The Bioscan
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
20(3): S.I(3). 1810-1825, 2025 www.thebioscan.com

# A Comparative Study of Probiotics as a Boon Towards Curse Pathogens

**Suyash Arunrao Kathade***

School of Life Sciences, S.R.T.M. University, Nanded- 431 606, Maharashtra, INDIA.

**Email:** Suyash.kathade9@gmail.com

**DOI: 10.63001/tbs.2025.v20.i03.S.I(3).pp1810-1825**

**KEYWORDS:**

**Antibiotics, probiotics, pathogenic bacteria.**

**Received on:**

**15-09-2025**

**Accepted on:**

**01-10-2025**

**Published on:**

**20-11-2025**

**ABSTRACT**

Antibiotics are therapeutic substances widely used to control pathogenic bacteria. Indiscriminate use of antibiotics has often led to the development of resistance in the pathogens as well as many side effects in the consumer. Moreover, antibiotics damage the microbial ecosystem inside the gut, leading to further complications. The search for an alternative to antibiotics has revealed the potential features of probiotics. Probiotics are live bacteria that provide health advantages to their host. Various scientific articles have reported on the proven benefits of probiotics, particularly *Lactobacillus* and *Bifidobacterium*, for animal and human health. Well-studied probiotic cultures have anti-inflammatory, antiallergic, and other beneficial characteristics. The ability of many probiotic bacteria to inhibit specific pathogenic bacteria has been highlighted in their therapeutic applications. This review aims to explore the potential of probiotic bacteria as an alternative to antibiotics.

## INTRODUCTION

The word antibiotic was first described by Selman Waksman in 1941 as any molecule produced by microbes to inhibit the growth of other microbes [1,2]. Currently, there are 43 classes of antibiotics, many of which are derivatives of first-generation antibiotics. Initially, antibiotics were very effective in inhibiting the pathogens and controlling the diseases; however, they were also instrumental in the evolution of drug-resistant bacteria. Numerous studies have shown that antibiotics have a significant impact on the development of the gut microbiome. These disruptions of the microbiome can impact the community [3,4] and can ultimately affect the normal function of the commensal microbiome [6].

In recent years, there has been an increase in the number of reports on research in the field of the gut microbiome, isolation of probiotic microorganisms from various sources, and production of antimicrobial compounds [6]. Probiotics are live microorganisms when administered in an adequate amount, confer health benefits to the host [9]. Once established, these probiotic bacteria can exert their beneficial effect in many ways. There are reports of the ability to probiotics to produce vitamins, maintain gut pH, as well as modulate the immune response of the host [12]. Moreover, they are well characterized for their ability to maintain the gut microflora, especially after an antibiotic course.

Imbalance in the gut flora, also known as dysbiosis, is the decrease in the number of desirable microorganisms and an increase in the number of undesirable microorganisms in the gut. Dysbiosis can lead to infections, poor nutrition, lack of nutrient absorption, etc. [33, 34] as well as acute and chronic disorders such as IBD and IBS [35-39]. Dysbiosis is one of the major side effects of antibiotic use.

Antibiotics are widely used to control various infections and are a major boon for medical science. However, indiscriminate use of antibiotics has led to the development of many drug-resistant pathogens. Moreover, many side effects have been reported due to the overuse of antibiotics. Hence, there is a need for an alternative to the currently used antibiotics. Commonly used probiotics such as *L. acidophilus, Bifidobacterium, L. plantarum, L. pentosus, L. lactis, L. casei, B. breve, and B. longum* are reported for their ability to inhibit many pathogenic bacteria that can cause gastrointestinal disorders. Considering these, probiotics are generally regarded as living drugs with immunomodulatory, anti-carcinogenic, anti-allergic, and anti-inflammatory effects. Even though many reports are available regarding the inhibition of pathogenic bacteria by probiotics, there is ambiguity regarding the use of probiotics against pathogens. Hence, this review focuses on the antimicrobial activities of probiotics.

**Probiotics and their benefits**

The term "Probiotics" was derived from the Greek word for life [14]. Ellie Metchnikoff was the first researcher to propose the health benefits of probiotics, after observing the correlation between daily consumption of fermented food and health in Bulgarian populations. She explained that the microbiota present in fermented food plays a major role in maintaining a healthy gut environment [15, 17].

Currently, many probiotics have been isolated from various sources and characterized for various health benefits. Probiotic characterization involves various experiments laid down by WHO-FAO, ICMR-DBT, and WGE for evaluating (i) toxicity of the culture, (ii) its ability to tolerate various pH, temperature, and digestive enzymes, (iii) to adhere and grow in the alimentary canal while exerting the beneficial effect on the host [1,2]. Complete molecular identification of the culture is also essential for defining the culture as a probiotic.

