Chapter 8
Probiotics for Human Health

Savitri and Prem Lata

Abstract Probiotics are beneficial microorganisms which when consumed live impart positive health effects to the consumer. Bacteria, yeast, and mold are the microorganisms that are used as probiotics but the majority of the microorganisms used as probiotics are bacteria from genus *Lactobacillus*, *Lactococcus*, *Bifidobacterium,* and *Streptococcus*. These are similar to those naturally found in the intestine and have an important role in improving the general health of human and other animals which provides protection from different kinds of ailments. Probiotics provide various health benefits such as improvement of gut health, boosting of immune response, reduction in serum cholesterol level and blood pressure through a variety of mechanisms thereby improving overall health of the consumers. Competition for binding sites with pathogens on the epithelial cells of GI tract thus preventing the infection, generation of certain metabolites like bacteriocins which reduces pathogenic bacterial growth, strengthening of the epithelial barrier, improved adhesion to intestinal mucosa, and resulting in the inhibition of pathogenic adhesion and immune system modulation are some key *mechanisms* of *probiotic action*. Thus these have the potential to treat many diseases like gastroenteritis, cancer, diarrhea, inadequate lactose digestion, irritable bowel syndrome, allergies, urogenital infections, cholesterolaemia, *Helicobacter pylori* infections, and inflammatory bowel disease (IBD). Due to their numerous claimed health benefits, probiotics are attaining more interest as alternatives for anti-inflammatory drugs or antibiotics that have led to the growth of probiotic market. Presently, a number of probiotic products with claimed therapeutic values are available in the market. Further, more research on probiotics and their therapeutic benefits is required which will provide scientific basis for using probiotics for prevention and treatment of many diseases. In this chapter, the various roles played by probiotics in maintaining and improving health of human beings will be discussed.

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8.1 Introduction

A large and diverse number of microbes inhabit the gastrointestinal tract (GIT) of mammals; where along with their genomes these constitute the microbiome of gut (Marchesi and Ravel 2015). Within the host, bacteria, archaea, fungi, protozoa, and viruses coexist and interact reciprocally and also with epithelial and immune cells of the host. The immune-mediated disorders like allergic diseases are increasing rapidly which is linked to the little exposure to microorganisms at the initial stages of life. The intestine, which is called the largest immune organ, contains most of the antibody-producing cells. Several studies showed that gut microbiota play an important role in maintaining the homeostasis, health, and disease in human. Gastrointestinal function, appetite, and immune response are some areas that are associated with microbiome of the gut (van de Wouw et al. 2017).

Probiotics are viable microorganisms that enhance the well-being of the host. Mostly, probiotics are bacteria which are similar to beneficial gut microorganisms of human. Probiotics in the form of capsules, tablets, liquid form, gel, paste, and powders as foods and dietary supplements and beauty products are available in market. Milk products (both fermented and unfermented) such as *tempeh*, *miso*, soy beverages, and different types of juices are examples of foods that contain probiotics. Probiotics are already present or added in the preparation of food items. A single bacterial strain or an association of more bacterial strains (consortium) is used as probiotics. Various health benefits are provided by probiotics as they improve gut health, act as an enhancer of the immune response, and reduce the serum cholesterol; they are also used in the treatment of different types of diarrhea, irritable bowel syndrome, urogenital infections, and improvement of lactose metabolism.

8.2 History of Probiotics

During the late nineteenth century, microbiologists discovered that the microbes which are present in the GI tract of disease-free human are different from those in persons with any disease. These microorganisms which are found in the GI tract provide beneficial effects and were termed as probiotics. In its truest sense, probiotics means "for life." Fundamentally, probiotics are microorganisms that put forth health promoting influence on humans as well as in animals.

Elie Metchnikoff during 1900 hypothesized that the utilization of fermented milk is the reason behind the healthy and long lives of Bulgarian peasants. This hypothesis leads to the development of idea of probiotics. During his study, he suggested that beneficial microorganisms contained in the yogurt protect the host from the detrimental effects of other pathogenic microorganisms (Metchnikoff and Metchnikoff 1908). He isolated various strains of lactobacilli from yogurt and named them *Lactobacillus bulgaricus*. According to his study, fermented milk products can be prepared by using pure cultures of *L. bulgaricus*. Metchnikoff hypothesized that lactobacilli eliminate pathogenic toxin-producing bacteria from the intestine. In 1912 at Saint Petersburg the first bacterial drug, Lactobacillin also promoted by Metchnikoff, was manufactured [http://www.probiotics-help.com/mutaflor.html]. Further, Rettger and colleagues extensively researched the mechanism of the probiotic effects and the use of intestine-derived species after Metchnikoff's death.

The very first clinical trials to check the effectiveness of probiotics in relieving constipation was carried out in the 1930s. Later in 1950s, a probiotic product was authorized as a drug for the treatment of scouring caused by *E. coli* among pigs by the United States Department of Agriculture (Orrhage et al. 1994). Many probiotic species have been used in the elimination and for the treatment of diverse range of diseases. The blood serum cholesterol can be reduced by consuming the fermented yogurt containing *Lactobacillus* sp. which opened a new area of research. Reduction in the serum cholesterol was also reported in the infants when cells of *Lactobacillus acidophilus* were added to their formula. As the commonly used antibiotics are becoming useless due to antibiotic resistance, so the World Health Organization in 1994 described probiotics as the subsequent vital immune defense system.

Probiotics play various roles, for instance, the production of antimicrobial compounds such as lactic acid which help in the preservation of milk and also produce flavor compounds like acetaldehyde in yogurt and cheese. Probiotics give a product with the organoleptic characters by the generation of certain metabolites (e.g., extracellular polysaccharides) and also help in bio-enrichment of food items by the synthesis of vitamins and free amino acids. In addition to basic nutritional value, probiotics are widely reported to provide various health benefits to the consumers (Benchimol and Mack 2004). These are also reported to control the level of serum cholesterol thus showing exceptional prophylactic or remedial properties. The remedial benefits include the prevention against a number of intestinal infections, and improving the lactose metabolism of lactose-containing foods.

8.3 Probiotic Microorganisms

The microorganisms used as probiotics are bacteria, yeast, and mold, but the majority of probiotics used are bacteria. The microbial strains used as probiotics include the different species of *Bacillus*, *Lactobacillus*, *Lactococcus*, *Bifidobacterium*, *Streptococcus*, *Enterococcus*, *E. coli*, a range of yeast species, and undefined varied cultures of microbes. In humans, *Lactobacillus* and *Bifidobacterium* species are most extensively used as probiotics, while species of *Enterococcus*, *Bacillus*, and *Saccharomyces* have been commonly used in farm animals. Among LAB, species of *Lactobacillus acidophilus, L. bulgaricus,* *L. brevis, L. casei, L. delbrueckii, L. fermentum, L. helveticus, L. johnsonii, L. lactis, L. rhamnosus, L. reuteri, L. plantarum, L. salivarius, L. sporogenes, L. farciminis,* and *L. paracasei* are used. *Streptococcus thermophilus, S. cremoris, Enterococcus faecalis, E. faecium, Bifidobacterium bifidum, B. breve, B. infantis, B. adolescentis, B. lactis, B. longum, Leuconostoc mesenteroides, Pediococcus* spp., *Propionibacterium* spp. are also reported to be used as probiotics. Yeasts and molds belonging to *Saccharomyces cerevisiae, Saccharomyces boulardii*, *Candida pintolopesii, Aspergillus niger,* and *A. oryzae* are also used in different probiotic products (Amara and Shibl 2015) and these microorganisms/products are used in prevention and curing of many diseases (Table 8.1).

