Chapter

Indian Traditional Fermented Foods: The Role of Lactic Acid Bacteria

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Abstract

Fermentation technology is an important field comprising the use of microorganisms and enzymes to produce the compounds that have applications in the food, pharmaceutical, energy, and chemical industries. Although food fermentation processes have been used for generations as a prerequisite for sustainable food production, today it has become more demanding to obtain functional and therapeutic food products through the application of continuous creations and advancement of innovative fermentation processes. For these reasons, efforts are directed toward designing new processes, concepts, and technologies. Fermentation is a natural process whereby microorganisms such as lactic acid bacteria and yeast convert carbohydrates such as starch and sugar into alcohol or acids, both of these act as a natural preservatives. This process is still used today to produce foods such as wine, cheese, sauerkraut, yogurt, and other types of traditional foods. Traditional fermented foods are popularly consumed and form an integral part of our diet since early history. They are recognized as having multiple benefits related to nutritive values, therapeutic properties, and sensory attributes. In most fermented foods, the fermentation process is predominantly initiated by lactic acid bacteria. These organisms have been termed as probiotic bacteria—a group that appears to have specific health-promoting attributes.

Keywords: lactic acid bacteria, probiotics, prebiotics, traditional fermented foods, human health

1. Introduction

The production of fermented foods is one of the oldest food processing technologies well known to mankind. Since the beginning of civilization, methods of fermenting milk, cereals, legumes, vegetables, and meats have been described [1]. The preparation of these kinds of fermented foods will be with us in the far future, as they are a source of alcoholic foods/beverages, vinegar, pickled vegetables, sausages, cheeses, yogurts, vegetable protein amino acid/peptide sauces, and pastes with meat-like flavors, and leavened and sourdough breads, and so on. Fermented foods are of great importance because they provide and preserve an enormous amount of nutritious foods with a wide variety of flavors, aromas, and textures that enrich the human diet. As used herein, the term "nutrition" or "nutrient" will include providing the consumer with calories/energy, protein, essential amino acids/peptides, essential fatty acids, vitamins, and mineral requirements that contribute to the solution of nutritional problems and diseases in the human population [2].

In most cases, the procedures and knowledge associated with the manufacture of these food products were passed on from generation to generation within local communities, monasteries, and medieval farms. In the mid-nineteenth century, two events occurred that had a significant impact on our understanding of the method and process of food fermentation. First, a huge number of residents from the villages started moving toward the towns and cities due to the more opportunities in industrial sectors. Hence, the practicing of conventional methods to prepare food for more population was no longer operative. This led to inventing new processes for the manufacturing of vast quantities of food products, which demanded the industrialization of the food sector. Second, the progress in the field of microbiology in the 1850s led to an understanding of the basic science of the fermentation process for the first time. Consequently, the important function of lactic acid bacteria, yeasts, and molds in the production of fermented foods was understood, which eventually led to a more controlled and efficient fermentation process [3].

For many fermented foods particularly dairy products, the characterization of microorganisms that are responsible for fermentation is very important for their usage in the dairy industry. Therefore, in the late nineteenth-century isolation of starter cultures and manufacturing on a large scale was initiated to supply to the factories involved in the manufacture of dairy products [3]. Generally, starter culture strains are often used to improve the nutritive value and sensory characteristics of fermented foods, maintain safety and quality, and promote nutrition [4]. In recent years, it has been a great strategy in food microbiology to study microorganisms with various functions, to use as a starter culture [5]. Several studies have reported the preparation of food products using multifunctional microorganisms, wherein lactic acid bacteria (LAB) are particularly recommended as starter cultures for the fermentation process due to their benefits in terms of probiotic properties, antimicrobial production, beneficial enzyme production, and enhancement of other functionality [6–11]. They are normally considered safe and widely used as a starter culture in the production of fermented foods [12]. Due to the unique metabolic characteristics, they are involved in many fermentation processes of milk, cereals, vegetables, and meats. They are effective as probiotics and exhibit beneficial properties such as the production of antimicrobial compounds, enzymes, involvement in immune regulation, and antioxidant activity [13]. The microbiota in the human gut displays significant influence on host immunity, nutrition supply to the body as well as a contribution toward physiological function, whereas the enhanced therapeutic role of beneficial microbes in the gut is mainly due to the improvement of their population in intestinal microbial communities and their subsequent correlation with human physiology and disease pathogenesis [14]. In 2006, FAO/WHO defined probiotics as "live microorganisms, which upon ingestion in adequate amounts confer a health benefit to the host [15]." Hence, probiotics are considered as safe products for the host when consumed. The key criteria for the selection of probiotics which are mainly based on the FAO/WHO guidelines include safety (nonpathogenic strains without toxicity), resistance to gastric and bile acids, adhesion to epithelial cells, and antimicrobial activity (antagonism against pathogens). These guidelines recommend performing *in vivo* experiments on strains that have demonstrated potential health benefits based on *in vitro* experiments. In addition, probiotic properties are strain-specific, and hence, each strain characteristic needs to be verified [16].

The lactic acid bacteria (LAB) are considered as probiotics and play important role in the preservation and production of healthy fermented food products. The genera of LAB consist of *Lactobacillus*, *Leuconostoc*, *Lactococcus*, *Enterococcus*, *Pediococcus*, *Streptococcus*, *Weisiella*, etc. The genus *Lactobacillus* includes 261 species that differ greatly in their phenotypic, genotypic, and ecological properties. Recently, [17] proposed reclassification of lactic acid bacteria into 25 genera. The phylogeny is based on whole-genome sequences, which includes the revised genera *Lactobacillus* and *Paralactobacillus*. The remaining 23 genera are novel: *Holzapfelia*, *Amylolactobacillus*, *Bombilactobacillus*, *Companilactobacillus*, *Lapidilactobacillus*, *Agrilactobacillus*, *Schleiferilactobacillus*, *Loigolactobacilus*, *Lacticaseibacillus*, *Latilactobacillus*, *Dellaglioa*, *Liquorilactobacillus*, *Ligilactobacillus*, *Lactiplantibacillus*, *Furfurilactobacillus*, *Paucilactobacillus*, *Limosilactobacillus*, *Fructilactobacillus*, *Acetilactobacillus*, *Apilactobacillus*, *Levilactobacillus*, *Secundilactobacillus*, and *Lentilactobacillus*. Those LAB belong to the homo- and hetero-fermentative groups and generally require enriched artificial media. They grow naturally on most food substrates which led to the lowering of pH to a point where other competing microorganisms are unable to grow. For example, *Lactococcus* and *Leuconostoc* normally lower the pH to 4.0–4.5, whereas *Lactobacilli* and *Pediococci* lower the pH to 3.5 as reported by [18]. Several research studies have shown that the use of LAB as fermentation agent for the preparation of food products is considered as safe for consumption [7, 10, 11].

It is well-known fact that India is recognized for its rich traditional fermented food products. Generally, in the Indian subcontinent, fermented foods are prepared using indigenous food crops and other biological resources. Hence, the nature of food products and their base materials varies in each province. Presently, there are a number of fermented food products with different base materials and preparation methodologies have been reported. Each fermented food is allied with a unique group of microbiota, which has the potential to increase the level of proteins, vitamins, essential amino acids, and fatty acids. In local communities, the preparation of traditional fermented foods is still done by spontaneous fermentation method and their microbiota profile get varies each time. Hence, limited knowledge is available about the microbiota of these kinds of food products [19, 20].

