Lactobacillus Probiotics: Mechanisms, Health Benefits, and Applications in Combating Pathogenic Bacteria

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Abstract

This research paper explores the potential of *Lactobacillus* probiotics as a safe and cost-effective alternative to conventional antibiotics for combating antibiotic-resistant pathogenic bacteria. With the rise of multidrug-resistant pathogens posing a significant threat to global health, there is an urgent need for innovative therapeutic strategies. Probiotics, particularly lactic acid bacteria such as *Lactobacillus*, offer promising health benefits, including enhancing gut microbiota balance, strengthening immune responses, and producing antimicrobial compounds that inhibit pathogenic bacteria. The study highlights the mechanisms by which *Lactobacillus* strains exert their beneficial effects, such as competitive exclusion of pathogens, production of bacteriocins, modulation of gut barrier function, and immunomodulation. Additionally, probiotics demonstrate efficacy in treating gastrointestinal disorders, metabolic imbalances, and even chronic conditions like cancer and mental health disorders. Beyond human health, their applications extend to agriculture, where they contribute to sustainable practices by improving plant resilience and soil health. Despite these advantages, further research is needed to optimize strain-specific effects, dosages, and long-term impacts. Collaborative efforts among researchers, clinicians, and policymakers are essential to integrate probiotics into mainstream healthcare and environmental management. Embracing probiotics as part of daily nutrition and therapeutic regimens could revolutionize public health, reduce reliance on antibiotics, and promote ecological sustainability. In conclusion, *Lactobacillus* and other probiotic bacteria represent a bridge between natural microbial solutions and modern medicine, offering innovative approaches to address global health challenges while aligning with sustainable practices. Continued exploration of their potential promises to unlock new avenues for improving health across diverse ecosystems.

Keywords: *Lactobacillus*, Probiotics, Antibiotic Resistance, Gut Microbiota, Antimicrobial Mechanisms, Health Benefits

1. Introduction

Probiotics are live microorganisms which upon ingestion in sufficient concentrations can exert health benefits to the host. This definition of probiotics was derived in 2001 by the United Nations Food and Agriculture Organization (FAO) and the World Health Organization (WHO), and has been the term of reference for science and regulation thereafter [8]. Demand for food containing probiotics is expanding globally due to the continuous generation of research evidence indicating their potential health benefits to consumers [20]. An integral part of the treatment of bacterial infections is the administration of antibiotics that target etiologic. The technology requires a thorough understanding of the physiological obstacles to effective drug delivery, such as the movement of drugs through cells and tissues and the transport of drugs through the circulatory system and metabolism.

The proper administration of medications is dependent on a number of factors, and the study of the drug delivery system is multidisciplinary [4]. The most frequent and recommended method of administering medications, whether they are in solid or liquid dosage forms, is oral administration.

Antibacterial drugs as we know them in today′s medicine have been used for 80 years. Despite the great expansion of antibacterial in the 1960s and 1970s, as documented by the development of a range of new products and their introduction into practice, bacterial infections remain a major issue of increasing importance [34]. Modern medicine is even confronted with the real threat that antibiotics may lose their effect on bacteria and the associated ability to treat bacterial infections [19]. The increasing resistance of bacterial pathogens to antibacterial drugs; for example, the rising prevalence of bacteria producing broad-spectrum beta-lactamases, including metallobeta-lactamases and carbapenems, raises the possibility of a return to a new "antibiotic-free era" in which adequate antibiotics will not be available for the treatment of bacterial infections with an etiological role of multidrug-resistant bacteria [2, 3]. Due to their properties, several strains of this group have been identified as probiotics, defined by FAO and WHO as "live microorganisms which when administered in adequate amounts confer a health benefit on the host" [4, 5] and their inactivated cells or their cell-free supernatants (CFS) hosting numerous beneficial components are also considered postbiotics, defined as "preparation of inanimate microorganisms and/or their components that confers a health benefit on the host" [33]. They are also part of the human natural bacterial flora, in which they have a regulatory role in protecting hosts against colonization by pathogens and exert beneficial effects, such as increasing and improving nutrient assimilation during digestion or stimulating host tissues [17]. Hundreds of different bacteria species are the natural and predominant constituents of intestinal microbiota. Among the numerous intestinal microbes, those anticipated to exhibit potential health benefits to the host through modulation of the intestinal microbiota are commonly selected as probiotics. Species belonging to the genera Lactobacillus and *Bifidobacterium* have been reported to be the beneficial probiotic bacterial strains. The representative species include *L. acidophilus*, *L. casei*, *L. plantarum*, *B. lactis*, *B. longum*, and *B. bifidum* [6]. Some of the major health benefits attributed to probiotics include improvement of gastrointestinal microflora, enhancement of immune system, reduction of serum cholesterol, cancer prevention, treatment of irritable bowel-associated diarrhoeas, antihypertensive effects as well as improvement of lactose metabolism [40]. This article reviews on the past studies involving the use of probiotics in strengthening the immune system, prevention of bowel diseases, modulation of hypocholesterolemic effect as well as promoting dermal and oral health [1]. Besides that, potential uses of probiotics for the management of anxiety and depression as well as boosting dermal and oral health are also discussed. he *Lactobacillus delbrueckii* group consists of what were previously considered to be four separate species with very similar phenotypes (Lb. delbrueckii, Lb. leichmannii, Lb. lactis and Lb. bulgaricus). The genotypes of these four previous species show 80% DNA homology and, because of this similarity, are now retained as a single species with three subspecies. The subspecies, which are not separated by rRNA sequence analysis, are Lb. *delbrueckii* subsp. lactis (includes the previous species Lb [7]. lactis and Lb. leichmannii), Lbdelbrueckii subsp. delbrueckii and Lb. delbrueckii subsp. bulgaricus. Two of the three subspecies from the Lb. delbrueckii group are important thermophilic *Lactobacillus* starters in dairy fermentations. *Lactobacillus delbrueckii* subsp. bulgaricus is used extensively as a starter for yoghurt manufacture. Lactobacillusdelbrueckii subsp. bulgaricus and Lb.delbrueckii subsp.