The most common beneficial activity of probiotics is (i) balancing the intestinal microbial diversity, (ii) helping to absorb nutrients, (ii) producing vitamins, enzymes, and (iv) inhibition of pathogenic organisms through various mechanisms. Recently, researchers have proven the ability of probiotics to control cholesterol in the blood, as well as shown the link between probiotics in reducing heart disease, cancer, and diabetes. There is a proven link between the types of microflorae present in the gut and the onset of a disease. Evidence accumulated in the last decade clearly emphasizes the importance of probiotic intervention for good microbiome health and clinical applications [32].

A major setback in maintaining the gut microflora is the use of antibiotics. If probiotic bacteria can function as an antimicrobial agent, they would not only inhibit the pathogenic microorganisms but also provide many other benefits for healthy living. Hence, it is essential to know the antimicrobial potential of probiotics and to understand the mechanism by which they inhibit pathogens.

**Antimicrobial Probiotics and their mechanism of inhibition.**

There are various known ways of antagonistic effects of probiotic bacteria, including alteration of the gut microbiota, competitive adherence to the mucosa, epithelial strengthening of the gut epithelial barrier, and manipulation of the immune system to provide an advantage to the host [67]. Antagonistic activity of probiotics can be because of epithelial barrier antimicrobial substances, bacteriocins, adhesion, competitive exclusion, defensins, mucins, bacterial adhesion, antifungals, intestinal microbiota, and anti-inflammatory activity. Enhancement of epithelial barrier, Intestinal epithelial cells are in permanent contact with the diverse microbial community, and epithelial integrity is essential to defend from pathogenic microorganisms [68]. Once the barrier function is disturbed, bacterial dietary antigens can penetrate the submucosa and induce an inflammatory response, leading to infectious illnesses such as IBD [69-72]. Consumption of probiotic microorganisms can maintain epithelial barrier and intestinal barrier function.

According to a study, boosting the expression of genes involved in tight junction signalling could be a viable option. *Lactobacillus* can influence a number of genes and junction proteins, such as E-cadherin and β-catenin [73].

**Increase adherence to the intestinal mucosa.**

Adherence is important to the interaction between probiotics and the host [74-76] it also plays an important role in the modulation of the immune system [90-94].

Intestinal epithelial cells (IECs) secrete mucin which is a complex glycoprotein mixture that can prevent the adhesion of pathogenic microorganisms [78] because it presents lipids, free proteins, immunoglobulins, and salt prevent mucous gel adhesion can leads to competitive exclusion of pathogenic bacteria [79]. Probiotics such as *L. fermentum, L.plantarum* are reported to induce MUC2 and MUC3 mucin and *E.coli* [90]. Establishment of a stable population or commercial microbiota will reduce nutrient availability for entering pathogenic micro-organisms and inhibit their colonization to produce epithelial cells, which is responsible for inhibiting adherence of enteropathogenic.

**Production of Antimicrobial Substances**

Probiotic microorganisms produce organic acids, particularly acetic acid; lactic acid has a strong inhibitory effect on Gram-negative bacteria and is considered the primary antibacterial chemical [80-82]. Organic acids dissociate inside its cytoplasm, eventually reducing the intracellular pH and forms organic acids might lead to the death of harmful microorganisms [108-109]. They also produce antimicrobial peptides, some specific antibacterial compounds could be specific to pathogens, example *Bifidobacterium sp.* which is Bifidocin-B specifically inhibit *Salmonella and E. coli* [86]. Probiotics are known for de conjugate bile acids which shows strong antimicrobial compound [87].

**Against viral infections**

Although probiotics doesn't possess direct effect against viruses, but can be depicted by immune stimulation [92]. It also contains potential antiviral effects. *B. breve* can increase the production of IgA and IgG [93]. Anti-hepatitis A, B can be reduced by *L. acidophilus, B. bifidum* against hepatitis A and B virus [94. *Thermophilus spp*. work as anti-herpetic [95]. *Bifidobacterium lactis* and *Saccharomyces boulardii* can be used as antiviral therapy against rotavirus [96]. Against HIV AIDS - probiotics raise CD4 count in blood and lower the incidence of diarrhoea in HIV infected patients [96].

**Immunomodulatory and Antimicrobial**

Probiotic bacteria have an immunomodulatory function and interact with cells, dendritic cells, monocytes/macrophages, and lymphocytes. Probiotics have been shown to interact with IECs and DCs, both of which play significant roles in innate and adaptive immunity, via pattern recognition receptors (PPRs) [88, 89].

