Lactobacillus Species as Probiotics: Isolation Sources and Health Benefits

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Abstract

Recently, the attention to exploring and applying probiotics has been increased. Probiotics are living microscopic organisms that have valuable impacts on health when consumed in adequate amounts. One of the most popular widespread utilized probiotics for many years until now is the Lactobacillus species which exemplifies the hugest heterogeneous group among the lactic acid bacteria (LAB) that normally occupy many environments that contain high nutrient levels such as soil, humans, waters, plants, animals and even air without causing any illness. The purpose of this work is to review and demonstrate the wide diversity of lactobacilli isolation sources and related health benefits applications of the strains discovered in order to break the familiar sources of lactobacillus spp., thereby encouraging more research into unconventional sources and opening up opportunities for clinical applications of Lactobacillus spp. As a result, the isolation sources of lactobacillus spp. in this review have been split into two groups based on the environmental condition, including fermented and non-fermented habitats described as lactobacilli probiotic sources. The unique Lactobacilli isolated from various sources are regarded as potential therapies for a variety of illnesses and physiological abnormalities, including immunomodulation, suppression of carcinogenesis, and cholesterol reduction, in addition to their capacity to guard against infections. This will be highly significant for revealing updated information about Lactobacillus spp. that has attracted considerable attention due to its potential application in clinical practices.

Keywords: Lactobacillus spp., LAB, Probiotics, Health Benefits, Isolation Sources
INTRODUCTION

Probiotics

The probiotic term refers to nonpathogenic living microorganisms that are intended to have beneficial health to humans and animals when consumed in adequate volumes. The term was created from the Greek words Pro (favor) and bios (life). Probiotics have earned enormous attention due to their valuable impacts on health. Furthermore, probiotics can be considered a healthy alternative therapeutic method to minimize drug resistance due to the excessive use of antibiotics to fight infections in people and animals. They can be helpful for the host by enhancing the intestinal microbial balance in the gastrointestinal tract, strengthening the epithelial barrier, and improving mucosal immunity. In addition, boost-up the immune system and its own antagonistic activity against many pathogens by producing antimicrobial compounds such as bacteriocins. Probiotics can prevent and heal many health issues and diseases including decreasing liver lipids concentrations, common cold, Fever blisters, Lyme disease, improving the general digestion problems, constipation, cancers, cardiovascular diseases, diabetes, allergic diseases, Helicobacter pylori infection, and even relief of anxiety and depression. According to the statement of a conducted study related to antibiotics, probiotics particularly the ones that belong to the genus lactobacillus found powerful enough to kill the HIV-1 virus when given at a high dosage. Moreover, Ligilactobacillus salivarius had the ability to inhibit the formation of cariogenic biofilms of Streptococcus mutans and Candida albicans reducing its pathogenicity. Probiotics contain several genera and species of bacteria, yeast, and molds such as Lactobacillus, Bifidobacterium, Candida pintolespai, Streptococcus, Aspergillus niger, Leuconostoc, Aspergillus oryzae, Propionibacterium, Bacillus, Pediococcus, Saccharomyces cerevisiae, and Enterococcus. Among the above-mentioned, the widely used genera belong to bacteria and particularly to the lactic acid bacteria (LAB) mainly represented by Bifidobacterium and Lactobacillus. The LAB that belongs to the genus of Lactobacillus has been one of the most popular and widely used probiotics for many years until now which exemplifies the hugest heterogeneous group among LAB. Lactobacilli are members of LAB, a diversified group of catalase-negative, Gram-positive, non-spore-forming and anaerobic or aero tolerant, cocobacilli, or rod-shaped that is mainly characterized by the lactic acid production as the main end product of their carbohydrate fermentation. Lactobacilli occupy many nutrient-rich habitats and environments such as spoiled and fermented food and are found in animal feed, soil, and body of invertebrate and vertebrate animals. They live naturally in our body by inhabiting the digestive tract, oral cavity, genital and urinary system. Members of the Lactobacilli group have been generally renowned as safe (GRAS) by Food and Drug Administration (FDA) due to their frequent abundance in our food like cheese and yogurt without causing illnesses.

Lactobacillus genus characterized by a massive genome possesses a high grade of genetic diversity and physiology which make them a targeted candidate in many important applications, such as the production of fermented food, food bio preservation strategies to prolong the shelf life while guaranteeing their safety, and in health improvement applications. The reason behind the focus on Lactobacillus is due to their vast impact on the host immune system, considered safe in use, show a competitive exclusion, and own a high adhering ability. This work is aimed to review the wide variety of lactobacilli isolation sources and associated health benefits applications of the strains discovered to break the acquainted sources of lactobacillus spp., thus also inspiring more research to isolate new strains from unconventional sources and providing possibilities for more clinical applications.

Taxonomy of Lactobacilli

Lactobacilli were one of the earliest classified bacteria due to their ubiquitous existence in many fermented products. Numerous classifications have been improved since the first description of the Lactobacillus genus by Beijerinck in 1901.
The base of the initial taxonomy of \textit{lactobacilli} was depend on the observable and measurable traits including cell morphology, gram stain, colony appearance, optimum growth temperature, pH tolerance, oxygen requirements, and pathways for carbohydrate fermentation which classified \textit{lactobacilli} according to the type of fermented sugars and fermentation products into three general groups; obligate homofermentative, facultative heterofermentative and obligate heterofermentative.\textsuperscript{27,28}

In the 1980s, with the entrance of bacterial taxonomy the genetic age, genotypic and chemotaxonomic characteristics were used in classification. The availability of 16S rRNA sequencing allowed the first phylogenetic analysis of the \textit{Lactobacillus} which uncovered an extensive diversity by the generation of a true phylogenetic tree that contributed to the development of the taxonomy of \textit{lactobacilli}.\textsuperscript{27,28} After the evolution of molecular techniques, most species have been named again and some reclassified to other genera.

