**"Harnessing Probiotics for Human Health: Exploring Their Role in Nutritional and Therapeutic Insights"- A Comprehensive Review**

**Abstract**: Probiotics are strains of selected microorganisms that provide a health benefit to the host. Probiotics must meet certain functional, technological, and safety requirements to be considered a probiotic. Through this study, we learned about the various probiotic microorganisms that are found in nature, as well as their traits, mode of action, and advantageous effects upon human health and the diseases as they are seen as major threats to food safety. The need for environmentally friendly agriculture and aquaculture is driving an increase in research on probiotics. Live microbial feed additives, or probiotics, have been shown to enhance the health of both people and other animals. This review's primary goals are to outline current developments in the field of gut microbiota research and demonstrate the crucial role those intestinal bacteria play in the emergence of many medical diseases. Lastly, probiotics hold enormous promise as a different and eco-friendly strategy and seem to be an effective way to manage microbial infections in various contexts. Studies on their actions and potential mechanisms of action against several pathogenic bacteria are highlighted in this review. As the probiotics industry develops further, this review study is a useful tool for scientists, medical professionals, and health enthusiasts looking for a more nuanced understanding of the potential and difficulties of using bacteria for human health and more.

**Keywords:** Probiotics, Gut microbiota, Human health, Digestive health, Immune modulation.

1. **Introduction:**

The term "probiotic" refers to bacteria that have positive impacts on human and animal health and is a modern term that means "for life" (Bagchi, T. 2014). The term "probiotic" originates from the Latin word "pro", which means "for", and the Greek adjective "biotic", or "bios", which means "life". Probiotics are defined as "living strains of strictly selected microorganisms which, when administered in adequate amounts, execute a health benefit on the host" in a 2002 definition created by experts from the working groups of the World Health Organization and the Food and Agriculture Organization of the United Nations” (Kerry et al., 2018). The International Scientific Association for Probiotics and Prebiotics (ISAPP) has revised the criteria, stating that "live microorganisms that, when administered in adequate amounts, confer a health benefit on the host" are now considered qualifying (Hill et al., 2014).

Elie Metchnikoff, a Russian-born novelist, initially developed the idea of probiotics in 1907.

He saw that the long and healthy lives of the Bulgarian villagers who drink fermented milk. Metchnikoff found that the culture of Lactobacillus, which he isolated from fermented milk, produced a lot of lactic acid and was able to survive in the colon (Sanders et al., 2012).

An essential mechanism by which the native (autochthonous) gut bacteria preserve their existence and provide niche protection against recently ingested microorganisms, including pathogens, is the advantageous use of intestinal microflora, also known as "colonization resistance" or the "barrier effect" (Lewis et al., 2015; Perez et al., 2015).

Probiotics plays a crucial role in initiating intestinal angio genesis by vascular endothelial growth factor receptor (VEGFR) signaling that, in turn, regulates acute and chronic inflammation in intestinal mucosal tissue produced by the advancement of inflammatory bowel disease (IBD) (Bakirtzi et al.,2016; Chen et al., 2013).

Probiotics also begins the activation of particular genes in localized host cells, which stimulates, modifies, and controls the host's immunological response. As part of the gut-brain axis, they even control the release of hormones from the gastrointestinal tract and govern brain activity through bidirectional neural communication (Kristensen et al., 2016). The review aims to highlight the potential benefits of probiotics for enhancing human health, optimizing nutrition, and controlling common metabolic illnesses or irregularities. This study's main goal is to investigate the safety, technological, and functional needs of probiotic microbes while also analyzing the positive health impacts they have on people. Furthermore, it aims to evaluate the potential of probiotics in illness prevention and management as well as the crucial role that gut microbiota plays in the emergence of numerous medical disorders. In addition, the study intends to clarify the ways in which probiotics combat infections, demonstrating its environmentally beneficial qualities while offering a current analysis for academics and medical practitioners.

 **2. Selection criteria of probiotics:**

Numerous studies have demonstrated the possible unique capabilities of probiotics. In order to be selected and used as a probiotic, it must meet certain functional, technological, and safety requirements. Additionally, the following requirements must be met, as listed in table 1.

Table 1: Different selection criteria for Probiotics has been shown in table 1.

|  |  |  |
| --- | --- | --- |
| Criteria | Required Properties | References |
| Safety | 1. Originating from either human or animal sources.
2. Isolated from healthy persons' gastrointestinal tracts.
3. Demonstrated history of safe use, showing non-pathogenicity and non-toxicity.
4. Accurate diagnostic identification using phenotype and genotype traits.
5. No evidence linking them to infectious diseases.
6. Lack of ability to break down bile acid salts.
7. No adverse effects reported.
 | (Bandhopadhay et al., 2014) (O’Bryan et al., 2013) (Hill et al., 2014) (Abetenh et al., 2018) (Howarth, G. S. & Wang, H. 2013) (Miriam at al., 2012) (Taverniti et al., 2013)(Revata et al., 2016)(Divya, P. 2016)(Bayane et al., 2010) |
| Functionality | 1. Has the ability to compete with the existing gut microbiota.
2. Ability to survive, metabolize, and grow in the target site, including functions like cholesterol assimilation and vitamin production.
3. Resistance to bile salts, digestive enzymes, and low stomach pH.
4. Ability to compete with other gut bacteria, including closely similar species.
5. Antagonism towards pathogens such as-*Salmonella* spp., *Listeria* spp., and *Helicobacter pylori*, monocytogenes.
6. Resistance to acids and bacteriocins generated by the gut microbiota.
7. Ability to adhere and colonize in particular areas of the host, with a reasonable rate of survival in the gastrointestinal tract.
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| Technological Usability | 1. Ability to produce high biomass and cultures efficiently.
2. Maintaining viability and stability of desired properties during processing (e.g., freezing, drying), preparation, and distribution of probiotic products.
3. High survival rate in both aerobic and micro-aerophilic settings for completed products.
4. Ensuring that final products have the necessary sensory qualities, particularly in the food sector.
5. Genetic stability.
6. Ability to withstand bacteriophages.
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Table 2: Species Types utilized as Probiotics

Various types of Species of microorganisms used as probiotics are given in table no 2.

