agricultural and Food Chemistry* 57 (14):6148–55. doi: 10.1021/jf900492h.

Araki, Y., Y. Fujiyama, A. Andoh, S. Koyama, O. Kanauchi, and T. Bamba. 2000. The dietary combination of germinated barley foodstuff plus Clostridium butyricum suppresses the dextran sulfate sodium-induced experimental colitis in rats. *Scandinavian Journal of Gastroenterology* 35 (10):1060–7. doi: 10.1080/003655200451180.

Arena, M., G. Caggianiello, D. Fiocco, P. Russo, M. Torelli, G. Spano, and V. Capozzi. 2014. Barley β-glucans-containing food enhances probiotic performances of beneficial bacteria. *International Journal of Molecular Sciences* 15 (2):3025–39. doi: 10.3390/ijms15023025.

Arora, S., S. Jood, and N. Khetarpaul. 2010. Effect of germination and probiotic fermentation on nutrient composition of barley based food mixtures. *Food Chemistry* 119 (2):779–84. doi: 10.1016/j.foodchem.2009.07.035.

BBC. 2020. Probiotics in food, beverages, dietary supplements and animal feed. https://www.bccresearch.com/market-research/food-and-beverage/probiotics-market-ingredients-supplements-foods-report.html. Accessed May 11, 2020.

Begum, P. S., G. Madhavi, S. Rajagopal, B. Viswanath, M. A. Razak, and V. Venkataratnamma. 2017. Probiotics as functional foods: Potential effects on human health and its impact on neurological diseases. *International Journal of Nutrition, Pharmacology, Neurological Diseases* 7 (2):23.

Bernardeau, M., J. P. Vernoux, and M. Gueguen. 2002. Safety and efficacy of probiotic lactobacilli in promoting growth in post-weaning Swiss mice. *International Journal of Food Microbiology* 77 (1–2): 19–27. doi: 10.1016/S0168-1605(02)00059-4.

Blandino, A., M. E. Al-Aseeri, S. S. Pandiella, D. Cantero, and C. Webb. 2003. Cereal-based fermented foods and beverages. *Food Research International* 36 (6):527–43. doi: 10.1016/S0963-9969(03)00009-7.

Borén, M., H. Larsson, A. Falk, and C. Jansson. 2004. The barley starch granule proteome—internalized granule polypeptides of the mature endosperm. *Plant Science* 166 (3):617–26. doi:10.1016/j.plantsci.2003.10.028.

Chandrasekara, A., and F. Shahidi. 2018. Herbal beverages: Bioactive compounds and their role in disease risk reduction - A review. *Journal of Traditional and Complementary Medicine* 8 (4):451–8. doi: 10.1016/j.jtcme.2017.08.006.

Charalampopoulos, D., R. Wang, S. S. Pandiella, and C. Webb. 2002. Application of cereals and cereal components in functional foods: A review. *International Journal of Food Microbiology* 79 (1–2):131–41. doi: 10.1016/s0168-1605(02)00187-3.

Charalampopoulos, D., S. S. Pandiella, and C. Webb. 2003. Evaluation of the effect of malt, wheat and barley extracts on the viability of potentially probiotic lactic acid bacteria under acidic conditions. *International Journal of Food Microbiology* 82 (2):133–41. doi: 10.1016/s0168-1605(02)00248-9.

Chavan, M., Y. Gat, M. Harmalkar, and R. Waghmare. 2018. Development of non-dairy fermented probiotic drink based on germinated and ungerminated cereals and legume. *LWT* 91:339–44. doi: 10.1016/j.lwt.2018.01.070.

Chen, S., L. Chen, L. Chen, X. Ren, H. Ge, B. Li, G. Ma, X. Ke, J. Zhu, L. Li, et al. 2018. Potential probiotic characterization of Lactobacillus reuteri from traditional Chinese highland barley wine and application for room-temperature-storage drinkable yogurt. *Journal of Dairy Science* 101 (7):5780–8. doi: 10.3168/jds.2017-14139.

Coda, R., A. Lanera, A. Trani, M. Gobbetti, and R. Di Cagno. 2012. Yogurt-like beverages made of a mixture of cereals, soy and grape must: Microbiology, texture, nutritional and sensory properties. *International Journal of Food Microbiology* 155 (3):120–7. doi: 10.1016/j.ijfoodmicro.2012.01.016.