Based on NCBI taxonomy, the current taxonomic hierarchy for \textit{Lactobacillus} is Domain: Bacteria, Phylum: Firmicutes, Class: Bacilli, Order Lactobacillales, Family Lactobacillaceae, Genus: \textit{Lactobacillus}.

The \textit{Lactobacillus} genus implicates more than 200 species distinguished by phylogenetic and metabolic diversity. About 540 species and 54 subspecies of this genus have been named again and some reclassified to other genera.

Isolation Sources of \textit{Lactobacillus} spp.

**Biological Sources**

\textit{Lactobacillus} spp. are food spoilage organisms that control the vast majority of the microbiota of fermented foods.\textsuperscript{30,31} Fermented vegetables, silage, also various grains rely on the basic material type as an inoculum source. Other fermented sources such as the majority of dairy fermentations, fermented meats, and sourdough, are produced by the manufactured environments of diverse lactic acid bacteria isolated from natural sources.\textsuperscript{32,33} Microorganisms in fermented products are subjected to centuries of growing continuously, becoming accustomed to the fermented product.\textsuperscript{34,35} As a consequence of \textit{lactobacillus}' capacity to adapt to multiple conditions in different environments, \textit{lactobacilli} isolation may be inoculated into many different types of goods or natural environments in order to produce novel strains and, as a result, prospective therapeutic uses.

Traditional fermented foods have recently been investigated as potential natural probiotic bacteria sources, according to recent studies. The \textit{Lactobacillus} genus is home to the bulk of microorganisms isolated from fermented environments.\textsuperscript{36} The Genus of \textit{Weissella} was obtained from traditional food under fermentation conditions in Nigeria followed by an evaluation of potential probiotics abilities in a recent investigation.\textsuperscript{37} \textit{Lactobacillus delbrueckii} subsp. \textit{bulgaricus} appears to be adapting to conditions in fermented products, as evidenced by a rapid and continuing decrease in the size of the genome.\textsuperscript{37} As a result, despite the fact that the vast majority of the strain types were obtained from fermented foods, they are improbable to serve as \textit{Lactobacillus}' main habitat. \textit{Lactobacillus} species can be isolated directly from a variety of natural and man-made fermented environments and products:

**Dairy Products**

Probiotics are used in a variety of dairy products, including sour/fermented milk, cheese, yogurt, butter/cream, new-born formula, and ice cream, according to the dairy industry. Probiotics are also utilized as starting cultures in conventional starters, either alone or in combination, or integrated into dairy products after fermentation, where their presence adds many functional characteristics to the fermented product (for example, improved taste, aroma, and textural characteristics), as well as conferring many health-promoting effects.\textsuperscript{38}

The fermented milk includes multiplex species of LAB and hence serve as an excellent probiotic supply. It should come as no surprise that \textit{Streptococcus thermophilus} and \textit{L. delbrueckii}
subsp bulgaricus are the most prevalent microbiological communities were found recently in the fermented yak milk (Kurut).\textsuperscript{39} Furthermore, probiotic lactobacillus strains and yeasts were identified from kefir grains, Koumissm, a fermented milk drink; and Masai milk; these bacteria have the capacity to favorably alter immunological responses.\textsuperscript{30,41}

Some products, such as yogurt, cheese, and butter, can benefit from the addition of starting cultures made from milk or milk alone. In comparison to the traditional Luria-Bertani medium, milk whey, a dairy by-product from the cheese manufacturing industry, is utilized to develop LAB to create more lactic acid. As a result, it might be one of several sources from which advantageous LAB strains can be obtained\textsuperscript{42} (Figure 1).

**Meats**

LAB strains used to be detected in a variety of traditional fermented foods, such as beef,\textsuperscript{43} fish,\textsuperscript{44} pork,\textsuperscript{45} and seafood.\textsuperscript{46} Enterococcus is the most common LAB strain recovered from fermented crustaceans and fishes, whereas Lactobacillus is the most common LAB obtained from fermented meats and plants.\textsuperscript{47,48} Due to the complex components of meats, LAB extracted from such environments is likely to be more diversified functionally and physiologically and it is likely to provide further therapeutic applications than LAB isolated from other sources (Figure 1).

**Grains, Fruits & Vegetables**

Lactobacilli strains from Plant-derived LAB are the most halophilic and flourished at NaCl concentrations greater than 22%. Significance species of lactobacillus were collected from fermentation condition of the plant parts are L. plantarum and L. fermentum. In addition, the various basic substance of dry wheats, garlic, olives, as well as parsley used in fermented food are high in LAB and may be tested for probiotic strains.\textsuperscript{45} Lactobacilli isolated from the natural brine of Algren, green olive fermented, was discovered in recent research.\textsuperscript{48} Several health benefits can be obtained from L. buchneri P2 as a potential probiotic collected from pickle juice was proved to have properties of antimicrobial activity, cholesterol reduction, and tolerance to acid and bile juice.\textsuperscript{49}

Lactobacillus spp. or Leuconostoc spp. Were represented the majority of LAB isolated in a study from sauerkraut fermentations and investigated to discover their probiotic properties and determined genotypic and phenotypic characterization of the isolates were found in four different sauerkraut fermentations\textsuperscript{10} (Figure 1).

LAB isolated from manufactured fermented products that basically contain plant parts are generated due to the contamination conditions during production processes or from endophytes bacteria. Endophytes lactobacillus spp. recovered from plant parts have the capacity to survive in a wide variety of PH gradients, allowing LAB to be separated from mild PH conditions of plant tissues or surfaces. lactobacilli did, however, exhibit a definite preference for improved development in a low pH environment.