|  |  |  |
| --- | --- | --- |
| Group of Microbes | List of Probiotic Species | Reference |
| Lactic Acid Producing Bacteria | *Lactobacillus acidophilus, Lactobacillus bulgaricus, Lactobacillus casei,*  | (Miriam at al., 2012) (Taverniti et al., 2013)(Revata et al., 2016)(Divya, P. 2016)(Bayane et al., 2010)(Adel, M.M. & Sari, A.M. 2017) (Mohammed et al., 2017)  |
| Non-Lactic Acid Producing Bacteria | *Bifidobacterium adolescentis, Bifidobacterium bifidum, Bifidobacterium infantis, Streptococcus thermophiles, Propinobacterium* |
| Non-Pathogenic Yeast | *Saccharomyces boulardii* |
| Non-Spore Forming Bacteria | *Coccobacillus, Lactobacillus, Streptococcus, Leuconostoc, Lactococcus lactis subsp. Bacillus coagulans, Bacillus subtilis, Saccharomyces cerevisiae, Candida pintolopesii, Aspergillus niger, A. oryzae, Bacillus lichenformis, Streptococcus thermophiles* |

**3. Mode of action of Probiotics in regard to Human Health:**

Probiotics can act in many different ways- they can modulate the host's good microflora, which involves improving the good microbial balance through the interaction of oral viable microbes with the microflora in the gastro-intestinal tract lumen; they can alter the host's metabolic activities, such as by stabilizing the pattern of digesting enzymes; and they can alter the host's immune system, which involves activating and regulating responses related to the mucosa and the systemic immune system. Additionally, these forms of action rely on strain (Hill et al., 2014). Some important mechanisms of action are described here-

**3.1 Gut microbiota modulation:**

Probiotics restore microbial equilibrium by promoting the growth of good bacteria and suppressing harmful strains (Hemaiswarya et al., 2013; Latif et al., 2023). They promote the growth of natural digestive microorganisms, which is essential for preserving intestinal health (Latif et al., 2023).

3.2 **Competition for nutrients with pathogens:**

It can be observed in gut health that both harmful and good bacteria use the same kind of nutrients. As resulted, there is widespread competition among the bacteria for these nutrients in order for them to proliferate and grow (Vanderpool et al., 2008). Probiotics compete with pathogens for nutrients and receptor-binding sites, making their survival difficult in the gut (Plaza-Diaz et al., 2019).

**3.2 Barrier Function:**

Probiotics enhance the function of the intestinal barrier by promoting the synthesis of mucin proteins (Chang et al., 2021). Modifications in intestinal permeability, mucin composition, and the balance between the rate of damaged enterocyte death and the generation of new enterocytes all impact the integrity of the intestinal barrier. An upset stomach barrier can result from illnesses including colon cancer and inflammatory bowel disease. Some probiotics have the capability to alter the properties of the gut (Abatenh et al., 2018). *Lactobacillus* species have been observed to enhance the expression of mucin in vitro in human intestinal epithelial cells, thereby blocking the adhesion and invasion of pathogenic *Escherichia coli.* It has been shown that *Lactobacillus rhamnosus* GG (LGG) possesses mitogenic qualities, stimulates mucosal regeneration, and prevents intestinal epithelial cells from inflaming and dying on their own (Gogineni et al., 2013).

* 1. **Production of antimicrobial substances:**

Probiotics hinder infections and stop epithelial invasion by either releasing peptides directly or by stimulating host cells to create them. The intestinal epithelial cells express antimicrobial peptides called defensins (hBD protein) and cathelicidins, which demonstrate antibacterial efficacy against a variety of fungus, bacteria, and viruses. Probiotics have been observed to inhibit the growth of pathogens by releasing a range of antimicrobial agents, including nitric oxide, hydrogen peroxide, defensins, and short chain fatty acids (SCFA), which lower the pH of the lumen. Gram-negative pathogens' outer membranes can be damaged by SCFA, which inhibits the pathogen's ability to proliferate (Gogineni et al., 2013, Rastall, R.A. & Gibson, G.R., 2014).

* 1. **Immune modulation:**

In a manner unique to each strain, probiotic bacteria bind to epithelial cells and the mucous membrane that surrounds them to combat invasive infections. The reduced bacterial adherence has been shown to be caused by a heat-labile component secreted by *S. boulardii* (Parvez et al., 2006). Additionally, probiotics control the innate and adaptive immune response by influencing B and T lymphocytes, dendritic cells (DC), and macrophages. Probiotics also interact with intestinal epithelial cells, draw in macrophages and mononuclear cells, and enhance the synthesis of anti-inflammatory cytokines (Petruzziello et al., 2023).

**3.5** **Immunoglobulin Responses:**

Major antibody immunoglobulin A (IgA) is released across intestinal mucosal linings and is essential for mucosal immunity consumption of probiotics on increased host immunity through IgA synthesis (Howarth, G.S & Wang. H., 2013).

* 1. **Interference with quorum sensing signaling:**

According to research by Medellin-Pena et al., *Lactobacillus acidophilus* secretes a chemical that either directly interacts with the *E. coli* O157 gene transcription, which is involved in colonization, or suppresses quorum sensing signaling, hence preventing bacterial toxicity (Gogineni et al., 2013; Rastall, R.A. & Gibson, G.R., 2014; Parvez et al., 2006; Howarth, G.S & Wang. H., 2013; Medellin et al., 2007). Here in the table different mode of action of probiotics are shown here.

**3.7 Gut-Brain Axis:**

Through the gut-brain axis, probiotics can cause the gut to create neurotransmitters. Certain probiotic stains can alter mood, behaviour, gastrointestinal motility, and stress-related pathways via modifying serotonin, gamma-aminobutyric acid (GABA), and dopamine levels (Srivastav et al., 2019; Sajedi et al., 2021; Gangaraju et al., 2022).

* 1. **Stimulating Host Digestion:**

Probiotics encourage the growth of good bacteria while suppressing bad ones, assisting in the balance of the gut microbiota. Effective digestion and nutrient absorption depend on this balance (Hori et al., 2020). Proteases and peptidases, two host digestive enzymes necessary for the breakdown of proteins, can be activated by probiotics. Additionally, by strengthening the transport mechanisms and absorption capacity of the epithelium, they improve the absorption of tiny peptides and amino acids. Furthermore, probiotics can release exoenzymes that facilitate the digestion of proteins and control gut microbiota, favorably affecting microorganisms engaged in proteolysis (Wang and Ji, 2019). Additionally, they aid in the synthesis of short-chain fatty acids (SCFAs), which are important for gut health and nutrient absorption (Rajasekaran, 2024)

* 1. **Antioxidant Activity:**

Probiotics demonstrate antioxidant activity in a number of ways, such as by altering the gut microbiota and strengthening the host's antioxidant defenses. These helpful bacteria can lessen oxidative stress, which is a disorder marked by an imbalance between antioxidants and free radicals that can cause illnesses and cellular damage. Both direct and indirect mechanisms are used by probiotics' strain-specific antioxidant activity to preserve redox equilibrium and guard against oxidative damage. It has been demonstrated that probiotics such as *Lactobacillus plantarum* and *Lactobacillus salivarius* enhance the activity of antioxidant enzymes such catalase, glutathione peroxidase, and superoxide dismutase. This improvement lessens oxidative stress in host cells and neutralizes free radicals. ((Jing et al., 2021; Tsao et al., 2021). In Table 3 different mechanism of action of several probiotics have been mentioned.

