Chapter

# Lactobacilli: Application in Food Industry

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## Abstract

*Lactobacillus* is an important class of Gram-positive, non-spore-forming bacteria for food industrial applications. The genus *Lactobacillus* is a potential candidate in fermentation technology for the production of fermented food, feed, and pharmaceutical products. The diverse features of *Lactobacilli* based on their capability to produce acids, enzymes, bacteriocins by fermenting carbohydrates. *Lactobacilli* have probiotic potential and therefore applied in dairy [cheese, yoghurt, fermented milk] and nondairy products such as sausages, juices as well as in animal feed in the form of starter culture. Among *Lactobacilli*, lactic acid-producing bacteria are applied as starter cultures in a variety of fermented foods. *Lactobacilli* are the natural microflora of the gastrointestinal tract and play a beneficial role against infections. The ability of *Lactobacilli* to produce bacteriocins and other antifungal compound lead to the development of bioprotective cultures for use in different foods. Bacteriocins has wide applications in food industries for preventing the attack of foodborne pathogens and for manufacturing active packaging materials. This chapter aimed to review significant industrial applications of *Lactobacilli* with specified strains and also starter cultures with their potential beneficial effects are engrossed. The chapter highlights the commercial applications of *Lactobacilli* in the food, feed, wine and pharmaceutical industries.

**Keywords:** *lactobacillus*, zoo-technical, probiotics, *Lb. rhamnosus*, Bacteriocins

## 1. Introduction

The genus *Lactobacillus* was discussed for the first time in 1901. These are rod-shaped, nonspore-forming, Gram-positive bacteria found in fermented foods and are member of the gastro-intestinal tract and vaginal cavity of humans [1–4]. *Lactobacillus* is a group of bacteria with diverse species having higher GC content ranging from 32 to 53 mol% [3]. Morpho-microscopically *Lactobacilli* are rod shaped, non-motile and varying in length ranging from short to long. *Lactobacilli* are comprised a group of multifunctional microbes with shelf life extending characters of food as well as improving human health in the form of probiotics [4]. Studies of the whole bacterial genomic sequence enabled, the scientists to reclassify the species of *Lactobacilli* into 25 genera including an edited genus of *Lactobacillus* i.e. *Paralactobacillus* and *Lactobacillus delbrueckii* group and 23 other novel genera containing *Acetilactobacillus, Agrilactobacillus, Amylolactobacillus, Apilactobacillus, Bombilactobacillus,*

*Companilactobacillus, Dellaglioa, Fructilactobacillus, Furfurilactobacillus, Holzapfelia, Lac ticaseibacillus, Lactiplantibacillus, Lapidilactobacillus, Latilactobacillus, Lentilactobacillus, Levilactobacillus, Ligilactobacillus, Limosilactobacillus, Liquorilactobacillus, Loigolactobacilus, Paucilactobacillus, Schleiferilactobacillus,* and *Secundilactobacillus* [5]. Overall, more than 250 species have been assigned to the genus *Lactobacillus previously and* are now referred to with a new genus name. *Lactobacillus* releases lactic acid as the major end product of metabolism during fermentation of glucose with small amounts of acetic and succinic acid [2, 3].

The most common habitat of *Lactobacilli* is the gastro-intestinal tract of mammals where these bacteria may colonize. This group of bacteria is also commonly found in mouth such as in tooth plaque, saliva, vaginal tract of humans and mammals [2, 3]. *Lactobacillus* species commonly isolated from GI tract are *Lactobacillus acidophilus, L. brevis, L. plantarum, Lactobacillus salivarius and Lactobacillus fermentum*. *Lactobacillus* are significantly required for gastrointestinal health and are not considered as a pathogen in healthy individuals except when having an association with dental caries [6, 7]. *Lactobacilli* are usually reflected as proactive microbes as they inhibit the growth of pathogenic microorganisms by producing lactic acid and other metabolic compounds [8]. While in immunocompromised patients' lactobacilli are intricate as pathogens and various reports of AIDS, organ transplant, neutropenia caused by lactobacillus infection has been published [9–11]. The most common infections caused by *Lactobacilli* are abscesses, bacteremia, endocarditis, neonatal meningitis, dental caries and chorioamnionitis [5, 12]. The chapter focuses on an exploration of the industrial potential of *Lactobacilli* for manufacturing a diversity of products. The purpose of this chapter is to gather literature related to the utilization of *Lactobacillus* species as a microbial candidate for commercial-scale production of valuable products for improving human and animal health by protecting them against pathogenic microflora. The major emphasis is to strive for the attention towards the sustainable application of potent *Lactobacillus* species for futuristic prosperities of mankind.

## 2. Lactobacillus in food industry

*Lactobacillus* has a long history of use in biotechnology predominantly in manufacturing and conserving food ingredients by the process of fermentation, yoghurt, cheese, kefir, sauerkraut and many other fermented food products productions with the addition of animal feeds manufacture [13]. Further bioprocess technology has developed the specified production aids and procedures for food and feed ingredients [14].

*Lactobacilli* were the first microbes used by human beings for processing foods and preservation of foods by inhibiting other microbial invasions that can cause food spoilage and ultimately results in foodborne illness [15, 16]. *Lactobacillus* is a significant genus to recent food and feed technologies, not only because of its cumulative interest in valuable functional properties. The dairy industry and self-care health productions are dynamically engaged in promoting the usage of *L***actobacilli** in food, [17]. Some traditional fermented foods (**Table 1**) based on *L***actobacillus** fermentation from different origins, cultures, civilizations, customs, social relations and sometimes customized with religions were reported by Food and Drug Administration [18, 19]. Because of the characteristic to produce organic acids by using carbohydrates *L***actobacilli** have extensive application in the food industry [20].

| Name | Country of origin | Description | *Lactobacillus* Species |
|---|---|---|---|
| Gundruk | Nepal | Prepared by fermentation of leafy vegetables. It is an appetizer. | *Lb. cellobiosus* and *Lb. plantarum*. |
| Kefir | Caucasus | Fizzy fermented milk | *Lb. kefir*, *Lb. casei*, *Lb. acidophilus*, *Lb. bulgaricus* |
| Coffee | Africa, Asia and Latin America | A fine dark brown powder made from roasted coffee beans. Brewed with boiling water and consumed as a drink | *Lb. plantarum*; *Lb. brevis*. |
| Kishk | Egypt | Dried mixture of fermented milk with cereal. | *Lb. bulgaricus*, *Lb. plantarum*, *Lb. casei*, *Lb. brevis* |
| Laban zeer | Egypt | Concentrated sour buttermilk used in the manufacturing of Kishk, sometimes used in salad or to make a beverage after dilution with water; semisolid consistency, tart and salty taste | *Lb. casei*, *Lb. plantarum*, *Lb. brevis* |
| Koumiss | Kazakhstan and Kyrgyzstan | Milk is processed into a drink by lactic acid and alcoholic fermentation | *Lb. salivarius*, *Lb. buchneri*, *Lb. helveticus*, *Lb. plantarum*, *Lb. acidophilus* |
| Zabaday | Egypt | Set fermented milk; characteristic taste and aroma; full, pleasant, mildly sour taste | *Lb. bulgaricus*, *Lb. casei*, *Lb. fermentum*, *Lb. helveticus*, *Lb. viridescens*. |
| Zincica | Czech Republic | Salted kefir-like beverage made from coagulated whey proteins | *Lb. casei*, *Lb. plantarum*, *Lb. lactis* |

**Table 1.**
*Traditional foods containing lactobacilli.*

## 2.1 Lactobacilli as starters in food processing industries

*Lactobacilli* are mainly used as a starter culture in the contemporary food processing industry. The starter culture may contain only one pure strain or a combination of strains from different species of microbes [20]. Starter cultures can be well-defined as the enormous number of cell preparations, any of a single strain type or an assortment of two or more microbial strain/species that are supplemented in foods to get the advantage of consequent products or compound obtained from their metabolic or enzymatic activity [21]. Since starter cultures are used in food production settings to accomplish processes of fermentation, their usage is globally a common practice in food manufacturing industry. This has led to the commercialization of numerous products such as probiotics or starters, bio-protective cultures that are intended to deliver foods with specific nutritional and sensual characteristics, prospective health benefits and assurance of food safety [22]. Starter cultures are practically applied in a wide array of food industries such as the dairy productions for the manufacture of yoghurt, cheese and other fermented