Probiotics boost the immune system by raising the concentration of IgA-producing plasma cells, improving phagocytosis, and boosting the concentration of T-lymphocytes and natural killer cells [90, 91] modulation to upregulate the antibody secretion to improve defence against pathogenic microorganisms [97-99]. Probiotics can increase the level of anti-inflammatory cytokines such as TNF [96].

Probiotics primarily produce lactic and acetic acids as end products of carbohydrate metabolism, as well as an increase in butyrate and other SCFA production [43-45]. Also, by producing bacteriocins, bacteriocin contains antimicrobial proteins, peptides, antibiotic compound, etc. can be active against pathogenic microorganisms.

After consumption of prebiotics, such as Galactooligosaccharides (GOS) induces immunity by enhancing phagocytosis and maintain Th1/Th2, although probiotics may show positive effects by enhancing non-specific (innate) and antigen-specific (adaptive) Immunity [41, 42].

**Can we take probiotics instead of antibiotics? How to use probiotics effectively?**

Probiotics are routinely given to people to help reduce the gastrointestinal side effects of oral antibiotic therapy. It is a widely held belief that consuming large amounts of bacteria, such as probiotics, can restore the intestinal microflora after the changes caused by antibiotics [21]. To avoid digestive issues, probiotics can be given in conjunction with multidrug-resistant antibiotics to help them survive in the presence of other medicines. Aside from their innate sensitivity, probiotics can be vulnerable to the majority of antibiotics, or they can be multidrug-resistant naturally or through treatment. In the latter situation, they can be combined with antibiotics to reduce gastrointestinal adverse effects associated with oral antibiotic treatment. According to WHO, 35% of adults over 20 and 400 million people were obese in 2008 [54] and till 2015 it reaches to 700 million found to be obese and research states that these changes are because of change of eating habit, intake of abundant food and decrease in expenditure energy and because of high-fat sugar, and low fibre playing a key role in chronic diseases and metabolic syndrome such as obesity, diabetes, and cardiovascular etc.

In a recent study, microbial profile in obese and lean people are different, when obese loses weight microflora reverted [55]. Probiotics can modulate the markers of metabolic stress [56] and also help to decreases adiposity, fatty liver, glucose level in different mice models [57, 58]. The gut microbiome contributes significantly in obesity and insulin resistance [62, 63] which is associated with low-grade inflammation [64]. Modulation of gut microflora can be a potential target to treat obesity and diabetes with *Bifidobacterium* and *Lactobacillus* sh owed beneficial effects [65]. Studies reported, with increased Phyla Bacteroidetes as compare to firmicutes in the diabetic condition can aid in diabetes, hypertensive condition which is closely related to diabetes, Bifidobacterium reported for levering insulin resistance [50].

A recent study indicates that dietary polyphenols contribute to maintaining gut microbial health, stimulation of the good microbiome which is very low in diabetic patient polyphenols may reduce postprandial glucose response by increasing gut microbial health [38].

**Disease-specific probiotics**

Recent advances have been made in the understanding of probiotics and their beneficial and appropriate uses as therapeutic agents. It can be disease-specific probiotics, as stated by reported studies.

Change in the Gut microbiome may be the centre point which can be responsible for various clinical conditions, and maintaining the normal flora of gut may be the best therapy to overcome [47]. Hundreds of studies are carried out on the association of the human microbiome and diseases, and reported study states that a consistent pattern of the microbiome was found at specific diseases and can vary by disease to disease. Some of the diseases are associated with over 50 genera, and some are 10-15 genus-level changes [48].

Modulation in gut microbiome can leads to a specific disease condition, which includes metabolic disorders, inflammatory and autoimmune diseases, neurological conditions and cancer [48-52]. The depletion in specific microbial community is associated with physiological condition [52]. The studies reported with various clinical conditions, patients with inflammatory conditions, such as IBD, as compared with healthy controls. Faecal microbial transplantation (FMT), which become a successful therapy for *C. difficile* infection patients can be reverted with modulation of gut microbiome [46].

**Inflammation/Arthritis**

Probiotics have a direct effect on the gastrointestinal tract, which leads to an impact on immunity through changes in inflammatory cytokines [22]. Probiotics may control inflammation linked with rheumatoid arthritis [22, 23]. *Lactobacillus GG* has the potential to reinforce mucosal barrier mechanisms in inflammation. Probiotics are known to increase phagocytosis and also help to increase anti-inflammatory cytokines like TNF [40].

**Lactose intolerance**

Lactose intolerance is defined as the inability to digest milk sugar (lactose) or the lactose digestive enzyme, lactase. Lactose intolerance symptoms include gas, cramps, nausea, diarrhoea, abdominal pain, and flatulence. Lactose intolerance can be cured by administering probiotic bacteria. Probiotic microorganisms like *L. acidophilus* and *bifidobacteria are* reported to improve lactose digestion [10, 24].