**Traditional Food & Beverages**

Many of the isolated species of Traditional fermented foods and drinks flourished in NaCl concentrations of less than 6%.\textsuperscript{51} Traditional Thai salted crab also contains NaCl-like LAB (Poo-Khem). The fish dressing is identified as meal prepared under fermentation condition created from various basic ingredients including fish and shellfish. Probiotic isolates of L. plantarum was isolated from fermented soybean, popular traditional food in India, in addition, other genera of LAB including Lactobacillus, Vagococcus, Weissella, and Enterococcus were discovered.\textsuperscript{52} After conducting several tests to determine LAB genera isolated from natural fermented dry sausage, L. plantarum and L. brevis have been identified as the crucial lactobacillus spp.\textsuperscript{53} The majority of L. plantarum isolates from LAB came from traditional fermented Turkish beverages (Boza). To overcome Bacteria that cause disease including B. subtilis, B. cereus, E. coli, P. aeruginosa, L. monocytogenes, and K. pneumoniae, the antagonistic activity of isolates was examined by produced substances (primarily hydrogen peroxide and organic acids).\textsuperscript{54} In addition, various studies reported that probiotic LAB was collected from ungerminated cereal crops mixed with millet cereals known as (Kunu-zaki) as a traditional fermented beverage in Nigeria\textsuperscript{55} (Figure 1).
Lactobacilli utilized in traditional meals are either mesophilic or thermophilic, depending on the kind of ingredients and preparation circumstances, and may live at low temperatures as Psychrophilic bacteria. Lactobacillus spp. thrive in a wide range of temperatures, putting them at the forefront of bacterial species found in traditional meals.

Waste & Sewage

L. delbrueckii is one of the other species of lactobacillus that can be obtained from Fermented veggies that were discarded and inhibited the development of various harmful bacteria such as E. coli, P. aeruginosa and P. vulgaris.56

Lactobacilli can be discovered in sewage due to fecal contamination.57 Potential probiotics had been located in diffusion of areas of the human body, consisting of human feces remoted from each healthy adult and youngsters58 and breast-fed newborns59 (Figure 1).

Lactobacilli found in waste or sewage come from a variety of original environments, including humans, animals, and plants. Because of the abundance of complex components and the availability of growth nutrients, waste circumstances enable optimal development for Lactobacillus spp.

Probiotic lactobacilli Sources

1. Traditional food & beverages
   Beverages are made from raw materials, including cereals, millets, legumes, fruits and vegetables

2. Grains, Fruits & vegetables
   Tomatoes, pineapple, olives, papaya, cassava, sugar cane

3. Vertebrate & Invertebrate
   Animal intestines, human breast milk, faeces of infants, human GIT

4. Traditional food & beverages
   Fish sauce, traditional fermented soybean

5. Grains, Fruits & vegetables
   Fermented plant materials: wheat, garlic, parsley and olives

6. Meats
   Fish, beef, pork, salted crab, fermented sausages

7. Dairy products
   Yogurt, cheese, butter/cream, ice cream

8. Waste & Sewage
   Lactobacillus kunkeei is one of the most common strains from the majority of Lactobacillus spp. among LAB. These species have been shown to have antibacterial properties against yeast development as well as spoilage-related effects.
in honey by yeast. Several studies have indicated that fruit juice, vegetables, and long grass may be used to isolate LAB. Green olives were used to isolate *L. plantarum*, *L. pentosus*, and *L. paracasei*, whereas *L. mesenteroides* and *L. pentosus* were isolated from dark olives.

Several characteristics were examined to identify the probiotic potential of specific strains after isolation in a propitiate nutrient media of LAB. Plants Sources like papaya, yam, cassava, sugarcane, and tamar leaves were confirmed to contain isolates of *lactobacillus* spp. by reading the sequence of 16S rDNA of the samples, species were recognized as *L. paraplantarum* and *L. plantarum* isolated from crops leaves.

According to one study, these LAB isolated from plant sources may not be present in the regular microflora of plants grown recently, *Lactobacillus* spp. can be isolated from dead plants or raw materials such as olives, cabbage, carrots, beets, and fruits (for example pears and grapes). However, identification of *lactobacillus* spp. from surfaces of flowers or in the tissues of the other plant parts is restricted.

The leaves of *P. aquilinum* and, Aloe Barbadensis, also seeds of *L. usitatissimum*, roots of *D. carota*, and flowers of *P. cerasifera* were investigated, and 14 distinct LAB were identified as Lactococcus and *Lactobacillus*, as well as 8 various enterococci. species were initially identified by API kit, and then again analyzed given information by PCR technology, which corroborated the biochemical outcomes. The strains of LAB were isolated from plants’ parts comprised of *Lactobacillus delbrueckii* subsp. *Bulgarcus*, *Lactobacillus brevis*, *Lactococcus lactis*, *Lactobacillus acidophilus*, and some species of *Leuconostoc* (Figure 1).

The epiphyte *Lactobacillus* spp. outnumbered the endophyte bacteria, the reason may back to the species coming from surrounding sources such as animals, humans, waste, and soil. Climate, geographical factors, plant type, resident microbial communities, and Physical factors of the environment can impact *lactobacilli* dispersion in plants.

**Vertebrate & Invertebrate**

Animal intestines, according to Siddique et al., are the most likely source of LAB. Several probiotic strains have been identified from human sources, including human breast milk, from various regions of the human body.

the non-sterile breast milk, even if massed aseptically, still makes the chance of containing isolates of *lactobacillus* spp. in high odds. Breast milk bacteria were long thought to be the result of cutaneous or fecal infections. Although genotypes of *lactobacillus* spp. in breast milk differ from the genes of the isolates *lactobacilli* collected from the skin, also the strains of LAB detected in breast milk also were discovered inside newborns' excrement. *Lactobacillus* spp. can be found in numerous amounts in breast milk as a natural source of probiotics to be for incorporation into food products.