Damodharan, K., S. A. Palaniyandi, J.-W. Suh, and S. H. Yang. 2020. Probiotic Characterization of Lactobacillus paracasei subsp. paracasei KNI9 Inhibiting Adherence of Yersinia enterocolitica on Caco-2 Cells In Vitro. *Probiotics and Antimicrobial Proteins* 12 (2):600–7. doi:10.1007/s12602-019-09535-8. PMID:31289994

Di Stefano, E., J. White, S. Seney, S. Hekmat, T. McDowell, M. Sumarah, and G. Reid. 2017. A novel millet-based probiotic fermented food for the developing world. *Nutrients* 9 (5):529. doi: 10.3390/nu9050529.

Đorđević, T. M., S. S. Šiler-Marinković, and S. I. Dimitrijević-Branković. 2010. Effect of fermentation on antioxidant properties of some cereals and pseudo cereals. *Food Chemistry* 119 (3):957–63. doi: 10.1016/j.foodchem.2009.07.049.

El-Aidie, S. A. A., S. M. El-Dieb, M. El-Nawawy, E. Emara, and H. Sobhy. 2017. Nutraceutical food based on cereal and probiotic fermented milk. *International Journal of Dairy Science* 12 (6):377–84. doi: 10.3923/ijds.2017.377.384.

Elsanhoty, R. M., and M. F. Ramadan. 2018. Changes in the physicochemical and microbiological properties of probiotic-fermented low-fat yoghurt enriched with barley β-glucan during cold storage. *Mljekarstvo: časopis za Unaprjeđenjeproizvodnje i Prerademlijeka* 68 (4):295–309.

Elsanhoty, R., A. Zaghlol, and A. H. Hassanein. 2009. The manufacture of low fat labneh containing barley β-glucan 1-chemical composition, microbiological evaluation and sensory properties. *Current Research in Dairy Sciences* 1 (1):1–12. doi: 10.3923/crds.2009.1.12.

Enujiugha, V. N., and A. A. Badejo. 2017. Probiotic potentials of cereal-based beverages. *Critical Reviews in Food Science and Nutrition* 57 (4):790–804. doi: 10.1080/10408398.2014.930018.

Fastnaught, C. E. 2001. Barley fibre. In *Handbook of dietary fibre*, ed. S. Cho and M. Dreher, 519–42. New York: Marcel Dekker.

FDA. 2006. *21CFR101.81 Health claims: Soluble fiber from certain foods and risk of coronary heart disease (CHD)*. Washington, DC: FDA

Fenster, K., B. Freeburg, C. Hollard, C. Wong, R. Rønhave Laursen, and A. Ouwehand. 2019. The production and delivery of probiotics: A review of a practical approach. *Microorganisms* 7 (3):83. doi: 10.3390/microorganisms7030083.

Food and Drug Administration. 2005. Food labeling: Health claims; oat and coronary heart disease; final rule federal register doc. 97-1598. Filed 1-22-1997.

Friedrich, W., A. Eberhardt, and R. Galensa. 2000. Investigation of proanthocyanidins by HPLC with electrospray ionization mass spectrometry. *European Food Research and Technology* 211 (1):56–64. doi: 10.1007/s002170050589.

Gangopadhyay, N., M. B. Hossain, D. K. Rai, and N. P. Brunton. 2015. A review of extraction and analysis of bioactives in oat and barley and scope for use of novel food processing technologies. *Molecules (Basel, Switzerland)* 20 (6):10884–909. doi: 10.3390/molecules200610884.

Ganguli, S., S. Kumar, A. K. Singh, and L. Sabikhi. 2014. Effect of fermentation by probiotic Lactobacillus acidophilus NCDC 13 on nutritional profile of a dairy cereal based composite substrate. *Journal of Food and Nutritional Disorders*.

Ganguly, S., and L. Sabikhi. 2012. Fermentation dynamics of probiotic Lactobacillus acidophilus NCDC-13 in a composite dairy-cereal substrate. *International Journal of Fermented Foods* 1 (1):33–46.

Ganguly, S., L. Sabikhi, and A. K. Singh. 2019. Effect of whey-pearl millet-barley based probiotic beverage on Shigella-induced pathogenicity in murine model. *Journal of Functional Foods* 54:498–505. doi: 10.1016/j.jff.2019.01.049.