**Vaginosis**

Microbiota is important to maintain vaginal health, vaginosis can cause by several different organisms, and in many cases. *Lactobacilli* predominate into the healthy vagina, and a lack of LAB or normal flora can lead to vaginosis. The *Lactobacilli* species can maintain the favourable pH in vaginal tract by producing bacteriocin, organic acid, hydrogen peroxide and other antimicrobial compounds to maintain healthy vaginal track. Studies suggests that *Lactobacilli* may help to control the incidence of vaginal infections [25].

**Diarrhoea**

Probiotics are commonly used to treat diarrhoeal disorders. Preventing and managing acute viral and bacterial diarrhoea, as well as controlling antibiotic-associated diarrhoea, have considerable potential benefits. *Lactobacillus GG, L. reuteri*, *Saccharomyces boulardii*, and *Bifidobacterium*, are beneficial against diarrhoea [26-29] and *Saccharomyces boulardii* reported effective against antibiotic-associated diarrhoea [30, 31].

**Elevated blood cholesterol**

Cholesterol is important to maintain and body functions properly. Cholesterol plays an important role in the production of vitamins and hormones it acting as a precursor. In the human body, cholesterol is important to various body functions, and the body synthesizes and maintains the appropriate amount for smooth function. However, cholesterol is considered as a risk factor for heart and cardiovascular diseases.

Probiotics are well known for excess cholesterol reduction and shows considerable effects on lowering of LDL [10, 59]. Studies reported specifically *Lactobacillus* and *Bifidobacter ium* are effective to reduce cholesterol from blood serum [60, 61].

**CONCLUSION**

Antibiotics have various side effects, and there is a need to explore alternatives to antibiotics. Probiotics are well studied and safe for consumption and recommended to maintain the gut microbial ecosystem and various health benefits. It can boost immunity and prevent various infectious diseases. Reported probiotic cultures are well known for lactose intolerance, improving intestinal health. There is a need to explore disease-specific probiotics by avoiding the use of antibiotics and replacing them with probiotics can lead to a healthy life.

## ACKNOWLEDGEMENTS

The author is indebted to Rajiv Gandhi Institute of IT and Biotechnology, Bharati Vidyapeeth Deemed University (BVDU), Pune, and Swami Ramanand Teerth Marathwada University, Nanded, for support.

## CONFLICT OF INTEREST

The authors report no conflicts of interest.

## REFERENCES

1. Fullteri R. (1989). Probiotics in man and animals: A review, *J appl. Bacteriol*. 66(5):365-368.
2. Gourama H and L.B. Balerman. (1995). Antimycotics and antiflatoxigenic effect of lactic acid bacteria. *A review J Food production.* 58(11): 1275-1280.
3. Becattini, S., Taur, Y. & Pamer, E. G. (2016). Antibiotic-induced changes in the intestinal microbiota and disease. *T1rends Mol. Med.* 22: 458–478.
4. Rashid, M. U. (2015). Determining the long-term effect of antibiotic administration on the human normal intestinal microbiota using culture and pyrosequencing methods. *Clin. Infect. Dis.* 60: S77–S84.
5. Khisti U. V, Kathade S. A, Aswani M. A, Anand P. K, Bipinraj N. K. (2019). Isolation and Identification of Saccharomyces Cerevisiae from Caterpillar Frass and Their Probiotic Characterization. *Biosci Biotech Res Asia*. 16: (1).
6. Jernberg, C., Lofmark, S., Edlund, C. & Jansson, J. K. (2007). Long-term ecological impacts of antibiotic administration on the human intestinal microbiota. *ISME J*. 1: 56–66.
7. Bouton, Y., Guyot, P., Beuvier, E., Tailliez, P. & Grappin, R. (2002). Use of PCR-based methods and PFGE for typing and monitoring homofermentative lactobacilli during Comte´ cheese ripening. *Int J Food Microbiol* 76, 27–38.
8. Dethlefsen, L., Huse, S., Sogin, M. L. & Relman, D. A. (2008). The pervasive effects of an antibiotic on the human gut microbiota, as revealed by deep 16S rRNA sequencing. *PLoS Biol*. 6: e280.
9. N.K. Ganguly, S.K. Bhattacharya, B. Sesikeran, G.B Nair, B.S.

Ramakrishna, H.P.S. Sachdev, V.K. Batish, A.S. Kanagasabapathy, Vasantha Muthuswamy, S.C Kathuria, V.M. Katoch, K. Satyanarayana, G.S Toteja, Manju Rahi, Spriha Rao, M.K Bhan, Rajesh Kapur, R Hemalatha. 2011. *Indian J Med Res.* Jul; 134(1): 22–25.