This chapter outlines the role of lactic acid bacteria in food fermentation, their probiotic properties (gastrointestinal tract acidic tolerance, adhesion, hydrophobicity, and auto-aggregation), multifunctional characteristics (antimicrobial, antioxidant, phytase, and β-galactosidase activities), and the mechanisms of antagonistic nature of LAB as well as a brief explanation of some significant traditional fermented foods from India. It is expected that more research needs to be carried out toward strain improvement with beneficial properties in order to use in the fermentation of food products, which would benefit both the producer and consumer.

2. Contributions of fermented foods to human nutrition

Human health is one of the main reasons behind food choices and this has led to a diverse range of food formulations with specific functionalities that provide better health and wellness. One of the common health disorders associated with diet patterns is gastrointestinal (GI) disorders. Such GI disorders can be prevented to some extent through routine consumption of foods with specific functionality [21]. Hence, the concept of functional foods evolved as the role of food in maintaining health and well-being and therefore gained greater scientific and commercial interest [22]. Lactic acid bacteria and bifidobacteria are well known for their extensive use in the preparation of functional food products [21]. These organisms have been termed as "probiotic bacteria," which does impart certain specific health-promoting attributes through oral feeding. Simultaneously with probiotics, the other term "prebiotics" are known to be non-digestible food ingredients (higher polysaccharides) that have a beneficial effect on the host by selectively stimulating the growth and/or activity of a selected group of bacterial genera and species that are normal colon inhabitants [23].

Probiotics should have the competence to grow and sustain in the human gut in order to deliver health benefits to the host. Therefore, they must have the characteristics to survive while passing *via* the gastrointestinal tract (GIT). During this process, they get exposed to the acidic environment in the stomach, while the bile acid is in the small intestine [24]. Most of the probiotic strains are natural inhabitants of the human intestine and are generally regarded as safe (GRAS) along with acid and bile tolerance and the ability to adhere to gut epithelial cells [25, 26]. Hence, the best designed route for the entry of these probiotic bacteria is the diet, both for animals and human beings [27]. Fermented foods based on milk, cereals, and legumes are among the most accepted food carriers for the delivery of viable probiotic cultures [24]. Probiotic bacteria and their fermentation products appear to influence human health, wherein they provide colonization resistance against potentially pathogenic microorganisms [28].

Fermentation plays mainly important roles like improving the nutritional qualities of food by enhancing the flavor, aroma, and texture of food, contributing toward the preservation of food by the production of main compounds such as lactic acid, acetic acid, alcohol, and alkaline contents. The protein, vitamins, essential amino acids, and fatty acids are enriched by converting the food substrates naturally. During fermentation processes detoxify the food products. Finally, it can be claimed that the fermentation process decreases the cooking periods and requirements of fuel [2].

In several studies, researchers have demonstrated the ability of probiotic bacteria to inhibit pathogenic bacteria by the production of organic acids like lactic and acetic acids during the fermentation process, which lowers the pH of the intestine and consequently inhibits the growth of the undesirable bacteria [29]. In addition to these beneficial health effects, researchers have demonstrated that the major end products of fermentation in humans are short-chain fatty acids (SCFA) like those of acetate, propionate, and butyrate [30, 31]. Besides, a few other antimicrobial substances produced widely by lactic acid bacteria include hydrogen peroxide, carbon dioxide, diacetyl, and bacteriocins [32]. Probiotic bacteria like LAB and bifidobacteria are also known to synthesize folate, vitamin B_{12}, and vitamin K, which are vital components of the human diet and involved in the biosynthesis of nucleotides and cofactors in many metabolic reactions [33].

There has been substantial evidence for the benefits of probiotics and prebiotics in the lowering of (i) lactose intolerance through the activity of β-galactosidase; (ii) antibiotic-associated diarrhea; (iii) colon carcinogenesis; (iv) hypocholesterolemic effect, and (v) gut mucosal dysfunction [34–38].

3. Traditional fermented foods

3.1 Background scenario

Fermentation is one of the oldest methods of preserving food, which became popular at the beginning of civilization as it led to the development of a variety of tastes, flavors, textures, forms, and other sensory attributes. As a process, it involves the transformation of simple raw materials into a range of value-added products, using the phenomena of microorganism growth and their activities on different substrates. Therefore, knowledge of microorganisms' characteristics is essential to understand the fermentation process [4]. Indian-fermented foods such as *dahi*, *rai*, *gundruk*, *koozh, kanjika, sinki*, *iromba*, *handua,* and *iniziangsang* have been considered as important nutritious diets with significant medicinal properties. Among these fermented food products *koozh*, *dahi,* and *kanjika* are habitually consumed by the local population because of their health benefits [39]. Currently, various fermented foods and beverages have evolved over the years.

3.2 Nutritional status of Indian traditional foods

In the background of a diverse range of traditional Indian foods, the most popular and widely consumed are those based on either milk alone or cereals and legumes with milk. The scientific knowledge on nutritional benefits derived from milk and dairy products is well documented. On the other hand, the same is not true with those of cereals and legumes-based foods, as the raw materials available are specific to the region and store house of complex nutrients. This complexity is linked to the type of fermentation process, product preparation parameters, and final profile that offers ample opportunities to highlight the importance of nutritional constituents in cereals and legumes-based Indian traditional foods.

Cereals and legumes are considered one of the most important sources of dietary proteins, carbohydrates, vitamins, minerals, and fiber for human nutrition. Often, the nutritional quality of cereals and legumes is not on par with that of milk and dairy products. This is further attributed to the complex nature of macronutrients, as well as the prevalence of antinutritional factors, which makes their bioavailability more difficult [40]. In addition, processing methods like soaking, sprouting, milling, fermentation, and cooking/heating have enabled the improvement of nutritional attributes of cereals and legumes [41].

In general, the natural fermentation of cereals and legumes leads to a decrease in the level of complex carbohydrates such as non-digestible poly- and oligosaccharides. In addition, certain amino acids and vitamins, especially B-group vitamins, can be synthesized and become available. Increased amounts of riboflavin, thiamine, niacin, and lysine due to the action of LAB in fermented cereal mixtures were reported in some of the studies [42, 43]. Fermentation also provides ideal pH conditions for the enzymatic degradation of phytate, which is present in cereals in the form of complexes with iron, zinc, calcium, magnesium, and proteins. This reduction in phytate can increase the bioavailability of iron, zinc, and calcium in several folds [40, 44–48]. Thus, fermentation is known to prolong shelf life and impart improved and acceptable texture, taste, and aroma to the final product. During the cereal fermentation process, several volatile compounds are formed, which contribute to a complex mixture of flavors in the products [40]. The presence of aromas representative, that is, diacetyl, acetic acid, and butyric acid make fermented products based on cereals and legumes more appetizing. In many parts of the world, traditional fermented foods are prepared from the most common types of cereals and pulses, such as rice, wheat, soy bean, sorghum. Some of them are utilized as breakfast or light meals, beverages, and colorants, while some are used as main food meals in the regular diet.

Most of these food products are naturally fermented, which mainly encompasses mixed cultures of LAB, yeasts, and fungi. Often, the predominant microflora can be functionally similar, while few others can become functional in a sequential manner with an altered environment due to the fermentation process. Common fermenting bacteria are species of *Lactobacillus, Leuconostoc, Streptococcus, Pediococcus, Micrococcus,* and *Bacillus*. The fungal genera known to be commonly present are *Aspergillus, Cladosporium, Fusarium, Penicillium,* and *Trichothecium*. Common fermenting yeasts are species of *Saccharomyces*, which generally predominate in an alcoholic fermentation [49]. The type of bacterial flora developed in each fermented food depends on the water activity, pH, salt concentration, temperature, and the composition of the food matrix.