8.4 Mechanism of Probiotic Action

Probiotics, mostly lactic acid bacteria and their food variants, provide various important nutritional and remedial health benefits to the consumers such as anticarcinogenic and antimutagenic activity (Lee et al. 2004). These provide health benefits to the consumers by a variety of mechanisms.

Following are the mechanisms through which probiotics confer health benefits to the organisms:

8.4.1 Competition with Pathogens

Probiotics maintain or restore the balance of host-microbial association and therefore reduce intrusion and colonization of pathogens. The endogenous microbes remain present in all the functional niches in our gut; thereby reducing the pathogenic foray and establishment in that ecological community. Probiotics can also reside in useful niches or they can change the local environment directly by secreting short-chain fatty acids (SCFAs), bacteriocins, lactic acid, and reactive oxygen species that suppress the growth of pathogens (Harper et al. 2018).

8.4.2 Production of Metabolites

Several species of the gut microbiome impart the production of SCFAs and various vitamins (nicotinic acid, thiamine biotin, vitamin B_{12}, folate, pyridoxine, and vitamin K) (Vandenplas et al. 2015). Moreover, probiotic microorganisms also produce butyrate which plays a major source of energy for enterocytes and is involved in the wear and tear of the gastrointestinal wall (Rios-Covian et al. 2016).

Table 8.1 Probiotics used in prevention and treatment of various diseases/disorders

Type of diseases or disorders	Probiotic strains used	References
Kidney/Urinary stones	*L. acidophilus* LA-14, *L. plantarum* PBS067, *B. longum* PBS078, *B. breve*PBS077, *Oxalobacter formigenes*	Giardina et al. (2014)
Atopic Diseases	*Lactobacillus casei, L. acidophilus, L. salivarius, B. bifidum, B. lactis, L. rhamnosus lactis, L. GG, L. fermentum,* and *Lactococcus lactis*	Doege et al. (2012)
Colic	*L. casei, L. rhamnosus, L. delbrueckii* subsp. *bulgaricus, S. thermophilus, L. reuteri* DSM 17938, *L. acidophilus, B. infantis, B. breve*	Nation et al. (2017)
Helicobacter pylori Infection	*Lactobacillus, Bifidobacterium,* and *L. johnsonii* *L. rhamnosus GG* *Bifidobacterium animalis* ssp. *lactis* (DSM15954) *L. reuteri* DSM 17938 Mixture of *L. bulgaricus* and *L. acidophilus* and *S. thermophilus* and *B. bifidum* and galacto-oligosaccharides *Streptococcus faecalis, L. acidophilus, Bacillus subtilis* *Bacillus clausii* (Enterogermina strains) *Saccharomyces boulardii* CNCM I-745 *L. reuteri* ATCC 6475 and *L. reuteri* DSM 17938	Yvan et al. (2015) Dang et al. (2014) Hauser et al. (2015) Manfredi et al. (2012) Du et al. (2012) Emara et al. (2014)
Acute and antibiotic associated diarrhea	*Lactobacillus rhamnosus, L. reuteri, L. rhamnosus GG*, and *L. acidophilus* *Saccharomyces boulardii, B. animalis* subsp. *lactis* alone or in mixture with *S. thermophilus*, *L. casei* Yogurt having *L. casei* DN114, *S. thermophilus* and *L. bulgaricus* *Bifidobacterium lactis* W18, *B. longum* W51, *B. bifidum* W23, *L. acidophilus* W37 and W55, *L. rhamnosus* W71, *Enterococcus faecium* W54, *L. salivarius* W24, *L. paracasei* W72, and *L. plantarum* W62 *L. rhamnosus GG, Enterococcus faecium* SF68, *L. bulgaricus, B. longum, L. acidophilus* and *Saccharomyces boulardii*	Phavichitr et al. (2013) Hempel et al. (2012) Koning et al. (2008) Tiwari et al. (2012)
Candida infection	*Lactobacillus rhamnosus, Lactobacillus reuteri, Propionibacterium freudenreichii*	Jørgensen et al. (2017)
Constipation	*Bifidobacterium* sp., *B. lactis, B. infantis, B. breve, L. casei, B. longum, L. rhamnosus, Streptococcus thermophilus, L. bulgaricus, L. acidophilus* *L. acidophilus* (KCTC 11906BP), *B. bifidum* (KCTC 12199BP), *Streptococcus thermophilus* (KCTC 11870BP), *B. lactis* (KCTC 11904BP), *B. longum* (KCTC 12200BP), and *L. rhamnosus* (KCTC 12202BP) Fructo-oligosaccharides (FOS) with the cultures of *L. acidophilus* (NCFM), *L. paracasei* (Lpc-37),	Sadeghzadeh et al. (2014) Yeun and Lee (2015) Waitzberg et al. (2013) Ojetti et al. (2014)

(continued)

Table 8.1 (continued)

Type of diseases or disorders	Probiotic strains used	References
	B. lactis (HN019), and *L. rhamnosus* (HN001) *L. reuteri* DSM 17938	
Irritable bowel syndrome	*B. bifidum* MIMBb75, *B. lactis, L. casei, L. acidophilus,* and *L. plantarum, S. cerevisiae* *L. acidophilus* NCIMB 30175, *L. plantarum* NCIMB 30173, *L. rhamnosus* NCIMB 30174, and *Enterococcus faecium* NCIMB 30176 fructo-oligosaccharides and *Bacillus coagulans* *L. delbrueckii* ssp. *bulgaricus* LBY-27, *L. acidophilus* LA-5, *L. animalis* ssp. *lactis* BB-12, *S. thermophilus* STY-31 *S. boulardii* CNCM I-745 *E. coli* DSM17252 *L. plantarum* 299v (DSM 9843) *B. animalis* DN-173010, *B. infantis* 35,624 in fermented milk (along with *L. bulgaricus* and *S. thermophilus*) *L. acidophilus* SDC 2012, 2013 *B. animalis* ssp. *lactis* Bb12 DSM 15954, *L. rhamnosus* LC705, *L. rhamnosus GG, Propionibacterium freudenreichii* ssp. *shermanii* JS DSM 7067 *L. plantarum* CECT 7485, *L. plantarum* CECT 7484, *Pediococcus acidilactici* CECT 7483 *Bacillus coagulans* GBI-30, 6086	Cayzeele-Decherf et al. (2017) Ducrotté et al. (2012) Ford et al. (2014) Sisson et al. (2014) Rogha et al. (2014) Jafari et al. (2014) Choi et al. (2011) Guglielmetti et al. (2011) Moayyedi et al. (2010) Agrawal et al. (2009) Sinn et al. (2008) Kajander et al. (2008) Lorenzo-Zúñiga et al. (2014) Dolin (2009)
Acute viral upper respiratory infections	*L. paracasei, L. rhamnosus, L. acidophilus, B. bifidum, L. casei Shirota*, *L. plantarum* and *B. animalis* ssp. *Lactis, Streptococcus salivarius*	Shida et al. (2017)
Modulation of gut – brain axis	*L. lactis* ssp. *lactis* and *B. animalis* ssp. *Lactis*	Liu et al. (2015)
Colon Cancer	Lactic acid bacteria	Kahouli et al. (2013)
Diabetes and Obesity	*L. rhamnosus* CGMCC1.3724, *L. gasseri* SBT2055, *L. acidophilus* NCFM	Sanchez et al. (2014)
Clostridium difficile–associated diarrhea	Yogurt with *L. bulgaricus* and *L. casei* DN114 and *S. boulardii* CNCM I-745, *S. thermophilus* *L. acidophilus* NCFM with *L. rhamnosus* HN001 *B. bifidum* with *L. acidophilus* (Cultech strains) *L. casei* LBC80R and *L. acidophilus* CL1285	Goldenberg et al. (2017) Lahtinen et al. (2012) Plummer et al. (2004) Johnson et al. (2012)

