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Indian probiotic food: Gut health management: An updated review

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Abstract

Probiotics are defined as live microorganisms which, when ingested in adequate amounts, confer health benefits on the host. Chronic diseases such as diabetes, non-alcoholic fatty liver disease, coronary artery disease, gynecological discorders, a variety of chronic inflammatory disorders with an immune basis, and some forms of cancer are increasing in incidence around the world and in India, and may be attributable in part to rapid changes in our lifestyle. Yeast exhibit several beneficial properties, such as the prevention and treatment of diarrhea, the production of antimicrobial agents, the prevention of pathogen adherence to intestinal sites, the maintenance of microbial balance, the modulation of the immune system, antibiotic resistance, amongst others. The probiotic industry in India is experiencing strong growth, fuelled by increasing consumer awareness of gut health and a rising demand for functional foods. The market has nearly doubled in the past five years, reaching ₹2,070 crore (approximately US$242 million) in 2025. In terms of segment, probiotic food and beverages was the largest revenue generating form in 2023 in India. Probiotic dietary supplements is the most lucrative form segment registering the fastest growth during the forecast period. In terms of revenue, India accounted for 6.5% of the global probiotics market in 2023. Some popular probiotic-rich foods in India include yogurt (dahi), buttermilk (chaas), idli, dosa, dhokla, kanji, and various pickles (achaar). Fermented soybean products like tempeh and natto, as well as kefir, also offer probiotic benefits. The probiotic effects ranged from antimicrobial activity to gut flora restoration, immune modulation and glycemic control, antioxidant properties, cholesterol reduction, bile salt resistance, adherence to the gut lining, pathogen inhibition, and biofilm formations. The microbiome of a healthy individual consists of balanced populations of both beneficial and harmful microorganisms. The oral administration of S. *Saccharomyces boulardii* changes in the gut microbial combinations in various clinical reports.

Keywords: Dosa; Dhokla; Probiotics; India; Idli; *Lactobacillus gasseri*; *Saccharomyces boulardii*; Yeast

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1. Introduction

Probiotics are living microorganisms, principally bacteria or yeasts that are safe for human consumption and, when ingested in sufficient quantities, have beneficial effects on human health, beyond basic nutrition[1, 2-20, 22]. There is considerable public interest in India in the consumption of probiotic foods [1-16]. According to Chalannavar et al., (2025) [1, 2] and Jayashree et al., (2025) [112], probiotics are defined as live microorganisms which, when ingested in adequate amounts, confer health benefits on the host [1, 2]. Chronic diseases such as diabetes, non-alcoholic fatty liver disease, coronary artery disease, a variety of chronic inflammatory disorders with an immune basis, and some forms of cancer [1, 2, 104-112] are increasing in incidence around the world and in India, and may be attributable in part to rapid changes in our lifestyle [1-20, 22, 104-112]. An ideal probiotic preparation should have the characteristics such as high cell viability, and thus, they must be resistant to low pH and acids, ability to persist in the intestine even if the probiotic strain cannot colonize the gut, and adhesion to the gut epithelium to cancel the flushing effects of peristalsis [22- 112]. They should be able to interact to send signals to the immune cells associated with the gut, and they should be of human origin, should be non-pathogenic, resistance to processing, and must have the capacity to influence local metabolic activity [1-22].

Moonsamy et al., (2024) [30, 31] reported that the use of probiotics has been gaining popularity in terms of inclusion into human diets over recent years [30]. Based on properties exerted by these organisms, several benefits have been elucidated and conferred to the host [1-30]. Bacteria have been more commonly used in probiotic preparations compared to yeast candidates[30]. Generally, only bacterial and yeast organisms have been classified as probiotics, with the most common being *Lactobacilli, Bifidobacteria, Enterococci, Faecalibacterium, Clostridia*, and more recently *Propionibacteria* [30]. However, yeast exhibit several beneficial properties, such as the prevention and treatment of diarrhea, the production of antimicrobial agents, the prevention of pathogen adherence to intestinal sites, the maintenance of microbial balance, the modulation of the immune system, antibiotic resistance, amongst others [1-30]. The probiotic effects ranged from antimicrobial activity to gut flora restoration, immune modulation and glycemic control, antioxidant properties, cholesterol reduction, bile salt resistance, adherence to the gut lining, pathogen inhibition, and biofilm formations [1-30, 112].