*Lactobacillus* species are among the most common bacteria isolated from breast milk, also its consumption promotes the predominance of one more source of probiotics in the human intestinal tract. over 500 various species of bacteria can be obtained from the stomach of adult humans. Indeed, many of today’s probiotic strains, including *L. gasseri* and *L. reuteri*, were isolated from this source. It’s a common misconception that the digestive tract should be the sole residence for the probiotics strains to be more beneficial.

Probiotics are present in the stomachs of many animals, including rats, pigs, and even chickens. Lately, strains of *Lactobacillus johnsonii*, collected from *Apis mellifera* stomach, were proven to boost honeybee colonies. Probiotics’ isolates were also identified from the digestive tract of freshwater and marine fish, including *Carassius auratus gibelio*, rainbow trout, and shrimp.

*In vitro* research has shown that some strains of bacteria obtained from meats (*lactobacillus sakei*, *Staphylococcus carnosus*, and *lactobacillus curvatus*) and fruits (*L. plantarum* and *L. paracasei*) exhibit functional and metabolic features comparable to bacteria of adult’s intestine.

*Lactobacilli* may be isolated consistently from a broad variety of insects, including bees and flies, as well as vertebrates such as rodents, birds, people, and agricultural animals. Because scientific research has mostly concentrated on domesticated animals and people, the host range is likely to be substantially greater. *Lactobacilli*
tend to favor food storage organs in animal hosts, such as the crop and forestomach. Insects including bees, flies, bumblebees, and vertebrates’ organs were used to isolate lactobacillus species. Digestive tract, mouth cavity, vagina, and saliva and feces of healthy adults can be considered as non-fermented sources of lactobacillus isolates.\(^93\) Tajabadi et al. extracted LAB from honey collected from massive honeybees.\(^94\) Lactic Acid Bacteria (LAB) from ten healthy wild giant freshwater prawns’ stomachs and hepatopancreas, Macrobrachium rosenbergii, were identified in a recent study to investigate native probiotic strains for additional uses. According to the findings, two LAB isolates, L. plantarum and E. faecalis, have been recommended as prospective Probiotics derived from huge freshwater prawns to enhance the aquaculture sector\(^95\) (Figure 1).

The presence of Lactobacillus spp. species in many terrestrial and marine organisms gives a clear indication of the concept of one health approach. Therefore, the balance of these species in other organisms and environments can provide solutions for environmental balance, food security, and public health alike.

Environmental Sources

Environments around food products, for example, have also been isolated as unconventional sources of high potential probiotics.

Air

The air in the surrounding environs, as well as the air in a bakery’s storage and working rooms, can be a source of lactobacilli during the sourdough preparation process. L. plantarum was discovered in the samples, which is comparable to the one collected from the dough. In addition, Lactobacilli were isolated from the air around palm plants\(^56\)\(^,\)\(^96\) (Figure 1).

Soils

Probiotic bacteria isolated from soil in Japan and Taiwan have been discovered and categorized. In order to isolate LAB in Japan and Taiwan, 68 soil samples were collected from various animal areas including the area surrounding the horse farm and floors of the henhouses. Several tests were conducted Physiologically and genetically to determine strains of LAB. 54 out of 68 isolates identified as LAB. This clearly indicates the existence of LAB in significant numbers. According to the findings, dirt may be a frequent source of lactic acid bacteria isolation.

The initial habitat of many isolates came from soil sources. These lactobacillus isolates can be transferred to any product or habitat derived from the rhizosphere or phyllosphere of plants\(^57\)\(^,\)\(^74\)\(^,\)\(^97\) (Figure 1).

Aquatic Environments

In aquatic environments, scientists are interested in isolates from the gastrointestinal tract of marine organisms. Lactobacillus spp. were collected from the GIT of several fish and shrimp. However, the environment surrounding and hydro planktons that form as nutrients for the marine organisms are rich in probiotic strains (Figure 1).

The Significant Roles of lactobacillus Species in Our Life

Human has very tight contact with an enormous number of microorganisms that exist in the mouth, skin, or in gut. Some of them possess remarkable health functions such as inducing the immune system, owning an agnostic activity against invading pathogens, enhancing the digestion process, and amending many diseases.\(^98\)

There are many identified Lactobacillus species that have been reported as probiotics and have beneficial effects on health (Figure 2).

Protection against Pathogens

Inhibiting the growth of pathogens is one of the ways probiotics benefit human health. These probiotics compete for resources that pathogens would use for growth and proliferation. As a result, they provide protection against pathogens colonization by causing direct death and competing for resources.\(^99\)

In the Gastrointestinal Tract

Probiotics are one of the most effective ways to influence human health and disease by balancing the gut flora.\(^100\) Several studies demonstrated the role of Lactobacillus as a probiotic against many pathogens such as Lactobacillus acidophilus is safe for human epithelial colorectal cells and efficacious enough to be utilized as a supplementary.
treatment for reducing toxin generation in *Vibrio cholerae* and *Shigella dysenteriae* caused acute infectious diarrhea.\textsuperscript{101}

Furthermore, it was reported that taking *Lactobacillus rhamnosus* HN001 on a regular basis lowered the risk of *Staphylococcus aureus* carriage in the human gastrointestinal tract (GI). Competitive inhibition is the key possible mechanism of *L. rhamnosus* HN001, in which pathogen colonization is limited by beneficial commensal microbes out-competing them for vital resources in the GI tract.\textsuperscript{102}

In another study, Jun Meng and others found that the surface layer protein (SLP) of *Lactobacillus casei* fb05 might reduce *Escherichia coli* and *Salmonella*’s harmful effects on the digestive tract in two ways: by lowering pathogen adherence and avoiding apoptosis caused by pathogens.\textsuperscript{103}

The leading cause of disruption of the normally protective gastrointestinal microbiota is *Clostridium difficile* infection (CDI) and antibiotic usage is a common cause of this condition. However, the supplementation of a certain probiotic combining *Lactobacillus casei*, *L. rhamnosus*, and *L. acidophilus* strains has been shown to be effective in inhibiting a number of undesirable consequences, including CDI and antibiotic-associated diarrhoea.\textsuperscript{104} The information about the gut microbiome is constantly accumulating which has heightened the interest in gut microbiome-based healthcare (Figure 3).