Table 3: Mode of action of different Probiotics

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Mode | Process | Mechanism of action | Example | References |
| Barrier Function | Reduced cell apoptosis | Decreased production of TNF-α | *Lactobacillus rhamnosus GG* | (Vanderpool et al., 2008) (Abetenh et al., 2018) (Howarth, G. S & Wang H, 2013) (Miriam at al., 2012),(Revata et al., 2016)(Divya, P. 2016)(Bayane et al., 2010)(Adel, M.M. & Sari, A.M., 2017) (Mohammed et al., 2017)(Gogineni et al., 2013) (Rastall, R.A. & Gibson, G.R., 2014) (Parvez et al., 2006) (Howarth, G.S. & Wang. H., 2013) (Medellin et al., 2007) (McFarland, L.V., 2006) |
| Increased mucin production | Enhanced expression of MUC 2 | *Lactobacillus species* |
| Antimicrobial Peptides in Host Cells | Defensins (hBD protein) | Increased production of defensin | *E. coli strain* DSM 17252S2 |
| Cathelicidins | Induced by butyrate production |
| Antimicrobial Factors of Probiotic | Decreases luminal pH | Secretion of SCFA’s | Maximumprobiotic bacteria |
| Production of Bacteriocin | Generated by probiotics that are Gram-positive |
| Microcin production | Produced by Gram-negative probiotics |
| Epithelial Adherence | Competition with pathogens | Blocking adherence directly or by producing proteins | *-* |
| Immune Modulation | Inhibiting pro-inflammatory molecules | Attenuating IL-8 secretion or blocking IκB degradation | *Salmonella typhimurium* VSL#3probiotics |
| Enhancing mucosal immunity | Increasing IgA production | *L. casei* |
| Interference with Signals from Quorum Sensing | Disrupting pathogenic bacteria communication | Producing molecules that block quorum sensing signaling | *L. acidophilus* |

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**Figure 1: Proposed mode of action of probiotics**

1. **Health benefits and therapeutic effects of using probiotics:**

Probiotics repair damaged digestive systems, reduce inflammation, boost immunity, and fortify the lining of your stomach to cure allergies. Probiotics alter antigen structures, decreasing intestinal permeability, immunogenicity, and the production of pro-inflammatory cytokines that are prominent in individuals with a wide range of allergy problems. In addition to reducing the symptoms of food allergies, *Lactobacillus GG* and *L. rhamnosus GG* also significantly lower the chance of acquiring allergic illness (Abatenh et al., 2018).

**4.1 Anti- pathogenic activity of Probiotics:**

Probiotics are thought to have anti-pathogenic activity because, in contrast to traditional antibiotics, they prevent disruption or change in the complex population of the gut microbiota (Kerry et al., 2018). Probiotics include yeast and a variety of bacterial species, such as *Lactobacillus fermentum, Lactobacillus acidophilus, and Lactobacillus rhamnosus GG. Saccharomyces boulardii* are useful in lowering the frequency of diarrhea brought on by antibiotics (McFarland, L.V 2006). *Lactobacillus* *GG* demonstrated efficacy against viral and idiopathic diarrhea, but *Saccharomyces boulardii* was found to be more efficient against bacterial diarrhea. To avoid traveler's diarrhea, prophylactic usage of lactobacilli, bifidobacteria, enterococci, and streptococci has been implemented (McFarland, L.V 2007). By producing bacteriocins (nisin A, pediocin PO2, leucosin K, and reuterin 3-hydroxy propionaldehyde) and short-chain fatty acids (formic, acetic, propionic, butyric, and lactic), probiotics can suppress *H. pylori*. Several probiotics have been researched in recent years to see if they can eradicate *H. pylori* (Rijkers et al., 2011). Tejero-Sarinena et al. (2013) claimed that probiotics work by preventing the synthesis of short-chain fatty acids (SCFAs), which include lactic, propionic, butyric, and acetic acids, which inhibit infections. SCFAs support the colonic lumen's proper pH, which is necessary for the production of several bacterial enzymes as well as the gut's digestion of foreign substances and carcinogens.

**4.2 Anti-cancer activity of probiotics:**

Some LAB (*Lactobacillus delbrueckii subsp. bulgaricus*) stains can bind with heterocyclic amines, which are carcinogenic and can help prevent colon cancer, these stains have demonstrated anti-mutagenic benefits (Iqbal et al., 2014). Probiotic strains Lactobacillus fermentum NCIMB-5221 and -8829 have been shown in vitro to be extremely effective at inhibiting colon rectal cancer cells and promoting the proliferation of normal epithelial colon cells by producing SCFAs (ferulic acid). Additionally, this capability was contrasted with those of other probiotics, specifically *L. acidophilus* ATCC 314 and *L. rhamnosus* ATCC 51303, both of which have been shown to exhibit tumorigenic activity (Kahaouli et al., 2015). Yet again, it has been discovered that two distinct probiotic strains, *Lactobacillus acidophilus* LA102 and *Lactobacillus casei* LC232, exhibit strong cytotoxic properties, as well as in vitro anti-proliferative activity against two colorectal cancer cell lines (Caco-2 and HRT-18) (Awaisheh et al., 2016).