Saccharomyces boulardii is by far the most studied strain [1-30]. *Saccharomyces boulardii*, *Saccharomyces cerevisiae*, and *Candida* spp. are the most common yeasts used as probiotics, and are used most for the treatment of *Clostridium difficile* diarrhea [1-30]. *Saccharomyces boulardii* was first isolated from litchis in Indochina and is not autochthonous in the microbiome [1-30]. However, this non-pathogenic yeast, amongst other species such as *Saccharomyces cerevisiae, Pichia kudriavzevii, Candida famata, Kluyveromyces lactis, Debaryomyces hansenii*, and *Issatchenkia orientalis*, have been found to confer the probiotic effects to the host, advocating their use for health benefits [1-30]. However, the potential use of other yeast candidates, such as *Kluyveromyces lactis* and *Debaryomyces hansenii*, amongst others, have also been evaluated[1-30-112]. In the following section, the role of yeast and bacterial probiotics, updates on Indian probiotic industries have been discussed and updated.

2. Yeast Probiotics

Yeasts that have been classified as generally regarded as safe (GRAS) have been shown to have several health implications on the human host [1-30, 44-47]. These influences may include but are not limited to being effective on gut microbiota dysbiosis and possess anti-inflammatory, anti-proliferative, anti-cancer and anti-allergenic properties [1-33]. Furthermore, a special focus has been made regarding the production considerations for yeast-based probiotics and their formulation into different delivery formats[1-30, 44-47, 112]. Most yeast isolates that have been isolated from the human microbiome include *Candida albicans*, *Torulopsis glabratra, Candida ropicalis*, *Malassezia* spp., and *Saccharomyces* spp. [4,7, 44, 47, 44, 47]. Other probiotic yeast candidates include *Cryptococcus* spp., *Candida famata*, C. *tropicalis, Debaryomyces hansenii,, Issatchenkia orientalis, Kluyveromyces lactis, Kluyveromyces marxianus,, Metschnikowia gruessii,, Pichia jadinii, Pichia kluyveri*, *Pichia kudriavzevii*, *Pichia pastoris* , *Pichia guilliermondii,, and Wickeramomyces anomalus* [1-34]. The ability to resist low pHs, the presence of digestive enzymes, bile salts, and organic acids make these organisms ideal candidates to serve as probiotics. Moonsamy et al., (2024) [30, 31] also indicated that the use of yeasts, both wild-type and genetically modified candidates, can extend beyond gut health to support skin, the respiratory system, and overall immune health[1-33].

In the early 1990s, Nobel Laureate Elie Metchnikoff (1845–1916), whilst working in Bulgaria, noticed how a certain population in the country had lived a longer life span than others. Upon further investigation, the researcher discovered that this population con- sumed fermented drinking yoghurt daily [1-30]. This preliminary study laid a foundation for the study of probiotics and the use of functional foods as a dietary supplement containing beneficial microorganisms

containing either bacterial or yeast cultures or a combination of both. *S. boulardii*, a known yeast probiotic, has been isolated from dairy products, including milk, yoghurt, cream, cheese, and kefir [1-34]. Dairy products have been the most utilized carrier/formulation of bacterial probiotics with limited applications for yeast strains [1-34]. Upon assessing the literature landscape, it was found that the *Saccharomyces, Pichia, Candida, Meyerozyma, Debaryomyces*, and *Kleuveromyces* genera found in different types of fermented vegetables, cheese, and kefir [1-34]. Additionally, *Wickerhamomyces, Torulaspora, Yarrowia*, and *Metschnikowia* are the other yeast genera present in fermented fish, legumes, and meat products [1-34, 44-47]. The use of dairy- based food as a means for probiotic delivery is largely affected by poor shelf-life[1-34]. As a result, non-dairy-based probiotic formulations have been evaluated for their potential as an alternative solution. The functionality of yeasts as probiotics is not only limited to their use as whole-cell therapeutics[1-34]. Furthermore, the metabolic by-products, such as folic acid and β-glucan, may have an effect on cancerous cells by being able to affect pathogenic bacteria; inactivate carcinogenic compounds, particularly those derived from food; improve intestinal barrier function; and modulate host immune responses, antitoxic functions, apoptosis, and anti-proliferative effect[1-34, 44-47].