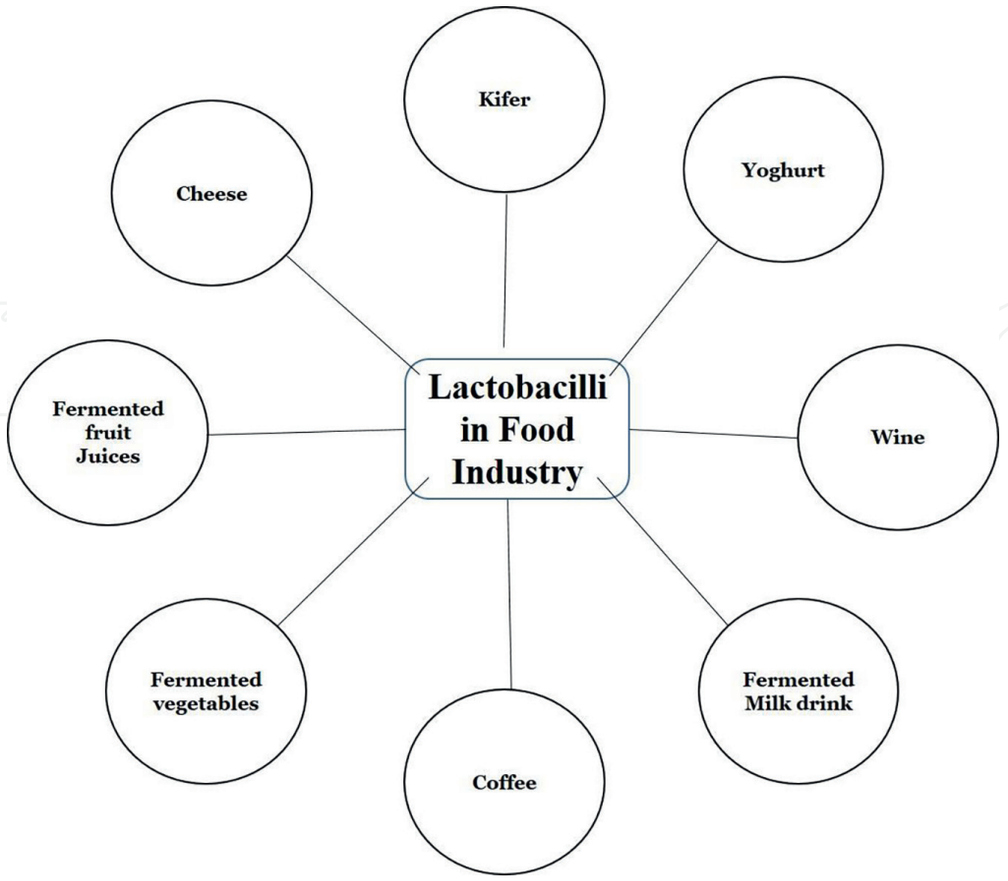


**Figure 1.**
*Application of lactobacillus in food industry.*

products from dairy milk [23], sausage manufacture in meat industry [24], in wine and beer industry for the production of alcohol [25, 26], production of vinegar [27], preparation of soy and rice-based oriental foodstuffs [28], fermented cereals and bakery products [29], and in making of fermented products from fruits and vegetables [30–32]. **Figure 1** clearly illustrates the industrial potential of lactobacilli.

Starter cultures may contain any type of microbes such as bacteria, yeast, mold or any type of fungal culture. But the species of *Lactobacilli* reported in the literature have vast potential for usage as starter culture because of its antimicrobial effects which ultimately prove beneficial for food safety. Potential antimicrobial properties of some lactobacilli have been described by scientists such as *Latilactobacillus sakei* isolated from meat sausages have an antimicrobial effect against *Listeria monocytogenes*, *Salmonella spp.* and *E. coli* in combination of garlic powder and wine [33]. Another strain of *lactobacillus* i.e. *Lactiplantibacillus plantarum* was found effective against pathogenic bacteria of the *Enterobacteriaceae* family when used as a starter in Vacuum packaged products [34].

## 2.2 Lactobacilli in dairy industry

The *Lactobacillus* genus comprise a large number of diverse species with relatively large degree of variation and diversity. It is one of the largest genus in the group of lactic acid bacteria of over fifty species [35]. *Lactobacilli* are the important lactic acid producing bacteria and are responsible for the development of microflora in the most dairy products particularly cheese and fermented milk. *Lactobacillus* is

the significant microorganism for development of color, flavor and texture of dairy products via acidification owed to lactic acid and by metabolizing milk proteins. The commonly used species of *L***actobacilli** in the dairy industry are *Lb. lactis*, *Lb. casei*, *Lb. rhamnosus*, *Lb. helveticus*, *Lb. plantarum* and *Lb. curvatus* [36]. Moreover, *lactobacilli* are incorporated in the preparation of cheese, yoghurt and fermented milk as probiotic cultures because of their potential benefits for the treatment of acute and chronic inflammation of the gastrointestinal tract [37]. *Lactobacilli* can additionally be used for the preservation of dairy products as they can produce bacteriocins which are usually inhibiting the growth of other non-desired microbes [38]. The species of *Lb. delbrueckii* encompasses three subspecies that is *subsp. bulgaricus*, subsp. *delbrueckii* and subsp. *lactis* [35] are used as a starter culture for yoghurt preparation. The information related to the use of other cultures for yoghurt manufacturing and safety is scarce.

The strain *Lb. paracasei subsp. paracasei* is recovered commonly from ripened cheese and forms a constitute with *Lb. curvatus*, *Lb. plantarum*, *Lb. casei* and *Lb. rhamnosus* is the primary microbiota of the non-starter Lactic acid bacteria group contributing to the process of cheese maturation [39, 40]. Among the species of lactobacilli *Lb. rhamnosus* is one that has been applied as a probiotic organism in functional foods. The strain *Lb. rhamnosus* has been identified and designated with a number HN001, has both probiotic and flavor improving qualities, hence, it can be useful as an adjunct in the manufacturing of cheese to decrease dangerous microflora, improve the flavor of cheese and increase the speed of cheese ripening [41, 42]. *Lactobacillus johnsonii* formerly known as *Lb. acidophilus* has been widely studied because of its probiotic characteristic and is commercialized for production of fermented milk (LC1) products [43]. The *Lb. johnsonii* displays antimicrobial [44–46] and immunomodulatory properties [47, 48] properties. A thermophilic starter culture of *Lactobacillus helveticus* is used in the production of a numeral fermented products of dairy [49] and develops on a comparatively limited number of carbohydrates such as galactose and lactose with typical requirement of few vitamins for growth [50, 51]. Knowledge about the biodiversity of *L***actobacillus** can be employed as a starter culture in different dairy products described in previous literature is provided in the tabulated form (**Table 2**).

### 2.3 Lactobacilli in non-dairy food products of plant and animal origin

The species of *Lactobacillus* are useful for production of fermented foods other than dairy such as sauerkraut by fermenting cabbage. Usually, normal microflora of cabbage with added *Lb. plantarum* act as starter and salt like sodium chloride is used for preventing the growth of foodborne pathogenic microorganisms [68]. An additional study reported the use of both *Lb. plantarum* and *Lb. brevis* for production of sauerkraut [69]. Another food product in which the genus lactobacillus is involved is pickle where the propagation of starter culture of *Lb. plantarum* is responsible for achieving the desired effect. Another investigation reported the involvement of *Lb. versmoldensis* sp. nov.; *Lb. plantarum*; *Lb. casei*; *Lb. pentosus* for the production of fermented green olives [70–72]. The *L***actobacillus** species such as *Lb. sakei* and *Lb. curvatus* were found in dry sausages [73–75]. A previous study reported the presence of *Lb. sanfranciscensis*, *Lb. reuteri* and *Lb. pontis* in sourdough [76].

*L. acidophilus* was reported in chocolate by Rosell [77] and *Lb. plantarum* was found in juice drinks [78] as well as *Lb. rhamnosus* was described as a microbe found in juice drinks (Valio Gelfilus) GG (ATCC 53103) [64].