Gull, A., K. Prasad, and P. Kumar. 2016. Evaluation of functional, antinutritional, pasting and microstructural properties of Millet flours. *Journal of Food Measurement and Characterization* 10 (1):96–102. doi: 10.1007/s11694-015-9281-0.

Gupta, M., N. Abu-Ghannam, and E. &Gallaghar. 2010. Barley for brewing: Characteristic changes during malting, brewing and applications of its by-products. *Comprehensive Reviews in Food Science and Food Safety* 9 (3):318–28. doi: 10.1111/j.1541-4337.2010.00112.x.

Gupta, M., N. Khetarpaul, and B. M. Chauhan. 1992. Preparation nutritional value and acceptability of barley rabadi-an indigenous fermented food of India. *Plant Foods for Human Nutrition (Dordrecht, Netherlands)* 42 (4):351–8. doi: 10.1007/BF02194096.

Hasani, S., A. A. Sari, A. Heshmati, and M. Karami. 2017. Physicochemical and sensory attributes assessment of functional low-fat yogurt produced by incorporation of barley bran and Lactobacillus acidophilus. *Food Science & Nutrition* 5 (4):875–80. doi: 10.1002/fsn3.470.

Helland, M. H., T. Wicklund, and J. A. Narvhus. 2004. Growth and metabolism of selected strains of probiotic bacteria, in maize porridge with added malted barley. *International Journal of Food Microbiology* 91 (3):305–13. doi: 10.1016/j.ijfoodmicro.2003.07.007.

Hernandez-Ledesma, B., C. C Hsieh, and B. O De Lumen. 2013. Chemopreventive properties of Peptide Lunasin: A review. *Protein and Peptide Letters* 20 (4):424–32.

Hole, A. S., I. Rud, S. Grimmer, S. Sigl, J. Narvhus, and S. Sahlstrøm. 2012. Improved bioavailability of dietary phenolic acids in whole grain barley and oat groat following fermentation with probiotic Lactobacillus acidophilus, Lactobacillus johnsonii, and Lactobacillus reuteri. *Journal of Agricultural and Food Chemistry* 60 (25):6369–75. doi: 10.1021/jf300410h.

Hung, T. V., and T. Suzuki. 2016. Dietary fermentable fiber reduces intestinal barrier defects and inflammation in colitic mice. *The Journal of Nutrition* 146 (10):1970–9. doi: 10.3945/jn.116.232538.

Idehen, E., Y. Tang, and S. Sang. 2017. Bioactive phytochemicals in barley. *Journal of Food and Drug Analysis* 25 (1):148–61. doi: 10.1016/j.jfda.2016.08.002.

Ismail, M. M., M. F. Hamad, and E. M. Elraghy. 2018. Using goat's milk, barley flour, honey, and probiotic to manufacture of functional dairy product. *Probiotics and Antimicrobial Proteins* 10 (4):677–91. doi: 10.1007/s12602-017-9316-4.

Izydorczyk, M. S., and C. G. Biliaderis. 2007. Arabinoxylans: Technologically and nutritionally functional plant polysaccharides. In *Functional food carbohydrates*, 258–99. Boca Raton, FL: CRC Press.

Izydorczyk, M. S., and J. E. Dexter. 2008. Barley β-glucans and arabinoxylans: Molecular structure, physicochemical properties, and uses in food products–a Review. *Food Research International* 41 (9): 850–68. doi: 10.1016/j.foodres.2008.04.001.

Jalili-Firoozinezhad, S., F. S. Gazzaniga, E. L. Calamari, D. M. Camacho, C. W. Fadel, A. Bein, B. Swenor, B. Nestor, M. J. Cronce, A. Tovaglieri, et al. 2019. A complex human gut microbiome cultured in an anaerobic intestine-on-a-chip. *Nature Biomedical Engineering* 3 (7):520–31. doi: 10.1038/s41551-019-0397-0.

Johnston, T. P., T. A. Korolenko, M. Pirro, and A. Sahebkar. 2017. Preventing cardiovascular heart disease: Promising nutraceutical and non-nutraceutical treatments for cholesterol management. *Pharmacological Research* 120:219–25. doi: 10.1016/j.phrs.2017.04.008.