Yeast probiotic antagonism is facilitated by various factors, including the production of bioactive compounds such as enzymes, antioxidants, antimicrobial agents, and volatile organic compounds [1-34]. Probiotics secrete proteases, amylases, lipases, and cellulases. These enzymes contribute to digestion, the maintenance of balance in the gut microbiome, and functions that support the intestinal barrier [1-30]. Additionally, chitinases and glucanases also aid in antagonistic function in yeast probiotic [1-30]. Another mode of action in which probiotics regulate antagonistic functions is through the competitive exclusion of pathogens for both nutrients and binding sites. The antioxidant activity of *S. boulardii* has also been shown to play a role in bio- therapeutic properties (the reduction of oxidative stress) of this probiotic [1-34]. Other modes of action that probiotics utilize include hydrophobicity, auto-aggregation, and biofilm formation. All these ultimately contribute to the modulation of immunity on the hosts [1-30-50].

The microbiome of a healthy individual consists of balanced populations of both beneficial and harmful microorganisms [1-34, 44-47]. These play a major role in providing the host with physiological, metabolic, and immune functions that are useful in warding off pathogens, and any imbalance results in increased levels of harmful microbes[1-34]. There is a mutual relationship between the gut and human flora [1-34, 44-47]. The colon harbors the highest population; however, only <0.1% of these are fungi, and *Saccharomyces* and *Candida* are the dominant genera [1-34-55]. As the most commercialized probiotic yeast, *Saccharomyces boulardii* is widely used in the treatment of gut-related diseases, such as Traveler's diarrhea, AIDS-associated syndrome, irritable bowel syndrome, and Crohn's disease[1-34]. The oral administration of *Saccharomyces boulardii* alone or in combination with other probiotics has been proven to induce changes in the gut microbial combinations in various clinical reports [1-34]. *Saccharomyces boulardii* influences the host microbiome through the direct inhibition of pathogenic intestinal microbes and by normalizing the pH of the gastrointestinal tract; this is achieved by reducing the pathogenicity of toxic microorganisms [1-34].

Yeasts have shown the ability to produce enzymes that synthesize milk proteins. However, this property is only activated once lactic acid bacteria (LAB) break down the lactose present in dairy-based foods into glucose and galactose [1-34]. Once this conversion is finished, both the yeasts and LAB cultures use the available sugar as a carbon source to grow and replicate [1-30]. Furthermore, yeasts such as *Saccharomyces boulardii* should be included in products solely as a probiotic, as it offers no benefits to some dairy products, such as yoghurts[1-30]. However, in cheeses, yeasts make important contributions to the process of cheese maturation[1-30]. They contribute to the development of cheese flavor and texture through proteolysis, lipolysis, and the utilization of lactic acid [1-30-60].

It has been found that in most instances, yeasts such as *Saccharomyces boulardii* do not naturally occur in food and are instead added as a supplement. *Saccharomyces boulardii* is commonly added into cereals and legumes to stabilize nutrients using its enzymes [1-30]. One of the nutrients that is present and broken down by the organisms is phytate or phytic acid, which is the primary storage compound for phosphorus in seeds[1-30]. This compound binds to metals, rendering them insoluble and thus inaccessible as nutritional components [1-30-56]. *Saccharomyces boulardii* is added to synthesize the phytates using phytases, which in turn enhance the bioavailability and absorption of important essential minerals, such as iron, zinc, magnesium, and phosphorus [1-30]. *Saccharomyces boulardii* be supplemented with cereal-based or low-water-activity foods to be used as vehicles for the addition of this probiotic yeast[1-30]. Additionally, the application of *Saccharomyces boulardii* has been successfully added to fermented drinks, which include beers, grain drinks, malts, and fruit/veggie juices[1-34]. Other avenues being explored for probiotic administration indicated that meat and meat products are emerging as potential routes when supplemented with probiotics [1-34]. The most common probiotics used in meat products are mainly from the *Lactobacillus* and *Bifidobacterium* genus, and yeasts such as *Saccharomyces boulardii* may be explored in future research [1-34-67]. Probiotics in meat products have been used as bioprotective cultures against harmful and pathogenic bacteria. This probiotic effect is mainly centered on the production of bacteriocins, which aid the host [1-34-60].