| Products | Diversity of Lactobacilli |
|---|---|
| Unpasteurized milk | *Lb. casei subsp. casei*; *Lb. paracasei subsp. paracasei*; *Lb. rhamnosus*; *Lb. plantarum*; *Lb. fermentum*; *Lb. brevis*; *Lb. buchneri*; *Lb. curvatus*; *Lb. acidophilus*; *Lb. pentosus* [52] |
| Cheese | *Lb. helveticus*; *Lb. delbrueckii subsp. lactis*; *Lb. delbrueckii subsp. bulgaricus*; *Lb. casei*; *Lb. paracasei subsp. paracasei*; *Lb. paracasei subsp. tolerans*; *Lb. rhamnosus* [53] |
| Natural Argentine fermented hard cheese | *Lb. delbruecki subsp. lactis*; *Lb. helveticus* [54] |
| Fioro Sardo | *Lb. paracasei*; *Lb. plantarum*; *Lb. rhamnosus*; *Lb. pentosus*; *Lb. paraplantarum*; *Lb. sake*; *Lb. graminis* and *Lb. curvatus* [55] |
| Emmental, Comte | *Lb. casei*; *Lb. helveticus*; *Lb. delbrueckii ´ subsp. lactis* [56] |
| Camembert | *Lb. paracasei subsp. paracasei*; *Lb. plantarum*; *Lb. delbrueckii subsp. lactis*; *Lb. acidophilus*; *Lb. delbrueckii subsp. bulgaricus*; *Lb. casei subsp. casei* [57] |
| Batzos, a traditional Greek cheese from unpasteurized goat's milk | Lb. plantarum; Lb. paraplantarum; Lb. paracasei subsp. tolerans; Lb. sake; Lb. curvatus; Lb. pentosus [58] |
| Mozzarella | *Lb. delbrueckii subsp. bulgaricus*; *Lb. plantarum* [59] |
| Ricotta | *Lb. acetotolerans*; *Lb. alimentarius*; *Lb. gasseri*; *Lb. hilgardii*; *Lb. zeae*; *Lb. brevis*; *Lb. plantarum*; *Lb. paraplantarum* [60] |
| Yoghurt | *Lb. delbruecki subsp. bulgaricus* according to the Codex Alimentarius standard [61] |
| Fermented milk | *Lb. kefir* [62] |
| Kumys | *Lactobacillus delbrueckii subsp. bulgaricus* [63] Adapted from Codex Alimentarius (2011) |
| Infant formula | *Lb. rhamnosus* GG (ATCC 53103) http://www.valio.f [64] |
| Frozen yoghurt | *Lb. delbrueckii subsp. bulgaricus*; *Lb. acidophilus* [65] |
| Ice cream | *Lb. acidophilus*; *Lb. johnsonii* La1 [43, 66] |
| Fruit yoghurt | *Lb. casei* [67] |
| Probiotic yoghurt drink | *Lb. acidophilus* La5 and *Lb. casei* |
| Stirred yoghurt | *Lb. lc1* |
| Fruit layer yoghurt | *Lb. acidophilus* La5 *LBifidobacterium animalis subsp. lactis* BB12 |
| Fermented soya drink | *Lb. acidophilus* |
| Yoghurt drink | *Lb. acidophilus* La5 |
| Fromage frais blanc | *Bifidobacterium*, *Lb. acidophilus* |
| Live natural yoghurt | *Lb. acidophilus*, *Lb. casei*, |
| Yoghurt drink (Yakult) | *Lb. casei* |
| Fruit yoghurt smoothie | Yoghurt culture, *Lb. acidophilus*, *Bifidobacterium* |
| Goat milk yoghurt | *Lb. acidophilus*, *Lb. bulgaricus*, *S. thermophilus*, *Bifidobacterium* |
| Fermented milk drink | *Lb. casei* Shirota |
| Fruit yoghurt drink | *Lb. casei* |
| Bio pouring yoghurt | Probiotic |
| Fat-free yoghurt drink | *Lb. casei* |
| Natural Greek style yoghurt | *Lb. acidophilus*, *Lb. bulgaricus*, *S. thermophilus* |

| Products | Diversity of Lactobacilli |
|---|---|
| Goat fruit yoghurt | *S. thermophilus*, *Lb. casei* |
| Natural goat yoghurt | *Bifidobacterium longum*, *Lb. acidophilus* |
| Fruit yoghurt | *B. animalis subsp. lactis*, *Lb. acidophilus* |
| Thick and creamy yoghurt | *Bifidobacterium*, *Lb. acidophilus*, *S. thermophilus* |
| Natural fresh and mild yoghurt | *Lb. acidophilus*, *B. longum*, *S. thermophilus* |
| Organic natural yoghurt | *Lb. acidophilus*, *Bifidobacterium* |

**Table 2.**
*Species of lactobacilli present naturally or added as starter in dairy products.*

*L. fermentum* has been used extensively as a probiotic strain and may be found in cereal-based fermented foods and many other vegetables [79]. The predominant bacteria of sourdough and cereal based fermented products is *Lb. plantarum* and is a leading microbe because it applied for producing corn dextrins after the reduction of fermentable sugars [80] *Lactobacillus sanfranciscensis* is the leading lactic acid bacteria in sourdough [80] and 14 genome assemblies of *Lb. sanfranciscensis* have been reported [35].

A fermented beverage tea known as Kombucha is prepared by the traditional fermentation process of fermenting sweetened black tea with tea fungus which contains a consortium of yeasts and acetic acid-producing bacteria. The viability of selected strains of *Lactobacilli* throughout the fermentation process of Kombucha and their interaction with tea fermenting fungus and their role in obtaining a tea beverage with improved functional properties were tested by scientists [81] Five wild strains (*Lactobacillus hilgardii*, *L. fermentum*, three strains of *L. plantarum*) isolated from conventional fermented foods and were added separately in Kombucha on the second day of fermentation. The addition of wild species of Lactobacillus during fermentation of Kombucha contributed significantly to increasing the lactic acid content of the tea beverage. The strain of *Lactobacillus plantarum* was reported for the highest lactic acid production during Kombucha fermentation. The *L. hilgardii* strain isolated from sour dough exhibited the highest sustainability in Kombucha and also has possible probiotic characteristics. So this strain can be used in Kombucha fermentation.

## 2.4 Lactobacilli in wine industry

**The major role of lactic acid bacteria in wine production is to conduct** the process of **malolactic** fermentation. The process of wine fermentation reduces the acidity in wine, enhances the mouth feel and aroma and also improves the microbial stability of wine. **Therefore,** *Lactobacilli* **have application in** the **production process of wine from both grapes and fruits** cider [82]. During the process of malolactic fermentation malic acid is converted into lactic acid and carbon dioxide which is extensively required for the maturation of fruit wine [83]. The recent efforts focused towards discovering the biodiversity of geographic areas associated for wine production with the purpose of finding new strains of lactic acid bacteria which can be used as starters [84]. For instance, two potent new autochthonous malolactic fermentation starters i.e. *Lactobacillus paracasei* UVI-2 and *Lb. hilgardii* UVI-23, have been isolated

and identified from Albariño grapes in Val do Salnés, Spain [84]. The following species of *L***actobacilli** such as *Lb. plantarum* [85], *Lb. brevis*; *Lb. collinoides*; *Lb. hilgardii*; *Lb. paracasei*; *Lb. pentosus*; *Lb. plantarum*; *Lb. mali* [86] are naturally present or added as a starter during the fermentation processing of wine. *Lactobacillus sakei subsp. sakei* was first isolated from rice alcoholic beverage i.e. sake and it is the product from which its name was taken [35].

## 3. Lactobacilli in feed industry

Many potential strains of *L***actobacilli** having probiotic effect are applied in feed production for poultry and other animals for beneficial purposes. There is no case of foodborne illness has been reported by ingestion of feed containing *L***actobacilli** [12]. In agricultural practice, *L***actobacilli** have long been applied for the preservation of grass or maize in the form of fodder [87] where these bacteria accelerate the rate of decline in pH while protecting plant carbohydrates through homofermentation and also conserving proteins from plants by reducing proteolysis and by deamination [88–91]. According to literature the species of *L***actobacillus Lb. casei**, *Lb. buchneri* [92], *Lb. paracasei subsp. paracasei* [93], *Lb. plantarum* [94], *Lb. buchneri*, *Lb. fermentum* [95] and *Lb. diolivorans* sp. nov. [96] have been applied in silage production. Probiotic *L***actobacilli** are used as an alternative to antibiotics in animal feed because of the safety concerns of antibiotics [97]. Probiotic microbes in animal feed should be live and have zootechnical properties to convert feed and increase weight gain [98]. The supplementation of probiotics has been suggested for handling numerous stress conditions or for preventing diseases in several animal species [17]. The studies which have highlighted the value of lactobacilli

| Animal species | Lactobacillus species | Benefits |
|---|---|---|
| Poultry industry | *Lactobacillus johnsonii* FI9785 | Controls endemic necrotic enteritis due to *Clostridium perfringens*, reducing economic losses associated with the decrease in antibiotic use [99] |
| Chicks | *Lb. acidophilus* | Increases body weight gain, decreases fecal weight [100] |
| Broiler chickens | *Lb. acidophilus*, *Lb. casei* | Enhances production performance [101] |
| Late laying period hens | *Lb. species* | Increases egg production, decreases mortality, improves feed conversion but not egg quality [102] |
| Beef cattle | *Lb. acidophilus* | Reduces *E. coli* O157 levels [103] |
| Veal calves | Six *Lactobacillus sp.* | Enhances growth rate, body weight gain, Feed conversion and tends to decrease mortality [104] |
| Dairy cows | *Lb. acidophilus*, *Lb. buchneri* 40,788 | Significant increase (16.2%) in milk production Used to treat alfalfa silage. Increases the concentration of acetic acid. When fed to lactating cows, it improved the aerobic stability of the ration and increased milk production [105, 106] |
| Lambs | *Lb.* species *Lb. acidophilus*, *S. faecium*, *Lb.casei*, *Lb. fermentum* and *Lb. plantarum* | Stimulates feed intake and daily weight gain Reduces fecal shedding of *E. coli* O157:H7 [107, 108] |

**Table 3.**
*Health promoting properties of lactobacilli for animal.*

for various animal species are tabularized herein (**Table 3**). Probiotic treatment is becoming progressively popular in veterinary medicine, particularly for pets.