Jood, S., N. Khetarpaul, and R. Goyal. 2012. Efficacy of barley based probiotic food mixture in treatment of pathogenic E.coli induced diarrhoea in mice. *Journal of Food Science and Technology* 49 (2): 200–6. doi: 10.1007/s13197-011-0270-y.

Kedia, G., J. A. Vázquez, and S. S. Pandiella. 2008. Evaluation of the fermentability of oat fractions obtained by debranning using lactic acid bacteria. *Journal of Applied Microbiology* 105 (4):1227–37. doi: 10.1111/j.1365-2672.2008.03864.x.

Keşkekoğlu, H., and A. Üren. 2013. Formation of biogenic amines during fermentation and storage of tarhana: A traditional cereal food. *Quality Assurance and Safety of Crops & Foods* 5 (2):169–76. doi: 10.3920/QAS2012.0150.

Kockova, M., and Ľ. Valík. 2014. Development of new cereal-, pseudocereal-, and cereal-leguminous-based probiotic foods. *Czech Journal of Food Sciences* 32 (No. 4):391–7. doi: 10.17221/553/2013-CJFS.

Koehler, P., H. Wieser, and K. Konitzer. 2014. Gluten—The precipitating factor. In *Celiac disease and gluten*, 97–148. San Diego, CA: Elsevier.

Kumar, B. V., S. V. N. Vijayendra, and O. V. S. Reddy. 2015. Trends in dairy and non-dairy probiotic products-a review. *Journal of Food Science and Technology* 52 (10):6112–24. doi: 10.1007/s13197-015-1795-2.

Lagassé, S. L., D. W. Hatcher, J. E. Dexter, B. G. Rossnagel, and M. S. Izydorczyk. 2006. Quality characteristics of fresh and dried white salted noodles enriched with flour from hull-less barley genotypes of diverse amylose content. *Cereal Chemistry Journal* 83 (2):202–10. doi: 10.1094/CC-83-0202.

Laurent-Babot, C., and J. P. Guyot. 2017. Should research on the nutritional potential and health benefits of fermented cereals focus more on the general health status of populations in developing countries? *Microorganisms* 5 (3):40. doi: 10.3390/microorganisms5030040.

Lazaridou, A., A. Serafeimidou, C. G. Biliaderis, T. Moschakis, and N. Tzanetakis. 2014. Structure development and acidification kinetics in fermented milk containing oat β-glucan, a yogurt culture and a probiotic strain. *Food Hydrocolloids* 39:204–14. doi: 10.1016/j.foodhyd.2014.01.015.

Malmo, C., I. Giordano, and G. Mauriello. 2021. Effect of microencapsulation on survival at simulated gastrointestinal conditions and heat treatment of a non probiotic strain, Lactiplantibacillus plantarum 48M, and the probiotic strain Limosilactobacillus reuteri DSM 17938. *Foods* 10 (2):217. doi: 10.3390/foods10020217.

Mantzourani, I., A. Terpou, A. Bekatorou, A. Mallouchos, A. Alexopoulos, A. Kimbaris, E. Bezirtzoglou, A. A. Koutinas, and S. Plessas. 2020. Functional pomegranate beverage production by fermentation with a novel synbiotic L. paracasei biocatalyst. *Food Chemistry* 308:125658. doi: 10.1016/j.foodchem.2019.125658.

Markowiak, P., and K. Śliżewska. 2017. Effects of probiotics, prebiotics, and synbiotics on human health. *Nutrients* 9 (9):1–30. doi:10.3390/nu9091021

Maselli, L., and S. Hekmat. 2016. Microbial vitality of probiotic milks supplemented with cereal or pseudocereal grain flours. *Journal of Food Research* 5 (2):41–9. doi: 10.5539/jfr.v5n2p41.

Michida, H., S. Tamalampudi, S. S. Pandiella, C. Webb, H. Fukuda, and A. Kondo. 2006. Effect of cereal extracts and cereal fiber on viability of Lactobacillus plantarum under gastrointestinal tract conditions. *Biochemical Engineering Journal* 28 (1):73–8. doi: 10.1016/j.bej.2005.09.004.

Millette, M., A. Nguyen, K. M. Amine, and M. Lacroix. 2013. Gastrointestinal survival of bacteria in commercial probiotic products. *International Journal of Probiotics and Prebiotics* 8 (4):149–156.