10. Seema J Patel*. (2015). A comprehensive review on Probiotics. *Int. J. Pure App. Biosci.* 3 (2): 286-290.
11. Carlos Ricardo Soccol *et. al. (2010). The Potential of Probiotics: A Review, *Food technology and biotechnology.* 48(4): 413-434.
12. Hawrelak J, BNat(Hons). 2013. Probiotics. In: Pizzorno JE, Murray MT, editors. Textbook of Natural Medicine. 4th ed. St. Louis, Missouri: Churchill Livingstone *Elsevier.* p. 979–94.
13. Czerucka D, Piche T, Rampal P, (2007). A review article yeast as probiotic saccharomyces boulardii alimentory pharmacology and therapeutics 20:30-35
14. Gismondo, M.R., Drago, L., Lombardi, A. 1999. review of probiotics available to modify gastrointestinal flora. *International Journal of Antimicrobial Agents.* 12:287-292.
15. Guarner, F., Perdigon, G., Corthier, G., Salminen, S., Koletzko, B. and Morelli, L. 2005. Should yoghurt cultures be considered probiotic? *British Journal of Nutrition.* 93:783-786.
16. Çakır, İ. 2003. Determination of some probiotic properties on Lactobacilli and Bifidobacteria. *Ankara University Thesis of Ph.D.*
17. Naidu, A. S., Bidlack, W. R. and Clemens, R. A. 1999. Probiotic spectra of lactic acid bacteria (LAB). *Critical Reviews in Food Science and Nutrition* 39(1):13-126.
18. Ouwehand, A.C. and Vesterlund, S., 2004. Antimicrobial components from lactic acid bacteria. In: Salminen, S., Von Wright and Ouwehand, A. (eds.) Lactic acid bacteria: microbiological and functional aspects. Marcel Dekker Inc., New York, NY, USA, pp. 375-395.
19. Jeanne A. Drisko, MD, CNS; Cheryl K. Giles, MD; Bette J. Bischoff, RD PROBIOTICS IN HEALTH MAINTENANCE AND DISEASE PREVENTION. 8(2): 20003143-155
20. C. Shortt, (1999) The probiotic century: Historical and current perspectives, *Trends Food Sci. Technol*. 10: 411–417
21. Patrice Courvalin* Unite des Agents Antibact eriens, Institut Pasteur, 2001. Antibiotic resistance: the pros and cons of probiotics.8 Suppl 2:S261-5.
22. Jon A Vanderhoof. 2001. Probiotics: future directions. *The American Journal*

*of Clinical Nutrition*, Volume 73, Issue 6, June, Pages 1152S–1155S

23. Madsen KL, Doyle JS, Jewell LD, et al. 1999. Lactobacillus species prevents colitis in interleukin 10 gene-deficient mice. *Gastroenterology*.116:1107-1114.
24. Cunningham-Rundles S, Ahrne S, Bengmark S, et al. 2000. Probiotics and immune response. *Am J Gastroenterol.* 95:S22-S25.
25. Schrezenmeir J, de Vrese M. (2004). Probiotics, prebiotics and synbiotics—approaching a definition. *Am J Clin Nutr*, 73: 361–364.
26. Walker WA. 2000. Role of nutrients and bacterial colonization in the development of intestinal host defense. *J Pediatr Gastroenterol Nutr;*30:S2-S7.
27. Vanderhoof JA, Young RJ. 1998. Use of probiotics in childhood gastrointestinal disorders. *J Pediatr Gastroenterol Nutr*;27:323-332.
28. Pelto L, Isolauri E, Lilius EM, et al. 1998. Probiotic bacteria down-regulate the milk-induced inflammatory response in milk-hypersensitive subjects but have an immunostimulatory effect in healthy subjects. *Clin Exp Allergy*;28:1474-1479.
29. Gorbach SL, Chang TW, Goldin B. 1987. Successful treatment of relapsing Clostridium difficile colitis with Lactobacillus GG. *Lancet* 2:1519.
30. Gionchetti P, Rizzello F, Venturi A, Campieri M. 2000. Probiotics in infective diarrhoea and inflammatory bowel diseases. *J Gastroenterol Hepatol*. 15:489-493.
31. L. Anderson, PharmD. 2017. Antibiotics, invention and innovation, Common Side Effects from Antibiotics, and Allergies and Reactions.
32. Sanders, M.E., Merenstein, D.J., Reid, G. *et al.* (2019) Probiotics and prebiotics in intestinal health and disease: from biology to the clinic. *Nat Rev Gastroenterol Hepatol* 16, 605–616.
33. Dethlefsen, L. & Relman, D. A. (2011).. Incomplete recovery and individualized responses of the human distal gut microbiota to repeated antibiotic perturbation. *Proc. Natl Acad. Sci. U. S. A.* 108 (Suppl. 1), 4554–4561
34. Gagliardi, A. et al. (2018). Rebuilding the gut microbiota ecosystem. *Int. J. Environ. Res. Public Health* 15, E1679 .
35. Hatton, G. B., Madla, C. M., Rabbie, S. C. & Basit, A. W. (2018). All disease begins in the gut: influence of gastrointestinal disorders and surgery

on oral drug performance. *Int. J. Pharm.* 548, 408–422.