Some feed additives of European origin such as BIACTONs N1 12 for piglets contain *Lb. farciminis* [109]; PROVITA LEs N1 E1706 for calves & piglets contain *Lb. rhamnosus* DSM 7133 and *Enterococcus faecium* DSM 7134 [109]; CECT4 529 N123 feed for laying hens hold *Lb. acidophilus* [110] and *Lb. acidophilus* was added to the cats and dogs feed [111]. Other Non-European feed additives such as Silage (PROSTOREs USA) have *Lb. casei*; *Lb. plantarum*; *Lb. brevis* and other lactic acid bacteria and fungi [112]. HP BIOs a feed for cows in USA comprised of *Lb. fermentum*; *Lb. acidophilus*; *Lb. plantarum*; *Lb. casei*; and lactic acid bacteria [112]. Another feed additive named E-BIOTICTM equine in USA contained *Lb. lactic*; *Lb. acidophilus*; *Lb. plantarum* and other LAB [113].

## 4. Lactobacilli in the pharmaceutical industry

The use of *Lactobacilli* has frequently been associated with the prevention of disease. It has been revealed from the literature that the oral administration of large dosages of lactobacilli is an effective and nontoxic in patients having Crohn's disease, AIDS and various types of enteritis, and in premature babies, children or the senior adults, all of those are possibly at risk of lactobacillemia [114–120]. In some cases, enteral administration of *Lactobacillus* species may be favorable [121] in rats and humans [122]. *Lactobacilli* may also have positive effects in the oral cavity, inhibiting cariogenic *Candida* and *streptococci* species [123]. Tallying to these trials, efficient medicines containing viable *Lactobacilli* with no side effects have developed (**Table 4**).

## 5. Beneficial role of *lactobacillus*

*Lactobacilli* can produce lactic acid in large amounts by a biotechnological process through fermentation. Among **lactobacilli**, lactic acid-producing bacteria play an important role in the production of fermented dairy products and the enzyme beta-galactosidase. Because these bacterial species are generally recognized as safe so enzyme purification does not require any extensive purification processes and also there is no damage to fermented food products [124].

A large number of Gram-negative and Gram-positive bacteria produce antimicrobial protein structures during their growth (either polypeptides or proteins) called bacteriocins [125]. Now a days Lactic acid bacteria have gained specific consideration among the Gram-positive bacterial strains because of the production of bacteriocins

| Lactobacillus species | Trademark | Dose (Adult) – Comments |
|---|---|---|
| *Lb. casei rhamnosus* | Bacilors (347961.2) | Ingestion, 2 to 8 capsules/day, anti-diarrhea |
| *Lb. acidophilus* | Lacteols (305665.6) | Ingestion, 5 tablets/3 to 5 times/day, anti-diarrhea |
| *Lb. rhamnosus* | Antibiophiluss | Capsule ingestion, anti-diarrhea |

**Table 4.**
*List of drugs (capsule, tablet or gel) based on lactobacilli (http://www.vidalpro.net).*

[126]. The bacteriocins can be functional in the food industry by employing as natural preservatives. The application of produced bacteriocins having antimicrobial compounds as a natural barrier against food spoilage causing pathogenic microbes has been confirmed to be effective [38]. The following approaches of bacteriocin application in food are usually adopted for the purpose of biopreservation: adding semi purified or pure bacteriocin as additive in food; food is inoculated with the bacteriocin-producing strain; and practice of previously fermented product with a strain having ability to produce bacteriocin as an ingredient in food processing [38]. A new application of bacteriocins is in bioactive packaging which is a procedure that can defend the food from exterior contaminants [126].

Lactobacilli having probiotic effects in humans are completely documented and are dose and strain dependent [127]. Numerous articles, reviews and book chapters have documented the potential lactobacilli to promote overall health: help to mitigate lactose intolerance [128], positively affect the flora of intestinal tract [129], prevent gastrointestinal infections [130, 131], stimulate the immune system [132], decrease in allergies or inflammation responses [133, 134], regulate the motility of gut [135], and promotion of sensation of well-being [136]. Particular health effects such as colon cancer prevention of [137–139] and decreases in blood lipid concentration and heart disease [140] antihypertensive effects have also been reported. **Figure 2** shows the use of probiotics in different food items.

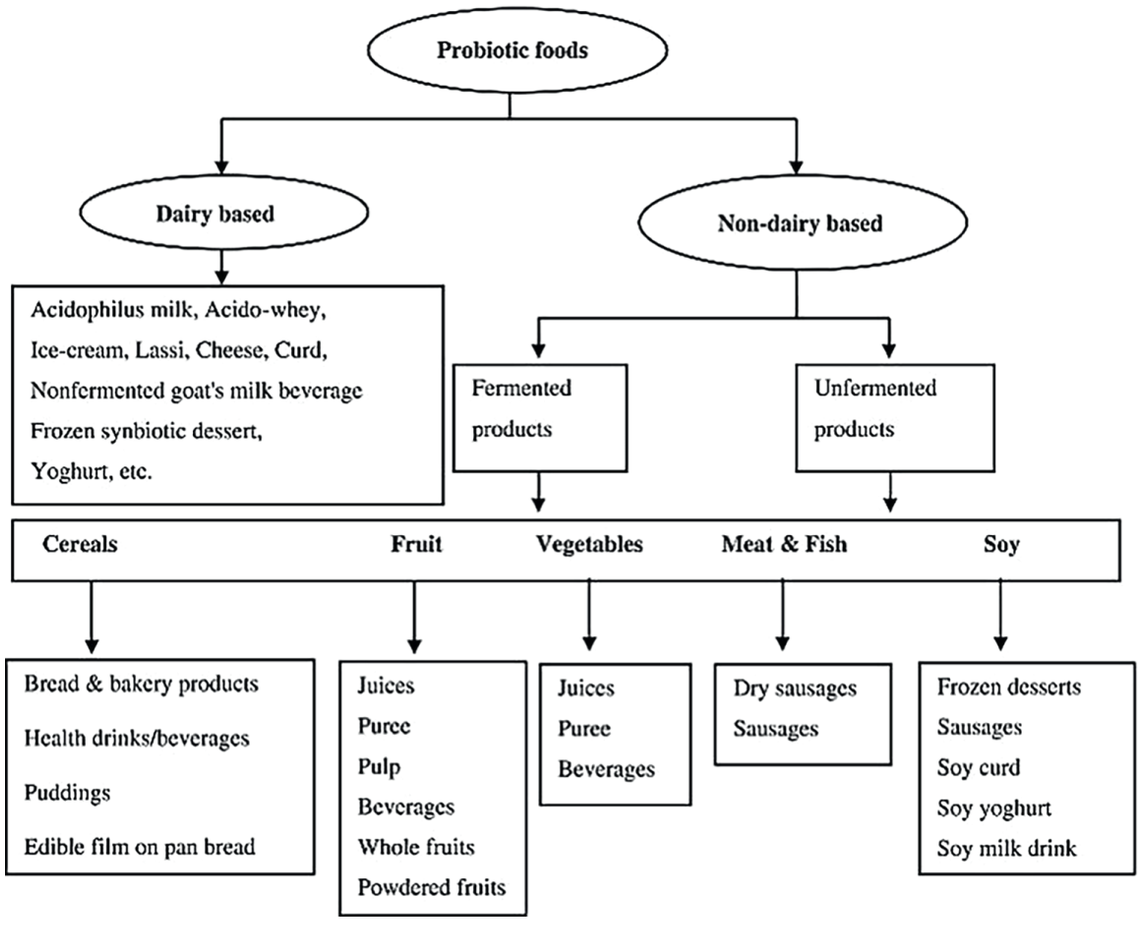


**Figure 2.**
*Probiotic foods in which lactobacilli are applied as a probiotic strain.*

## 6. Contribution of lactobacilli to the United Nations development goals

*Lactobacilli* in the form of starter culture have prospective potential for application in foods of animal origin. The starter cultures are extensively used in in the meat industry for production of sausage, the dairy industry for yoghurt, cheese and other fermented dairy products and in the fishery industry for fermented fish products. The starter cultures are mainly used in food of animal origin for quick lactic acid production which causes a decrease in pH and thus preventing the growth of spoilage and foodborne pathogenic microbes which ultimately increasing the shelf-life of fermented food products. Also, release of other metabolic compounds (e.g., acetic acid, lactic acid, benzoic acid, propionic acid and hydrogen peroxide or bacteriocins) helps in improving the safety of foods [141]. Since starter cultures have developed as the predominant microbiota of fermented foods and allows the food processors to control the process of fermentation by eliminating the objectionable microflora and reducing the manufacturing and hygienic risks. Another important role of starter cultures is the chemical safety of fermented products/foods by decreasing aromatic polycyclic hydrocarbons and biogenic amine contents. Therefore, the futuristic application of lactobacilli and other microbes as starter culture crucially helps in reducing hunger by elimination of food spoilage which is the main cause of food insecurity and play a significant role in improving health and wellbeing by providing essential nutrients and reducing the population of undesirable microbiota and increasing the shelf life of foods. So the lactobacillus with other microbes can significantly effective for their progressive utilization in important areas of sustainable development goals agenda of 2030, the number one is huger and second is health and wellbeing. At the same time lactobacilli have huge industrial potential and it is the dire need of the day to explore more potential lactobacilli with multiple characteristics for food and pharmaceutical industry.