lactis are two of the three thermophilic *Lactobacillus* used in cheese manufactured with elevated cooking temperatures. They are usually paired with *Streptococcus thermophilus*, show associative growth with this starter and contribute other attributes, including flavour and texture modifications, to the fermented dairy products in addition to rapid acid development. Lactobacillus is a bacterium used in the dairy industry, improving dairy products' organoleptic characteristics and nutritional value. Preclinical studies have demonstrated the probiotic effects of these microorganisms. However, unlike other lactic acid bacteria species, few studies have explored *L. delbrueckii* strains, using a probiogenomics approach, about their benefits and safety for host health. Lactic Acid Bacteria (LAB) constitute a highly diverse taxonomic group with significant commercial and biotechnological potential, offering several health benefits to the host [32, 4]. Due to their well-documented probiotic properties, LAB has been widely studied at the genomic level to uncover genetic factors and mechanisms underlying their survival and adaptation in the gastrointestinal tract (GIT), beneficial effects on host health [46] and safety aspects for human consumption or market application [50]. LAB strains, mainly those belonging to the *Streptococcus thermophilus* and *Lactobacillus delbrueckii* species, are widely used as starter microorganisms in the dairy industry for processes such as fermentation and food preservation [8]. Nevertheless, despite their industry importance, data concerning the characterization of novel probiotic candidates within the *L. delbrueckii* species, using phenotypic and omics approaches, remain limited [16]. Thus, this is the first review to comprehensively outline the probiotic properties and underlying mechanisms of *L. delbrueckii* strains, building upon the available information in this area. In addition, through multi-omics data, this review elucidates the potential genetic determinants of these strains, supporting their probiotic features, safety profile for consumption, and possible applications in commercial, biotechnological, or clinical contexts [9, 25].

1.1. Common microbes used as probiotics

The microbes used as Probiotics represent different types such as bacteria, yeast or mold. However, there are more common species of each such as: 1 – Bacteria: (i) Lactobacillus: acidophilus, sporogenes, plantarum, rham nosum, delbrueck, reuteri, fermentum, lactus, cellobiosus, br evis, casei, farciminis, paracasei, gasseri, crispatus; (ii) *Bifidobacterium*: bifidum, infantis, adolescentis, longum , thermophilum, breve, lactis, animalis;(iii) *Streptococcus*: la ctis, cremoris, alivarius, intermedius, thermophilis, diacetyla ctis; (iv) *Leuconostoc mesenteroides*; (v) *Pediococcus*; (vi) *Propionibacterium*; (vii) *Bacillus*; (viii) *Enterococcus*; (ix) *Enterococcus faecium*; 2 – Yeast and molds: *Saccharomyces cerevisiae*, *Saccharomyces boulardii*, *Aspergillus niger*, *Aspergillus oryzae*, *Candida pintolopesii*, *Saccharomyces boulardii*. *Lactobacillus delbrueckii* as a potential probiotic Probiotics are "live

microorganisms that, when administered in adequate amounts, confer a health benefit on the host" [36]. The action mechanisms of probiotics to exert health benefits include (i) enhancing intestinal barrier function, (ii) competitive exclusion and antagonism of pathogens, (iii) local and systemic immunomodulation, and (iv) Regulation of gut microbiota. The type of the microbes used as Probiotics increased due to the increase in the research concerning the subject as well as by the increase of the newly discovered and identified microbes, which could be used as Probiotics. One should update his microbial flora from time to time and follow the research and the published data about Probiotics to gain more knowledge and ideas.