(continued)

Table 8.1 (continued)

Type of diseases or disorders	Probiotic strains used	References
Hepatic encephalopathy	Combination of different strains of *L. delbrueckii* ssp. *bulgaricus*, *L. acidophilus, L. casei, L. plantarum, B. breve, B. longum, B. infantis,* and *S. salivarius* ssp. *thermophilus* Yogurt containing *L. acidophilus, L. bulgaricus, L. casei, S. thermophilus,* and *bifidobacteria*	Lunia et al. (2014) Shukla et al. (2011)
NAFLD	Yogurt containing *S. thermophilus* and *L. bulgaricus* supplemented with *B. lactis* Bb12 and *L. acidophilus* La5 Combination of *L. acidophilus, L. rhamnosus, L. casei, B. longum, S. thermophilus, L. bulgaricus,* and *B. breve* with fructo-oligosaccharides	Nabavi et al. (2014) Eslamparast et al. (2014)
NASH	*B. longum* W11 + FOS *S. thermophilus* and *L. bulgaricus*	Malaguarnera et al. (2012) Aller et al. (2011)
IBD—pouchitis and lcerative colitis	Mixture containing strains of *L. delbrueckii* ssp. *bulgaricus, L. plantarum, L. acidophilus, L. casei, B. breve, B. longum*, *B. infantis,* and *S. salivarius* ssp. *thermophilus*	Gionchetti et al. (2007)
Lactose intolerance	Yogurt containing alive cultures of *S. thermophilus* and *L. delbrueckii* ssp. *bulgaricus*	EFSA (2010)
Acute gastroenteritis	*L. rhamnosus GG* *S. boulardii* CNCM I-745 *L. acidophilus* *L. reuteri* DSM 17938 *B. bifidum* and *L. acidophilus* *B, infantis* and *L. acidophilus* *E. coli* Nissle 1917 *L. rhamnosus* GC, *L. casei* strain *Shirota*, *L. acidophilus, B. bifidum* and *S. thermophilus, L. reuteri, E. faecium* SF68, *L. delbrueckii* var. *bulgaricus, S. boulardii*	Szajewska et al. (2014) Szajewska and Skórka (2009) Klanifar et al. (2009) Urbańska et al. (2016) Lee et al. (2001) Canani et al. (2007) Rafeey et al. (2008) Tiwari et al. (2012)
Traveler's diarrhea	*L. fermentum* strain KLD, *L. acidophilus, L. rhamnosus GG, L. bulgaricus,* and *S. boulardii*	Tiwari et al. (2012)

8.4.3 Immunomodulatory Effects

Since so long, probiotics are known to have diverse positive effects on the immune system. These probiotic strains have the property of inducing IL-12 and also have natural killer (NK) cell immunity and thus considered to possess immune-stimulatory effects (Aziz and Bonavida 2016). Other species are immune-regulatory due to their ability to regulate T cell pathways and stimulation of interleukin IL-10 (Azad et al. 2018). The specific probiotic species or strains have a specific effect with some species performing as pro-inflammatory and others as anti-inflammatory agents on the immune system.

8.4.4 Removal of Contaminants/Heavy Metals

Some probiotics have the ability to lower the risk of ingested heavy metals and hazardous chemicals. Cell wall of probiotic bacteria plays an important role in the removal of metals. The bacterial cell wall binds to the metals by using three main mechanisms, firstly, by ion exchange reactions with teichoic acid and peptidoglycan, secondly, by nucleation reactions causing precipitation, and thirdly, by forming complexes with oxygen and nitrogen ligands (Mueller et al. 1989). For example, *Pediococcus pentosaceus* destroy fumonisins, cluster of mycotoxins produced by fungi (Vandenplas et al. 2015).

8.4.5 Metabolism of Xenobiotics and Drugs

Research on gut microbiome revealed that *p*-cresol metabolite of gut microbe inhibits the liver enzyme hepatic sulfotransferase by competitive inhibition thus reducing the ability of the liver to metabolize paracetamol. The similar role in drug and xenobiotic metabolism played by the microorganisms present in gut could have a significant effect on therapy options in the times to come (Jandhyala et al. 2015). Furthermore, several studies showed that pollutants from dietary and environmental chemicals interfere with gut bacterial function and therefore can induce a pro-inflammatory response and affect host health (Defois et al. 2018). Supplementation of probiotics can further help gut flora to effectively metabolize various drugs and even xenobiotics.

8.4.6 Bile Acid Metabolism

Primary bile acids are deconjugated and dehydrated by some species of the gut microbiota—like *Bacteroides intestinalis*—and convert them into secondary bile acids (Jandhyala et al. 2015). Secondary bile acids are responsible for inhibition of spore germination in *Clostridium difficile* and, hence, restrain the growth of vegetative forms of *C. difficile*.

8.5 Effects on Health

Probiotics have a variety of beneficial health effects on human as well as on animals. Probiotics have potential to treat certain diseases like gastroenteritis, cancer, diarrhea, inadequate lactose digestion, irritable bowel syndrome, allergies, cholesterolaemia, *Helicobacter pylori* infections, and IBD. Other than these effects, probiotics furthermore stimulate immune system by a variety of mechanisms thereby improving overall health of the consumers. The positive effects of probiotics on some diseases/physiological conditions are being discussed in the following sections:

8.5.1 Hypertension

Several studies revealed that the probiotics and their products play an important role in improving the cholesterol level in the body that helps in balancing the blood pressure (Guo et al. 2011). Probiotics decrease the blood pressure via different mechanisms, for instance, by insulin resistance, lowering in the level of blood sugar, and by regulation of rennin-angiotensin system which further results in decrease in the blood or serum cholesterol. In hypertensive conditions, probiotic supplementation might be helpful in reducing blood pressure. Various clinical studies and primary studies on animals showed that the probiotics and their products take part in controlling the blood pressure. During a clinical trial on hypertensive patients, there is considerable decrease in both systolic and diastolic blood pressure when patients were supplemented with fermented milk containing starter culture of bacteria, *Lactobacillus helveticus,* and yeast, *Saccharomyces cerevisiae* (Hata et al. 1996). A study revealed that two tripeptides (isoleucine-proline-proline and valine-proline-proline) function as angiotensin-I-converting enzyme inhibitors and helps in the reduction of blood pressure. These tripeptides were isolated from the milk-based medium in which starter culture of *Saccharomyces cerevisiae* and *Lactobacillus helveticus* was used (Figueiredo et al. 2018). Many probiotic strains like *Lactobacillus acidophilus, L. bulgaricus, L. casei, L. delbrueckii, L. helveticus, L. kefiri*, *L. rhamnosus*, *L. rhamnosus GG, Bifidobacterium longum, Bifidobacterium breve, Streptococcus thermophiles, Saccharomyces cerevisiae* are used for anti-hypertension treatment (Rerksuppaphol and Rerksuppaphol 2015; Ekhlasi et al. 2017).