## 7. Conclusions

*Lactobacilli*, a potentially significant group of microorganisms that play a fundamental role in the fermentation industry for the production of numerous valuable products such as cheese, yoghurt, fermented milk, kefir, enzymes, medicines, etc. Because of the diverse applications lactobacillus genus open new doors for exciting research areas. The application of lactobacilli in feed, pharmaceuticals and probiotics ensures to reduce the rate of mortality and morbidity associated with gastroenteritis and viral infections. The extensive industrial application of Lactobacilli demanded further research to enhance the potential of the species of this group and to isolate efficient strains which can produce multiple products of commercial practice. *Lactobacilli* have the futuristic potential for utilization in a diversity of industrial applications and hence can be considered a significant candidate for poverty elimination, reducing hunger by producing a diverse range of food products, increasing the shelf life by preserving the food and providing valuable pharmaceutical products.

## Conflict of interest

"The authors declared no conflict of interest."

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## References

[1] Cannon JP, Lee TA, Bolanos JT, Danziger LH. Pathogenic relevance of lactobacillus: A retrospective review of over 200 cases. European Journal of Clinical Microbiology & Infectious Diseases. 2005;**24**:31-40. DOI: 10.1007/s10096-004-1253-y

[2] Madigan MT, John MM, Thomas DB. Prokaryotic diversity: The bacteria. In: Madigan MT, Martinko JM, editors. Brock: Biology of Microorganisms. Upper Saddle River, NJ: Prentice Hall; 2006. pp. 329-418

[3] Kononen E, Wade WG. Propionibacterium, lactobacillus, Actinomyces, and other non-sporeforming anaerobic gram-positive rods. In: Murray PR, editor. Manual of Clinical Microbiology. Washington, DC: ASM Press; 2007. pp. 872-888

[4] International Scientific Association for Probiotics and Prebiotics. New names for important probiotic lactobacillus species. In: ISAPP Science Blog. Sacramento: ISAPP 2020; 2020 [about 2 screens]. Available from: https://isappscience.org/new-names-for-important-probiotic-lactobacillus-species/

[5] Zheng J, Wittouck S, Salvetti E. A taxonomic note on the genus lactobacillus: Description of 23 novel genera, emended description of the genus lactobacillus Beijerinck 1901, and union of Lactobacillaceae and Leuconostocaceae. International Journal of Systematic and Evolutionary Microbiology. 2020;**70**:2782-2858. DOI: 10.1099/ijsem.0.004107

[6] Aguirre M, Collins MD. Lactic acid bacteria and human clinical infection. The Journal of Applied Bacteriology. 1993;**75**:95-107. DOI: 10.1111/j.1365-2672.1993.tb02753.x

[7] Sharpe ME, Hill LR, Lapage SP. Pathogenic lactobacilli. Journal of Medical Microbiology. 1973;**6**:281-286. DOI: 10.1099/00222615-6-3-281

[8] Husni RN, Gordon SM, Washington JA, Longworth DL. Lactobacillus bacteremia and endocarditis: Review of 45 cases. Clinical Infectious Diseases. 1997;**25**:1048-1055. DOI: 10.1086/516109

[9] Abgrall S, Joly V, Derkinderen P, Decré D, Carbon C, Yeni P. Lactobacillus casei infection in an AIDS patient. European Journal of Clinical Microbiologyv & Infectious Diseases. 1997;**16**:180-182. DOI: 10.1007/BF01709485

[10] Chomarat M, Espinouse D. Lactobacillus rhamnosus septicemia in patients with prolonged aplasia receiving ceftazidime-vancomycin. European Journal of Clinical Microbiology & Infectious Diseases. 1991;**10**:44. DOI: 10.1007/BF01967099

[11] Schlegel L, Lemerle S, Geslin P. Lactobacillus species as opportunistic pathogens in immunocompromised patients. European Journal of Clinical Microbiology & Infectious Diseases. 1998;**17**:887-888. DOI: 10.1007/s100960050216

[12] Harty DWS, Oakey HJ, Patrikakis M, Hume EB, Knox KW. Pathogenic potential of lactobacilli. International Journal of Food Microbiology. 1994;**24**:179-189. DOI: 10.1016/0168-1605(94)90117-1

[13] Inglin CR. High-throughput screening assays for antibacterial and

antifungal activities of lactobacillus species. Journal of Microbiological Methods. 2015;**114**:26-29. DOI: 10.1016/j.mimet.2015.04.011

[14] Holzapfel WH. Appropriate starter culture technologies for small-scale fermentation in developing countries. International Journal of Food Microbiology. 2002;**75**:197-212. DOI: 10.1016/s0168-1605(01)00707-3

[15] Konigs WN, Kok J, Kuipers OP, Poolman B. Lactic acid bacteria: The bug of the new millennium. Current Opinion in Microbiology. 2000;**3**:276-282. DOI: 10.1016/s1369-5274(00)00089-8

[16] Adams MR. Safety of industrial lactic acid bacteria. Journal of Biotechnology. 1999;**68**:171-178. DOI: 10.1016/s0168-1656(98)00198-9

[17] Marion Bernardeau M, Guguen M, Vernoux JP. Beneficial lactobacilli in food and feed: Long-term use, biodiversity and proposals for specific and realistic safety assessments. FEMS Microbiology Reviews. 2006;**30**:487-513. DOI: 10.1111/j.1574-6976.2006.00020.x

[18] Battcock M, Azam-Ali S, FAO. Fermented Fruits and Vegetables. A Global Perspective. Agricultural Support Systems D. Rome, Italy: FAO; 1998. Available from: http://www.fao.org

[19] Saloff-Coste CJ. *Lactobacillus casei*. Danone World Newsletter; 1995. pp. 2-8. Available from: http://www.danonevitapole.com/nutri_views/newsletter/eng/news_7

[20] Ross RP, Desmond C, Fitzerald GF, Stantch C. Overcoming the technological hurdles in the development of probiotic foods. Journal of Applied Microbiology. 2005;**98**:1410-1417. DOI: 10.1111/j.1365-2672.2005.02654.x

[21] Fox PF, Guinee TP, Cogan TM, McSweeney PLH. Pathogens in cheese and foodborne illnesses. In: Fundamental of Cheese Science. New York, NY, USA: Springer; 2017. pp. 681-713

[22] Hammami R, Fliss I, Corsetti A. Application of protective cultures and bacteriocins for food biopreservation. Frontiers in Microbiology. 2019;**1561**:594. DOI: 10.3389/fmicb.2019.01561

[23] Aryana KJ, Olson DWA. Yogurt and other cultured dairy products. Journal of Dairy Science. 2017;**100**:9987-10013

[24] Laranjo M, Elias M, Fraqueza MJ. The use of starter cultures in traditional meat products. Journal of Food Quality. 2017;**2017**:9546026. DOI: 10.1155/2017/9546026

[25] Romano P, Capece A. Wine microbiology. In: Speranza B, Bevilacqua A, Corbo MR, Sinigaglia M, editors. Starter Cultures in Food Production; Chapter 13. West Sussex, UK: John Wiley & Sons, Ltd.; 2017. pp. 255-282

[26] Vaughan A, O'Sullivan T, Van Sinderen D. Enhancing the microbiological stability of malt and beer—A review. Journal of the Institute of Brewing. 2005;**111**:355-371. DOI: 10.1002/j.2050-0416.2005.tb00221.x

[27] Mas A, Torija MJ, García-Parrilla MDC, Troncoso AM. Acetic acid bacteria and the production and quality of wine vinegar. Scientific World Journal. 2014;**2014**:394671. DOI: 10.1155/2014/394671

[28] Gao L, Yang H, Wang X, Huang Z, Ishii M, Igarashi Y, et al. Rice straw fermentation using lactic acid bacteria. Bioresource Technology. 2008;**99**:2742-2748. DOI: 10.1016/j.biortech.2007.07.001

[29] Ashaolu TJ, Reale AA. Holistic review on euro-Asian lactic acid bacteria fermented cereals and vegetables. Microorganisms. 2020;**8**:1176. DOI: 10.3390/microorganisms8081176

[30] Arroyo-López FN, Garrido-Fernández A, Jiménez-Díaz R. Starter cultures in vegetables with special emphasis on table olives. In: Speranza B, Bevilacqua A, Corbo RM, Sinigaglia M, editors. Starter Cultures in Food Production. West Sussex, UK: John Wiley and Sons; 2017. pp. 283-298

[31] Brandt MJ. Starter cultures for cereal based foods. Food Microbiology. 2014;**37**:41-43. DOI: 10.1016/j.fm.2013.06.007

[32] Szutowska J. Functional properties of lactic acid bacteria in fermented fruit and vegetable juices: A systematic literature review. European Food Research and Technology. 2020;**246**:357-372. DOI: 10.1007/s00217-019-03425-7

[33] Linares MB, Garrido MD, Martins C, Patarata L. Efficacies of garlic and *L. sakei* in wine-based marinades for controlling listeria monocytogenes and salmonella spp. in chouriço de vinho, a dry sausage made from wine marinated pork. Journal of Food Science. 2013;**78**:M719-M724. DOI: 10.1111/1750-3841.12094

[34] Sun Q, Sun F, Zheng D, Kong B, Liu Q. Complex starter culture combined with vacuum packaging reduces biogenic amine formation and delays the quality deterioration of dry sausage during storage. Food Control. 2019;**100**:58-66. DOI: 10.1016/j.foodcont.2019.01.008