3. Indian Probiotcs Food Industries: Market Growth

The probiotic industry in India is experiencing strong growth, fuelled by increasing consumer awareness of gut health and a rising demand for functional foods. The market has nearly doubled in the past five years, reaching ₹2,070 crore (approximately US$242 million) in 2025 [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 112]. According to The Economic Times. Pharmaceutical companies and dairy brands are major players, with a growing presence from startups. The Indian probiotics market generated a revenue of USD 5,738.1 million in 2023 and is expected to reach USD 16,151.1 million by 2030. The Indian market is expected to grow at a CAGR of 15.9% from 2024 to 2030 [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. In terms of segment, probiotic food and beverages was the largest revenue generating form in 2023 in India. Probiotic Dietary Supplements is the most lucrative form segment registering the fastest growth during the forecast period. In terms of revenue, India accounted for 6.5% of the global probiotics market in 2023[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111]. Country-wise, U.S. is expected to lead the global market in terms of revenue in 2030. In Asia Pacific, China probiotics market is projected to lead the regional market in terms of revenue in 2030. India is the fastest growing regional market in Asia Pacific and is projected to reach USD 16,151.1 million by 2030 [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Gut-friendly products are a growing focus for the dairy industry in India, where probiotics have long been a central part of the country's cuisines [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Brands are launching probiotics, promoting the products through educational and advertisement campaigns with encouraging results. "Rising disposable income, growing consumer interest towards health and wellness, and enhanced favorability towards dairy-based products are driving growth in the category [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Though currently a niche segment, the probiotic dairy products category is expected to grow at an annual compound growth of around 25% by 2032, as per industry estimates. India-based management consultants IMARC Group put the sales of probiotic drinks, curd and yogurt in India at $2.2bn in 2024 and forecast they will reach $10bn by 2033, representing a compound annual growth rate (CAGR) of 17.8% [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111]. These growth projections are encouraging Indian dairy companies. Hyderabad-based Heritage Foods launched a probiotic buttermilk. It is growing very rapidly and by next year it would probably be double current volumes. The success of probiotic products has been delivered by supermarket chains and home delivery services[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. While supermarket chains account for a substantial portion of these sales, the trend is gaining momentum due to the rapid growth of organized home delivery. By contrast prebiotics, probiotics, and postbiotics. which are an ingredient group that has become closely linked with gut health in other markets, under-index for positive health perceptions in India [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111]. With a large percentage of the Indian population lactose intolerant or vegetarian and vegan in their dietary habits, there's increased demand for plant-based and dairy-free probiotics [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Producers are taking notice, creating probiotics from sources such as soy, coconut, and fermented vegetables. The alternatives appeal not just to dietary needs but to the environmentally sensitive looking for sustainable choices. The increase in plant-based probiotics is a sign of a larger trend towards inclusive and ethical consumption patterns. With the market growing, we can anticipate more innovation in this category, providing consumers with a greater range of options that are aligned with their health and ethical concerns[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111].

Indian consumers are increasingly incorporating probiotics into daily diets in the form of functional foods and drinks [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Foods such as probiotic yogurts, beverages, and fortified snacks provide a handy means of promoting gut health and immunity. The trend is also in line with the increasing requirement for health food that is adapted to busy lifestyles. Companies are innovating by providing varied forms, including plant-based and dairy-free alternatives, to suit different dietary needs [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. The popularity of such products is due to their potential to offer health benefits in addition to normal nutrition, and thus they are well-liked by health-conscious consumers. With growing awareness of the connection between gut health and overall health, the functional food category is likely to maintain its strong growth in India [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. In India, there is a growing awareness about health and wellness, with consumers increasingly focusing on prevention rather than treatment. The prevalence of conditions like *Vulvovaginal candidiasis* (VVC), affecting 10% to 35% of women, highlights the importance of maintaining overall health. This shift in mindset is driving the demand for natural, holistic solutions such as probiotics in India [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Probiotics, known for their benefits in gut health, digestion, and immunity, are gaining popularity as consumers recognize their long-term health advantages. With the influence of media, healthcare professionals, and lifestyle coaches, more individuals are turning to functional foods like probiotics as part of their balanced diets. This cultural shift towards wellness is significantly fuelling the Indian probiotics market growth[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111].

The Indian probiotics market is witnessing rapid expansion, driven by growing consumer awareness of digestive health, rising incidences of gastrointestinal and lifestyle-related disorders, and increased demand for functional foods and beverages [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. It includes both established players and new brands competing to gain consumer attention in health and wellness. Innovation is one of the primary differentiators, with businesses creating a range of product formats like capsules, powders, yogurts, and beverages to suit various consumer groups.

The market is also seeing more and more collaboration among food technologists, scientists, and marketing professionals to provide scientifically-supported and consumer-friendly offerings[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Digital marketing, influencer marketing, and e-commerce marketing are commonly practiced to foster brand loyalty. Compliance with regulations, quality control, and product differentiation continue to be key to competitiveness. The market's growth opportunities in India continue to entice new players, increasing competition and fuelling ongoing innovation[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111].