In hypertensive patients, the administration of powdered probiotic cell extracts results in a reduction in heart rate and blood pressure. The role of consumption of probiotic on heart disease by lowering the blood pressure and blood lipid levels can be assessed by long-term and well-controlled human studies. As risk of heart disease is widespread so the regular consumption of probiotics may act as preventive measure against heart disease.

8.5.2 Urogenital Infections

The abnormal vaginal condition that is comprised by vaginal discharge which is due to the overgrowth of atypical bacteria in the vagina is called bacterial vaginosis. Urogenital infections happen because of alteration in vaginal environment where concentration of lactobacilli is less or absent. The intestinal tract is the prevalent cause of pathogens for urogenital infection in women. Vaginal infections are mainly due to *Trichomonas*, *Candida, Mycoplasma hominis,* and *Gardnerella vaginalis*. The causative organisms of urinary tract infections are *Escherichia coli*, *Chlamydia,* and *Candida, Proteus* spp., *Staphylococcus* spp., and *Klebsiella* spp. (Lim et al. 2009). Vaginal infections lead to many problems including low birth-weight neonate, immature delivery, abdomen infections which can cause sterility, and sexually transmitted diseases.

The major microbial factor which is responsible for the protection of urogenital cells is *Lactobacillus* spp. *Lactobacilli* are main bacteria associated with vaginal health where they reduce the growth of bacterial pathogens (Cadieux et al. 2002; Reid and Bruce 2001; McLean and Rosenstein 2000). These species regulate the occurrence, expansion, establishment, and perseverance of non-endogenous microbes in vagina. Probiotic microorganisms, viz. *Lactobacillus acidophilus, L. crispatus, L. rhamnosus, L. reuteri, L. gasseri, L. vaginalis,* and *Streptococcus thermophilus,* are used for the elimination of recurring bacterial vaginosis (Ya et al. 2010; Siroli et al. 2017). The consumption of products containing these microorganisms can effectively help in treating UTIs. The thought of oral probiotic use is based on the fact that pathogens that cause most of the urinary tract infections progress from the rectum to the vagina and the mesentery. Probiotics help in the reduction of urogenital infection by the stimulation of immune response, and produce some organic acids that reduce the vaginal pH, competitive exclusion, and generation of certain antimicrobial substances (bacteriocins and hydrogen peroxide).

Alternative medicines are beneficial to those with chronic vaginal symptoms (Nyirjesy et al. 1997), while intake of probiotics such as lactobacilli can prevent the occurrence of vaginal infection, by the recolonization of lactobacilli in the vaginal tract. Although the application of lactobacilli in UTIs (urinary tract infections) has been studied, but until now the oral administration method is not used (Reid et al. 1998).

The dried lactobacilli (⍰10^9 colony-forming units/dose) were given weekly through intravaginally to premenopausal women and it was observed that the urinary tract infection reduced to 5 percent in a year (Reid and Bruce 1995). In placebo-controlled trials including 38 women, vaginal lactobacilli were found to decrease the possibility of urinary tract infection (Reid 1995). These studies suggested that *lactobacilli* play a major role to prevent urogenital infections in women by suppressing pathogenic bacteria.

8.5.3 Lactose Intolerance

Major carbohydrate present in milk is lactose. For the absorption of lactose from milk, sufficient lactase activity should be present in the small intestine. This enzyme is present in children, however, reduced in adults in the majority of the people (Daliria and Lee 2015). Several studies showed that lactose absorption from yogurt is improved in lactose deficient in lactase activity (Mustapha et al. 1997) having milk with *Lactobacillus acidophilus* culture than with normal milk.

Yogurt containing starter cultures of *Lactobacillus delbrueckii* subsp. *L. bulgaricus,* and *Streptococcus thermophilus* are reported to effectively improve lactose break down in lactose maldigesters by lactase (β-galactosidase) enzyme present in the bacteria. Various studies showed that lactic acid present in the yogurt reduces the lactose intolerance problem in lactase-deficient persons. The activity of enzyme lactase or β-galactosidase in small intestine is enhanced by the presence of lactic acid bacteria in fermented milk (Marteau et al. 1990).

Various studies were conducted on human, in which the intake of yogurt containing live culture was compared with that of a pasteurized product, resulting in improved digestion and absorption of lactose in yogurt containing live cultures (Labayen et al. 2001). Studies showed that *Yakult,* in which mixture of *Lactobacillus casei shirota* and the bacterium *Bifidobacterium breve* were used, had satisfactory effects on patients with lactose intolerance (Vonk et al. 2012).

8.5.4 Cholesterol Removal

Cholesterol plays a significant role to perform several functions in human. Cholesterol is a constituent of cell membrane that functions as a precursor to many vitamins and hormones. However, an increase in the level of both low-density lipoprotein cholesterol and high-density lipoprotein cholesterol is a threat factor for various cardiovascular diseases. The risk of heart attack is three times more in patients with increased blood cholesterol level as compared to the persons having normal blood lipid value (Ghosh 2012). Cholesterol is synthesized within the human body to maintain the minimum level and diet also affects the serum cholesterol level, while the effects vary from person to person. Several human studies suggested that the probiotic products have the potential to lower the level of blood serum cholesterol.

Probiotic bacteria are reported to decrease the cholesterol levels via different mechanisms such as assimilation of cholesterol by microorganisms, de-conjugation of bile acids, and by attachment of cholesterol to the cell wall of bacteria. By using cholesterol, liver produces bile acids that are released into the intestine, and from the intestine, they are absorbed again and returned to the liver. Probiotic bacteria of the intestine deconjugate these bile acids as a result decreases the total blood cholesterol (Bordoni et al. 2013). Certain animal studies evidenced that greater the number of bacteria in gut, greater elimination of bile acids is there (Mott et al. 1973). Probiotic bacteria degrade the bile acids and reduce the reabsorption of bile salts. Due to the reduction in reabsorption, cholesterol storage in liver begins to reduce.

A study on animals suggested that high level of cholesterol was observed in the excreta of conventional animals than germ-free animals, which is due to the existence of microbes in the gut of conventional animals affecting the serum cholesterol levels. During a trial on human, a decrease in blood cholesterol and low lipid levels by 4.4 and 5.4%, respectively, was observed when treated with yogurt containing starter culture of *L. acidophilus* for various weeks as compared with control (Schaafsma et al. 1998). Mann (1977) suggested that 3-hydroxy-3-methyl glutaric acid (HMG) found in fermented milk suppresses the enzyme, i.e., hydroxymethyl glutaryl CoA reductase that is used in the synthesis of cholesterol. It was also observed that the probiotics may suppress cholesterol synthesis in liver and its transportation to liver by generating the metabolites exclusively short-chain fatty acids (Pereira and Gibson 2002). Several in vitro studies showed that the cultures of probiotics are capable of removing cholesterol from culture media hence more emphasis has been given to this aspect of the probiotics. Removal of cholesterol is due the bile salt hydrolase enzyme produced by probiotic bacteria which hydrolyzed the acids (Parvez et al. 2005).