**4.3 Anti-diabetic activities of probiotics:**

The gut microenvironment is dominated by two distinct bacterial phyla: Gram-negative Bacteroidetes and Gram-positive fungi. Obesity is linked to a gradual rise in Bacteroidetes and a decrease in firmicutes, according to recent studies (Barz et al., 2015; Kobiliak et al., 2016). More precisely, the Bacteroidetes/firmicutes ratio has increased in patients with type-2 diabetes due to a considerable decrease in firmicutes species, which has a positive correlation with plasma glucose concentration (Barret et al., 2012). Modulating gut hormones, such as glucagon-like peptide-1 and gastric inhibitory polypeptide, using probiotic and prebiotic therapies is another compelling method for managing type-2 diabetes. In this scenario, hormones are involved in glucose homeostasis, which counteracts the condition brought on by peripheral insulin resistance or b-cell inability to make insulin (Grover et al., 2012).

**4.4 Anti-inflammatory activity of probiotics:**

Ulcerative Colitis is a chronic inflammatory illness of the rectum's mucous membrane or the rectum and colon that can cause perforation, ulceration, and necrosis in certain cases (Sarowska et al., 2013). Utilizing several probiotic species such as *Bifidobacterium bifidum,* *Lactobacillus casei*, and *S. boulardii* has demonstrated encouraging outcomes (Pandey et al., 2015).

IBDs such as Crohn's disease, which can occur anywhere from the mouth to the end of the rectum, typically affect the intestines. It results in inflammation and ulceration, which impairs the body's capacity to properly digest food, absorb nutrients, and get rid of waste. It has shown to be more successful in keeping Crohn's disease patients from relapsing. There has been some evidence that *S. boulardii* can effectively relieve the symptoms of active Crohn's disease, such with decreased frequency of stools and disease activity (Khan, M.A. & Moshed, M.N, 2015)

**4.5 Anti-obesity activity of probiotics:**

Probiotics have physiological properties that help maintain the host environment's health by controlling microorganisms. Most of the time, thermogenic and lipolytic reactions that activate the sympathetic nervous system aid in weight loss (Karimi et al., 2015). *Lactobacillus gasseri* BNR17, a probiotic strain, has demonstrated the ability to reduce leptin release by preventing the growth of adipocyte tissue, which is the primary source of leptin and adiponectin (Kang et al., 2013).

**4.6 Effect of probiotics on brain and CNS:**

Both gastrointestinal and GIT disorders are closely linked to the microbial colonization in the GIT. Furthermore, a lot of research has been done recently to clarify how the gut microbiota affects the central nervous system. The GIT and CNS exchange regulatory signals to create the "microbiota-gut-brain axis", an interactive, two-way communication system (Mayer et al., 2015). Probiotics' impact on the central nervous system has mostly been investigated in clinical studies, where it has been shown that gut bacteria affect how the human brain develops and functions (Tillisch K., 2014). Rao et al. demonstrated that giving *L. casei* strain Shirota to patients with chronic fatigue syndrome reduced their anxiety symptoms (Rao et al., 2009). According to Szajewska, administering *L. rhamnosus* to the mother four weeks prior to the anticipated delivery could prevent attention-deficit/hyperactivity problems and autism spectrum disorders in children (Szajewska H., 2016). Numerous gut bacteria have been shown to produce neuroactive substances that are comparable to those made in the host brain. G-aminobutyric acid, a brain neurotransmitter that aids in the suppression of anxiety and sadness in humans, has been found to be produced in significant quantities by human intestinally derived strains of *Bifidobacterium dentium* and *L. brevis* DPC6108 (Barret et al., 2012). It has been demonstrated that taking *L. acidophilus* orally helps people control their emotions toward rewards and addictive behavior. (Nogueiras et al., 2012)

**4.7 Effect of Probiotics on Urogenital Health Care:**

Many women experience a variety of urogenital issues that can impact their overall health and quality of life. Common conditions include urinary tract infections (UTIs), which occur due to bacterial invasion of the urinary system, leading to symptoms such as frequent urination, burning sensation, and pelvic discomfort. Other vaginal infections including bacterial vaginosis (BV) and yeast infections can cause irritation, abnormal discharge, and discomfort. In the vaginal microbiota of healthy women, lactobacilli are the most common microorganisms. They help to prevent infections and preserve ecological balance. Their protective function is mediated through various mechanisms, including adhesion and permanence in the epithelium and mucosa, competitive exclusion of pathogens, production of antimicrobial compounds, and host immunomodulation. Thus, vaginal lactobacilli in probiotic supplements represent a new approach to vaginal microbiota restoration (María Elena Fátima Nader-Macías, Priscilla Romina De Gregorio; 2022).

**4.8 Effect of Probiotics on Cardio-vascular Health:**

Probiotics' potential to reduce a number of cardiovascular risk factors has attracted plenty of attention to their impact on cardiovascular health. According to research, probiotics can have a beneficial impact on disorders like inflammation, high blood pressure, and high cholesterol, all of which are important for the management and prevention of cardiovascular diseases (CVD) (Mathur et al., 2024; López‐Yerena et al., 2024). According to a meta-analysis, probiotics have been demonstrated to dramatically lower blood pressure at both the diastolic and systolic levels. These effects are enhanced by greater dosages (>1.0 × 10^9 CFU) and longer treatment durations (>1.5 months) (Dixon et al., 2020).

**4.9 Effect of Probiotics on Oral Health:**

Probiotics have been shown to have an impact on the oral microbiome, especially in lowering dangerous bacteria like *Streptococcus mutans*, which is linked to periodontal disorders and tooth cavities. According to a systematic study, in orthodontic patients, probiotics may dramatically lower salivary S. mutans levels; nevertheless, clinical outcomes such as plaque and gingival indices revealed conflicting findings. Reducing S. mutans below 105 CFU/ml had a risk ratio of 2.05 according to the meta-analysis, which may have an impact on maintaining dental health when receiving orthodontic treatment (Chen et al., 2023). By strengthening immune responses and lowering dangerous bacteria, probiotics have demonstrated promise in pediatric populations, possibly reducing the incidence of gingivitis and dental caries (Talib et al., 2024)

**4.10 Effect of Probiotics on Respiratory infections:**

Probiotics have demonstrated encouraging results in lowering the frequency and severity of respiratory infections in a variety of populations, including athletes and children. Probiotics have been shown to alter the immune system, which reduces the likelihood of complications and shortens the length of illness. According to a systematic analysis, probiotic supplementation in athletes reduced the intensity of symptoms and inflammatory markers like TNF-α and IL-6 but did not significantly lower the number of upper respiratory tract infection episodes (Łagowska & Bajerska, 2021). Over a six-month follow-up, probiotics dramatically reduced recurrent respiratory infections, including infectious rhinitis and otitis media, according to another trial involving 70 children (Laghari et al., 2023).