Because of the strong connections between gut microbiota, health, and disease, there is a lot of interest in utilizing probiotics to alter the gut microbiota in order to treat or prevent certain diseases. However, more research is required to ascertain which probiotic species and strains, dosage, and duration of treatment are efficient. It is also necessary to look into any potential probiotic-diet interactions and interindividual variability that may result in disparate responses to probiotics.

**In the Vaginal Tract**

There are a variety of normal mycobiota and microbiota that colonize the human vagina, but *Lactobacillus* is the most prevalent bacteria

![Figure 2. Reported *Lactobacillus* species as probiotics](image-url)
found in the normal vaginal tract. These vaginal lactobacilli have been claimed as having the ability to prevent disease invasion by controlling their population.\textsuperscript{105}

*Lactobacillus* has been shown to have fundamental probiotic effects against infections in the vaginal tract in several investigations. Fermentation of *Lactobacillus* acidophilus KS400 has been shown to generate bacteriocin that prevents urogenital pathogens growth like *G. vaginalis*, *S. agalactiae*, and *P. aeruginosa*.\textsuperscript{106}

In addition, *Lactobacillus acidophilus* GLA-14 and *Lactobacillus rhamnosus* HN001 exhibit antibacterial activities against several pathogens that were responsible for aerobic vaginosis (*Staphylococcus aureus* and *Escherichia coli*) and bacterial vaginosis (*Atopobium vaginae* and *Gardnerella vaginalis*) by means of a co-culturing assay.\textsuperscript{107}

The *L. Plantarum* new isolates called ZX1, ZX2, ZX27, and ZX69 were found to limit *Gardnerella vaginalis* growth, the Bacterial vaginosis causative agent.\textsuperscript{108}

In another study, they demonstrated that the major *Lactobacillus* species linked to a healthy vagina is *L. crispatus* may effectively block the growth of *C. Albicans* and the formation of hyphae. In an NRG1-dependent way, *L. crispatus* may also suppress the hyphae-specific gene expression (ALS3, HWP1, and ECE1). Furthermore, *L. crispatus* B145 is an excellent candidate for probiotic research.\textsuperscript{109}

Also, a *Lactobacillus* dominated vaginal ecology has the ability to protect the host from human immunodeficiency virus (HIV) and sexually transmitted infections (STIs).\textsuperscript{110,111}

*L. crispatus* BC3 and *L. gasseri* BC12 protect isolated cells and ex vivo tissues from infection with the Human Immunodeficiency Virus 1 (HIV-1) by releasing their extracellular vehicles (EVs) this finding could lead to new HIV-1 prevention measures for male-to-female sexual transmission\textsuperscript{112} (Figure 3).

Moreover, *Lactobacillus* shows to be a promising influence to use in the prevention of vaginal infections such as vulvovaginal candidiasis (VVC) and bacterial vaginosis (BV).\textsuperscript{105}

To reduce the need for antimicrobial medications, a complementary method involving *Lactobacillus* to correct the imbalance of vaginal microbiota is urgently needed. To treat the heterogeneity of probiotic effectiveness, there should be more scientific investigations on the effectiveness of probiotic *lactobacilli* against vaginal infection.

**Figure 3.** Different *Lactobacillus* species identified as human body protectors against various pathogens in the gastrointestinal tract, the vaginal tract, and the skin
In Skin Health

The skin is one of the largest organs in the human body, and it serves as a vital barrier and protective barrier against pathogen invasion.113

For many years, various studies on Lactobacillus and skin health have been published, including prevention of skin illness and improvement of skin diseases.

Several studies have shown that exogenously applied lactobacilli, for example Lactobacillus rhamnosus GG and Lactobacillus reuteri DSM 17938 have been found to have anti-pathogenic properties both directly and indirectly. Lactobacilli or their lysates, through direct binding interactions, can prevent infections from adhering to keratinocytes or actively displace adherent pathogens, as proven in vitro against S. aureus. For L. rhamnosus GG at least in part, these effects appear to be caused by SpaCBA pili, it has a high level of adhesion to human keratinocytes.114-116

Furthermore, live L. reuteri DSM 17938 demonstrated antibacterial activity against pathogens on the skin including (Streptococcus pyogenes M1 Staphylococcus aureus, Pseudomonas aeruginosa, and Cutibacterium acnes AS12).116

Exopolysaccharides and the primary peptidoglycan hydrolase Msp1 were identified as important components of L. rhamnosus GG that reduced C. albicans hyphae production and attachment to host epithelial cells.117

Under the influence of Lactobacillus pentosus KCA1, L. rhamnosus GG, and L. plantarum WCFS1 has greatly reduced the lipase activity of Cutibacterium acnes that helps in the conversion of sebum into free fatty acids, contributing to acne (Figure 3).