1.2. Probiotic for Health Improvement

One of the points described in this review about Probiotics is their role in health improvement [48]. In fact, this is the most important point, where we expected that healthy persons will be the first in need to use Probiotics which will lead to improve their general health and as a result will protect them from different kinds of illness [70, 88]. Improving health will be an intelligent step for protecting us from different types of illness. Nevertheless, how could Probiotics do that? The following paragraphs will highlight the concept of how Probiotics could improve our health directly or indirectly [14].

1.3. Good and bad microbes

Our bodies have groups of microbes each working collectively to perform different functions. The most important ones are those existing in our digestive system [15, 72]. They improve food digestion and consumption. They are able to complement many deficiencies in our digestive system [39]. They decrease the steps needed in our bodies to change complicated food structures to simpler ones. Alternatively, many bad variants of different microbes will take their positions and will digest our food incorrectly [22].They will even add some toxins to our food during the digestive process. Hence, each food cycle will lead to a real deterioration to our health [28, 29].Many diseases are diagnosed incorrectly while their main actual elevating purpose is due to the existence of bad microbes in the digestive system, mainly due to the leakage in the feeding processes, the life style or even diseases which will direct the balance toward the bad microbes [60, 61]. The affected ones are humans because they did not follow the correct steps to protect themselves from losing the useful strains and gaining harmful ones. In such cases, Probiotics are needed to be given in higher dosages [12, 80].

1.4. Probiotic, the good against the bad microbes:

If harmful microbes colonized our digestive system, they will ferment food in incorrect ways and toxins, which will affect our health, might be produced. *What could Probiotics do*? Probiotics are able to regenerate our digestive system with good microbes that will neutralize the harmful ones. (13) Useful microbes will ferment our food correctly and improve our health. *Why must we use Probiotics*? During our lives, we are exposed to different types of microbes, which are unsuitable for our health. Antibiotic treatment could destroy our useful microflora. [38]. In such cases, Probiotics should be used to regenerate our microflora. If our daily food contains Probiotics, that will be the best and the cheapest way to recover any losses in our digestive system microflora and to improve our health. In olden civilizations, the public used to include food-containing Probiotics in their daily food [51, 52]. However, when our microflora has been affected severely due to any reasons, Probiotics should be given in large dosage as tablets or in any other suitable forms [76, 77]. A healthy intestine is one that maintains a significant balance of bacteria such as *Lactobacillus*, streptococci, clostridia, coliform, and bacteroides. [11]. Conditions such as stress, excessive alcohol use, high fat diets, meat, sugar, genetic disorders, chlorine and fluoride in drinking water, antibiotics, inadequate food, exposure to environmental toxins and many others factors could change the balance of our intestinal flora [66, 67]. In fact, our health is affected by many exogenous and endogenous factors that could change our microflora position. [10]. Useful microflora guarantees good health [18]. One cannot hear the sound of the daily battles between the good and the bad microbes in our bodies or see how they enter our bodies with each breath, talk and with each food consumed. Actually, they are essential for our health [20]. They build our immune system slowly to be ready for the pathogens [24, 25]. Those that live far away from such a lifestyle are more susceptible to infections and diseases [9]. Another side of the story, that such microbes and mainly those which are non-pathogenic, are like workers working in a big firm (our body), they do various jobs to support and assist us all the times. Mainly, they do that spontaneously. [23, 71] By doing such work, they save for us energy and power, or they even do what we could not do. Complementing the Lactose digestion deficiency is such an example [21, 55]. The existence of harmful bacteria could finding resistance in the body, so their negative effects might not appear directly, but after a considerable time [68, 69]. Alternatively, they are not few in number but produced in considerable amounts, at this point they will be really harmful [81]. Bad microbes, even though apparently non existant in a healthy person, actually, exist, but cannot do a lot of harm because of the existence of good bacteria [1, 56]. They are under continuous pressure from good bacteria. Good bacteria, fill in the spaces existing in our body, and prevent bad ones from taking their chances [77]. However, because of our misuse and misunderstanding of their behavior, we change the conditions usually towards the benefit of bad bacteria. By changing the balance toward the bad microbes, we will start to suffer, and our health will start to degrade [26, 27]. To prevent that, the bad microbes should be kept under control [44, 45]. Therefore, there is no better solution other than, letting good ones compete with them, take their places and in some cases omit them or decrease them to the minimum safe amount [62]. The intestinal tract is home to one hundred trillion (10^{14}) different types of microbes [75]. Many of the bad microbes like to live in alkaline or natural environment, that is why our stomach is acidic to kill most of them before they pass into the long intestine [2, 53, 54]. Bad microbes produce ammonia that change the intestinal tract pH to becoming more alkaline [83, 84]. One might observe that upon drinking fermented milk, which is weakly acidic, he feels good and relaxed. This is because of two factors, that fermented milk contains acids, which kill pathogenic bacteria, and at the same time contains good bacteria, which will directly fill the space of the just killed bacteria [73, 74]. Additionally, it still contains proteins that are able to reduce any extra-acidity [35]. One of the most important strains existing naturally in milk products is *Lactobacillus*. The microflora in our digestive system do crucial jobs, such as filling in digestive system spaces, food digestion, killing of pathogens, and secreting vitamins (e.g. vitamin B) and some essential amino acids, enzymes help in digesting complicated