36. John, G. K. et al. (2018). Dietary alteration of the gut microbiome and its impact on weight and fat mass: a systematic review and meta- analysis. *Genes (Basel)* 9, (E167
37. Yoshida, N., Yamashita, T. & Hirata, K. I. (2018). Gut microbiome and cardiovascular diseases. *Diseases* 6, E56.
38. Jairam K.P. Vanamala, Rob Knight, and Timothy D. Spector (2015). Can Your Microbiome Tell You What to Eat?,. *Cell Metabolism*. 960-961.
39. Rowland, I. et al. (2018). Gut microbiota functions: metabolism of nutrients and other food components. *Eur. J. Nutr.* 57, 1–24.
40. Klaenhammer, T. R., Kleerebezem, M., Kopp, M. V. & Rescigno, M. (2012). The impact of probiotics and prebiotics on the immune system. *Nat. Rev. Immunol.* 12, 728–734.
41. Vulevic, J., Drakoularakou, A., Yaqoob, P., Tzortzis, G. & Gibson, G. R. (2008). Modulation of the fecal microflora profile and immune function by a novel *trans*galactooligosaccharide mixture (B- GOS) in healthy elderly volunteers. *Am. J. Clin. Nutr.* 88, 1438–1446.
42. Vulevic, J. et al. (2015). Influence of galacto- oligosaccharide mixture (B-GOS) on gut microbiota, immune parameters and metabonomics in elderly persons. *Br. J. Nutr.* 114, 586–595.
43. Flint, H. J., Duncan, S. H., Scott, K. P. & Louis, P. (2015). Links between diet, gut microbiota composition and gut metabolism. *Proc. Nutr. Soc.* 74, 13–22
44. Aoudia, N. et al. (2016). Biofilms of *Lactobacillus plantarum* and *Lactobacillus fermentum*: effect on stress responses, antagonistic effects on pathogen growth and immunomodulatory properties. *Food Microbiol.* 53, 51–59
45. Rios- Covian, D. et al. (2016). Intestinal short chain fatty acids and their link with diet and human health. *Front. Microbiol.* 7, 185
46. Olbjorn, C. et al. (2019). Fecal microbiota profiles in treatment- naive pediatric inflammatory bowel disease - associations with disease phenotype, treatment, and outcome. *Clin. Exp. Gastroenterol.* 12, 37–49
47. van Nood, E. et al. (2013). Duodenal infusion of donor feces for recurrent *Clostridium difficile*. *N. Engl. J. Med.* 368, 407–415.

48. Duvallet, C., Gibbons, S.M., Gurry, T. *et al.* (2017). Meta-analysis of gut microbiome studies identifies disease-specific and shared responses. *Nat Commun* 8, 1784.
49. Zhu, L. et al. (2013). Characterization of gut microbiomes in non-alcoholic steatohepatitis (NASH) patients: a connection between endogenous alcohol and NASH. Hepatology 57, 601–609.
50. Son, J. et al. (2015). Comparison of fecal microbiota in children with autism spectrum disorders and neurotypical siblings in the simons simplex collection. *PLoS ONE* 10, e0137725.
51. Wang, T. et al. (2011). Structural segregation of gut microbiota between colorectal cancer patients and healthy volunteers. ISME J. 6, 320–329
52. Walters, W. A., Xu, Z. & Knight, R. (2014). Meta-analyses of human gut microbes associated with obesity and ibd. *FEBS Lett.* 588, 4223–4233
53. Cars, O., Ho¨ gberg, L. D., Murray, M., Nordberg, O., Sivaraman, S., Lundborg, C. S., So, A. D. & Tomson, G. (2008). Meeting the challenge of antibiotic resistance. *BMJ* 337, a1438.
54. Costelloe, C., Metcalfe, C., Lovering, A., Mant, D. & Hay, A. D. (2010). Effect of antibiotic prescribing in primary care on antimicrobial resistance in individual patients: systematic review and meta-analysis. *BMJ* 340, c2096.
55. WHO source: http://www.who.int/en/
56. An et al. (2011). Antiobesity and lipid-lowering effects of Bifidobacterium spp. in high fat diet-induced obese rats.; *Lipids Lipids Health Dis* 10:116.
57. Cani et al. (2009) Gut microbiota fermentation of prebiotics increases satietogenic and incretin gut peptide production with consequences for appetite sensation and glucose response after a meal.; *Am J Clin Nutr*. 90(5): 1236-1243
58. Cox et al. (2013).The nonfermentable dietary fiber hydroxypropyl methylcellulose modulates intestinal microbiota.; *FASEB J* 27(2): 692-702.
59. Pulusoni SR & Rao DR (1983) Whole body, liver and plasma cholesterol levels in rats fed Thermophilus bulgaricus and acidophilus milks. *J Food Sci* 48: 280–281.
60. Gopal A, Shah NP & Roginski H (1996) Bile tolerance, taurocholate and cholesterol removal by Lactobacillus acidophilus and Bifidobacterium spp. *Milchwissenschaft* 51:619–622.
61. Pereira DIA & Gibson GR (2002) Cholesterol assimilation by lactic acid bacteria and bifidobacteria isolated