These mechanistic insights have already been converted into positive therapeutic outcomes in a few clinical trials, demonstrating that topically applied lactobacilli can colonize the skin for a short period of time and improve skin health, However, in order to generate in vivo mechanistic insights and in-depth skin microbiome analyses, more and larger clinical studies are required.118,119

Numerous novel probiotic products are being developed for the treatment of various skin problems as a result of these studies on the gut and skin microbiomes, which have produced some extremely insightful findings. Additionally, Eczema, atopic dermatitis, acne, and allergic inflammation are just a few of the skin conditions that probiotic bacteriotherapy may help prevent and treat. It may also help reduce skin hypersensitivity and help protect against UV-induced skin damage and wounds. It can also be applied topically.

Combating Physiological Disorders

Lactobacillus probiotics have demonstrated effectiveness in a variety of clinical disorders and conditions ranging from diarrhea, female urogenital infection, Helicobacter pylori infections and inflammatory bowel disease to cancer98,119 (Table).

The impact of gut microbiota on host physiological regulation has recently gotten a lot of attention, especially in crucial areas including the immune system and metabolism.153

Immunomodulation

The immunomodulatory activities of probiotics can act both directly and indirectly. Directly such as by increasing the activity of natural killer cells or macrophages modulating the secretion of cytokines or immunoglobulins. Indirectly by competitive exclusion of other (pathogenic) bacteria, enhancing the gut epithelial barrier and altering the mucus secretion.154

Anti-commensal antibodies, innate cytokines, and Th17 responses were all reduced after oral gavage with L. reuteri, reducing immunological hyper-reactivity (Table). Also, autochthonous Lactobacillus may also aid in the restoration of immunological homeostasis and the resolution of infectious illness.155

Lactobacillus-free (LF) mice were used to establish the physiological relevance of L. reuteri’s immunological effects in vivo.156,157 Proinflammatory cytokines and chemokines generated by intestinal epithelial cells in the ileum and jejunum were activated as a result of the administration of L. reuteri in this animal.158

Furthermore, probiotics have been shown in multiple studies to strengthen the integrity of the intestinal barrier by increasing gene expression in tight junction signaling. By tight junctional protein phosphorylation, enhancing (actin, occludin) cytoskeletal or preserving (actin, ZO-1). L. acidophilus inhibited enter invasive E. coli
Table. Uses of Lactobacillus spp. as probiotic against various human diseases. The clinical outcomes had been conducted on humans as a subject.

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<th>Probiotic</th>
<th>Effective against</th>
<th>Clinical outcomes</th>
<th>Ref.</th>
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<tr>
<td><em>L. reuteri</em></td>
<td>Bowel diseases</td>
<td>Improved inflammation along with increased cytokine expression levels. Restoration of gut flora and the prevention of diarrhea.</td>
<td>120</td>
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<td>Coxackieviruses</td>
<td>Reduce the antiviral activity</td>
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<td>Periodontitis</td>
<td>Reduced abundance of the pathogenic bacterium</td>
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<td>Gingivitis</td>
<td>Decreased bleeding during chewing gums containing probiotics</td>
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<td>Type 2 diabetes mellitus</td>
<td>Beneficial effects on patients</td>
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<td>Diarrhea</td>
<td>Minimize the frequency and period of diarrhea</td>
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<td>Respiratory tract infection</td>
<td>Decrease the rate of the infection</td>
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invaded and adhered in the human colon cancer cell line (HT29) and Caco-2 cells.\textsuperscript{159}

**Inhibition of Carcinogenesis**

It is well proven that *Lactobacillus* can modulate-ameliorate specific mechanisms against cancers via stimulating anti-cancer effects like enhancing apoptosis of cancer cells and protecting them from oxidative stress.

Probiotic bacteria, particularly *Lactobacillus* microorganisms, have been reported to cause anti-cancer action through increasing apoptosis of cancer cells and the protection against oxidative stress.\textsuperscript{160,161}

In similar research involving colon cancer, it was demonstrated that the administration of *L. fermentum* NCIMB 5221 and *L. acidophilus* ATCC 314 in a murine colon cancer model had been discovered to stop or slow the growth of the tumor by triggering an anti-cancer immune response.\textsuperscript{162}

Moreover, in mice models of colorectal cancer and melanoma, it has been shown that the administration of live *L. rhamnosus* GG orally enhanced the antitumor effectiveness of anti-programmed cell death 1 (PD-1) immunotherapy by boosting tumor-infiltrating dendritic cells (DCs) and T cells.\textsuperscript{163}

In addition, *L. paracasei*, *L. casei*, *L. fermentum*, and *L. rhamnosus* were the most frequently isolated species from head and neck cancer patients. moreover, *L. paracasei* had the highest proportion of antimicrobial activity and the best acid-producing capacity against *S. mutans*.\textsuperscript{164}

Probiotics might alter the micro-environment of the intestine, causing pro-inflammatory cytokines to decrease. As in the study of Zaharuddin and his group they have shown that pro-inflammatory cytokines were reduced in colorectal cancer patients by using probiotics consisting of six live *Lactobacillus* and *Bifidobacteria* strains.\textsuperscript{165}

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In addition, in breast cancer metastases in a mouse model, it has been shown that the fermentation of milk by *Lactobacillus casei* CRL431 (probiotic fermented milk (PFM) help in breast cancer metastases by altering the immune response.\textsuperscript{166}

Furthermore, probiotic *L. rhamnosus* MD 1 produced metabolites that exhibited both cytotoxic and antigenotoxic potential against colon cancer.\textsuperscript{167}

Another study has shown that *lactobacillus* E6-1 can inhibit the proliferation of Cal-27 and effectively induce apoptosis of tumor cells *in vitro*.\textsuperscript{168}

The exopolysaccharide (EPS) generated by *L. plantarum*-12 was found to suppress the colon cancer cell line's proliferation HT-29 in humans via the mitochondrial route.\textsuperscript{169}

The finding of a study about colorectal cancer (CRC) suggested that consuming *Lactobacillus acidophilus* in persons with polyps and people that have a family history of CRC may be a means to prevent, treat, or lower the severity of CRC.\textsuperscript{170}

Because of their activity against cervix cancer cells, other research suggests that *Lactobacillus casei* SR1, *L. casei* SR2 and *L. paracasei* SR4 strains derived from the breast milk of humans can be employed as topical therapy with a potential therapeutic index.\textsuperscript{171}

The results of recent investigations support the hypothesis that probiotics may be used in cutting-edge cancer treatments. Therefore, to validate these findings and develop treatment plans, additional research on the subject is required. This could theoretically result in a breakthrough in many areas of medicine, including the support of immunotherapy in the treatment of cancer and the development and production of novel vaccines, as well as the improvement of drug delivery in the treatment of other bowel diseases while simultaneously preventing and reducing inflammation.