fibers in the food, acid (e.g. lactic acid) helps to prevent pathogenic microflora from exceeding their number limit, and to perform many other vital activities [41, 42, 43]. As well, Probiotic strains found in the colon help in digesting some forms of fiber. One should highlight that Probiotics are also able to some extent activate the immune system [64].

1.5. The relation of Probiotics to our health could be summarized in the following points and facts

Probiotics are useful and friendly microbes. They are able to compete with the bad microbes and colonize our digestive system [57]. They are able to ferment our food to simpler byproducts and could promote our health by many different mechanisms. Their amount could be deteriorated due to many factors, such as incorrect diet, alcohol, age and so on. This is why they should be taken through our regular diet. In particular cases such as after antibiotic treatments, where they are expected to be affected severely, they should be taken orally in considerable amounts or with food [4, 63].

Probiotics promote health while they:

Remove the side effect of the pathogens or the harmful microbes. Supply the body with useful byproducts. Reduce the jobs of our digestive system. Reduce the effect of the first attack of harmful compounds, instead of our cells, by their biofilm, which protects our digestive system. Reduce the amount of food needed by our bodies due to the correct digestion and metabolism of any amount of food. Probiotics in some cases could complement the deficiency in our genetic materials by helping us to borrow the products of their genes (such as in case of the lactose fermentation deficiency) [78, 79]. Here we should highlight that, Probiotics or anything in our lives should not exceed a certain limit and should be used wisely to give the best expected results [30].

1.6. Infection Control

The mechanisms by which Probiotics exert their effects are largely unknown, and there are still many open research points. However, Probiotics are involved in modifying gut pH, antagonizing pathogens through the production of antimicrobial compounds, competing for pathogen binding and receptor sites as well as for available nutrients and growth factors, stimulating immunomodulatory cells, and producing lactase [9]. The most important point of Probiotics is that they are proven to be safe, cost effective, and could interfere with the microbial infection. In 1994, the World Health Organization deemed Probiotics to be the next-most important immune defense system when commonly prescribed antibiotics are rendered useless by antibiotic resistance [79]. The use of Probiotics in antibiotic resistance is termed as microbial interference therapy [85, 86].

2. Mechanisms of Action

Outstanding advances have been made in the field of probiotics, but there has yet to be a key breakthrough in the documentation of their mechanism of action. Probiotics possibly exert a positive potential on the human body through these main mechanisms; competitive exclusion of pathogens, improvement in intestinal barrier functions, immunomodulation in the host's body, and production of neurotransmitters [31, 37]. Probiotics compete with pathogens for nutrients and receptor-binding sites, making their survival difficult in the gut [22]. Probiotics also act as anti-microbial agents by producing substances; short chain fatty acids (SCFA), organic acids, hydrogen peroxide [82]. and bacteriocins [47, 49]. thus decreasing pathogenic bacteria in the gut. Moreover, probiotics improve the intestinal barrier function by stimulating the production of mucin proteins [50]. regulating the expression of tight junction proteins, including occluding and claudin 1, and regulating the immune response in the gut [78].