**4.11 Effect of Probiotics on Liver:**

For cirrhosis and non-alcoholic fatty liver disease (NAFLD), in particular, probiotics have shown promise as an adjuvant treatment. By lowering liver enzyme, serum ammonia, and endotoxin levels, probiotics have been shown to dramatically enhance liver function. They also improve nutritional status and quality of life for people with liver disease. It has been demonstrated that probiotics lower levels of liver enzymes that are markers of liver function, including AST, ALT, and GGT. For example, a meta-analysis showed that patients with NAFLD had lower levels of ALT (−10.54 IU/L), AST (−10.19 IU/L), and GGT (−5.88 IU/L) (Musazadeh et al., 2022). Probiotics significantly lowered the levels of aspartate aminotransferase and gamma-glutamyl transferase in cirrhotic individuals, suggesting better liver function (Leitner et al., 2024).

Table 4: List of probiotic strains used for enhancing human health, preventing infections, treating illnesses, and management

|  |  |  |  |
| --- | --- | --- | --- |
| Disease Name | Probiotic Strains | Treatment Outcome | References |
| Constipation | *Bifidobacterium species, B. lactis, B. longum, B. breve, B. infantis, L. casei, L. rhamnosus, Streptococcus thermophiles, L. bulgaricus* | * Alters the microflora and restores the disturbed community in the gastrointestinal tract.
* Helps solve undesired gastrointestinal problems.
* Enhances and regulates frequency, uniformity, and whole-gut transit time.
 | (Howarth, G. S. & Wang, H., 2013) (Miriam at al., 2012), (Revata et al., 2016)(Divya, P., 2016)(Bayane et al., 2010)(Adel, M.M. & Sari, A.M., 2017) (Mohammed et al., 2017)(Gogineni et al., 2013) (McFarland, L.V., 2006)(McFarland, L.V., 2007)(Sarowska et al., 2013)(Pandey et al., 2015)(Khan, M.A. & Moshed, M.N., 2015)(Tuohy et al., 2003)(Rijkers et al., 2011)(Iqbal et al., 2014)(Abatenh et al., 2018) |
| Irritable Bowel Syndrome | *L. acidophilus, L. plantarum, L. casei, B. lactis, S. cerevisiae* | * Reduces the symptoms of irritable bowel syndrome (IBS)
* Effectively alleviates and manages symptoms of this condition.
 |
| Colon Cancer | Lactic acid bacteria | * Modifies the physicochemical conditions in the colon and binding sites, as well as the metabolic activities of the intestinal microbiota.
* Biodegrades potential carcinogens. - Produces anti-tumourous or mutagenic compounds by decreasing the activity of the enzyme β-glucuronidase.
* Increases the host immune response.
 |
| Diabetes and Obesity | *Lactobacillus acidophilus NCFM, Lactobacillus gasseri SBT2055, L. rhamnosus CGMCC1.3724* | * Decreases the risk of insulin resistance with type 2 diabetes mellitus.
* Improves and maintains the metabolic equilibrium of the host, leading to significant weight loss.
 |
| Acute Viral Upper Respiratory Infections | *B. animalis subsp. lactis, L. lactis subsp. Lactis* | * Improvises brain activity and provides mental health.
* Perpetuate the central nervous system's capacity via immunological, neuroendocrine, and metabolic processes.
* Aids the early development of typical social and cognitive behaviours.
* Beneficial strains alleviate diseases and have a direct favourable impact on the CNS.
 |
| Helicobacter pylori Infection | *Lactobacillus, Bifidobacterium, L. johnsonii* | * Decreases the adverse effects of *H. pylori* through the release of bacteriocins, production of organic acids, and competitive colonization in epithelial or mucosal cells, hindering its growth, adhesion, and bacterial load.
 |
| Atopic Disease | *Lactobacillus GG, L. rhamnosus Lactis, L. fermentum, Bifidobacterium bifidum, B. lactis, L. acidophilus, L. casei, L. salivarius, Lactococcus lactis* | * Reduces atopic eczema and improves skin condition.
* Removes the symptoms of atopic dermatitis in infants with moderate to severe conditions.
 |
| Colic | *L. casei, S. thermophilus, B. breve, L. acidophilus, B. infantis* | * Highly effective in reducing colic in breastfed infants and children.
 |

1. **Conclusion:**

This study not only tells us the importance of probiotics in human health but also in several sectors like aquaculture and agriculture. Through this study, we learned about the various probiotic microorganisms that are found in nature, as well as their traits, mode of action, and advantageous effects. Probiotics have significant functional qualities that could meet the majority of our fundamental needs for clinical supplements and nutrition. These microorganisms have demonstrated beneficial responses to clinical treatment for a number of illnesses and conditions, including rotavirus-related diarrhea, IBS, and food allergies. Furthermore, a fascinating and quickly developing field of study is the role that probiotics play in the prevention and treatment of diseases linked to pathogenic microbes, diabetes, obesity, and cancer. Dairy products are typically used in dietary probiotic supplementation, but probiotics can also be added to fermented food products that aren't dairy, offering a more beneficial and alternate source when testing out novel probiotic strains.
Additionally, recent nutritional and clinical analyses have been successful in highlighting some of the unique roles played by specific probiotic strains. Particularly, the control of energy in different catabolic and anabolic processes, tolerance to bile and acid, adhesion to gut epithelial cells, ability to fight off infections, and a few other qualities like their safety-enhancing qualities, suitability as food, and advantageous supplements for human health. Consequently, the current emphasis is on assessing novel probiotic strains and their suitability for biomedical and clinical research, opening up new avenues for probiotic exploration and exploitation targeted at enhancing human. Furthermore, some noteworthy roles of specific probiotic strains have been successfully revealed by recent clinical and nutritional assessments. In particular, energy regulation in different catabolic and anabolic processes, tolerance to acid and bile, adhesion to gut epithelial cells, ability to fight off infections, and a few other qualities like their safety-enhancing qualities, suitability as food, and health-promoting supplements. Thus, the current emphasis is on assessing novel probiotic strains and their suitability for biomedical and clinical research, opening up new avenues for probiotic exploration and exploitation with the goal of enhancing human health.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**References:**

Abatenh, E., Gizaw, B., Tsegay, Z., et al. (2018). Health benefits of probiotics. *Journal of Bacteriology & Infectious Diseases, 2*(1), 8-27.