[35] NCBI. Data Collected from Genbank. NCBI. Rockville Pike, Bethesda, MD, USA: National Center for Biotechnology Information, National Library of Medicine, National Institutes of Health; 2018. Available from: https:// www.ncbi.nlm.nih.gov/genome/browse/

[36] Jack RW, Tagg JR, Ray B. Bacteriocins of gram-positive bacteria. Microbiological Reviews. 1995;**59**:171-200

[37] Bernadeau M, Vernoux JP, Henri-Dubernet S, Gueguen M. The lactobacillus genus. International Journal of Food Microbiology. 2007;**126**:103-125

[38] Chen H, Hoover DG. Bacteriocins and their food applications. Comprehensive Reviews in Food Science and Food Safety. 2003;**2**:83-97. DOI: 10.1111/j.1541-4337.2003.tb00016.x

[39] Beresford T, Cogan T. Improving Cheddar cheese flavor. In: Proceedings of the 5th Cheese Symposium. Cork: Teagasc/University College Cork; 1997. pp. 53-61

[40] Picon A. Cheese microbial ecology and safety. In: Papademas P, Bintsis T, editors. Global Cheese Making Technology, Cheese Quality and Characteristics. Chichester: John Wiley & Sons Ltd.; 2018. pp. 71-99

[41] Upadhyay VK, McSweeney PLH, Magboul AAA. Proteolysis in cheese during ripening. In: Cheese: Chemistry, Physics and Microbiology, 4. London: Elsevier Academic Press; 2004. pp. 391-433

[42] Curtin AC, McSweeney PLH.: Catabolism of amino acids in cheese during ripening, In: Fox PF, McSweeney PLH, Cogan TM, et al., Editors, Cheese: Chemistry, Physics and Microbiology, London: Elsevier Academic Press; 2004. pp. 435-454

[43] Alamprese C, Foschino R, Rossi M, Pompei C, Savani L. Survival of lactobacillus johnsonii La1 and influence of its addition in retail-manufactured

ice-cream produced with different sugar and fat concentrations. Dairy Journal. 2002;**12**:201-208. DOI: 10.1016/S0958-6946(01)00159-5

[44] Bernet-Camard MF, Liévin V, Brassart D. The human lactobacillus acidophilus strain La1 secretes a non bacteriocin antibacterial substance active in vitro and in vivo. Applied and Environmental Microbiology. 1997;**63**:2747-2753. DOI: 10.1128/aem.63.7.2747-2753

[45] Sgouras DN, Panayotopoulou EG, Martinez-Gonzalez B, Petraki K, Michopoulos S, Mentis A. Lactobacillus johnsonii La1 attenuates helicobacter pylori associated gastritis and reduces levels of proinflammatory chemokines in C57BL/6 mice. Clinical and Diagnostic Laboratory Immunology. 2005;**12**:1378-1386. DOI: 10.1128/CDLI.12.12.1378-1386

[46] Pérez PF, Minnaard J, Rouvet M. Inhibition of Giardia intestinalis by extracellular factors from lactobacilli: An in vitro study. Applied and Environmental Microbiology. 2001;**67**:5037-5042. DOI: 10.1128/AEM.67.11.5037-5042.2001

[47] Link-Amster H, Rochat F, Saudan KY. Modulation of a specific humoral immune response and changes in intestinal flora mediated through fermented milk intake. FEMS Immunology And Medical Microbiology. 1994;**10**:55-64. DOI: 10.1111/j.1574-695X.1994.tb00011.x

[48] Schiffrin EJ, Rochat F, Link-Amster H. Immunomodulation of human blood cells following the ingestion of lactic acid bacteria. Journal of Dairy Science. 1995;**78**:491-497. DOI: 10.3168/jds.S0022-0302(95)76659-0

[49] Schleifer KH, Ludwig W. Phylogenetic relationships of lactic acid bacteria. In: The Genera of Lactic Acid Bacteria. London: Chapman & Hall; 1995. pp. 7-18

[50] Hassan AN, Frank JF. Starter cultures and their use. In: Marth EH, Steele JL, editors. Applied Dairy Microbiology, 2 Eds. New York: Marcel Dekker Inc.; 2001. pp. 151-206

[51] Hammes WP, Vogel RF. The genus lactobacillus. In: The Genera of Lactic Acid Bacteria. London: Blackie Academic and Professional; 1995. pp. 19-54. DOI: 10.1111/j.1574-6968.2006.00596.x

[52] Wouters JTM, Ayad EHE, Hugenholtz J, Smit G. Microbes from raw milk for fermented dairy products. International Dairy Journal. 2002;**12**:91-109. DOI: 10.1016/S0958-6946(01)00151-0

[53] Coppola R, Nanni M, Iorizzo M, Sorrentino A, Sorrentino E, Chiavari C, et al. Microbiological characteristics of Parmegiano Reggiano cheese during the cheese making and the first months of the ripening. Le Lait. 2000;**2000**:479-490. DOI: 10.1051/lait:2000139ff. ffhal-00895440

[54] Hebert EM, Raya RR, Tailliez P, de Giori GS. Characterization of natural isolates of lactobacillus strains to be used as starter cultures in dairy fermentation. International Journal of Food Microbiology. 2000;**59**:19-27. DOI: 10.1016/s0168-1605(00)00282-8

[55] Mannu L, Communian R, Scintu MF. Mesophilic lactobacilli in Fiore Sardo cheese: PCR-identification and evolution during cheese ripening. International Dairy Journal. 2000;**10**:383-389. DOI: 10.1016/S0958-6946(00)00074-1

[56] Depouilly A, Dufrene F, Beuvier E, Berthier F. Genotypic characterisation of the dynamics of the lactic acid bacterial population of Comte cheese.

Le Lait. 2004;**84**:155-167. DOI: 10.1051/lait:2003036ffhal-00895521

[57] Henri-Dubernet S. Etude par electrophore´ `se en gradient de temperature de la biodiversit ´ e et des dynamiques des ´ populations lactobacilles au cours de la transformation du lait cru en "Camembert de Normandie" [thesis]. Caen: Universite de´ Caen Basse-Normandie; 2004

[58] Psoni L, Tzanetakis N, Litopoulou-Tzanetaki E. Microbial characteristics of Batzos, a traditional Greek cheese from raw goat's milk. Food Microbiology. 2003;**20**:575-582. DOI: 10.1016/S0740-0020(02)00153-3

[59] Coppola R, Blaiotta G, Ercolini D, Moschetti G. Molecular evaluation of microbial diversity occurring in different types of mozzarella cheese. Journal of Applied Microbiology. 2001;**90**:414-420. DOI: 10.1046/j.1365-2672.2001.01262.x

[60] Baruzzi F, Morea M, Matarante A, Cocconcelli PS. Changes in the lactobacillus community during ricotta forte cheese natural fermentation. Journal of Applied Microbiology. 2000;**89**:807-814. DOI: 10.1046/j.1365-2672.2000.01183.x

[61] Codex alimentarius. Codex Standard for Fermented Milk. CODEX STAN; 243. Viale delle Terme di Caracalla, Rome, Italy: FAO USA; 2003. pp. 1-5

[62] Garrote GL, Delfederico L, Bibiloni R, Abraham AG, Perez PF, Semorile L, et al. Lactobacilli isolated from kefir grains: Evidence of the presence of S-layer proteins. The Journal of Dairy Research. 2004;**71**:222-230. DOI: 10.1017/S0022029904000160

[63] Alimentarius Codex. Milk and milk products (2nd ed.). Rome, Italy: WHO and FAO. Moreno, De, de LeBlanc A, Matar C, Farnworth E, & Perdigon G. Study of cytokines involved in the prevention of a murine experimental breast cancer by kefir. Cytokine. 2006, 2011;1-2:1-8

[64] http://www.valio.f

[65] Davidson RH, Duncan SE, Hackney CR, Eigel WN, Boling JW. Probiotic culture survival and implications in fermented frozen yogurt characteristics. Journal of Dairy Science. 2000;**83**:666-673. DOI: 10.3168/jds.S0022-0302(00)74927-7

[66] Hekmat S, McMahon DJ. Survival of lactobacillus acidophilus and Bifidobacterium bifidum in ice cream for use as a probiotic food. Journal of Dairy Science. 1992;**75**:1415-1422. DOI: 10.3168/jds.S0022-0302(92)77895-3

[67] Farahmand N, Ouoba LII, Raeisi SN, Sutherland J, Ghoddusi HB. Probiotic lactobacilli in fermented dairy products: Selective detection, enumeration and identification scheme. Microorganism. 2021;**2021**:2-16. DOI: 10.3390/microorganisms9081600

[68] Miller BM, Litsky W. Single Cell Protein in Industrial Microbiology. 1st ed. New York: McGrow-Hill Book Co; 1976. p. 408. DOI: ajft.2011.103.116

[69] Plengvidhya V, Breidt F, Fleming HP. Use of RAPD-PCR as a method to follow the progress of starter cultures in sauerkraut fermentation. International Journal of Food Microbiology. 2004;**93**:287-296. DOI: 10.1016/j.ijfoodmicro.2003.11.010