8.5.5 Cancer

Cell growth and cell division are controlled by abnormal genes and certain variations or stimulation of these abnormal genes cause cancer. Generally, cancer does not result from these abnormal cells as they exceed the normal ones. Most of the abnormal cells were recognized by the immune system itself and these are demolished. The prevalence of abnormal cells increases due to many processes or exposures; therefore, the chance of cancer can be decreased by reducing these exposures. Out of many exposures, chemical exposures are more likely risky exposures. Carcinogens can be produced by the microbes of the GI tract during digestion process. Further, the enzymes like Beta-glucuronidase and nitroreductase enzymes produced by enteropathogens, for example, *E. coli* and *Clostridium perferinges* transform pro-carcinogens into carcinogens. Probiotic bacteria reduce the exposure to chemical carcinogens by certain mechanisms including detoxification of engulfed carcinogens, and reduce the metabolic processes of bacteria that can produce carcinogens by changing the conditions of the intestine, generation of compounds that reduces the expansion of tumor cells, producing the metabolic products such as butyrate that enhances the capability of cell to die as it is supposed to die, and activating the immune system to provide protection against the production of cancer cells (Sanders 2009).

Several studies carried out involving humans have revealed that probiotics might inhibit the possibility of colon cancer by deactivating the mutagenic compounds, generating antimutagenic compounds, decreasing the assimilation of mutagens in the intestine, suppressing the conversion of pro-carcinogens to carcinogens, decreasing the proliferation of procarcinogenic bacteria, and improving immune functions (Gill and Guarner 2004). Epidemiological and population-based studies have showed that the utilization of fermented dairy foods with starter cultures lactobacilli or bifidobacteria decreases the occurrence of breast and colon cancer. Bifidobacterium decreases the pH of intestine through the generation of organic acids, specifically lactic acid that creates a bactericidal environmental for these enteropathogens. Bifidobacterium has antitumor properties, i.e., property to kill tumor cells caused by phagocyte activation (Sekine et al. 1994).

A study revealed that the utilization of *L. casei* strain Shirota might detain the reappearance of cancer in bladder. *L. casei* Shirota reduces the growth of tumor by stimulating the immune system, an increase in the number of T-helper cells and NK cells were reported in patients with colorectal cancer during the use of *L. casei* Shirota. According to a hypothesis, lactobacilli bind to the mutagens in the intestine and reduce the assimilation of these compounds, hence, prevent or delay the tumor development (Murch 2001; Isolauri 2004).

In the western world, main reason of death from cancer is colorectal cancer (CRC). Environmental factors, mainly the diet, are associated with approximately 70% of CRC. In vitro studies of human and animals revealed that fermented milk with probiotic cultures has protecting effects against CRC (Saikali et al. 2004). A study revealed that the probiotic yogurt prepared with starter culture of *Lactobacillus acidophilus* 145 and *Bifidobacterium longum* 913 considerably reduced fecal water genotoxicity in comparison to the yogurt without probiotics (Oberreuther-Moschner et al. 2004). Although, the probiotic treatment also enhances oxidative damage; this may be due to the pro-oxidative activity or activation of some defense systems.

A study on rats was done and it was observed that the use of product containing *L. acidophilus* leads to the decrease in the overall number of colon cancer cells (De Santis et al. 2000). Another study on animals was conducted where colon cancer was artificially induced and the treatment with *Lactobacillus GG* decreases the prevalence and many tumors. It was observed that *Bifidobacterium longum* also reduces the occurrence of mammary tumors, liver, colon, small intestinal tumors in rats (Orrhage et al. 1994).

The anticancerous activity was reported in the extract of *L. casei*, *L. helveticus*, and *L. acidophilus* when applied in the treatment of sarcomas in mice. During in vitro study, it was observed that fermented milk with starter culture of *L. delbrueckii* ssp. *bulgaricus* exhibits antimutagenic activities against 4-NQO (4-Nitroquinoline 1- oxide), a typical mutagen (Hosono et al. 1986).

8.5.6 Irritable Bowel Syndrome (IBS)

IBS is a persistent and frequent gastrointestinal disorder. Irritable bowel syndrome is characterized by abdominal pain, bloating, flatulence, and diarrhea. These conditions are not easy to treat and thus have a considerable influence on the lives of the patients. IBS is caused by different factors such as food ingestion, abnormal absorption of nutrients, and psychosomatic disorders and these factors affect the motor function of the gastrointestinal tract. Probiotics showed significant consequences on irritable bowel syndrome in the gut.

Different clinical trials revealed that the consumption of different species of lactic acid bacteria decreases the stomach ache, bloating, flatulence, and constipation. A study suggested that *Saccharomyces boulardii* decreases diarrhea, although not efficient in reducing other symptoms of IBS (Marteau et al. 2001).

A study on patients with IBS illustrated a satisfactory increase in relief of general symptoms of irritable bowel syndrome and of stomach ache with time when they receive consortia of *L. acidophilus* LA 102, *S. thermophilus* LA 104, *Lactococcus lactis* LA 103, *B. longum* LA 101 (Drouault-Holowacz et al. 2008). In another study, there was a significant decrease in symptoms of IBS in the experimental group as compared to the control group where experimental group was fed with a milk drink containing a mixture of probiotic strains (Kajander et al. 2008). Various studies revealed that *L. rhamnosus* GG is less effective for IBS, while *L. plantarum* 299 V had a pronounced positive effect on IBS (Niedzielin et al. 2001).

8.5.7 Allergy

During the last 50–60 years, the occurrence of allergy has increased in Western societies. An allergy is a response of immune system against foreign substances. There are two types of allergies: an antibody mediated allergy and a cell mediated allergy. When an individual is exposed to a stimulus at a higher dose, hypersensitivity reactions occur. The allergic reaction is caused by foreign substances (usually proteins) called allergens. The allergens enter into the human body by number of ways, for instance, through breathing, intake of food, and skin contact, or enter during the insect biting and are capable of reaching the immune system (Weiner et al. 2011). Atopy is a genetic tendency which occurs in childhood or adolescence to induce the production of IgE antibodies when foreign substances come in contact to immune system and produce signs like asthma, rhinoconjunctivitis, and atopic dermatitis. It has been observed that in every case of allergy, IgE mechanisms are not attributable (Fiocchi et al. 2012). The mechanisms of allergic diseases include genetic factors, relatedness of allergen exposure, host, and other environmental stimuli, for example, microflora of intestine and contagious agents (Chiang et al. 2012).

Several studies suggested that the allergy and their associated diseases are developed due to the insufficient exposure to environmental microbes. Allergies are related to the alteration in the ratio of T-helper 1 cytokine which leads to the stimulation of Th2 cytokine that results in the production of IgE and the liberation of different interleukins, i.e., IL-4, IL-5, and IL-13 (Michail 2009). Consumption of probiotics changes the microenvironment of gastrointestinal tract by changing the local microflora and change in the production of cytokine. Studies showed that probiotics change the Toll-like receptors (TLRs) and various recognition proteins present on intestinal lining which results in the stimulation of dendritic cells and Th1 cytokine response which results in the suppression of Th2 responses (Winkler et al. 2007).