The lactic fermentation process enhances the nutritional value, shelf life, safety, and acceptability of a varied range of cereal-based foods [50]. In this process, cereal grains are commonly cleaned, followed by immersion in water for a few days. During this period, there will be the progression of naturally occurring microorganisms which will result in an increase in the LAB population. Moreover, in this course, the endogenous amylases of the grains become active and produce fermentable sugars that aid as an energy source for the LAB. Considering that other practices including grinding, salting, or heating can also change the properties of the final product [47].

A variety of indigenous fermented foods that are prepared in India are basically using cereals with a combination of legumes, which improves the overall protein quality of the food products. Because, cereals contain the highest amount of cysteine and methionine, but lack lysine content, whereas legumes are rich in lysine but lack sulfur-containing amino acids. Therefore, the overall quality of the protein in food products can be improved by mixing both cereals and legumes [51].

In fermented foods like *idli*, *dosa,* and *dhokla*, the fermenting desirable microflora is considered essential for the leavening of the batter and for acid production in *idli* [52, 53]. Fermentation of *idli* batter appears to significantly increase the essential amino acids and simultaneously reduce the antinutrients (phytic acid), enzyme inhibitors, and flatus-causing sugars [54].

3.3 Milk-based fermented foods

Fermentation of milk, either knowingly or unknowingly, has occurred since the earliest times, resulting in various fermented milk products. Fermented dairy products are known for their taste, nutritive value, and therapeutic properties. The nature of these products differs from region to region depending on the indigenous microflora, which in turn depends upon the surrounding environmental factors [55]. The most popular traditional fermented milk products from the Indian subcontinent are *Dahi*, *Cheese* (*Chhurpi*), *Chhur churpen, Philu, mohi*, *Mishti doi*, *Shyow, Somar, Lassi*, *Shrikhand,* and others. The use of desired microorganisms as in the case of controlled fermentation would greatly increase the chances of obtaining products with uniform and consistent quality of acceptable attributes [56].

Lactic acid bacteria convert the lactose from the milk into lactic acid and selective strains produce an antibacterial substance, that is, bacteriocin to destroy milk curdling by unwanted bacteria. For example, in milk, when *Lactococcus lactis* is inoculated, it converts lactose into energy (Adenosine triphosphate ATP) by enzyme synthesis. Here, lactic acid is the byproduct of ATP that coagulates milk, which can be utilized for the preparation of whey and cheese. Therefore, the bacterium is not just curdling the milk, but it preserves the products by inhibiting the growth of unwanted microorganisms that is by lowering the pH of the product by lactic acid production.

Some "food grade" starter strains, that is, *L. lactis* ssp. *lactis* produce nisin, are an antibiotic-like substance called a bacteriocin. It has natural antimicrobial activity against a wide variety of Gram-positive bacteria, including food-borne pathogens such as *Listeria monocytogenes, Staphylococcus aureus*, *Bacillus cereus,* and *Clostridium* sp. It is believed that the nisin's primary target is the cell membrane, which does not need a receptor to interact with the cell membrane of the microbe. It is a natural preservative prevalent in cheeses prepared with *L. lactis* ssp. *lactis* and is currently recognized as a safe food preservative. Hence, it is used as a preservative in thermally processed and low pH foods, also in various pasteurized dairy products and canned vegetables, baked, beverages, high-moisture flour products, and pasteurized liquid eggs. As nisin cannot be chemically synthesized, the nisin-producing *L. lactis* strains are used for their industrial synthesis. A highly purified nisin preparation has led to an interest in the use of nisin for human ulcer therapy and mastitis control in cattle, while different enzymes and other metabolic products produced by *Lactococcus lactis* contribute to the more subtle aromas and flavors that distinguish different cheeses.

Most foods mentioned below in this category are prepared by simply adding LAB to the milk of cow, buffalo, or yak and allowed to ferment.

3.3.1 Dahi

Dahi is one of the most popular fermented dairy products on the Indian subcontinent highly accepted for its mild acidic taste and pleasant flavor. The main properties of good quality *dahi* are steady with uniform consistency, sweet aroma, and light sour taste. The surface of the *dahi* will be smooth, shiny, and free of cracks as well as gas bubbles. It is believed that *dahi* possesses nutritional and therapeutic values at a higher level when compared to the milk utilized for its preparation. *Dahi* is easy to digest and has been found to possess several health benefits [57]. One of the primary compositions of *dahi* made with whole milk is as follows: water 85–88%, fat 5–8%, protein 3.2–3.4%, lactose 4.6–5.2%, lactic acid 0.5–1.1%, ash 0.7–0.75%, calcium 0.12–0.14%, and phosphorus 0.09–0.11% as reported by Laxminarayana et al. [58].

The lactic acid bacterial cultures commonly associated with the inoculum are strains of *Lactococcus lactis* ssp. *lactis*, *Lactococcus lactis* ssp. *cremoris*, *Lc. lactis* ssp. *diacetylactis*, *Leuconostoc cremoris*, *Lactobacillus delbrueckii* ssp. *bulgaricus*, *Lactobacillus acidophilus*, and *Lactobacillus helveticus*. Choosing a good starter culture is important to attain a good flavor with desirable characteristics. Both mesophilic and thermophilic starters have been reported to be used in a number of different combinations [59, 60]. The addition of probiotic cultures such as *Lactobacillus* acidophilus and Bifidobacterium bifidum combined with the regular lactic cultures for *dahi* preparation helps to increase the therapeutic and nutritional value [61]. *Dahi* has been recognized as a potential source of lactic acid bacteria, chiefly species of *Lactobacillus* that are active against foodborne pathogenic and spoilage bacteria such as *Staphylococcus aureus*, *Bacillus cereus*, Bacillus licheniformis, Bacillus subtilis, Escherichia coli and *Klebsiella* sp., and *Pseudomonas* sp. [62]. In addition, a strain of *Lactobacillus* delbrueckii ssp. *bulgaricus* produces heat-resistant bacteriocin with broad-spectrum antibacterial activity and the potential for use as a food biopreservative isolated from *dahi* [63]. As such, *dahi* differs from yogurt in the use of mixed starters of mesophilic lactococci. Diacetyl is one of the main metabolites that induce flavor in *dahi* products, which is accepted more by South Asian origin people than acetaldehyde flavor in yogurt (**Figure 1**) [64].

Figure 1.
Dahi (courtesy: Zee news).

3.3.2 Cheese

Cheese (*Chhurpi*) made from yak and cattle milk is mainly consumed in the Himalayan plateau and industrial production of this product has not yet become the norm. *Chhurpi* is in white color, soft in texture with a mild to strong flavored taste, and is eaten as a curry blend with edible wild ferns (*Diplazium* spp.), pickles, and condiments along with cooked rice in meals [65]. Yak cheese contains the following chemical composition, 68.2% of total solid, 49.4% of butterfat on a dry matter basis, and 1.37% of salt [66, 67]. In mature *Chhurpi*, LAB count 7.5 log CFU/g was recorded. All LAB strains except *Leuconostoc mesenteroides* BFE1637 showed a high level of hydrophobicity. This is an important property of LAB that helps to colonize epithelial cells. LAB strains produce enzymes such as peptidases and esterase-lipases that play an important role in the improvement of *cheese* quality.