Adel, M. M., & Sari, A. M. (2017). Probiotic characterization of lactic acid bacteria isolated from local fermented vegetables (makdoos). *International Journal of Current Microbiology and Applied Sciences, 6*(2), 1673-1686.

Awaisheh, S. S., Obeidat, M. M., Al-Tamimi, H. J., Assaf, A. M., EL Qudah, J. M., Al-khazaleh, J. M., et al. (2016). In vitro cytotoxic activity of probiotic bacterial cell extracts against Caco-2 and HRT-18 colorectal cancer cells. *Milk Science International, 69*, 27-31.

Bagchi, T. (2014). Traditional food & modern lifestyle: impact of probiotics. *Indian Journal of Medical Research, 140*(3), 333-335.

Bakirtzi, K., Law, I. K. M., Xue, X., Iliopoulos, D., Shah, Y. M., & Pothoulakis, C. (2016). Neurotensin promotes the development of colitis and intestinal angiogenesis via Hif-1a-miR-210 signaling. *Journal of Immunology, 196*, 4311-4321.

Bandyopadhyay, B., & Mandal, N. C. (2014). Probiotics, prebiotics and synbiotics - In health improvement by modulating gut microbiota: The concept revisited. *International Journal on Current Microbiology & Applied Sciences, 3*(3), 410-420.

Barrett, E., Ross, R. P., O'Toole, P. W., Fitzgerald, G. F., & Stanton, C. (2012). γ-Aminobutyric acid production by culturable bacteria from the human intestine. *Journal of Applied Microbiology, 113*, 411-417.

Barrett, H. L., Callaway, L. K., & Nitert, M. D. (2012). Probiotics: a potential role in the prevention of gestational diabetes? *Acta Diabetologica, 49*, 1-13.

Barz, M. L., Anhe, F. F., Varin, T. V., Desjardins, Y., Levy, E., Roy, D., et al. (2015). Probiotics as complementary treatment for metabolic disorders. *Diabetes & Metabolism Journal, 39*, 291-303.

Bayane, A., Diawara, B., Dubois, R. D., et al. (2010). Isolation and characterization of new spore-forming lactic acid bacteria with prospects of use in food fermentations and probiotic preparations. *African Journal of Microbiology Research, 4*, 1016-1025.

Chang, Y., Jeong, C. H., Cheng, W. N., Choi, Y., Shin, D. M., Lee, S., et al. (2021). Quality characteristics of yogurts fermented with short-chain fatty acid-producing probiotics and their effects on mucin production and probiotic adhesion onto human colon epithelial cells. J. Dairy Sci. 104, 7415–7425. doi: 10.3168/jds.2020-19820

Chen, X., Yang, G., Song, J.-H., Xu, H., Li, D., Goldsmith, J., et al. (2013). Probiotic yeast inhibits VEGFR signaling and angiogenesis in intestinal inflammation. *PLoS One, 8*, 1-7.

Chen, W., Ren, J., Li, J., Peng, S.-M., Zhang, C., & Lin, Y. (2023). Effects of probiotics on the oral health of patients undergoing orthodontic treatment: a systematic review and meta-analysis. *European Journal of Orthodontics*, *45*, 599–611. https://doi.org/10.1093/ejo/cjad046

Dixon, A., Dixon, A., Dixon, A., Robertson, K., Yung, A., Que, M., Randall, H., Randall, H., Wellalagodage, D., Wellalagodage, D., Cox, T. M., Robertson, D., Chi, C., Sun, J., & Professor, D. (2020). Efficacy of Probiotics in Patients of Cardiovascular Disease Risk: a Systematic Review and Meta-analysis. *Current Hypertension Reports*, *22*(9), 1–27. https://doi.org/10.1007/S11906-020-01080-Y

Divya, P. (2016). Benefits of probiotics in oral cavity -- A detailed review. *Annals of International Medical and Dental Research, 2*(5), 1-8.

Gangaraju, D., Raghu, A. V., and Siddalingaiya Gurudutt, P. J. N. S. (2022). Green synthesis of γ-aminobutyric acid using permeabilized probiotic Enterococcus faecium for biocatalytic application. Nano Select 3, 1436–1447. doi: 10.1002/nano.202200059

Gogineni, V. K., Morrow, L. E., & Malesker, M. A. (2013). Probiotics: Mechanisms of action and clinical applications. *Probiotics & Health, 1*(1), 1-11.

Grover, S., Rashmi, H. M., Srivastava, A. K., & Batish, V. K. (2012). Probiotics for human health-new innovations and emerging trends. *Gut Pathogens, 4*, 1-14.

Hill, C., Guarner, F., Reid, G., Gibson, G. R., Merenstein, D. J., Pot, B., Morelli, L., Canani, R. B., Flint, H. J., Salminen, S., Calder, P. C., & Sanders, M. E. (2014). Expert consensus document. The International Scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic. *Nature Reviews Gastroenterology & Hepatology, 11*(8), 506-514. <https://doi.org/10.1038/nrgastro.2014.66>

Hemaiswarya, S., Raja, R., Ravikumar, R., & Carvalho, I. S. (2013). Mechanism of action of probiotics. *Brazilian Archives of Biology and Technology*, *56*(1), 113–119. <https://doi.org/10.1590/S1516-89132013000100015>

Hori, T., Matsuda, K., & Oishi, K. (2020). Probiotics: A Dietary Factor to Modulate the Gut Microbiome, Host Immune System, and Gut–Brain Interaction. *Microorganisms*, *8*(9), 1401. https://doi.org/10.3390/microorganisms8091401

Howarth, G. S., & Wang, H. (2013). Role of endogenous microbiota, probiotics and their biological products in human health. *Nutrients, 5*(1), 58-81. doi:10.3390/nu5010058

Iqbal, M. Z., Qadir, M. I., Hussain, T., Janbaz, K. H., Khan, Y. H., & Ahmad, B. (2014). Probiotics and their beneficial effects against various diseases. Probiotics and Their Beneficial Effects Against Various Diseases, 405-410.

Jing Wang, Haifeng Ji, Influence of Probiotics on Dietary Protein Digestion and Utilization in the Gastrointestinal Tract, Current Protein & Peptide Science; Volume 20, Issue 2, Year 2019, DOI: 10.2174/1389203719666180517100339

Kahouli, I., Malhotra, M., Alaoui-Jamali, M. A., & Prakash, S. (2015). In-vitro characterization of the anti-cancer activity of the probiotic bacterium *Lactobacillus fermentum* NCIMB 5221 and potential against colorectal cancer cells. *Journal of Cancer Science & Therapy, 7*, 224-235.