[70] Krockel L, Schillinger U, Franz CM, Bantleon A, Ludwig W. Lactobacillus versmoldensis sp. nov., isolated from raw fermented sausage. International Journal of Systematic and Evolutionary Microbiology. 2003;**53**:513-517. DOI: 10.1099/ijs.0.02387-0

[71] Caggia C, Randazzo CL, Di Salvo M, Romeo F, Giudici P. Occurrence of listeria monocytogenes in green table olives. Journal of Food Protection. 2004;**67**:2189-2194. DOI: 10.4315/0362-028X-67.10.2189

[72] Campaniello D, Bevilacqua A, D'Amato D, Corbo MR, Altieri C, Sinigaglia M. Microbial characterization of table olives processed according to Spanish and natural styles. Food Technology and Biotechnology. 2005;**43**:289-294

[73] Cocolin L, Rantsiou K, Iacumin L, Urso R, Cantoni C, Comi G. Study of the ecology of fresh sausages and characterization of populations of lactic acid bacteria by molecular methods. Applied and Environmental Microbiology. 2004;**70**:1883-1894. DOI: 10.1128/AEM.70.4.1883-1894.2004

[74] Huerta R, Jordano R, Medina LM, Lopez C. Population dynamics of the constitutive biota of French dry sausages in a pilot-scale ripening chamber. Journal of Food Protection. 2004;**67**:2306-2309. DOI: 10.4315/0362-028X-67.10.2306

[75] Fontana C, Sandro-Cocconcelli P, Vignolo G. Monitoring the bacterial population dynamics during fermentation of artisanal Argentinian sausages. International Journal of Food Microbiology. 2005;**103**:131-142. DOI: 10.1016/j.ijfoodmicro.2004.11.046

[76] Vogel RF, Knorr R, Muller MRA, Steudel UG, anzle MG, Ehrmann MA. Non-dairy lactic fermentations: The cereal world. Antonie Van Leeuwenhoek. 1999;**76**:403-411. DOI: 10.1023/A:1002089515177

[77] Rousselin-Rousvoal F. L'Institut Rosell met des probiotiques dans le chocolat. Process. 2005;**1215**:50-51

[78] Luckow T, Delahunty C. Which juice is 'healthier'? A consumer study of probiotic non-dairy juice drinks. Food Quality Preference. 2004;**15**:751-759. DOI: 10.1016/j.foodqual.2003.12.007

[79] Park JS, Shin E, Hong H. Characterization of lactobacillus fermentum PL9988 isolated from healthy elderly Korean in a longevity village. Journal of Microbiology and Biotechnology. 2015;**25**:1510-1518. DOI: 10.4014/jmb.1505.05015

[80] Bintsis T. Lactic acid bacteria: Their applications in foods. Journal of Bacteriology and Mycology. 2018;**6**:89-94. DOI: 10.15406/jbmoa.2018.06.00182

[81] Dragoljub C, Aleksandra R, Dragiša S, Nataša J, Ana V, Lato P, et al. Survival of wild strains of lactobacilli during Kombucha fermentation and their contribution to functional characteristics of beverage. Polish Journal of Food and Nutrition Sciences. 2019;**69**:407-415. DOI: 10.31883/pjfns/112276

[82] Virdis C, Sumby K, Bartowsky E, Jiranek V. Lactic acid bacteria in wine: Technological advances and evaluation of their functional role. Frontiers in Microbiology. 2021;**11**:1-16. DOI: 10.3389/fmicb.2020.612118

[83] Liu SQ. Practical implications of lactate and pyruvate metabolism by lactic acid bacteria in food and beverage fermentations. International Journal of Food Microbiology. 2003;**83**:115-131. DOI: 10.1016/s0168-1605(02)00366-5

[84] López-Seijas J, García-Fraga B, da Silva AF, Zas-García X, Lois LC, Gago-Martínez A. Evaluation of malolactic bacteria associated with wines from Albariño variety as potential starters: Screening for quality and safety. Food. 2020;**9**:9-99. DOI: 10.3390/foods9010099

[85] Spano G, Beneduce L, Perrotta C, Massa S. Cloning and characterization

of the hsp 18.55 gene, a new member of the small heat shock gene family isolated from wine lactobacillus plantarum. Research in Microbiology. 2005;**156**:219-224. DOI: 10.1016/j.resmic.2004.09.014

[86] Rodas AM, Ferrer S, Pardo I. Polyphasic study of wine lactobacillus strains: Taxonomic implications. International Journal of Systematic and Evolutionary Microbiology. 2005;**55**:197-207. DOI: 10.1099/ijs.0.63249-0

[87] Adesogan AT, Salawu MB. The effect of different additives on the fermentation quality, aerobic stability and in vitro digestibility of pea/wheat bi-crop silages containing contrasting pea to wheat ratios. Grass and Forage Science. 2002;**57**:25-32. DOI: 10.1046/j.1365-2494.2002.00298.x

[88] Seale DR. Bacterial inoculants as silage additives. The Journal of Applied Bacteriology. 1986;**8**:9S-26S

[89] Kung L, Ranjit NK. The effect of lactobacillus buchneri and other additives on the fermentation and aerobic stability of barley silage. Journal of Dairy Science. 2001;**84**:1149-1155. DOI: 10.3168/jds.S0022-0302(01)74575-4

[90] Hristov AN, McAllister TA. Effects of inoculants on whole-crop barley silage fermentation and dry matter disappearance in situ. Journal of Animal Science. 2002;**80**:510-516. DOI: 10.2527/2002.802510x

[91] Holzer M, Mayrhuber E, Danner H, Braun R. The role of lactobacillus buchneri in forage preservation. Trends in Biotechnology. 2003;**21**:282-287. DOI: 10.1016/S0167-7799(03)00106-9

[92] Nishino N, Wada H, Yoshida M, Shiota H. Microbial counts, fermentation products, and aerobic stability of whole crop corn and a total mixed ration ensiled with and without inoculation of lactobacillus casei or lactobacillus buchneri. Journal of Dairy Science. 2004;**87**:2563-2570. DOI: 10.3168/jds.S0022-0302(04)73381-0

[93] Schwenninger SM, Von Ah U, Niederer B, Teuber M, Meile L. Detection of antifungal properties in lactobacillus paracasei ssp. paracasei SM20, SM29, and SM63 and molecular typing of the strains. Journal of Food Protection. 2005;**68**:111-119. DOI: 10.4315/0362-028x-68.1.111

[94] Filya I, Sucu E, Karabulut A. The effect of Propionibacterium acidipropionici, with or without lactobacillus plantarum, on the fermentation and aerobic stability of wheat, sorghum and maize silages. Journal of Applied Microbiology. 2004;**97**:818-826. DOI: 10.1111/j.1365-2672.2004.02367.x

[95] Adesogan AT, Salawu MB, Ross AB, Davies DR, Brooks AE. Effect of lactobacillus buchneri, lactobacillus fermentum, Leuconostoc mesenteroides inoculants, or a chemical additive on the fermentation, aerobic stability, and nutritive value of crimped wheat grains. Journal of Dairy Science. 2003;**86**:1789-1796. DOI: 10.3168/jds.S0022-0302(03)73764-3

[96] Krooneman J, Faber F, Alderkamp AC, Elferink SJ, Driehuis F, Cleenwerck I, et al. Lactobacillus diolivorans sp. nov., a 1,2-propanediol-degrading bacterium isolated from aerobically stable maize silage. International Journal of Systematic and Evolutionary Microbiology. 2002;**52**:639-646. DOI: 10.1099/00207713-52-2-639

[97] Brambilla G, De Filippis S. Trends in animal feed composition and the possible consequences on residue tests. Analytica Chimica Acta. 2005;**2005**:7-13. DOI: 10.1016/j.aca.2004.07.067

[98] Simon O, Jadamus A, Vahjen W. Probiotic feed additives–effectiveness and expected modes of action. Journal of Animal and Feed Sciences. 2001;**10**:51-67. DOI: 10.22358/jafs/70012/2001

[99] La Ragione RM, Narbad A, Gasson MJ, Woodward MJ. In vivo characterization of lactobacillus johnsonii FI9785 for use as a defined competitive exclusion agent against bacterial pathogens in poultry. Letters in Applied Microbiology. 2004;**38**:197-205. DOI: 10.1111/j.1472-765x.2004.01474.x

[100] Li Z, Weiwei W, Dan L, Yuming G. Effects of lactobacillus acidophilus on the growth performance and intestinal health of broilers challenged with Clostridium perfringens. Journal of Animal Science and Biotechnology. 2018;**9**:9-25. DOI: 10.1186/s40104-018-0243-3

[101] Huang MK, Choi YJ, Houde R, Lee JW, Lee B, Zhao X. Effects of lactobacilli and an acidophilic fungus on the production performance and immune responses in broiler chickens. Poultry Science. 2004;**83**:788-795. DOI: 10.1093/ps/83.5.788