Similarly, *Chhu*, *Shyow*, *Mohi*, *Somar*, and *Philu* are traditional fermented milk products in the Himalayan plateau, predominantly fermented by LAB. *Chhu* (*Sheden*) is a strong-flavored cheese-like product, LAB were mainly present at 8.1–8.8 log CFU/g. *Shyow* is a thick curd-like product, prepared with yak milk. *Mohi* is buttermilk, prepared with churning *dahi*, consumed as a refreshing beverage. *Somar* is a soft paste, strong flavored with a bitter taste, eaten as a soup along with cooked rice or finger-millets, whereas *Philu* is a typical indigenous cream-like milk product obtained from cow milk or yak milk and is consumed as a cooked paste delicacy with boiled rice [68, 69]. These products are rich in LAB that produces various enzymes such as esterase, phosphatase, leucine-arylamidase, β-galactosidase, and peptidase. These bacterial strains inhibited the growth of pathogens such as Enterobacter agglomerans, Enterobacter cloacae, and Klebsiella pneumoniae. Fermented milk products have been reported to contain more common LAB such as Streptococcus cremoris, Streptococcus lactis, Streptococcus thermophilus, *Lactobacillus* bulgaricus, *Lactobacillus* acidophilus, *Lactobacillus* helveticus, *Lactobacillus cremoris, Lactobacillus* plantarum, *Lactobacillus* curvatus, *Lactobacillus* fermentum, *Lactobacillus* paracasei *subsp. pseudoplantarum, Lactobacillus* alimentarius, *Lactobacillus kefir, Lactobacillus* hilgardii, Enterococcus faecium, *L. mesenteroides, Lactobacillus* farciminis, *Lactobacillus* brevis, Lactococcus lactis *subsp. cremoris, Lactobacillus* casei *subsp. Casei*, and *Lactobacillus* bifermentans (**Figure 2**) [39].

Figure 2.
Cheese (courtesy: Healthy nibbles).

3.3.3 Mishti doi

Mishti doi also called as *lal dahi* or *payodhi* is most popular in eastern India. It is a blend of sweet *dahi* that usually appears as a light brown color and has a firm texture with a cooked or caramelized flavor. There are two types of formulations have been recognized for the preparation of *Mishti doi* [70]. One combination involves the use of *Streptococcus salivarius* ssp. *thermophilus, Lactobacillus acidophilus* and *Lactobacillus delbrueckii* ssp. *Bulgaricus,* and the other formula are on *Lactobacillus* acidophilus, Lactococcus lactis ssp. *Lactis*, and *Saccharomyces cerevisiae*. Microbiological study of market samples of *mishti doi* showed the presence of yeast such as *Saccharomyces*, *Candida,* and *Rhodotorula*, as well as the LAB such as *Lactobacillus, Lactococcus,* and *Streptococcus*. Protease peptone, a trace protein of milk, plays a key role in imparting the brown color to the product (**Figure 3**) [71].

3.3.4 Lassi

Lassi also known as buttermilk from an Indian perspective and is one of the popular lactic-fermented milk-based beverages in the Indian subcontinent, which is consumed predominantly during hot and warm seasons. It is a by-product obtained during the desi butter preparation from *dahi* by churning. It is also made by crushing

Figure 3.
Mishti doi (courtesy: Babs projects).

the set *dahi* with the agitator and adding the required amount of water, sugar, or salt and flavor compounds. Rangappa and Achayya in 1974 [72] stated that the composition of each *Lassi* differs mainly due to the variety of milk used, the amount of dilution made while churning, and the efficiency of fat removal. A typical composition of *Lassi* includes water 96.2%, fat 0.8%, protein 1.29%, lactose 1.2%, lactic acid 0.44%, ash 0.4%, calcium 0.6%, and phosphorus 0.04%. To extend the shelf life of *Lassi* beyond 6 days 0.03–0.35% sodium metabisulfite must be added and stored at 37°C. The sulfur flavor developed by the preservative can be masked by adding 0.07–0.09% crushed ginger and 0.5–0.7% salt [73]. The preservative effect of nisin in improving the shelf life of *Lassi* has been studied, wherein *Lassi* could be stored for 32–48 h at 30°C with the addition of Nisaplin at a concentration of 200–500 IU/ml, while the stability was 8–10 days when stored in a refrigerator [74]. In order to increase the therapeutic value of *Lassi*, the method of preparation has been standardized using probiotic culture of *Lactobacillus* acidophilus along with Streptococcus thermophilus to obtain a desirable flavor in the final product (**Figure 4**) [75].

3.3.5 Shrikhand

Shrikhand is a sweetened fermented traditional dairy product extensively consumed in the western and northern parts of India. It has a refreshing taste with a pleasant aroma, smooth and homogenous texture, and firm consistency. The preparation of *Shrikhand* includes curd products (*dahi*) made by lactic fermentation of complete milk, either cow or buffalo milk, after which whey is removed from the curd using a hanging muslin cloth bag hung for 6–8 h. The resultant solid mass (called chakka) is evenly mixed with ground sugar (44–45%) and prepared as a semi-solid mass to which flavorings such as cardamom and saffron are mixed. The cultures used are mesophilic LAB, the same cultures involved in the preparation of *dahi* [76].

The technological and microbiological aspects of the *Shrikhand* preparation are reported in an earlier study [77]. Preparation of nutritional *Shrikhand* using buffalo skimmed milk fermented with a combined culture of 2% *Lactobacillus acidophilus* (NDRI-AH1) and Str*eptococcus salivarius* ssp. *thermophilus* (NDRI-YHS) has been

Figure 4.
Lassi (courtesy: Swasthi's recipes).

Figure 5.
Shrikhand (courtesy: Babs projects).

reported to reduce the high-fat content in the final product [78]. A change in the mineral content profile of milk for the final *Shrikhand* product was studied [79]. Post-production heat treatment (PPHT) of *Shrikhand* at 70°C for 5 min improved the shelf life up to 15 days at 35°C and up to 70 days at 8–10°C [80, 81]. *Shrikhand* powder has been developed by spray drying method that is by exposing the product at 160–170°C of inlet temperature and 100°C of outlet temperature. Dehydrated *Shrikhand* would have a shelf life of 90 days when stored in gas-packed containers at 30°C (**Figure 5**) [82, 83].

3.4 Cereal and legume-based fermented foods

Cereal and legume-based fermented foods are regarded as staple foods in their respective provinces. They are a major source of economical dietary energy and nutrients throughout the world. In Indian subcontinent, region-specific cereals or legumes are subjected to natural or controlled fermentation to obtain desirable end products through the involvement of desirable microorganisms, mainly LAB, yeasts, and fungi, and have been well documented [84–86], and these organisms have the ability to increase palatability, maintaining the quality, safety, and nutritional value of the raw materials. The successive phase of growth of microorganisms in the fermentation of cereals and legumes also favors the growth of yeasts, which often occurs as a component of mixed microflora and gives specific characteristics to the product [87].