Kang, J.-H., Yun, S.-I., Park, M.-H., Park, J.-H., Jeong, S.-Y., & Park, H.-O. (2013). Anti-obesity effect of *Lactobacillus gasseri* BNR17 in high sucrose diet-induced obese mice. *PLoS One, 8*, 1-8.

Karimi, G., Sabran, M. R., Jamaluddin, R., Parvaneh, K., Mohtarrudin, N., Ahmad, Z., et al. (2015). The anti-obesity effects of *Lactobacillus casei* strain Shirota versus Orlistat on high fat diet-induced obese rats. *Food & Nutrition Research, 59*, 1-8.

Khan, M. A., & Morshed, M. N. (2015). Probiotics: Insights on probiotic effects and next-generation therapy to combat inflammatory bowel diseases. *Journal of Bacteriology and Mycology, 2*(1).

Kobyliak, N., Conte, C., Cammarota, G., Haley, A. P., Styriak, I., Gaspar, L., et al. (2016). Probiotics in prevention and treatment of obesity: a critical view. *Nutrition & Metabolism, 13*, 1-13.

Kristensen, N. B., Bryrup, T., Allin, K. H., Nielsen, T., Hansen, T. H., & Pedersen, O. (2016). Alterations in fecal microbiota composition by probiotic supplementation in healthy adults: a systematic review of randomized controlled trials. *Genome Medicine, 8*, 1-11.

Laghari, I. K., Nawaz, T., Mustafa, S., Jamali, A. A., & Fatima, S. (2023). Role of multi-strain probiotics in preventing severity and frequency of recurrent respiratory tract infections in children. *BMC Pediatrics*, *23*. https://doi.org/10.1186/s12887-023-04338-x

Łagowska, K., & Bajerska, J. (2021). Effects of probiotic supplementation on respiratory infection and immune function in athletes: systematic review and meta-analysis of randomized controlled trials. *Journal of Athletic Training*, *56*(11), 1213–1223. https://doi.org/10.4085/592-20

Latif, A., Shehzad, A., Niazi, S., Zahid, A., Ashraf, W., Iqbal, M. W., Rehman, A., Riaz, T., Aadil, R. M., Khan, I., Özoğul, F., Rocha, J. M., Esatbeyoglu, T., & Korma, S. A. (2023). Probiotics: mechanism of action, health benefits and their application in food industries. *Frontiers in Microbiology*, *14*. <https://doi.org/10.3389/fmicb.2023.1216674>

Leitner, U., Brits, A., Wang, W., Patil, S., & Sun, J. (2024). Efficacy of probiotics on improvement of health outcomes in cirrhotic liver disease patients: A systematic review and meta-analysis of randomised controlled trials. *European Journal of Pharmacology*, *981*, 176874. https://doi.org/10.1016/j.ejphar.2024.176874

Lewis, B. B., Buffie, C. G., Carter, R., Leiner, I., Toussaint, N. C., Miller, L., et al. (2015). Loss of microbiota-mediated colonization resistance to *Clostridium difficile* infection is greater following oral vancomycin as compared with metronidazole. *Journal of Infectious Diseases, 212*, 1656-1665.

López-Yerena, A., de Santisteban Villaplana, V., Badimon, L., Vilahur, G., & Padro, T. (2025). Probiotics: A Potential Strategy for Preventing and Managing Cardiovascular Disease. *Nutrients*, *17*(1), 52. <https://doi.org/10.3390/nu17010052>

María Elena Fátima Nader-Macías, Priscilla Romina De Gregorio, Chapter 18 - Probiotics and urogenital health, Probiotics, Academic Press, 2022, Pages 355-388, ISBN 9780323851701, https://doi.org/10.1016/B978-0-323-85170-1.00016-6.

Mayer, E. A., Tillisch, K., & Gupta, A. (2015). Gut/brain axis and the microbiota. *Journal of Clinical Investigation, 125*, 926-938.

Mathur A, Malik S, Ganti L. Benefit of Probiotics on Cardiovascular Health- A Narrative Review. *Health Psychology Research*. 2024;12. doi:[10.52965/​001c.123856](https://doi.org/10.52965/001c.123856)

McFarland, L. V. (2006). Meta-analysis of probiotics for the prevention of antibiotic-associated diarrhea and the treatment of *Clostridium difficile* disease. *The American Journal of Gastroenterology, 101*(4), 812-822. doi:10.1111/j.1572-0241.2006.00465.x

McFarland, L. V. (2007). Meta-analysis of probiotics for the prevention of traveler's diarrhea. *Travel Medicine and Infectious Disease, 5*(2), 97-105. doi:10.1016/j.tmaid.2005.10.003

Medellin-Peña, M. J., Wang, H., Johnson, R., Anand, S., & Griffiths, M. W. (2007). Probiotics affect virulence-related gene expression in *Escherichia coli* O157:H7. *Applied and Environmental Microbiology, 73*(13), 4259-4267. doi:10.1128/AEM.00159-07

Miriam, B. B., Julio, P. D., Sergio, M. Q., et al. (2012). Probiotic mechanisms of action. *Annals of Nutrition & Metabolism, 61*, 160-174.

Mohammad Kazem, S. Y., Abolfazl, D., Hamid Reza, K. Z., et al. (2017). Characterization and probiotic potential of lactic acid bacteria isolated from Iranian traditional yogurts. *Italian Journal of Animal Science, 16*(2), 185-188.

Musazadeh, V., Roshanravan, N., Dehghan, P., & Ahrabi, S. (2022). Effect of Probiotics on Liver Enzymes in Patients With Non-alcoholic Fatty Liver Disease: An Umbrella of Systematic Review and Meta-Analysis. *Frontiers in Nutrition*, *9*. https://doi.org/10.3389/fnut.2022.844242

Nogueiras, R., Romero-Pico, A., Vazquez, M. J., Novelle, M. G., & Lopez, M. (2012). The opioid system and food intake: homeostatic and hedonic mechanisms. *Obesity Facts, 5*, 196-207.