With India launching a comprehensive programme to prevent and control lifestyle diseases, the potential of probiotics as a preventive intervention to be integrated in our lifestyle practices is significant [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. The Indian probiotic market is driven by emphasis on preventive health care, changing demographics and emergence of wellness related chains. The widespread availability of e-commerce websites has drastically altered the distribution of probiotic products in India. It has become easier for consumers to access a variety of probiotics through brand websites and online stores[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111]. It promotes increased convenience, customized shopping, and access to descriptive product information. Direct-to-consumer models permit brands to have closer interactions with consumers, collect feedback, and customize products according to individual needs [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111]. The online environment also enables educational content to guide consumers into well-informed decisions regarding the use of probiotics. With internet penetration and digital literacy increasingly on the rise, the e-commerce and DTC channels are likely to play a crucial part in the India probiotics market outlook[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. When referring to probiotic products, these include functional foods, food additives and supplements, animal and/or human drugs/therapeutics, cosmetic raw materials, fermented milk, kefir, amongst others [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. As consumers are becoming more health conscious, their search for probiotic additives has increased. In another development, due to high levels of dietary intolerance, there is also an increase in demand for non-diary-based formulations containing probiotics in India [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111].

Probiotics have always been an integral part of Indian cuisine and *Ayurvedic* texts and western-style dairy products[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. In 2023, the Food Safety and Standards Authority of India (FSSAI) published a book entitled *Healthy Gut, Healthy You – Traditional Recipes with Potential Probiotic Benefits*. It stressed that probiotics have always been an integral part of Indian cuisine and *Ayurvedic* texts have elaborated on the effects of fermented milk products in preventing and treating many digestive disorders [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Indian food and medicine is culturally inclined towards gut health even before it became a popular health trend in western markets. The government of India has also been supportive in encouraging improved dietary habits, and this has indirectly supported the probiotics industry [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Initiatives promoting improved nutrition practices have helped raise functional foods such as probiotics to public awareness. By providing transparent guidelines on labelling and safety for probiotic products, the regulatory agencies have also fostered consumer confidence. This regulatory clarity stimulates innovation and investment on the part of companies, which in turn creates an increased diversity of probiotic options for consumers[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Moreover, the Indian government's emphasis on encouraging health and wellness through various public health campaigns is likely to further propel consumer demand for probiotics. In India, several foods naturally contain probiotics or are prepared through fermentation processes that introduce beneficial bacteria [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111].

Some popular probiotic-rich foods in India include yogurt (dahi), buttermilk (chaas), idli, dosa, dhokla (Karnataka, Gujarat, Goa and Maharashtra) kanji, and various pickles (achaar), Koozhu (Tamilnadu), Kinema from soyabeans in Darjeeling, Ambali (Karnataka), Pazhaiya soru (Tamilnadu), Kallappam (South India), Chhurpi from Yaks milk in Arunachal Pradesh, Chhu, philu, shyow from Yaks or cow milk in Arunachal Pradesh, Mohi or somar from cow milk, Khadi from buttermilk in Gujarat, Tungrymbai from soyabeans in Meghalaya, wadi from blackgram in Maharashtra, Gujarat, Punjab, wari in UP, Kulu (Himachal Pradesh), Rabdi (Rajasthan), Bhaturu, Mor kuzhambu, Khalpi from cucumber (Sikkim), Eup from bamboo shoots (Arunachal Pradesh), Soidon from bamboo shoots (Manipur), soibum from bamboo shoots in Nagaland, sinki from Radish roots in North East India, and Gundrum from leaves of cauliflower, radish and mustard in Arunachal Pradesh [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111]. Fermented soybean products like tempeh and Natto, as well as kefir, also offer probiotic benefits. Additionally, some Indian dishes like khaman, appam, and handvo are fermented and thus probiotics [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111]. With a regulatory regime that is open to new health products, the stage is set or the probiotics sector to continue on its upward path in India. Probiotics market with detailed profiles of all major companies in India including: Amul (GCMMF), Epigamia (Drums Food International Private Limited), Heritage Foods Limited, Mother Dairy Fruits and Vegetables Pvt. Ltd., Milkmantra Dairy Pvt. Ltd., Milky Mist Dairy Food Private Ltd.Nestle India Limited (Nestle SA), Yakult Danone India Pvt. Ltd [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97].