Misra, S., P. Pandey, and H. N. Mishra. 2021. Novel approaches for co-encapsulation of probiotic bacteria with bioactive compounds, their health benefits and functional food product development: A review. *Trends in Food Science & Technology* 109:340–51. doi: 10.1016/j.tifs.2021.01.039.

Mitsou, E. K., N. Panopoulou, K. Turunen, V. Spiliotis, and A. Kyriacou. 2010. Prebiotic potential of barley derived β-glucan at low intake levels: A randomised, double-blinded, placebo-controlled clinical study. *Food Research International* 43 (4):1086–92. doi: 10.1016/j.foodres.2010.01.020.

Mokhtari, S., S. M. Jafari, M. Khomeiri, Y. Maghsoudlou, and M. Ghorbani. 2017a. The cell wall compound of Saccharomyces cerevisiae as a novel wall material for encapsulation of probiotics. *Food Research International* 96:19–26. doi: 10.1016/j.foodres.2017.03.014.

Mokhtari, S., M. Khomeiri, S. M. Jafari, Y. Maghsoudlou, and M. Ghorbani. 2017b. Descriptive analysis of bacterial profile, physicochemical and sensory characteristics of grape juice containing Saccharomyces cerevisiae cell wall-coated probiotic microcapsules during storage. *International Journal of Food Science & Technology* 52 (4):1042–8. doi: 10.1111/ijfs.13370.

Montemurro, M., E. Pontonio, M. Gobbetti, and C. G. Rizzello. 2019. Investigation of the nutritional, functional and technological effects of the sourdough fermentation of sprouted flours. *International Journal of Food Microbiology* 302:47–58. doi: 10.1016/j.ijfoodmicro.2018.08.005.

Moreau, R. A., R. A. Flores, and K. B. Hicks. 2007. Composition of functional lipids in hulled and hulless barley in fractions obtained by scarification and in barley oil. *Cereal Chemistry Journal* 84 (1): 1–5. doi: 10.1094/CCHEM-84-1-0001.

Mridula, D., and M. Sharma. 2015. Development of non-dairy probiotic drink utilizing sprouted cereals, legume and soymilk. *LWT-Food Science and Technology* 62 (1):482–7.

Nakkarach, A., and U. Withayagiat. 2018. Comparison of synbiotic beverages produced from riceberry malt extract using selected free and encapsulated probiotic lactic acid bacteria. *Agriculture and Natural Resources* 52 (5):467–76. doi: 10.1016/j.anres.2018.11.013.

Newman, C. W., and R. K. Newman. 2006. A brief history of barley foods. *Cereal Foods World* 51 (1):4–7.

Nghiem, N. P., W. S. Brooks, C. A. Griffey, and M. J. Toht. 2017. Production of ethanol from newly developed and improved winter barley cultivars. *Applied Biochemistry and Biotechnology* 182 (1): 400–10. doi: 10.1007/s12010-016-2334-y.

Nigam, P. S. 2017. An overview: Recycling of solid barley waste generated as a by-product in distillery and brewery. *Waste Management (New York, N.Y.)* 62:255–61. doi: 10.1016/j.wasman.2017.02.018.

Nilsson, A., E. Johansson-Boll, J. Sandberg, and I. Björck. 2016. Gut microbiota mediated benefits of barley kernel products on metabolism, gut hormones, and inflammatory markers as affected by co-ingestion of commercially available probiotics: A randomized controlled study in healthy subjects. *Clinical Nutrition ESPEN* 15:49–56. doi: 10.1016/j.clnesp.2016.06.006.

Oberoi, K., A. Tolun, K. Sharma, and S. Sharma. 2019. Microencapsulation: An overview for the survival of probiotic bacteria. *Journal of Microbiology, Biotechnology and Food Sciences* 9 (2): 280–7. doi: 10.15414/jmbfs.2019.9.2.280-287.

OECD (Organisation for Economic Co-operation and Development). 2004. Environmental health and safety publications, series on the safety of novel foods and feeds, no. 12, consensus document on compositional considerations for new varieties of barley. (Hordeum vulgare L.): Key Food and Feed Nutrients and Anti-nutrients [Internet]. Paris, France. Accessed April 10, 2021. https://www.oecd.org/env/ehs/biotrack/46815246.pdf.