Most foods such as *idli, dosa, dhokla, khadi, Punjabi warri, adai dosa, kallappam, ambali* or *pazhaiya soru, koozhu, nan,* and *parotta* are routine food products of the native population. For the preparation of this type of fermented food products, chiefly use cereals such as rice (*Oryza sativum*), wheat (*Triticum* spp.), ragi (*Eleusine coracana*), barley (*Hordeum vulgare*), whereas pulses include black gram, green gram, and red gram. These cereals and legumes are cultivated in India since the Indus valley civilization period, that is, 9000–5500 BC [88], and are commonly used as main components in the preparation of significant amounts of food products. They are one of the effective substrates for the preparation of functional foods combined with probiotics. Since these products are rich in non-digestible carbohydrates, which help in the growth of Lactobacilli and Bifidobacteria. They consist of water-soluble fibers such as β-glucan, galactooligosaccharides, fructooligosaccharides, and arabinoxylan, and these fibers can be digested by selective LAB strains [89].

In the preparation of fermented foods such as *idli, dosa, adai dosa, kallappam,* and *dhokla,* the batter is prepared from the basic ingredients such as milled rice (*Oryza sativus*) and dehulled Black gram (Phaseolus mungo), and left the batter to ferment overnight at room temperature. For this, sodium bicarbonate can be added to create anaerobic conditions for LAB and yeast growth. In case of *Kallappam* preparation, the batter can be supplemented with fermented toddy to provide the extra LAB source. Leuconostoc mesenteroides are the most commonly encountered bacterium [90]. *Lactobacillus* plantarum AS1 isolated from fermented food from Southern Indian *Kallappam* successfully prevented colonization of entero-virulent bacterium Vibrio parahaemolyticus in HT-29 cell line and colorectal cancer in male Wistar rats [91, 92].

Preparation of *Pazhaiya soru* or *ambali* (Fermented rice) involves adding water to the cooked rice and later incubating the mixture overnight. Before consuming buttermilk add salt directly [20]. In most parts of south India, farmers consume this as an early morning meal before heading to the farm-field. Major microbiota isolated from this type of food include *Lactobacillus plantarum, Lactobacillus fermentum, Leuconostoc mesenteroides*, *Pediococcus cerevisiae,* Pediococcus acidilactici, Enterococcus faecalis, and Weissella paramesenteroides.

Koozhu is a traditional South Indian fermented food, a type of porridge made from finger millet and claimed to be a nutritious food. It is included in the daily diet of rural agricultural workers and urban households [93]. It is also given to children at weaning age [94]. It is made from Kezhvaragu or Cumbu flour and broken rice in a clay pot. *Koozhu* is easily digested and cools the body; therefore, during the summer, street vendors sell it as a cool drink in Southern India. There is an increase in thiamine, riboflavin, and niacin contents during its fermentation [95, 96].

In India, there are a large proportion of traditional fermented foods that are still unexplored for the microbiota and therapeutic values. Most of the research work has been done on the following fermented food products.

3.4.1 Idli

Among the closely related types of traditional fermented foods based on the combination of cereal and legume is the *idli*. It is a white, fermented (acid-fermented), steamed product with a soft and spongy texture, more popular and consumed throughout Southern India. It has been documented that *idli* batter fermentation has been in use since 1100 AD [97]. It is the resulting product of naturally fermented batter made from washed and soaked milled rice (*Oryza sativus*) and dehulled Black gram (Phaseolus mungo). From a nutritional and health point of view, *idli* seems to be an ideal human food for all ages of people and at all times. Investigations into the primary aspects of *idli* batter fermentation were started as early as in 1955 at the Central Food Technological Research Institute, Mysore, India. Several researchers have used different proportions of Black gram cotyledons to rice ranging from 4:1 to 1:4 weight to weight (w/w) for making *idli* with a preference for 2:1 and 3:1 over 4:1 [77, 98–101].

Studies have demonstrated the optimum fermentation conditions for obtaining good *idli*s as well as the physiochemical and microbiological changes that occur during intermittent periods of incubation at varying temperatures [98, 102, 103]. Typically, the microorganisms that develop during the initial and subsequent soaking of the ingredients are sufficient to cause fermentation. The microbiological changes during the fermentation period have shown the involvement of different genera and species of LAB and yeasts. The main bacterial floras identified include *Lactobacillus* brevis, Leu*conostoc mesenteroides, Lactobacillus* delbrueckii, *Lactobacillus* lactis, *Lb.*

fermentum, Pediococcus cerevisiae, and Str*eptococcus* faecalis, while the yeast flora comprised Torulopsis holmii*,* Torulopsis candida*, Candida kefyr, Candida cacaoi,* Can*dida* tropicalis*, Candida fragicola,* Hansenula anomala*,* and *Puccinia* graminis. Moreover, these studies have shown the presence of major microflora at different stages of *idli* fermentation [101, 102, 104–108].

Two important changes that occur during *idli* fermentation are acidification and the leavening of the batter. Comprehensive studies on the various changes that accompany *idli* batter fermentation have shown that in addition to a consistent increase in microbial populations, the pH dropped to 4.4–4.9 from an initial pH of 6.6 [102, 106]. Several attempts have been made to improve holding *idli* fermentation by standardizing various physicochemical factors. An increase in the fermentation rate of *idli* batter was observed to accompany a rise in temperature [98]. Fortification of *idli* batter with glucose at 1% level has shown a beneficial effect on the gas formation and leavening during fermentation [109]. Similarly, the relationship between microflora type and biochemical traits revealed an increase in the content of water-soluble group B vitamins during *idli* fermentation [110].

As a step toward convenience in preparation, the dry mix concept was proposed as early as in 1960 [98]. In a similar approach, a process related to an improved means of providing inoculum (LAB and yeast) in ready-to-use form *idli* fermentation was developed [111]. In order to reduce the fermentation time of *idli* batter and increase its shelf life of fermented *idli* batter, an Indian patent has been filed [112]. Simultaneously, the flavor profile of such controlled fermented *idli* batter has shown the presence of desirable flavor compounds such as ketones, diols, and acids for an 8-day storage period. This flavor profile can be a reliable qualitative and quantitative parameter for objective evaluation [113].

Plantaricin LP84, a bacteriocin produced by *Lactobacillus* planatrum NCIM 2084, was able to retard the growth of foodborne pathogens such as *Bacillus cereus* F 4810, *Escherichia coli* D 21, and Staph*ylococcus* aureus FRI 722 during *idli* batter fermentation [114]. Fermented *idli* is easy to digest and is often used as baby food. This is the prescribed diet in hospitals for patients undergoing treatment (**Figure 6**) [85].

3.4.2 Dosa

Dosa is a fermented, thin, crispy, baked, and pancake-like product widely consumed in southern and parts of western India. In recent years, *dosa* has become more

Figure 6.
Idli and batter (courtesy: Sharmis passions, Hebbars kitchen).

Figure 7.
Dosa (courtesy: Madhura's recipe).

prominent throughout India including in Indian restaurants around the world. The *dosa* batter preparation is nearly similar to the *idli* batter, except for the proportion of milled rice and Black gram dhal usage. In the preparation of *dosa* batter, an equal quantity of milled rice and dehulled black gram dhal is soaked in water for a period of 6–8 h at room temperature (25–30°C) and grinded into a fine paste using the required amount of water, that is, 2.0–2.5 parts by weight. Later allow the batter to undergo natural fermentation for a period of 10–12 h at room temperature (25–30°C). From this fermented batter, *dosa* can be made like thin, crispy, pancake-type product.

Even in fermented *dosa* batter also numerous biochemical changes occur due to the effect of lactic acid bacteria along with yeasts [115, 116]. The predominant species identified were *Leuconostoc mesenteroides, Lactobacillus fermentum, Lactobacillus delbrueckii, Pediococcus cerevisiae, Saccharomyces cerevisiae*, *Hansenula anomala*, and *Kluyveromyces* sp. Typically, these microorganisms come from raw materials such as rice and Black gram [106]. *Dosa* batter fermentation also resulted in increased biochemical attributes, including that of water-soluble group B vitamins such as thiamine, riboflavin, and cyanocobalamin.