from the human gut. *Appl Environ Microbiol* 68: 4689–4693.

62. Ley RE, Backhed F, Turnbaugh P, Lozupone CA, Knight RD & Gordon JI (2005) Obesity alters gut microbial ecology. *P Natl Acad Sci USA* 102: 11070–11075.
63. Ley RE, Turnbaugh PJ, Klein S & Gordon JI (2006) Microbial ecology: human gut microbes associated with obesity. *Nature* 444: 1022–1023.
64. Delzenne NM, Neyrinck AM, Ba¨ckhed F & Cani PD (2011) Targeting gut microbiota in obesity: effects of prebiotics and probiotics. *Nat Rev Endocrinol* 7: 639–646.
65. Aronsson L, Huang Y, Parini P, Korach-Andre M, Hakansson J, Gustafsson JA, Pettersson S, Arulampalam V & Rafter J (2010) Decreased fat storage by Lactobacillus paracasei is associated with increased levels of angiopoietin-like 4 protein (ANGPTL4). *PLoS ONE* 5: e13087.
66.
67. Collado mc, gueimonde m, salminen s:probiotics in adhesion of pathogens: mechanisms of action; in watson rr, preedy vr (eds): bioactive foods in promoting health, chennai, academic press, elsevier, 2010, vol 23, pp 353–370
68. ohland cl, macnaughton wk: probiotic bacteria and intestinal epithelial barrier function. Am j physiol gastrointest liver physiol 2010; 298:g807–g819.
69. hooper lv, wong mh, thelin a, hansson l, falk pg, gordon ji: molecular analysis of commensal host-microbial relationships in the intestine. Science 2001; 291: 881–884.
70. hooper lv, stappenbeck ts, hong cv, gordon ji: angiogenins: a new class of microbicidal proteins involved in innate immunity. Nat immunol 2003; 4: 269–273.
71. sartor rb: mechanisms of disease: pathogenesis of crohn's disease and ulcerative colitis. Nat clin pract gastroenterol hepatol 2006; 3: 390–407.
72. anderson rc, cookson al, mcnabb wc, park z, mccann mj, kelly wj, roy nc: lactobacillus plantarum mb452 enhances the function of the intestinal barrier by increasing the expression levels of genes involved in tight junction formation. Bmc microbiol 2010; 10: 316.
73. hummel s, veltman k, cichon c, sonnenborn u, schmidt ma: differential targeting of the e-cadherin/ _ -catenin complex by gram-positive probiotic lactobacilli improves epithelial barrier

function. Appl environ microbiol 2012; 78: 1140–1147.

74. juntunen m, kirjavainen pv, ouwehand ac, salminen sj, isolauri e: adherence of probiotic bacteria to human intestinal mucus in healthy infants and during rotavirus infection. Clin diag lab immunol 2001; 8: 293–296.

75. beachey eh: bacterial adherence: adhesinreceptor interactions mediating the attachment of bacteria to mucosal surfaces. J infect dis 1981; 143: 325–345.

76. schiffrin ej, brassart d, servin al, rochat f, donnet-hughes a: immune modulation of blood leukocytes in humans by lactic acid bacteria: criteria for strain selection. Am j clin nutr 1997; 66: 515s–520s.

77. hirano j, yoshida t, sugiyama t, koide n, mori i, yokochi t: the effect of *lactobacillus rhamnosus* on enterohemorrhagic *escherichia coli* infection of human intestinal cells in vitro. Microbiol immunol 2003; 47: 405– 409.

78. collado mc, gueimonde m, hernández m, sanz y, salminen s: adhesion of selected *bifidobacterium* strains to human intestinal mucus and the role of adhesion in enteropathogen exclusion. J food prot 2005; 68: 2672–2678.