Ooi, L. G., and M. T. Liong. 2010. Cholesterol-lowering effects of probiotics and prebiotics: A review of in vivo and in vitro findings. *International Journal of Molecular Sciences* 11 (6):2499–522. doi: 10.3390/ijms11062499.

Osman, A. M., S. M. Coverdale, K. Onley-Watson, D. Bell, and P. Healy. 2003. The gel filtration chromatographic-profiles of proteins and peptides of wort and beer: Effects of processing—malting, mashing, kettle boiling, fermentation and filtering. *Journal of the Institute of Brewing* 109 (1):41–50. doi: 10.1002/j.2050-0416.2003.tb00592.x.

Osman, A. M., S. M. Coverdale, N. Cole, S. E. Hamilton, J. Jersey, and P. A. Inkerman. 2002. Characterisation and assessment of the role of barley malt endoproteases during malting and mashing 1. *Journal of the Institute of Brewing* 108 (1):62–7. doi: 10.1002/j.2050-0416.2002.tb00125.x.

Ozcan, T., and O. Kurtuldu. 2014. Influence of dietary fiber addition on the properties of probiotic yogurt. *International Journal of Chemical Engineering and Applications* 5 (5):397–401. doi: 10.7763/IJCEA.2014.V5.417.

Perricone, M., A. Bevilacqua, C. Altieri, M. Sinigaglia, and M. R. Corbo. 2015. Challenges for the production of probiotic fruit juices. *Beverages* 1 (2):95–103. doi: 10.3390/beverages1020095.

Pourjafar, H., N. Noori, H. Gandomi, A. A. Basti, and F. Ansari. 2020. Viability of microencapsulated and non-microencapsulated Lactobacilli in a commercial beverage. *Biotechnology Reports* 25:1–9. doi: 10.1016/j.btre.2020.e00432.

Pourjafar, H., N. Noori, H. Gandomi, A. A. Basti, and F. Ansari. 2018. Stability and efficiency of double-coated beads containing Lactobacillus acidophilus obtained from the calcium alginate chitosan and Eudragit S100 nanoparticles microencapsulation. *International Journal of Probiotics & Prebiotics* 13:77–84.

Qi, X., S. Simsek, B. Chen, and J. Rao. 2020. Alginate-based double-network hydrogel improves the viability of encapsulated probiotics during simulated sequential gastrointestinal digestion: Effect of biopolymer type and concentrations. *International Journal of Biological Macromolecules* 165 (Pt B):1675–85. doi: 10.1016/j.ijbiomac.2020.10.028.

Rakhmanova, A., Z. A. Khan, and K. Shah. 2018. A mini review fermentation and preservation: Role of lactic acid bacteria. *MOJ Food Processing & Technology* 6 (5):414–7. doi: 10.15406/mojfpt.2018.06.00197.

Ranadheera, C. S., J. K. Vidanarachchi, R. S. Rocha, A. G. Cruz, and S. Ajlouni. 2017. Probiotic delivery through fermentation: Dairy vs. non-dairy beverages. *Fermentation* 3 (4):67. doi: 10.3390/fermentation3040067.

Rathore, S., I. Salmerón, and S. S. Pandiella. 2012. Production of potentially probiotic beverages using single and mixed cereal substrates fermented with lactic acid bacteria cultures. *Food Microbiology* 30 (1):239–44. doi: 10.1016/j.fm.2011.09.001.

Rizzello, C. G., L. Nionelli, R. Coda, and M. Gobbetti. 2012. Synthesis of the cancer preventive peptide lunasin by lactic acid bacteria during sourdough fermentation. *Nutrition and Cancer* 64 (1):111–20. doi: 10.1080/01635581.2012.630159.

Rozada-Sánchez, R., A. P. Sattur, K. Thomas, and S. S. Pandiella. 2008. Evaluation of Bifidobacterium spp. for the production of a potentially probiotic malt-based beverage. *Process Biochemistry* 43 (8):848–54. doi: 10.1016/j.procbio.2008.04.002.

Saarela, M., G. Mogensen, R. Fonden, J. Mättö, and T. Mattila-Sandholm. 2000. Probiotic bacteria: Safety, functional and technological properties. *Journal of Biotechnology* 84 (3):197–215. doi: 10.1016/s0168-1656(00)00375-8.