Attempts have been made to prepare products similar to *dosa* by replacing Black gram with other legumes like soy beans. Soy bean-based *dosa* batter was found to be nutritious but less preferred organoleptically (**Figure 7**) [117].

3.4.3 Dhokla

Dhokla is one of the famous steamed food products in the western part of India, especially in Gujarat and Maharashtra States. It is prepared with a mixture of Bengal gram (Cicer arietinum), dehulled black gram (Phaseolus mungo), and milled rice (Oryza sativa) in a ratio of 2:1:1. This composition gives the product a soft and spongy texture. The above-mentioned mixture of grains is soaked in water for 6 to 8 h and ground to a granular consistency. To the resultant batter, the curd is added to a proportion of 1:1.5 w/w, after which it is allowed to ferment for 16 to 18 h and then steamed the product. Usually, this product is consumed by seasoning with oil, spices, and coriander leaves for taste [85, 97].

Research studies have shown that the numbers of LAB and yeast cells are increased during the fermentation process. Major microorganisms such as *Lactobacillus fermentum*, *Leuconostoc mesenteroides*, and *Han. Silvicola* are present in this product, whereas biochemical changes such as pH, acidity, and volatile fatty acid content in the food product are also documented as influencing the increase in microbial counts [118].

Figure 8.
Dhokla (courtesy: Ram Asrey).

One more study found that *dhokla* batter was prepared using *Lactobacillus* species that exhibited antibacterial activity against harmful microorganisms such as B*acillus* subtilis, Bac*illus* licheniformis, and B*revib*a*cillus* laterosporus present as contaminants before processing. But in another study, it was reported that the same harmful bacterial species grew well in the *dhokla* batter that was prepared using *Lactococcus* species due to a lack of antibacterial activity [119, 120]. These results indicate that those LAB have an antagonistic nature and are able to provide healthy food products in terms of safety (**Figure 8**).

3.4.4 Kadhi

It is a traditional fermented food, prepared by boiling lactic fermented and agitated *dahi* with 5 to 8% (w/w) Bengal gram flour, that is, besan flour as a thickening agent. It is consumed in most parts of India as a cooked food that has a slightly sour taste and gives it a classic baked flavor. Considering the potential use of antagonistic LAB, studies have been carried out to evaluate the effectiveness of the antibacterial properties of selected LAB for foodborne pathogenic and spoilage bacterial species occurring in pre-processing and post-processing contaminants in *kadhi*. The study highlighted the benefits of using pure cultures of LAB with antagonistic nature such as *Lactobacillus delbrueckii* ssp. *lactis* CFR 2023 and *Lactobacillus* delbrueckii ssp. *bulgaricus* CFR 2028 in *kadhi* preparation with desirable quality attributes and preservation against foodborne pathogens [63, 120].

LAB isolated from *khadi* showed antibacterial activity against S*taphylococcus* aureus, Escherichia coli, and P*seudomonas* aeruginosa as well as exhibited probiotic properties [121]. The effectiveness of antagonistic cultures of *Lactobacillus* species was evaluated in terms of microbiological and sensory parameters in *kadhi* during storage at ambient and refrigerated temperatures [119]. Research studies have attempted to modify the *kadhi* preparation to provide better nutritional status through the use of smaller quantities of Bengal gram flour obtained from pre-soaked seeds. Based on the sensory attributes and the characteristic consistency of *kadhi*, the product prepared using Bengal gram flour (from pre-soaked seeds at 40 mg/g) showed better acceptance compared to the product prepared by a conventional method using 100 mg/g of besan (**Figure 9**) [56].

3.4.5 Punjabi warri

It is a pulse-based dried product, commonly prepared in north India. They are spicy, hollow, crunchy, small fried balls and used as a condiment in cooking with vegetables, soups, or Indian sambhar (dhal-based spicy liquid). It is prepared using dehulled black gram (Phaseolus mungo), which needs to be soaked overnight in water

Figure 9.
Kadhi (courtesy: We recipes).

and then ground into a soft batter. Different types of spices are added to this batter and made into small balls. After this allowed to ferment for a few hours and dried in an open space for 4 to 10 days [122].

Microbiological and biochemical aspects associated with Punjabi warri have been studied in some research investigations [106, 122]. These studies have established that the development and prevalence of microorganisms were affected by the seasons; summers are more favorable for bacteria and winters for yeasts. These microbial types tend to increase significantly as fermentation progresses. The microorganisms that are responsible for the fermentation of this product mainly include Leu*conostoc* mesenteroides, *Lactobacillus* fermentum, Str*eptococcus* faecalis, *Saccharomyces cerevisiae*, Pichia membranaefaciens, and *Trichosporon beigelii*. During this process, there is an increase in enzyme activity such as amylase and other proteinase, which leads to the enhancement of water-soluble B-vitamins such as thiamine, riboflavin, and cyanocobalamin. These biological changes influence the nutritional quality of food products.

Some research studies have shown that the use of *Lactobacillus* delbrueckii ssp. *bulgaricus* CFR 2028 and *Lactobacillus* delbrueckii ssp. *lactis* CFR 2023 in warri preparations exhibited antibacterial activity against food-borne pathogens like B*revib*a*cillus* laterosporus, Bac*illus* licheniformis, and *Bacillus subtilis*. The preparation of this product involves combined fermentation and drying processes where *Lactobacillus* species act as biopreservative. Hence, pathogenic microbial growth was stopped while the storage period of 10 days at room temperature [119, 120].

In addition to the above, there are several other documented cereal and legume-based traditional foods popular in specific regions of India. However, detailed scientific and technological studies have not been much documented on these foods.

3.5 Milk and cereal/legume-based fermented foods

3.5.1 Rabadi

Rabadi is a fermented drink most commonly used in the Rajasthan province of India. It is made from a combination of pearl millet flour (Pennisetum typhoideum) or wheat flour and buttermilk, using an earthenware vessel as a container and then keeping it for natural fermentation for 4 to 6 h at room temperature. This is followed by dilution of the product with water, cooking, and adding salt to taste. This process improves the level of LAB that can be served as health drinks [123].

Rabadi fermentation of freshly ground wheat millet flour brought about a significant increase in the HCl-extraction capacity of calcium, iron, copper, zinc, manganese, and phosphorus [124]. Consumption of such fermented foods may help to improve prevailing mineral deficiencies due to their limited bioavailability of such coarse grains [125–128]. The effect of processing parameters such as dehulling, cooking, and fermentation on the antioxidants present in pearl millets during the preparation of *rabadi* revealed that cooking and fermentation result in improved flavonoids [129]. Furthermore, using germinated pearl millet grains, the optimization of *rabadi* preparation was performed by response surface methodology. The most acceptable product is prepared with 5.3% flour and 72% water based on the type of curd (**Figure 10**) [11, 130].

3.5.2 Kulcha

Kulcha is a popular product consumed in north India, which is lately gaining popularity in other provinces of India. It is prepared by mixing the main components such as white wheat flour, milk, sugar, salt, curd, dry yeast, baking powder, and water. It is thoroughly mixed and kneaded into firm dough. The dough is allowed to ferment naturally for a period of 6 to 8 h at room temperature (28 to 30°C). A small ball of dough of uniform size is used to make the thick disc-shaped *kulchas* by hand and then a flat dough is baked in a tandoor (a metallic baking sheet or special oven made of clay) to a golden brown color and served hot (**Figure 11**) [56].