**Reduction of Cholesterol Level**

Numerous studies have demonstrated *Lactobacillus* potential to lower cholesterol levels. Such as In C57BL/6 mice fed a hypercholesterolemia diet, *L. plantarum* H6 lowered serum cholesterol levels. It improved the microbial community of intestinal structure in mice by preventing the pathway of farnesoid X receptor to increase the synthesis of bile acids *in vivo* via promoting the expression of the CYP7A1 gene.\textsuperscript{172} (Table).

It was shown that *L. plantarum* YS5 can reduce the level of cholesterol by 84% due to its ability to remove cholesterol *in vitro*. Furthermore,
in male Wistar rats, probiotic supplementation was observed to lower serum total cholesterol, low-density lipoprotein cholesterol, and triglyceride levels.\(^{173}\)

There is evidence that consuming probiotic-rich dairy products lowers blood cholesterol, which could help prevent diabetes, obesity, cerebral stroke, and cardiovascular disease.\(^{174}\)

*Lactobacillus*, such as *L. fermentum*, *L. plantarum*, and *L. acidophilus* decrease cholesterol and ameliorate the advancement of nonalcoholic steatosis. Thus, *Lactobacillus* can be used as a beneficial strategy for non-alcoholic fatty liver disease (NAFLD) treatment.\(^{175}\)

Furthermore, the administration of *L. rhamnosus* BFE5264 resulted in a major reduction in serum cholesterol in a mouse model fed a high-cholesterol diet and changes in the gut flora and the production of short-chain fatty acids were also observed (SCFA). Also, this strain has a positive impact on the metabolism of cholesterol in the liver in a manner like that resulting from statin treatment, which is a drug that can inhibit the biosynthesis of cholesterol in the liver.\(^{176}\)

*L. kefiri* DH5 has anti-obesity benefits via lowering the lumen cholesterol and upregulating the PPAR gene in adipose tissues.\(^{177}\)

Along the AMP-activated protein kinase (AMPK) pathway, lactobacilli could exert cholesterol-lowering properties by AMPK phosphorylation that lowered 3-hydroxy-3-methylglutaryl-coenzyme A reductase (HMGCR) expression.\(^{178}\)

*L. plantarum* (LP06CC2) was tested for its effect on cholesterol metabolism in mice fed a cholesterol-rich diet. The consumption of LP06CC2 inhibited the hepatic damage indices as well as the increase of liver cholesterol. The deconjugation of bile acids was clearly boosted by LP06CC2, indicating that bile acid absorption was reduced. LP06CC2 appears to be a promising *Lactobacillus* for lowering cholesterol levels by modulating deconjugation of bile acid.\(^{179}\)

Probiotics' effects on total cholesterol levels have been thoroughly studied. Researchers have made an effort to elucidate the mechanisms of probiotics on the hypocholesterolemic effect through *in vitro* and *in vivo* experiments in order to explain the variable cholesterol-lowering effect displayed by distinct probiotic strains. Numerous theoretical explanations and experimental data focusing on cholesterol-lowering effects are still debatable. Therefore, better-designed *in vivo* studies may reveal more information that can help resolve disagreements, better understand underlying mechanisms, and determine whether a substance is safe to consume before it is used.

**Probiotics as “One Health” Perspective**

According to the World Health Organization, One Health is an integrated, unified strategy aimed at continuously balancing and optimizing the health of humans, animals, and ecosystems; in order to intimately connect the interdependence of all these domains.

Increasing the risks of antibiotic resistance and pathogen transmissibility between humans and animals, changing climatic conditions, people's migrations, and increasing the rate of communication are all factors that have contributed to disease spread and will require the application of the concept of "one health." Some of the most often used antimicrobial medications in animals, for example, are likewise reserved for the most difficult cases in humans.

Beneficial domestic multi-dominant agents such as probiotics, which are used to dwell in ecosystems and organisms, can apply the "one health" principle. Ecosystems contain and maintain the most biodiversity on the planet, which may be transmitted to humans via animal and plant products. Probiotics found in soil and plants are primarily favorable to humans and animals. Probiotics, which demonstrate dynamic relationships with different bacteria across the animal and plant kingdoms, developed alongside plants, invertebrates, and vertebrates, forming mutualism, symbiosis, commensalism, or even parasitic behavior with their hosts. *Lactobacillus* spp., with their ability to colonize the phyllosphere, endosphere, and rhizosphere, as well as the fruits and flowers of many plants, make these probiotics species suitable for achieving the "one health" notion.

The diverse *lactobacilli* isolation sources, as well as the species' capacity to transmit and reside in multiple locations and habitats, enhance the implementation of the "one health" concept. Many studies have shown that *Lactobacillus* spp.
can restore environmental balance and enhance human and animal health. For example, in human health, the remarkable flexibility and adhesion of *lactobacilli* in the host’s gastrointestinal system may help enhancement of the host’s gut health. Furthermore, *lactobacilli* species may be useful as plant growth promoters. Probiotics with the ability to ferment a wide range of carbohydrates, probiotic benefits on human and animal health, and are found in vegetables, dairy products, pickles, sauerkraut, cheeses, fish products, and sausages are likely the greatest candidates for "One Health."