O'Bryan, C. A., Pak, D., Crandall, P. G., Lee, S. O., & Ricke, S. C. (2013). The role of prebiotics and probiotics in human health. *Journal of Probiotics & Health, 1*, 108. <https://doi.org/10.4172/2329-8901.1000108>

Pandey, K. R., Naik, S. R., & Vakil, B. V. (2015). Probiotics, prebiotics and synbiotics - a review. *Journal of Food Science and Technology, 52*(12), 7577-7587. doi:10.1007/s13197-015-1921-1

Parvez, S., Malik, K. A., Kang, S. A., & Kim, H.-Y. (2006). Probiotics and their fermented food products are beneficial for health. *Journal of Applied Microbiology, 100*, 1171-1185.

Perez-Cobas, A. E., Moya, A., Gosalbes, M. J., & Latorre, A. (2015). Colonization resistance of the gut microbiota against *Clostridium difficile*. *Antibiotics, 4*, 337-357.

Petruzziello, C., Saviano, A., and Ojetti, V. J. V. (2023). Probiotics, the immune response and acute appendicitis: a review. Vaccines 11:1170. doi: 10.3390/ vaccines11071170

Plaza-Diaz, J., Ruiz-Ojeda, F. J., Gil-Campos, M., and Gil, A. (2019). Mechanisms of action of probiotics. Adv. Nutr. 10, S49–S66. doi: 10.1093/advances/nmy063

Rajasekaran, R. (2024). *Probiotics and Prebiotics* (pp. 485–492). Informa. https://doi.org/10.1201/9781003055211-51

Rao, A. V., Bested, A. C., Beaulne, T. M., Katzman, M. A., Iorio, C., Berardi, J. M., et al. (2009). A randomized, double-blind, placebo-controlled pilot study of a probiotic in emotional symptoms of chronic fatigue syndrome. *Gut Pathogens, 1*, 1-6.

Rastall, R. A., & Gibson, G. R. (2014). Recent developments in prebiotics to selectively impact beneficial microbes and promote intestinal health. *Current Opinion in Biotechnology, 32*, 42-46. doi:10.1016/j.copbio.2014.11.002

Renata, C., Magdalena, J., Teresa, B., et al. (2016). Characteristics of oral probiotics -- a review. *Pharmaceutical Medicine and Medical Sciences, 29*(1), 8-10.

Rijkers, G. T., de Vos, W. M., Brummer, R.-J., Morelli, L., Corthier, G., & Marteau, P. (2011). Health benefits and health claims of probiotics: Bridging science and marketing. *British Journal of Nutrition, 106*, 1291-1296. doi:10.1017/S000711451100287X

Rout, G. K., Patra, J. K., Gouda, S., Park, Y., Shin, H.-S., & Das, G. (2018). Benefaction of probiotics for human health: A review. *Journal of Food and Drug Analysis, 26*(3), 927-939. <https://doi.org/10.1016/j.jfda.2018.01.002>

Sajedi, D., Shabani, R., and Elmieh, A. J. C. (2021). Changes in leptin, serotonin, and cortisol after eight weeks of aerobic exercise with probiotic intake in a cuprizoneinduced demyelination mouse model of multiple sclerosis. Cytokine 144:155590. doi: 10.1016/j.cyto.2021.155590

Sanders, M. E., & Klaenhammer, T. R. (2012). Probiotics and prebiotics. In *Food Microbiology*. <https://doi.org/10.1128/9781555818463.ch38>

Sarowska, J., Choroszy-Król, I., Regulska-Ilow, B., Frej-Mądrzak, M., & Jama-Kmiecik, A. (2013). The therapeutic effect of probiotic bacteria on gastrointestinal diseases. *Advances in Clinical and Experimental Medicine, 22*(5), 759-766.

Srivastav, S., Neupane, S., Bhurtel, S., Katila, N., Maharjan, S., Choi, H., et al. (2019). Probiotics mixture increases butyrate, and subsequently rescues the nigral dopaminergic neurons from MPTP and rotenone-induced neurotoxicity. J. Nutr. Biochem 69, 73–86. doi: 10.1016/j.jnutbio.2019.03.021

Szajewska, H. (2016). What are the indications for using probiotics in children? *Archives of Disease in Childhood, 101*, 398-403.

Talib, E. Q., Taha, G. I., Shaker, R., Najm, A. Z., Talib, A., & abed, F. badri. (2024). Probiotics and pediatric oral health: An emerging antimicrobial tool against childhood infections. Microbes and Infectious Diseases (Print), 0(0), 0. <https://doi.org/10.21608/mid.2024.327613.2277>

Taverniti, V., Scabiosi, C., Arioli, S., et al. (2013). Short-term daily intake of 6 billion live probiotic cells can be insufficient in healthy adults to modulate the intestinal bifidobacteria and Lactobacilli. *Journal of Functional Foods, 6*, 482-491.

Tejero-Sarinena, S., Barlow, J., Costabile, A., Gibson, G. R., & Rowland, I. (2013). Antipathogenic activity of probiotics against *Salmonella Typhimurium* and *Clostridium difficile* in anaerobic batch culture systems: is it due to synergies in probiotic mixtures or the specificity of single strains? *Anaerobe, 24*, 60-65.

Tillisch, K. (2014). The effects of gut microbiota on CNS function in humans. *Gut Microbes, 5*, 404-410.

Tsao, S.-P., Nurrahma, B. A., Kumar, R., Wu, C.-H., Yeh, T.-H., Chiu, C.-C., Lee, Y.-P., Liao, Y.-C., Huang, C.-H., Yeh, Y.-T., & Huang, H.-Y. (2021). Probiotic Enhancement of Antioxidant Capacity and Alterations of Gut Microbiota Composition in 6-Hydroxydopamin-Induced Parkinson’s Disease Rats. *Antioxidants*, *10*(11), 1823. https://doi.org/10.3390/antiox10111823

Tuohy, K. M., Probert, H. M., Smejkal, C. W., & Gibson, G. R. (2003). Using probiotics and prebiotics to improve gut health: Therapeutic focus. *Drug Discovery Today, 8*(15), 692-700.

Vanderpool, C., Yan, F., & Polk, D. B. (2008). Mechanisms of probiotic action: Implications for therapeutic applications in inflammatory bowel diseases. *Inflammatory Bowel Diseases, 14*(11), 1585.

Wang, J., Zhang, W., Wang, S., Wang, Y., Chu, X., & Ji, H. (2021). Lactobacillus plantarum Exhibits Antioxidant and Cytoprotective Activities in Porcine Intestinal Epithelial Cells Exposed to Hydrogen Peroxide. *Oxidative Medicine and Cellular Longevity*, *2021*, 8936907. https://doi.org/10.1155/2021/8936907