3.5.3 Naan

Naan is a fermented flatbread baked in a clay oven called a tandoor and is widely consumed by people in northern India. In recent times, *naan* is becoming more

Figure 10.
Rabadi (courtesy: Dishes guru).

Figure 11.
Kulcha (courtesy: Times food).

Figure 12.
Naan (courtesy: Recipe pocket).

popular in other provinces of India. To make *naan*, the first dough is made using components such as white wheat flour, egg, milk, curd, baking powder, salt, and sugar. This is allowed for fermentation at room temperature for 1 to 2 h. A small portion of the dough is taken that is rolled out on a flat surface and roasted in a clay oven until it turns brown and crispy on both sides. Finally, it is served with butter (**Figure 12**) [56].

3.6 Vegetable-based fermented foods

The ancient civilization was well aware of the existence of natural microflora and its role in the fermentation of vegetables, which could result in palatable foods for human consumption. Vegetables contain low sugar, neutral pH, and their composition is not favorable to the spontaneous growth of LAB. However, over the centuries, people have traditionally developed methods of lactic fermentation that could stabilize and improve the nutritional quality of vegetables. Fermented vegetables represent an essential element of the human diet. Lactic acid fermentation, which improves the organoleptic and nutritional quality of the vegetables, has remained more of a domestic- or cottage-level process.

Spices and herbs impart a fine flavor and play a key role in fermented vegetables. Spices such as garlic, clove, and chili inhibit the growth of food-borne microorganisms because these spices contain antagonistic activity. Some aromatic compounds such as terpenes and polyphenols (found in spices), allyl isothiocyanate (found in mustard seed) as well as sulfur (found in garlic) have antimicrobial activity and selectively stimulate the growth of LAB. Mustard seed oil is most commonly used in north India since it has the property to promote the lactic fermentation of food products, which helps in their long storage. Apart from this, chemical preservatives such as sorbic and benzoic acids are used in the development of vegetable-based fermented products [131]. The concentration of salt induces plasmolysis in vegetables, thus promoting anaerobiosis for the proliferation of lactic acid bacteria. Some of the well-known vegetable-based lactic fermented products are presented in the following paragraphs.

Popular types of pickles consumed by the human population of India have been those based on unripe mangoes, goose berries, lemons, swallow root (*Decalepis hamitonii*), and a variety of mixed vegetables. In general, most of these pickles are prepared at home, subjecting the vegetables to natural fermentation. In a specific type of pickles, preservation is achieved through lactic acid fermentation and in the presence of high concentrations of salt. The process involves washing raw materials, then cutting them into appropriately sized shapes, and mixing them with salt at a level twice the weight of the raw material. Necessary spice powders are also used in the preparation. The powdered spice mix mainly includes chili, mustard, and coriander seeds. The product is allowed to ferment in the closed container for 8 to 10 days at room temperature. The aging of the product gives it a slightly acidic taste and pickles develop acceptable organoleptic properties. Although not much research has been done on the nature of microflora and other attributes, it is believed that the microflora mainly comprises lactic acid bacteria and to some extent acetic acid bacteria.

In another specific type of pickle that is devoid of any liquid, the raw materials for the preparation of the pickle are the same as described above and preservation is achieved through a high concentration of salt, a mixture of spices, and edible oil. The prepared pickle product is intermittently fried with oil for 3 to 4 times and placed in a closed container to ferment. Moreover, the product should be covered with a sufficient quantity of edible oil, where the oil used depends on the specific regions of this country. In this specific type of preparation, fermentation occurs naturally with the predominance of LAB, which can survive and grow in the presence of high concentrations of salt. Regardless of the type of pickle preparation, the shelf life is quite reasonable, extending to periods of 6 months and beyond if proper hygiene and sanitation practices are in place during the preparation and subsequent storage. In the absence of any microbiological studies on the nature of pickle fermentation, from the product profile, it appears that species of *Pediococcus* tend to predominate over other LAB.

There are several other traditional fermented vegetable-based foods, which are more popular in eastern, northern, and north-eastern regions of India. A few of them known by traditional names are *gundruk*, *sinki*, *Iromba*, *rai, Kanjika* or *kanji,* and others. They are considered as good appetizers and tribal people use these foods for indigestion therapies [132]. *Gundruk* soup is usually given to breast-feeding mothers to improve milk efficiency. It is considered as a tonic for elderly people [133]. *Sinki* is a fermented radish root that more effectively cures diarrhea and stomach pain. *Iromba* made from tree bean (Parkia roxburghii) is used as a starter [133]. Fermented *rai* has

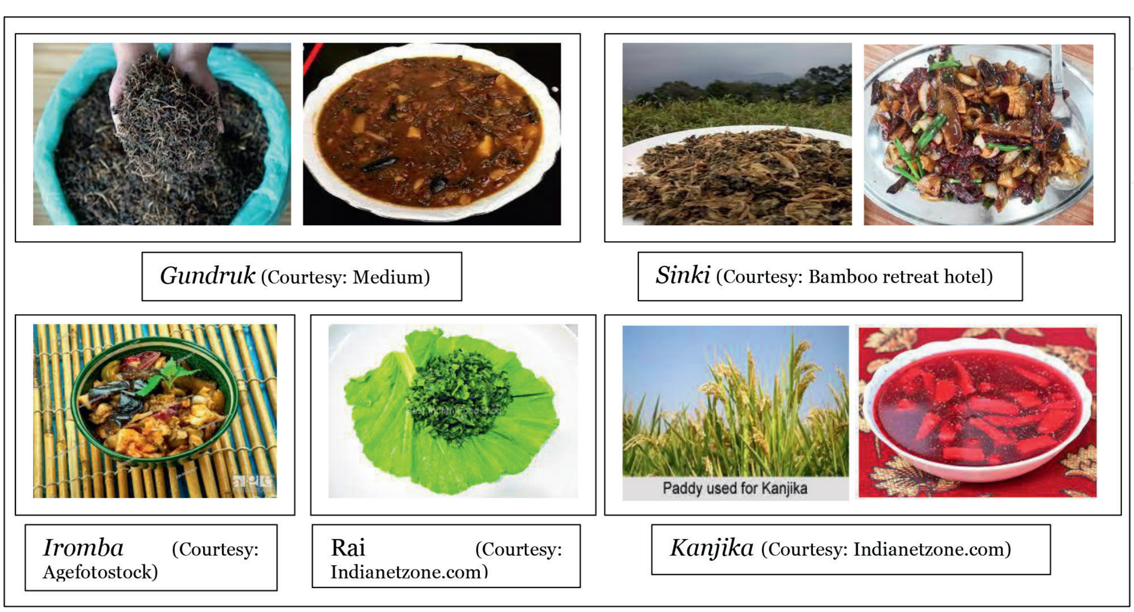

Figure 13.
Vegetable-based fermented foods.