Several studies have shown that probiotics exert the positive outcome on the allergic diseases through the development of mucosal barrier and stimulation of the immune system. Several studies on atopic eczema and food allergy suggested that probiotic bacteria play an important role in down-regulating inflammation during hypersensitivity reactions (Pohjavuori et al. 2004; Isolauri 2004). Supplementation of *Lactobacillus rhamnosus GG* during the perinatal stage in infants with eczema decreased the occurrence of disease by one half. In newly born baby, the very first bacteria which occupy the gastrointestinal tract can set up a stable niche and these bacteria are important in regulation of immune system and therefore also in developing atopic disorders. Studies on atopic children revealed that probiotics upregulate anti-inflammatory cytokines like interleukin-10.

Toh et al. (2012) suggested that the probiotics result in the stimulation of B and T cell responses specific to allergens and mucosal IgA level which reduces the effect of allergic diseases. Other studies also proposed that the association between the bacteria and host can stimulate the growth of T regulatory cells, production of cytokines like IL-10, and alteration of growth factor-beta. Toll-like receptors, a network of genes, various signaling molecules, and an increased IgA level are involved in these interactions making them quite complicated. Through these mechanisms, probiotics change the immune responses (adaptive and innate) against disease (Gourbeyre et al. 2011; McLoughlin and Mills 2011).

Probiotics are also useful for treatment of food allergies as they increase internal barriers of the intestine, reduce gut wall inflammation, and decrease the concentration of IgE in the serum (del Miraglia and De Luca 2004; Kalliomaki and Isolauri 2004). Defense barrier of the GI tract, i.e., non-immunologic and immunologic, is affected by probiotics which results in an increase in the inflammation in the case of food allergy. Consumption of *Bifidobacteria* and *Lactobacilli* enhanced the production of IgA in Peyer's patches as IgA is effective against potentially harmful antigens. Probiotics are also useful in facilitating the relief from milk protein related allergy, as these degrade the protein present in milk to smaller polypeptides or amino acids. By adding *Lactobacillus* GG in the meals of neonates on hydrolyzed whey formula, signs of eczema could be decreased (Majamaa and Isolauri 1997).

8.5.8 Antibiotic Associated Diarrhea

Antibiotic associated diarrhea (AAD) is described as diarrhea that happens due to the imbalance of microflora of GI tract caused by antibiotics. The origins of AAD are based on the alteration in the microflora of gut. The changes in the microflora of intestine reduce the number of anaerobic fecal bacteria and therefore, the breakdown of carbohydrates that causes the variations in their digestion resulting in the reduction in the assimilation of short chain fatty acids causing osmotic diarrhea (Doron et al. 2008). It was found that AAD exists in 5% to 39% of cases when patients are treated for 2 months. Antibiotics like aminopenicillins, clindamycin, and cephalosporins which act on bacteria are related with a higher possibility of AAD (Wistrom et al. 2001).

AAD can be started as mild diarrhea, however, if untreated it may further lead to a life-threatening disease called pseudomembranous colitis. In the majority of cases, the reason behind the diarrhea is unrevealed, although in the most severe forms and in patients with persistent illness, for instance, persons having inflammatory bowel disease, cystic fibrosis, and cancer, the disease-causing agent is *Clostridium difficile*. It has been observed that the frequency of AAD is lowered by the use of probiotics and their fermented products such as yogurt (Hill et al. 2014). The consumption of probiotics depends upon the theory that AAD occurs as a result of dysbiosis which is induced by antibiotics usage and that the probiotic interference also changes the microbiota of intestine. The strains of *Lactobacillus acidophilus, L. bulgaricus, L. rhamnosus,* and *Saccharomyces boulardii* have been used to restrain AAD.

Nosocomial diarrhea is prevalent worldwide in children and is a major problem. It is suggested that *Streptococcus thermophilus*, *Lactobacillus rhamnosus* GG, and *Bifidobacterium bifidum* are effective for newborn baby mainly for the elimination of acute diarrhea. Several studies suggested that several probiotics, comprising *Saccharomyces boulardii, Lactobacillus rhamnosus* GG*, L. reuteri, Bifidobacteria* spp., and others, have considerable benefits for diarrhea, travelers' diarrhea and diarrhea associated with rotaviruses (Marteau et al. 2001; Benchimol and Mack 2004; Vanderhoof 2000). Promising probiotic strains used in the treatment of diarrhea in children consist of *Lactobacillus* spp., *L. casei, L. reuteri, Bifidobacterium bifidum, Saccharomyces boulardii,* and *Streptococcus thermophilus* (Tomas et al. 2004).

Probiotics also compete for binding sites with pathogens to the intestinal lining thus preventing the infection. By the generation of certain metabolites, namely bacteriocins, probiotics reduce the growth of pathogens (del Miraglia and De Luca 2004). Several studies showed that the probiotics block the attachment of pathogenic bacteria to enterocytes. This blocking is thought to be intervened by increasing the expression of MUC2 and MUC3, intestinal mucins.

During the meta-analysis of 21 studies which include 4780 patients, it was observed that the *S. boulardii* reduces the chance of antibiotic associated diarrhea in children as well as in adult from 19 to 8.5%, with a risk ratio of 0.47. A study includes 82 randomized clinical trials with different probiotics (generally *Lactobacillus* spp., singly or in combination with *bifidobacteria*, *S. boulardii*, or *enterococci*), and a reduction in the antibiotic associated diarrhea with a risk ratio of 0.58 was observed. Most extensively used probiotics for curing the acute diarrhea are *S. boulardii, L. acidophilus, L. bulgaricus, L. rhamnosus, L. paracasei, B. longum,* and *B. breve* (Olveira and González-Moleroa 2016).

Floch et al. (2015) observed that probiotics also reduce the prevalence of illness caused by *C. difficile*, particularly when *S. boulardii* is administered. In another meta-analysis it was found that only four probiotic strains like *S. boulardii*, *L. casei* DN114001, a combination of *Bifidobacterium bifidum* and *L. acidophilus,* a mixture of *L. acidophilus*, *L. casei*, and *L. rhamnosus* considerably reduce the occurrence of diarrhea caused by *C. difficile* (McFarland 2015).

8.5.9 Inflammatory Bowel Diseases (IBD)

A group of diseases described as chronic inflammation of the gastrointestinal tract (specially the large or small intestine) are called inflammatory bowel diseases. The IBD are mainly of two types: Crohn's disease and ulcerative colitis (Iqbal et al. 2014). Chronic disease mainly damages the lower part of the small intestine and can also be seen anywhere along the lining of intestine, while damages to colon is called ulcerative colitis. In ulcerative colitis, the inflammation is limited to the intestinal epithelium, whereas in Crohn's disease the inflammation involves the entire intestinal wall (Palumbo et al. 2016). Abdominal pain, weight loss, intestinal ulcers, bleeding, and diarrhea are the symptoms of both of the cases, but narrowing of intestinal wall, fistulas, and fissures are frequent in Crohn's disease. A significant enhancement in signs of IBD, pouchitis, and ulcerative colitis with utilization of specific strains of *Lactobacilli* has been reported. Studies showed that lactic acid bacteria cause the reduction in gut pH by producing organic acids that can enhance intestinal mobility and relieve constipation.

Various studies revealed that inflammatory bowel diseases are positively modulated by gut microbiota or probiotics. With the supplementation of probiotics, prebiotics, and synbiotics, inflammatory bowel disorder can be treated (Spiller 2016). It has been reported that probiotic strains of *Lactobacillus rhamnosus* GG and *S. boulardii* enhance the level of IgA in the GI tract thus help in prevention as well as treatment of this disease.