Salari, M., S. H. Razavi, and S. M. T. Gharibzahedi. 2015. Characterising the synbiotic beverages based on barley and malt flours fermented by Lactobacillus delbrueckii and paracasei strains. *Quality Assurance and Safety of Crops & Foods* 7 (3):355–61. doi: 10.3920/QAS2013.0390.

Salmerón, I., K. Thomas, and S. S. Pandiella. 2015. Effect of potentially probiotic lactic acid bacteria on the physicochemical composition and acceptance of fermented cereal beverages. *Journal of Functional Foods* 15:106–15. doi: 10.1016/j.jff.2015.03.012.

Salmerón, I., P. Fuciños, D. Charalampopoulos, and S. S. Pandiella. 2009. Volatile compounds produced by the probiotic strain Lactobacillus plantarum NCIMB 8826 in cereal-based substrates. *Food Chemistry* 117 (2):265–71. doi: 10.1016/j.foodchem.2009.03.112.

Saxelin, M., B. Grenov, U. Svensson, R. Fonden, R. Reniero, and T. Mattila-Sandholm. 1999. The technology of probiotics. *Trends in Food Science & Technology* 10 (12):387–92. doi: 10.1016/S0924-2244(00)00027-3.

Schulte, D., T. J. Close, A. Graner, P. Langridge, T. Matsumoto, G. Muehlbauer, K. Sato, A. H. Schulman, R. Waugh, R. P. Wise, et al. 2009. The international barley sequencing consortium—at the threshold of efficient access to the barley genome. *Plant Physiology* 149 (1):142–7. doi: 10.1104/pp.108.128967.

Sharma, P., and S. L. Kotari. 2017. Barley: Impact of processing on physicochemical and thermal properties—A review. *Food Reviews International* 33 (4):359–81. doi: 10.1080/87559129.2016.1175009.

Sima, P., L. Vannucci, and V. Vetvicka. 2018. β-glucans and cholesterol. *International Journal of Molecular Medicine* 41 (4):1799–808.

Sindhu, S. C., and N. Khetarpaul. 2001. Probiotic fermentation of indigenous food mixture: Effect on antinutrients and digestibility of starch and protein. *Journal of Food Composition and Analysis* 14 (6):601–9. doi: 10.1006/jfca.2001.1022.

Sindhu, S. C., and N. Khetarpaul. 2003. Effect of feeding probiotic fermented indigenous food mixture on serum cholesterol levels in mice. *Nutrition Research* 23 (8):1071–80. doi: 10.1016/S0271-5317(03)00087-3.

Smith, K. N., K. M. Queenan, W. Thomas, R. G. Fulcher, and J. L. Slavin. 2008. Physiological effects of concentrated barley beta-glucan in mildly hypercholesterolemic adults. *Journal of the American College of Nutrition* 27 (3):434–40. doi: 10.1080/07315724.2008.10719722.

Soltani, M., S. Hekmat, and L. Ahmadi. 2018. Microbial and sensory evaluation of probiotic yoghurt supplemented with cereal/pseudo-cereal grains and legumes. *International Journal of Dairy Technology* 71:141–8. doi: 10.1111/1471-0307.12389.

Tosh, S. M. 2013. Review of human studies investigating the post-prandial blood-glucose lowering ability of oat and barley food products. *European Journal of Clinical Nutrition* 67 (4):310–7. doi: 10.1038/ejcn.2013.25.

Tricase, C., V. Amicarelli, E. Lamonaca, and R. L. Rana. 2018. Economic analysis of the barley market and related uses. In *Grasses as food and feed*. London, UK: IntechOpen.

Trujillo-de Santiago, G., C. P. Sáenz-Collins, and C. Rojas-de Gante. 2012. Elaboration of a probiotic oblea from whey fermented using *Lactobacillus acidophilus* or *Bifidobacterium infantis*. *Journal of Dairy Science* 95 (12):6897–904. doi: 10.3168/jds.2012-5418.

Turkmen, N., C. Akal, and B. Özer. 2019. Probiotic dairy-based beverages: A review. *Journal of Functional Foods* 53:62–75. doi: 10.1016/j.jff.2018.12.004.

Ullrich, S. E. 2010. Significance, adaptation, production, and trade of barley. *Barley: Production, Improvement, and Uses*, 3–13. Ames, IA, USA: Wiley-Blackwell.