3. Probiotic For Health Improvement

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4. Probiotic, The Good Against The Bad Microbes

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6. Hypocholesterolemic Effect

Probiotics have been suggested to have hypocholesterolemic effects through numerous mechanisms such as assimilation of cholesterol, binding of cholesterol to cellular surface [16]. co-precipitation of cholesterol [17]. interference with the formation of micelle for intestinal absorption, and bile acids deconjugation through the secretion of bile salt hydrolase (BSH) [34]. Hypocholesterolemic effects exhibited by probiotics is mostly claimed due to BSH activity and it can be detected in all *Lactobacillus* and bifidobacteria strains. The major role of BSH is deconjugation of bile acid, which makes the bile salt less soluble and be excreted out as free bile acid via faeces. This will reduce the cholesterol in serum and increase the de novo synthesis to replace the lost bile acid [77]. Besides that, cholesterol could be removed in greater amount in the presence of bile as it acts as a surfactant and allows cholesterol to attach onto bacterial cell membrane. Additionally, Lye *et al* [41]. reported that the attachment of cholesterol on the bacterial cell membrane was growth dependent.

7. Dermal Health

Probiotics have been proven to have some new benefits for skin health. Recent studies showed that probiotic could improve atopic eczema, wound and scar healing, and help skin-rejuvenation. To date, effects of probiotics on skin diseases are extensively studied via both administration and topical application methods. However, research data are still inconclusive to support the concerned potential of probiotics. Results from the clinical trial of probiotic treatments are conflicting due to differences in dosage, probiotic strain, duration of application, length of follow-up, and time slot of administration [59]. revealed that probiotics treatment containing *B. bifidum*, *L. acidophilus*, *L. casei*, and L. salivarius was effective in reducing atopic dermatitis patients' SCORing Atopic Dermatitis (SCORAD) index and in stimulating cytokine production. The authors suggested that the impact of probiotics on SCORAD could be due to the modification of immunogenicity of potential allergens. On the other hand, *Escherichia coli* Nussle 1917 (EcN, serotype O6: K5: H1) has been evaluated to be beneficial for the treatment of several chronic inflammatory diseases [80, 81]. demonstrated that oral administration of EcN induced the immune regulatory mechanisms in allergen-induced dermatitis mouse model (BALB/c mice) via stimulating the cytokine production. Lactic acid bacteria can produce bioactive peptides known as bacteriocins that possess antimicrobial activity against pathogenic bacteria [44]. revealed that in the presence of soluble molecules produced by lactic bacteria with probiotic potential, the expression of opportunistic bacterial virulence factors could be suppressed. These findings could lead to a new alternative treatment for bacterial infections although the exact mechanism of action remains to be ascertained. Based on the studies that have been done, probiotics pose a promising potential although its effects could be strain specific, dosage dependent, and application reliance. *Lactobacillus fermentum* is a Gram-positive lactic acid bacterium, commonly found in fermenting animal and plant material. It is also commonly found as a component of the human microbiota [19].

Health Benefits of *Lactobacillus fermentum*

Lactobacillus fermentum is a probiotic strain that has shown potential health benefits in various studies, though it is important to note that *L. fermentum* supplements are not FDA-approved for medical use. While regulatory standards ensure manufacturing quality, they do not guarantee safety or effectiveness. As with any supplement, it is advisable to consult a healthcare provider before use [4, 9].

2. Conclusion

The research underscores the profound significance of *Lactobacillus* and other probiotic bacteria in promoting human and plant health. As natural allies in maintaining microbial balance, probiotics like *Lactobacillus* offer a safer, cost-effective alternative to traditional antibiotics, particularly in combating antibiotic-resistant pathogens. Their multifaceted mechanisms—ranging from competitive exclusion of harmful microbes and production of antimicrobial compounds to immunomodulation and enhancement of intestinal barrier function—highlight their therapeutic potential. Probiotics demonstrate remarkable efficacy in treating gastrointestinal disorders, improving metabolic health, and even mitigating chronic conditions such as cancer and mental health disorders. Beyond human health, their applications extend to agriculture, where they contribute to sustainable practices by enhancing plant resilience and soil health. Despite these benefits, further research is needed to fully elucidate strain-specific effects, optimal dosages, and long-term impacts. Collaborative efforts among scientists, clinicians, and policymakers are essential to integrate probiotics into mainstream healthcare and environmental management. Embracing probiotics as part of daily nutrition and therapeutic regimens could revolutionize public health, reduce reliance on antibiotics, and foster a healthier, more sustainable future. In conclusion, *Lactobacillus* and probiotic bacteria represent a bridge between nature and modern medicine, offering innovative solutions to global health challenges while aligning with ecological and economic sustainability. Their continued exploration promises to unlock even greater potential for improving life across diverse ecosystems.

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