Production of short chain fatty acids (SCFAs) mainly, acetate, butyrate, and propionate could induce positive effects in IBD. The SCFAs are recognized to perform a vital function in maintaining colonic homeostasis. These are known to improve the colonic function and also have anti-inflammatory effects (Curro et al. 2017). Hence, the consumption of dietary fibers (prebiotics) alone, or along with probiotics to boost the generation of SCFAs, might be effective for remedial approaches.

8.5.10 Antioxidant Effects

During regular metabolism, there is generation of free radicals in the human body, but the production of radicals increases significantly when our cells are unveiled to xenobiotic compounds from food and external environment. The free radicals are not neutralized by the antioxidant system of the organism efficiently thus resulting into the lethal changes (like cell death) by the oxidation of membranous lipids, enzymes/proteins, and DNA. The free radicals cause damage to the cellular and sub-cellular level which plays a significant function in the development of cancer, heart diseases, allergies, arteriosclerosis, and other diseases. The patients with Alzheimer's disease were also detected with the immense destruction of essential molecules in the brain by oxidation (Filipcik et al. 2006).

The defense reactions of antioxidant in the body are comprised not only of internal antioxidants but also of external antioxidants from the food items such as vitamins C and E, carotenoids, phytoestrogens, folates, flavonoids, and selenium. Probiotics are known to have properties of trapping the reactive forms of oxygen. Kaizu et al. (1993) suggested that the deficiency of vitamin E improved by the intracellular extract from *Lactobacillus* sp. in vitamin E-deficient rats. Probiotic bacteria, *L. delbrueckii* ssp. *bulgaricus* and *Streptococcus thermophilus,* suppress the per-oxidation of lipids by removing the free radicals like hydroxyl or hydrogen peroxide.

Several bacteria found in fermented milk possess antioxidant activity which positively affects human health. Clinical studies also supported the antioxidant activity of goat fermented milk with *Lactobacillus fermentum* ME-3 strain (Songisepp et al. 2005). A group of healthy individuals were subjected to consume either sour or non-fermented 150 g of milk per day for 21 days. It was found that sour milk has extended the resistance of lipoprotein to oxidation, increased antioxidant activity of blood, and reduces the level of oxidized LDL and peroxide lipoproteins.

Certain antioxidant factors are generated by *lactobacilli* in the GI tract of human. Most of the milk bacteria by producing superoxide dismutase or glutathione eliminate the excess oxygen free radicals. The various researches are going on using milk bacteria as an option of food supplements to improve the antioxidant activity in human (Songisepp et al. 2005).

8.6 Probiotics in Oral Health

Different microorganisms like protozoa, fungi, viruses, archea, and bacteria are present in human mouth and are source of various diseases. The bacteria are generally responsible for two types of diseases: tooth decay and gum diseases. Strains of *Lactobacillus* and *Bifidobacterium* are extensively used as probiotics for oral health. A study revealed that the utilization of *Streptococcus salivarius* K12 reduces the development of dental plaque and furthermore decreases the accumulation of *Streptococcus mutans* (Burton et al. 2013). The suppression of periodontal pathogens has also been observed with the consumption of probiotic strains of *Streptococcus uberis* and *S. oralis*.

Furthermore, the consumption of probiotics can reduce the synthesis of halitosis (bad breath) and the volatile sulfur compounds. Bowen (2013) suggested that the cases of gum diseases are fewer as compared to the dental caries; however, the consumption of probiotics is found to be useful in controlling the oral diseases. Further researches are required to recognize the mechanism through which probiotics colonize and have an effect on oral cavity so that the understanding about the role of probiotics in improving oral health could be enhanced.

8.7 Probiotics and the Immune System

Utilization of probiotics like *Lactobacillus acidophilus* and *L. casei* strengthens both mucosal immunity and systemic immunity in the host. It was found that the probiotic species such as *Lactobacillus* induces the phagocytosis and stimulates the activation of T and B cells and IgM, IgA, and IgG antibodies production. Moreover, probiotics do not stimulate a considerable immune response as seen in the presence of pathogen so the consumption of probiotics on daily basis can be safe (Katelaris et al. 1995).

During the digestion process, larger particles of food are broken down into smaller particles by the enzymes so that nutrients can be assimilated by the body. Due to these enzymes, nutrients become easily available to the body and would not suffer from severe deficiencies caused by the absence of these nutrients (Land et al. 2005). Several digestive diseases, varying from gentle to harsh conditions, take place because of the non-digestible food present in the intestine. After colonization of probiotic bacteria in the gut, they take part in the digestion of food. These bacteria produce certain enzymes which increase the digestion of food, so that it can be easily assimilated. Therefore, the microflora of intestine plays an important role in the digestion, assimilation, and improvement in human health. Probiotics that are mainly present in intestine include *Lactobacillus acidophilus* and *L. casei.* These kinds of bacteria facilitate the digestion and absorption of food in the intestine and their intake balances the intestinal microflora. Consequently, they supply a number of good bacteria to the body and assist in absorption of nutrients, food digestion, and boost up the digestive system (Madsen et al. 2001). Probiotics also hamper the growth of pathogens so encourage the human health. Probiotics compete with infectious agents for food and hence for growth and expansion.

Many studies have proven that probiotics like *L. rhamnosus* strain GG and *L. plantarum* exhibit the capacity to block the adhesion of enteropathogenic *Escherichia coli* in the gastrointestinal tract (Wilson and Perini 1988). These bacteria also suppress the growth of infectious bacteria by producing the certain compounds, for example, organic acid (acetic and lactic acids) having strong inhibitory effect against pathogenic bacteria and antimicrobial compounds known as bacteriocins (Bermudez-Brito et al. 2012). Various probiotic species such as *L. acidophilus* (lactacin B), *Bifidobacterium bifidum* NCFB (bifidocin B), *L. plantarum* (plantaricin), and *Lactococcus lactis* (nisin) produce a variety of bacteriocins (Nielsen et al. 2010).

8.8 Anti-obesity Activities of Probiotics

Health is directly affected by the accumulation of excessive fat that leads to the obesity. The accumulation of fat is due to the increase in energy availability, little physical activity, and an imbalanced diet which causes disparity in energy intake and expenditure (Kobyliak et al. 2016). The intestinal flora from obese mice was when transplanted into germ-free mice they might replicate the obese phenotype and become more proficient at extracting energy from food and activating the lipogenesis.

Probiotic bacteria are known to have various properties that provide good health to the host by regulating intestinal microflora. In most cases, the sympathetic nervous system promotes the weight loss by lipolytic and thermogenic responses (Karimi et al. 2015). A study revealed that *Lactobacillus gasseri* BNR17 plays role in weight loss by limiting the secretion of leptin from adipocyte tissue (Kang et al. 2013). Various other probiotic species like *L. casei, L. acidophilus,* and *B. longum* are found to have hypocholesterolemic effects (Karimi et al. 2015).

8.9 Probiotic Products with Claimed Health Benefits

Due to the various health benefits, probiotics are gaining interest among consumers and probiotic consumption has become a global retail market with products including probiotic supplements, fermented milk products, and non-dairy based probiotic products. Among dairy based probiotic products, yogurt alone accounts for 75% of the total probiotic consumption. A range of probiotic products, dietary supplements, and therapeutic products are available in the global market (Table 8.2). The global probiotic market is expected to rise to around US$63 Billion by 2022. The main reason for this rise is the effectiveness of probiotic products in maintaining health of the consumers and disease treatment. Further, increasing health concerns, population explosion, and efficacy of probiotic products in providing health benefits are expected to complement the growth of probiotic products over the period of time.