Improving the quality of animal products, increasing production and food security, and lowering the risk of pathogenic agents can all be accomplished by using probiotics as nutritional supplements in scientifically studied ways, in addition to providing an alternative solution to the use of antibiotics. Despite its critical and helpful properties, a high concentration of *lactobacillus* spp. in food can induce food spoilage.

**CONCLUSION AND FUTURE PERSPECTIVES**

Almost a century after *Lactobacillus* species were initially characterized, researchers are constantly working to identify new *Lactobacillus* species from previously unknown sources. Probiotics may be found in a number of locations; however, as development techniques have been employed, scientists have begun to seek probiotics in unorthodox sources that can aid in the discovery of novel probiotic strains such as non-dairy fermented goods and inanimate surroundings. Lactose-intolerant persons are given probiotics obtained from plant sources, which also demonstrate potential new antibiotics activities of isolates that can be utilized as a replacement or supplement to current chemical antibiotics. *Lactobacillus* species may be separated from fermented and non-fermented biological sources, as well as from environmental sources. The *lactobacilli*’s unique habitat features and wide range of environments indicate the possibility of searching for and isolating new *lactobacillus* probiotics strains from unexpected sources.

It’s far viable that they may grow to be greater effective strategies inside the remedy of diverse issues which includes immune gadget stimulation, high cholesterol level, oral infections, urinary tract infections, vagina inflammation, diarrhea symptoms, and so forth as an alternative or supplement to other well-known treatments in the future. It is a natural remedy for newborn animals and humans, as well as for nutrition and sickness treatment. Aside from therapy, they are now widely used in newborn diets and milk. In terms of liver disease, lowering liver enzymes and bilirubin levels can be achieved by *Lactobacilli* isolated from sugar cane following the fermentation process.

Probiotics are vital for restoring normal gut flora, increasing the development of good bacteria, and decreasing the chance of acquiring chronic conditions including cardiovascular disease. As a result, there is widespread interest in these molecules as components for the development of innovative meals with functional qualities. seeking to the roles of native microbiota affecting health and balance restoration, the most current scientists in this regard are still in the early stages of discovering connections and relationships between native probiotics and intestinal microbiota, which might enable for successful customization of probiotic treatment, the commitment of supplementation time, and description of optimal doses for patients in order to improve cardiovascular efficiency or treat certain disorders.

Gut microbiome research is a young and difficult topic with methodologies that are a way to be uniform and coordinated. Massive datasets created from the microbiome, metabolomics, genomics, and transcriptomics are analyzed as consolidated investigation data could be a challenge to interpret, and a variety of complicated bioinformatics approaches have been conducted. The requirement for improving this field of inquiry is crucial through empirical and disarranged controlled studies. To increase existing understanding, well-designed clinical studies including all components of life routine, intestinal microbiome, metabolite, and genetics data are better to be improved.

Although additional clinical evidence is needed to further assess probiotics' therapeutic value, procaryotes such as *Lactobacilli* strains are now among the most extensively utilized agents in GIT diseases. According to *in vivo* investigations,
Lactobacillus survives well in the human GI tract. Lactobacilli are one of the most common LAB species that have played important therapeutic functions since their discovery. The increasing amount of research shows that it may be beneficial for diarrhea prevention and alleviation, as well as the treatment of recurring Clostridium difficile colitis.

By upgrading methodologies, tools, and techniques for isolation and identification, new pathways for probiotics will open, resulting in additional discoveries of local probiotic strains. New approaches, such as those that enable real-time human study and monitoring of a microbe’s integration into an established microbiome, are being developed, along with technologies capable of assessing hit points, which can move this area ahead. After moving on to physical tests henceforth, information on the presence of bacteria, their interaction with the host, and the effect of environmental stimuli (including medications, and nutrition) going to be routine. Revolutionary pattern technology will disclose how a probiotic interacts with the host in several stages such as immune machine, all microbiome components, and metabolism. The integrated approach will aid in the establishment of dose-response connections for diagnosis, as well as in coordinating what gets into our systems, which probiotic bacteria have the most predicted impact, and how they will be absorbed.

Probiotic strains isolated from marine organisms have several applications and can be used for Aquaculture species and to prevent microbial pathogens that could threaten marine life. Studies that aim to isolate novel strains of probiotics from aquatic organisms present alternative treatments for the human and marine organisms’ pathogens and shed the light on the significant importance to intensify research for probiotics isolated from marine organisms in the future.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS’ CONTRIBUTION

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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DATA AVAILABILITY

All datasets generated or analyzed during this study are included in the manuscript.

ETHICS STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors.

REFERENCES


32. Ripari V, Ganzle MG, Berardi E. Evolution of


57. Kvasnikov E, Kovalenko N, Nesterenko O. Lactic acid bacteria in nature and the national economy [USSR, excludes the dairy industry] [1983]. *Appl Biochem**


O'Hara AM, Shanahan F. The gut flora as a forgotten organ. EMBO Reports. 2006;7(7):688-693. doi: 10.1038/sj.embr.7400731


155. Heeney DD, Gareau MG, Marco ML. Intestinal Lactobacillus in health and disease, a driver or just along for the ride? Curr Opin Biotechnol. 2018;49:140-147. doi: 10.1016/j.copbio.2017.08.004


159. Resta-Lenert S, Barrett KE. Live probiotics protect intestinal epithelial cells from the effects of infection with enteroinvasive Escherichia coli (EIEC). Gut. 2003;52(7):988-997. doi: 10.1136/gut.52.7.988