79. van tassell ml, miller mj: *lactobacillus* adhesion to mucus. Nutrients 2011; 3: 613–636.

80. Alakomi HL, Skytta E, Saarela M, Mattila-Sandholm T, Latva-Kala K, Helander IM: Lactic acid permeabilizes gram-negative bacteria by disrupting the outer membrane. Appl Environ Microbiol 2000; 66: 2001–2005.

*81.* De Keersmaecker SC, Verhoeven TL, Desair J, Marchal K, Vanderleyden J, Nagy I: Strong antimicrobial activity of *Lactobacillus rhamnosus* GG against *Salmonella typhimurium* is due to accumulation of lactic acid. FEMS Microbiol Lett 2006; 259: 89–96.

82. Makras L, Triantafyllou V, Fayol-Messaoudi D, Adriany T, Zoumpopoulou G, Tsakalidou E, Servin A, DeVuyst L: Kinetic analysis of the antibacterial activity of probiotic lactobacilli towards *Salmonella enterica* serovar *typhimurium* reveals a role for lactic acid and other inhibitory compounds. Res Microbiol 2006; 157: 241–247.

83. Ouwehand AC: Antimicrobial components from lactic acid bacteria; in Salminen S, von Wright A (eds): Lactic Acid Bacteria: Microbiology and Functional Aspects. New York, Dekker, 1998, pp 139–159.

84. Russell JB, Diez-Gonzalez F: The effects of fermentation acids on bacterial growth. Adv Microb Physiol 1998; 39: 205–234.

85. Hassan M, Kjos M, Nes IF, Diep DB, Lotfipour F: Natural antimicrobial peptides from bacteria: characteristics and potential applications to fight against antibiotic resistance. J Appl Microbiol. 2012,

86. Gibson GR, Wang X: Regulatory effects of bifidobacteria on the growth of other colonic bacteria. J Appl Bacteriol 1994; 77: 412–420.

87. Oelschlaeger TA: Mechanisms of probiotic actions – a review. Int J Med Microbiol 2010; 300: 57–62.

88. Gómez-Llorente C, Muñoz S, Gil A: Role of Toll-like receptors in the development of immunotolerance mediated by probiotics. Proc Nutr Soc 2010; 69: 381–389.

89. Lebeer S, Vanderleyden J, De Keersmaecker CJ: Host interactions of probiotic bacterial surface molecules: comparison with commensals and pathogens. Nat Rev Microbiol 2010; 8: 171–184.

90. Reid G, Jass J, Sebulsky MT and McCormick JK (2003), Potential uses of probiotics in clinical practice. *Clin. Microbiol.*, 16: 658-672.

91. Ouwehand A, Leyer G and Carcano D (2008). Probiotics reduce incidence and duration of respiratory tracts infection symptoms in 3- to 5-year-old children. *Pediatrics*, 121: 115.

92. De Vrese M and Schrezenmeir J (2002), Probiotics and non-intestinal infectious condiditons, *Br. J. Nutr*, 88: 59-66.

93. Yadav H, Jain S and Sinha PR (2007). Antidiabetic effect of probiotic dahi containing Lactobacillus acidophilus and Lactobacillus casei in high fructose fed rats. *Nutr,* 23: 62-68

94. De Vrese and Schrezenmeir (2000), Effect of probiotics on a defined immunologic challenge with Hepatitis A and B vaccine. Annual Report, p.57.

95. Liaskovs'kyĭ TM, Rybalko SL, Pidhors'kyĭ VS, Kovalenko NK and Oleshchenko LT (2007). Effect of probiotic lactic acid bacteria strains on virus infection. *Mikrobiol Z.*, 69: 55-63.

96. Erdoğan O, Tanyeri B, Torun E, Gönüllü E, Arslan, H, Erenberk U and Oktem F (2012). The comparison of the efficacy of two different probiotics in rotavirus gastroenteritis in children. *J. Trop. Med.*, 2012: 1-5.

97. Przemska- Kosicka, A. et al. Effect of a synbiotic on the response to seasonal influenza vaccination is strongly

influenced by degree of immunosenescence. *Immun. Ageing* 13, 6 (2016).

98. Vitetta, L., Saltzman, E. T., Thomsen, M., Nikov, T. & Hall, S. Adjuvant probiotics and the intestinal microbiome: enhancing vaccines and immunotherapy outcomes. *Vaccines (Basel)* 5, (E50 (2017).

99. Childs, C. E. et al. Xylo-oligosaccharides alone or in synbiotic combination with *Bifidobacterium animalis* subsp. *lactis* induce bifidogenesis and modulate markers of immune function in healthy adults: a double- blind, placebo- controlled, randomised, factorial cross- over study. *Br. J. Nutr.* 111, 1945–1956 (2014).