Valero-Cases, E., and M. J. Frutos. 2017. Effect of inulin on the viability of L. plantarum during storage and in vitro digestion and on composition parameters of vegetable fermented juices. *Plant Foods for Human Nutrition (Dordrecht, Netherlands)* 72 (2):161–7. doi: 10.1007/s11130-017-0601-x.

Valero-Cases, E., D. Cerdá-Bernad, J. J. Pastor, and M. J. Frutos. 2020. Non-dairy fermented beverages as potential carriers to ensure probiotics, prebiotics, and bioactive compounds arrival to the gut and their health benefits. *Nutrients* 12 (6):1666. doi: 10.3390/nu12061666.

Vasiljevic, T., T. Kealy, and V. K. Mishra. 2007. Effects of β-glucan addition to a probiotic containing yogurt. *Journal of Food Science* 72 (7):C405–411. doi: 10.1111/j.1750-3841.2007.00454.x.

Vinderola, G., P. Burns, and J. Reinheimer. 2017. Probiotics in non-dairy products. In *Vegetarian and plant-based diets in health and disease prevention*, 809–35. London Wall, UK: Elsevier.

Wang, Y., N. P. Ames, H. M. Tun, S. M. Tosh, P. J. Jones, and E. Khafipour. 2016. High molecular weight barley β-glucan alters gut microbiota toward reduced cardiovascular disease risk. *Frontiers in Microbiology* 7:129.

Yao, M., J. Xie, H. Du, D. J. McClements, H. Xiao, and L. Li. 2020. Progress in microencapsulation of probiotics: A review.

Comprehensive Reviews in Food Science and Food Safety 19 (2):857–74. doi: 10.1111/1541-4337.12532.

Zhang, J. Y., X. I. A. O. Xiang, D. O. N. G. Ying, and X. H. Zhou. 2019. Anti-obesity action of fermented barley extracts with Lactobacillus plantarum dy-1 and associated microRNA expression in high-fat diet-induced obese rats. *Biomedical and Environmental Sciences : BES* 32 (10):755–68. doi: 10.3967/bes2019.095.

Zhang, J., X. Xiao, Y. Dong, L. Shi, T. Xu, and F. Wu. 2017. The anti-obesity effect of fermented barley extracts with Lactobacillus plantarum dy-1 and Saccharomyces cerevisiae in diet-induced obese rats. *Food & Function* 8 (3):1132–43. doi: 10.1039/c6fo01350c.

Zhang, J., X. Xiao, Y. Dong, T. Xu, and F. Wu. 2016. Dietary supplementation with Lactobacillus plantarum dy-1 fermented barley suppresses body weight gain in high-fat diet-induced obese rats. *Journal of the Science of Food and Agriculture* 96 (15):4907–17. doi: 10.1002/jsfa.7786.

Zhang, Z., M. Gu, X. You, D. A. Sela, H. Xiao, and D. J. McClements. 2021. Encapsulation of bifidobacterium in alginate microgels improves viability and targeted gut release. *Food Hydrocolloids.* 116:106634. doi: 10.1016/j.foodhyd.2021.106634.

Zhao, M., X. Huang, H. Zhang, Y. Zhang, M. Gänzle, N. Yang, K. Nishinari, and Y. Fang. 2020. Probiotic encapsulation in water-in-water emulsion via heteroprotein complex coacervation of type-A gelatin/sodium caseinate. *Food Hydrocolloids.* 105:105790. doi: 10.1016/j.foodhyd.2020.105790.

Zhong, Y., and M. Nyman. 2014. Prebiotic and synbiotic effects on rats fed malted barley with selected bacteria strains. *Food & Nutrition Research* 58 (1):24848. doi: 10.3402/fnr.v58.24848.

Zhu, Z., L. Rosendahl, S. S. Toor, D. Yu, and G. Chen. 2015. Hydrothermal liquefaction of barley straw to bio-crude oil: Effects of reaction temperature and aqueous phase recirculation. *Applied Energy* 137:183–92. doi: 10.1016/j.apenergy.2014.10.005.

Zielińska, D., and D. Kolożyn-Krajewska. 2018. Food-origin lactic acid bacteria may exhibit probiotic properties. *BioMed Research International* 2018:5063185. doi: 10.1155/2018/5063185.