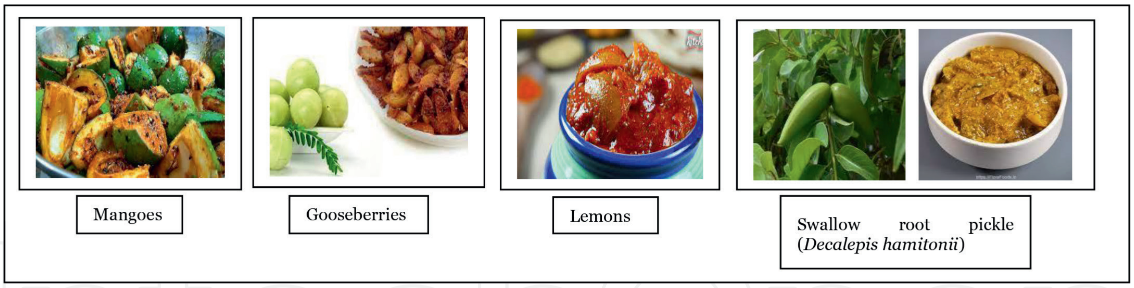

Figure 14.
Pickles (courtesy: Cookpad.com, times of India).

the therapeutic benefit which resolves stomach pain and gas problems and considerably improves digestion [133]. *Kanjika* or *kanji* is a lactic fermented rice product, recommended for several types of chronic diseases in Indian Ayurvedic medicine [134]. Carrot *Kanji* is known for its high nutritional value which has energizing as well as relaxing properties [135]. Beetroot *kanji* has the property to prevent infectious and malignant diseases (**Figures 13** and **14**) (**Table 1**) [136].

Product	Region	Microorganism(s)	Substrate
Milk-based			
Dahi	India	*Lactococcus lactis* ssp. *lactis*, *Lactococcus lactis* ssp. *cremoris*, *Lc. lactis* ssp. *diacetylactis*, *Leuconostoc cremoris*, *Lactobacillus delbrueckii* ssp. *bulgaricus*, *Lactobacillus acidophilus*, and *Lactobacillus helveticus*	Whole milk [57–64]
Cheese (*Chhurpi*, *Chhu*, *Shyow*, *Mohi*, *Somar*, and *Philu*)	Himalayan plateau	*Streptococcus cremoris*, *Streptococcus lactis, Streptococcus thermophilus, Lactobacillus bulgaricus, Lactobacillus acidophilus, Lactobacillus helveticus, Lactobacillus cremoris, Lactobacillus plantarum, Lactobacillus curvatus, Lactobacillus fermentum, Lactobacillus paracasei subsp. pseudoplantarum, Lactobacillus alimentarius, Lactobacillus kefir, Lactobacillus hilgardii, Enterococcus faecium, Leuconostoc mesenteroides, Lactobacillus farciminis, Lactobacillus brevis, Lactococcus lactis subsp. cremoris, Lactobacillus casei subsp. Casei*, and *Lactobacillus bifermentans*	Yak and cattle milk [39, 64–69]
Mishti doi (*lal dahi* or *payodhi*)	Eastern India	*Streptococcus salivarius* ssp. *thermophilus*, *Lactobacillus acidophilus*, *Lactobacillus delbrueckii* ssp. *Bulgaricus, Lactococcus lactis* ssp. *Lactis*, and *Saccharomyces cerevisiae*	Blend of sweet *dahi* [70, 71]
Lassi (Buttermilk)	Northern India	*Lactobacillus acidophilus*, *Streptococcus thermophilus*	By-product of Dahi (Butter) [72–75]
Shrikhand	Western and northern parts of India	*Lactobacillus acidophilus* and *Streptococcus salivarius* ssp. *thermophilus*	Cow or buffalo milk [76–83]
Cereal and legume-based			
Idli	Southern India	*Lactobacillus brevis, Leuconostoc mesenteroides, Lactobacillus delbrueckii*, *Lactobacillus lactis, Lb. fermentum*, *Pediococcus cerevisiae*, and *Streptococcus faecalis*, yeast flora comprised *Torulopsis holmii, Torulopsis candida, Candida kefyr, Candida cacaoi, Candida tropicalis, Candida fragicola, Hansenula anomala*, and *Puccinia graminis*	Milled rice (*Oryza sativus*) and dehulled Black gram (*Phaseolus mungo*) [77, 85, 97–114]

Product	Region	Microorganism(s)	Substrate
Dosa	Southern India	*Leuconostoc mesenteroides, Lactobacillus fermentum, Lactobacillus delbrueckii, Pediococcus cerevisiae, Saccharomyces cerevisiae*, *Hansenula anomala*, and *Kluyveromyces* sp.	Milled rice (*Oryza sativus*) and dehulled Black gram (*Phaseolus mungo*) [106, 115–117]
Dhokla	Western part of India	*Lactobacillus fermentum, Leuconostoc mesenteroides* and *Han. Silvicola*	Bengal gram (*Cicer arietinum*), dehulled black gram (*Phaseolus mungo*), and milled rice (*Oryza sativa*) [85, 97, 118–120]
Kadhi	Indian subcontinent	*Lactobacillus delbrueckii* ssp. *Lactis,* and *Lactobacillus delbrueckii* ssp. *bulgaricus*	Dahi (Curd) with 5 to 8% (w/w) Bengal gram flour [56, 63, 119–121]
Punjabi warri	Northern India	*Leuconostoc mesenteroides, Lactobacillus fermentum*, *Streptococcus faecalis*, *Saccharomyces cerevisiae*, *Pichia membranaefaciens,* and *Trichosporon beigelii*	Dehulled black gram (*Phaseolus mungo*) and different types of spices [106, 119–122]
Milk and cereal/legume based			
Rabadi	Western part of India	Lactic acid bacteria	Pearl millet flour (*Pennisetum typhoideum*) or wheat flour and buttermilk [11, 123–130]
Kulcha	Northern India	Lactic acid bacteria	White wheat flour, milk, sugar, salt, curd, dry yeast, baking powder, and water [56]
Naan	Northern India	Lactic acid bacteria	White wheat flour, egg, milk, curd, baking powder, salt, and sugar [56]
Vegetable-based [131–136]			
Pickles of unripe mangoes, goose berries, lemons, swallow root (*Decalepis hamitonii*) and a variety of mixed vegetables	Indian subcontinent	Lactic acid bacteria	Different types of vegetables along with spices like garlic, clove, chili, mustard seeds, mustard seed oil/groundnut oil, curry leaves,
Gundruk	North-eastern regions of India	Lactic acid bacteria	Green leaves of mustard, radish, and cauliflower
Sinki	North-eastern regions of India	Lactic acid bacteria	Radish root
Iromba	North-eastern regions of India	Lactic acid bacteria	Tree bean (*Parkia roxburghii*)

Product	Region	Microorganism(s)	Substrate
Rai	North-eastern regions of India	Lactic acid bacteria	Mustard green leaves
Kanjika or kanji	North-eastern regions of India	Lactic acid bacteria	Rice

Table 1.
Examples of traditional fermented foods of India.

4. Concluding remarks

Indigenous fermented foods have played a vital role in the history of human health. They can be produced and distributed at a relatively low cost. They are typically highly nutritious, providing calories, protein, vitamins, and minerals at prices most consumers can afford. As canned and frozen foods are unavailable or too expensive for hundreds of millions of economically deprived populations around the world, traditional fermented foods can fill this gap. Acid fermentation combined with salting remains one of the most practical methods to preserve and increase the organoleptic and nutritional value of fresh vegetables, cereal porridge, and milk-cereal mixtures. Furthermore, ethanol fermentation is very significant in preserving and increasing the nutritional value of cereal grains and fruit juices. Modern food technology exploits enrichment or fortification to improve the nutritional value of foods to reach consumer needs.

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