8.10 Conclusion

Probiotic microorganisms have become well-known from the last few decades as a consequence of the continuous research that provided scientific basis for positive impacts of probiotics on human health. In addition, the rising health awareness among the people in rapidly aging global population provides an opportunity for probiotic products and ingredients to capture a large market share. Probiotic supplements are not only practiced for the prevention/treatment certain disorders but these also provide certain ingredients in the body to complement the diet. Although, a lot of scientific evidences are available on positive health effects of probiotic microorganisms, still further research is needed for strengthening the utilization of probiotics for preventive medicine and reducing the chance of many diseases.

Table 8.2 Microorganisms used in different products prepared throughout world

Species	Name of product	Company	Country
Bifidobacterium bifidum No.1 or *B. bifidum* 791	Bifidumbacterin Bifidumbacterin forte	Biomed Metchnikoff JSC, FSUC "SIC "Microgen," Patrner LTD	Russia
B. bifidum No.1 and Lysozyme	Bifilis	Ferment, LTD	London
Lactobacillus plantarum or *L. fermentum*	Lactobacterin	Biomed Metchnikoff JSC, FSUC "SIC "Microgen" IM-Bio	Russia
Enterococcus faecium L3	Laminolact	Avena, LTD	Watton, UK
L. acidophilus	Acilact	Lekko, LTD	Russia
Bacillus cereus IP 5832	Bactisubtil	Aventis Pharma International	France
L. acidophilus D-75, D-76	Vitaflor	State Institute of Fine pure Biochemicals	New York
Escherichia coli M-17	Colibacterin	FSUC "SIC "Microgen"	Russia
L. acidophilus, *B. infantis*, *E. faecium*	Linex	Sandoz, Lek	Slovenia
*B. bifidum*No.1 and *E. coli* M-17	Bificol	Biomed Metchnikoff JSC, FSUC "SIC" "Microgen"	Russia
B. longum, *E. faecium* SF68	Bifiform	Ferrosan	Denmark
L. rhamnosus HN001 (DR20) *L. acidophilus* NCFM *B. lactis* HN019 (DR10)	Sold as ingredient	Danisco	Madison, Wisconsin
B. animalis ssp. *lactis* BB-12	–	Chr. Hansen	Denmark
L. fermentum VRI003 (PCC)	Sold as ingredient	Probiomics	Eveleigh, Australia
B. animalis ssp. *lactis* HN019 (DR10)	Howaru Bifido	Danisco	Denmark
L. paracasei CRL 431 *L. acidophilus* LA5	Sold as ingredient	Chr. Hansen	Milwaukee, Wisconsin
B. longum BB536	–	Morinaga Milk Industry	Japan
B. breve strain Yakult *L. casei* strain Shirota	Yakult	Yakult	Tokyo, Japan
E. coli Nissle 1917	Mutaflor	Ardeypharm	Germany

(continued)

Table 8.2 (continued)

Species	Name of product	Company	Country
B. animalis DN173 010 (“*Bifidus regularis*”)	Activia yogurt	Dannon	Tarrytown, New York
L. acidophilus LA-5	-	Chr. Hansen	Denmark
L. johnsonii Lj-1	LC1	Nestle	Lausanne, Switzerland
L. casei DN114001	Actimel/DanActive	Danone	France
L. rhamnosus 271	Sold as ingredient	Probi AB	Lund, Sweden
L. casei F19	Cultura	Arla Foods	Denmark
L. rhamnosus GG (“LGG”)	Danimals Culturelle; Dannon	The Dannon Company Valio Dairy	Tarrytown, New York Helsinki, Finland
*L. paracasei*St11	Lactobacillus fortis	Nestlé	Switzerland
L. salivarius UCC118	–	University College Cork	Cork, Ireland
Lactococcus lactis L1A	–	Norrmejerier	Sweden
L. acidophilus LB	Sold as ingredient	Lacteol Laboratory	Houdan, France
L. reuteri ATTC55730	–	BioGaia Biologics	Sweden
L. rhamnosus GM-020 *L. paracasei* GMNL-33 *L. paracasei* 33	Sold as ingredient	Gen Mont Biotech	Taiwan
*L. rhamnosus*LB21	Verum	Norrmejerier	Sweden
Bacillus coagulans BC30	Sustenex, Digestive Advantage and sold as ingredient	Ganeden Biotech Inc.	Cleveland, Ohio
B. breve, Yakult	Bifiene	Yakult	Japan
S. cerevisiae boulardii	Florastor	Biocodex	Creswell, Oregon
B. infantis 35,264	Align	Procter and Gamble	Mason, Ohio
Bacillus coagulans GBI-30, 6086	GanedenBC30	Ganeden Biotech	USA
L. acidophilus R0052 *L. rhamnosus* R0011	Sold as ingredient	Institut Rosell	Montreal, Canada
E. coli M-17	ProBactrix	BioBalance	New Zealand
B. lactis Bb-12	Sold as ingredient	Chr. Hansen	Milwaukee, Wisconsin
L. acidophilus DDS-1	–	Nebraska Cultures	Walnut Creek, US

(continued)

Table 8.2 (continued)

Species	Name of product	Company	Country
L. casei DN-114001 ("L. casei Immunitas")	DanActive fermented milk	Danone	Paris, France
L. acidophilus NCFM	–	Danisco	Denmark
L. rhamnosus GR-1 *L. reuteri* RC-14	Femdophilus	Urex Biotech Jarrow Formulas Chr. Hansen	London, Ontario, Canada Los Angeles, California Milwaukee, Wisconsin
L. casei CRL431	–	Chr. Hansen	Denmark
L. plantarum 299 V	Sold as ingredient; Good Belly juice product	NextFoods Probi AB	Boulder, Colorado Lund, Sweden
L. casei Shirota	Yakult	Yakult	Japan
L. reuteri ATCC 55,730 ("*L. reuteri Protectis*")	BioGaia Probiotic chewable tablets or drops	BioGaia	Stockholm, Sweden
L. johnsonii La1	–	Nestlé	Switzerland
Lactococcus lactis L1A *L. rhamnosus* LB21	Sold as ingredient	Essum AB	Umea, Sweden
*L. plantarum*299V	GoodBelly/ProViva/TuZen	NextFoods Probi Ferring	–
B. longum BB536	Sold as ingredient	Morinaga Milk Industry Co. Ltd.	Zama-City, Japan
L. rhamnosus ATCC 53013	Vifit and others	Valio	Finland
L. paracasei F19	Sold as ingredient	Medipharm	Des Moines, Iowa
Saccharomyces cerevisiae (*boulardii*) lyo	DiarSafe and others	Wren Laboratories and others	United States
L. plantarum OM	Sold as ingredient	Bio-Energy Systems, Inc.	Kalispell, Montana
L. gasseri EB01 *L. rhamnosus* PBO1	EcoVag	Bifodan	Denmark
S. rattus JH145 *Streptococcus oralis* KJ3 *S. uberis* KJ2	ProBiora3 EvoraPlus	Oragenics Inc.	Alachua, Florida

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