[102] Yoruk MA, Gul M, Hayirli A, Macit M. The effects of supplementation of humate and probiotic on egg production and quality parameters during the late laying period in hens. Poultry Science. 2004;**83**:84-88. DOI: 10.1093/ps/83.1.84

[103] Younts-Dahl SM, Osborn GD, Galyean ML, Rivera JD, Loneragan GH, Brashears MM. Reduction of Escherichia coli O157 in finishing beef cattle by various doses of lactobacillus acidophilus in direct-fed microbials. Journal of Food Protection. 2005;**68**:6-10. DOI: 10.4315/0362-028x-68.1.6

[104] Timmerman HM, Mulder L, Everts H, van Espen DC, Van der Wal E, Klaassen G, et al. Health and growth of veal calves fed milk replacers with or without probiotics. Journal of Dairy Science. 2005;**88**:2154-2165. DOI: 10.3168/jds.S0022-0302(05)72891-5

[105] Jaquette RD, Dennis RJ, Coalson J, Ware DR, Manfredi ET, Read PL. Effect of feeding viable lactobacillus acidophilus (BT1386) on the performance of lactating dairy cows. Journal of Dairy Science. 1988;**71**:219

[106] Kung L, Taylor CC, Lynch MP, Neylon JM. The effect of treating alfalfa with lactobacillus buchneri 40788 on silage fermentation, aerobic stability, and nutritive value for lactating dairy cows. Journal of Dairy Science. 2003;**86**:336-343. DOI: 10.3168/jds.S0022-0302(03)73611-X

[107] FAO. Poultry Development Review. Rome: FAO; 2013

[108] Lema M, Williams L, Rao DR. Reduction of fecal shedding of enterohemorrhagic Escherichia coli O157:H7 in lambs by feeding microbial feed supplement. Small Ruminant Research. 2001;**39**:31-39. DOI: 10.1016/s0921-4488(00)00168-1

[109] (http://www.efsa.eu.int)

[110] (D2/CSL http://www.efsa.eu.int)

[111] (DSM 13241 http://www.efsa.eu.int)

[112] (http://www.agrinutrition.com)

[113] (http://wysong.net)

[114] Donohue D, Salminen S. Safety of probiotic bacteria. Asia Pacific Journal of Clinical Nutrition. 1996;**5, 5**:25-28

[115] Salminen S, von Wright A, Laine M, Vuopio-Varkila J, Korhonen T, Mattila-Sandholm T. Development of

selection criteria for probiotic strains to assess their potential in functional foods: A Nordic and European approach. Bioscience and Microflora. 1996;**1996**:61-67. DOI: 10.12938/bifidus1996.15.61

[116] Salminen S, Von Wright A, Morelli L, Marteau P, Brassart D, De Vos R, et al. Demonstration of safety of probiotics–a review. International Journal of Food Microbiology. 1998;**44**:93-106. DOI: 10.1016/s0168-1605(98)00128-7

[117] Salminen MK, Tynkkynen S, Rautelin H, Saxelin M, Vaara M, Ruutu P, et al. Lactobacillus bacteremia during a rapid increase in probiotic use of lactobacillus rhamnosus GG in Finland. Clinical Infectious Diseases. 2002;**35**:1155-1160. DOI: 10.1086/342912

[118] Wolf BW, Wheeler KB, Ataya DG, Garleb KA. Safety and tolerance of lactobacillus reuteri supplementation to a population infected with the human immunodeficiency virus. Food and Chemical Toxicology. 1998;**36**:1085-1094. DOI: 10.1016/s0278-6915(98)00090-8

[119] Cunningham-Rundles S, Ahrne S, Bengmark S, Johann-Liang R, Marshall F, Metakis L, et al. Probiotics and immune response. The American Journal of Gastroenterology. 2000;**95**:22-S25. DOI: 10.1016/s0002-9270(99)00813-8

[120] Kullen MJ, Bettler J. The delivery of probiotics and prebiotics to infants. Current Pharmaceutical Design. 2005;**11**:55-74. DOI: 10.2174/1381612053382359

[121] Thorlacius H, Nobaek S, Wang XD, Andersson R, Molin G, Bengmark S, et al. Lactobacilli attenuate bacteremia and endotoxemia associated with severe intraabdominal infection. Surgery. 2003;**134**:467-473. DOI: 10.1067/s0039-6060(03)00246-0

[122] McNaught CE, Woodcock NP, Anderson AD, MacFie J. A prospective randomised trial of probiotics in critically ill patients. Clinical Nutrition. 2005;**24**:211-219. DOI: 10.1016/j.clnu.2004.08.008

[123] Meurman JH. Probiotics: Do they have a role in oral medicine and dentistry? European Journal of Oral Sciences. 2005;**113**:188-196. DOI: 10.1111/j.1600-0722.2005.00191.x

[124] Zacharof MP, Lovitt RW, Ratanapongleka K. The importance of lactobacilli in contemporary food and pharmaceutical industry a review article. In: Conference Paper Proceedings of 2010 International Conference on Chemical Engineering and Applications (CCEA 2010). Swansea, UK: Multidisciplinary Nanotechnology Center, Swansea University; 2010. pp. 13-18

[125] Beasley SS, Saris PEJ. Nisin-producing *Lactococcus lactis* strains isolated from human Milk. Applied and Environmental Microbiology. 2004;**70**:5051-5053. DOI: 10.1128/AEM.70.8.5051-5053.2004

[126] Ross RP, Morgan S, Hill C. Preservation and fermentation: Past, present and future. International Journal of Food Microbiology. 2002;**79**:3-16. DOI: 10.1016/s0168-1605(02)00174-5

[127] Gill HS, Guarner F. Probiotics and human health: A clinical perspective. Postgraduate Medical Journal. 2004;**80**:516-526. DOI: 10.1136/pgmj.2003.008664

[128] Levri KM, Ketvertis K, Deramo M, Merenstein JH, D'Amico F. Do probiotics reduce adult lactose intolerance? A systematic review. The Journal of Family Practice. 2005;**54**:613-620

[129] Qin HL, Shen TY, Gao ZG, Fan XB, Hang XM, Jiang YQ, et al. Effect of

lactobacillus on the gut microflora and barrier function of the rats with abdominal infection. World Journal of Gastroenterology. 2005:2591-2596. DOI: 10.3748/wjg.v11.i17.2591

[130] Macfarlane GT, Cummings JH. Probiotics, infection and immunity. Current Opinion in Infectious Diseases. 2002;**15**:501-506. DOI: 10.1097/00001432-200210000-00008

[131] Reid G, Burton J. Use of lactobacillus to prevent infection by pathogenic bacteria. Microbes and Infection. 2002;**4**:319-324. DOI: 10.1016/s1286-4579(02)01544-7

[132] Cross ML. Microbes versus microbes: Immune signals generated by probiotic lactobacilli and their role in protection against microbial pathogens. FEMS Immunology and Medical Microbiology. 2002;**34**:245-253. DOI: 10.1111/j.1574-695X.2002.tb00632.x

[133] Bongaerts GP, Severijnen RS. Preventive and curative effects of probiotics in atopic patients. Medical Hypotheses. 2005;**64**:1089-1092. DOI: 10.1016/j.mehy.2004.10.018

[134] Viljanen M, Savilahti E, Haahtela T, Juntunen-Backman K, Korpela R, Poussa T, et al. Probiotics in the treatment of atopic eczema/dermatitis syndrome in infants: A double-blind placebo-controlled trial. Allergy. 2005;**60**:494-500. DOI: 10.1111/j.1398-9995.2004.00514.x

[135] Hamilton-Miller JM. Probiotics and prebiotics in the elderly. Postgraduate Medical Journal. 2004;**80**:447-451. DOI: 10.1136/pgmj.2003.015339

[136] Torriani S, Marzotto M. Probiotic as promoters of human wellbeing: Proven effects and quality assessment of selected cultures. Industria del Latte. 2003;**39**:29-46

[137] Roller M, Pietro Femia A, Caderni G, Rechkemmer G, Watzl B. Intestinal immunity of rats with colon cancer is modulated by oligofructose-enriched inulin combined with lactobacillus rhamnosus and Bifidobacterium lactis. The British Journal of Nutrition. 2004;**92**:931-938. DOI: 10.1079/bjn20041289

[138] Floch MH. Use of diet and probiotic therapy in the irritable bowel syndrome: Analysis of the literature. Journal of Clinical Gastroenterology. 2005;**39**:243-246. DOI: 10.1097/01.mcg.0000156104.67505.5b

[139] Usman HA. Hypocholesterolemic effect of lactobacillus gasseri SBT0270 in rats fed a cholesterol-enriched diet. The Journal of Dairy Research. 2001;**68**:617-624. DOI: 10.1017/s0022029901005179

[140] Liong MT, Shah NP. Acid and bile tolerance and cholesterol removal ability of lactobacilli strains. Journal of Dairy Science. 2005;**2005**:55-66. DOI: 10.3168/jds.S0022-0302(05)72662-X

[141] García-Díez J, Cristina S. Use of starter cultures in foods from animal origin to improve their safety. International Journal of Environmental Research and Public Health. 2021;**18**:2544. DOI: 10.3390/ijerph18052544