Natural probiotics are living microorganisms that offer health benefits when consumed adequately [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97, 111]. Unlike synthetic supplements, natural probiotics are found in certain foods that undergo fermentation, allowing beneficial bacteria to thrive. Natural probiotics work by colonizing the gut and promoting a healthy balance of bacteria[1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. The fermentation process in natural probiotic foods breaks down sugars and starches, leading to lactic acid formation and enhanced flavour [1- 97-103-111]. This process boosts the food's probiotic content, which includes various strains beneficial for gut health. Natural probiotics can be sourced from various fermented foods that undergo a microbial transformation process [1- 97-103]. These include traditional dairy products like yoghurt and kefir, which are rich in probiotic bacteria such as *Lactobacillus* and *bifidobacterium*[1- 97-103]. Fermented vegetables are excellent sources of natural probiotics, offering a wealth of beneficial bacteria to support gut health Additionally, fermented vegetables like sauerkraut and kimchi offer a plant-based source of probiotics, containing strains like lactobacillus plantarum and lactobacillus kimchi[1- 97-103]. Other probiotic-rich options include fermented soy products like tempeh and miso, beverages like kombucha, and traditional fermented teas. Incorporating natural probiotic-rich foods into our diet can improve overall gut health and well-being[1- 97-103]. These foods offer diverse beneficial bacteria that support digestion, immune function, and more. Whether to take a probiotic supplement depends on individual health needs, dietary habits, and medical history. While natural probiotic-rich foods offer a source of beneficial bacteria, supplements can provide concentrated doses of specific strains. Probiotic supplements may sometimes be recommended to address specific health concerns[1- 97-103].

While natural probiotics offer numerous health benefits, consuming them excessively can lead to certain side effects, such as: Digestive issues such as abdominal discomfort, bloating, and diarrhoea [1- 97-103]. An imbalance in gut bacteria leads to dysbiosis and gastrointestinal disturbances. Exacerbation of existing digestive conditions like irritable bowel syndrome (IBS) or inflammatory bowel disease (IBD). Potential allergic reactions or sensitivities to certain probiotic strains. Increased risk of infection in individuals with compromised immune systems [1- 97-103].

The list of foods and beverages covers a range of possibilities that appeal to Indian palates are from traditional Indian staples such as curd, buttermilk, and fermented rice to tasty beverages such as kanji and lassi [1- 97-103]. All these probiotic foods maintain the balance of gut bacteria, strengthen immunity, and ensure overall health, making them simple and effective inclusions in our daily diet for improved gut health. Some of the top Indian probiotic foods and drinks which can have daily for a healthy gut: 1. Curd (Dahi) 2. Buttermilk (Chaas) 3. Kanji Lassi 5. Idli / Dosa 6. Dhokla 7. Handvo 8. Appam 9. Khusha 10. Khambral (Kombucha) 11. Pickles (Achaar) 12. Sauerkraut (Homemade) 13. Pakhala / Panta Bhat 14. Fermented Soy (Tempeh/Natto) 15. Khaman 16. Fermented Porridge 17. Kimchi (Indian-style) 18. Fermented Peanut Chutney 19. Ragi Malt (Fermented) 20. Kefir (Homemade) [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97].

Fermented vegetables are excellent sources of natural probiotics, offering a wealth of beneficial bacteria to support gut health. 1. Sauerkraut (Fermented cabbage packed with probiotics. A cup of sauerkraut contains about three billion CFUs.). 2. Kimchi (Spicy fermented cabbage, carrots, and radishes provide 10 billion CFU of probiotics per 100 g). 3. Pickled Cucumber (Cucumbers fermented in brine, offering probiotics along with a crunchy texture.). 4. Miso (Fermented soybean paste, commonly used in soups and sauces, is rich in probiotics and savoury flavour). 5. Tempeh (Fermented soybean cake, dense in protein and probiotics, with a nutty flavour and firm texture). 6. Natto (Fermented soybeans with a sticky texture, packed with probiotics and distinctive umami flavour.). 7. Pickled Beets (Beets pickled in vinegar or brine, providing probiotics and a slightly sweet, earthy taste). 8. Pickled Radish (Radishes fermented in brine or vinegar offer probiotics and a tangy, crunchy bite). 9. Pickled Carrots (Carrots pickled in brine or vinegar, rich in probiotics and featuring a sweet and tangy flavour) [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97].

While fruits may not be as commonly associated with probiotics as vegetables, certain fruits undergo fermentation and contain beneficial bacteria. Here are some fruits high in natural probiotics: 1. Apple (Apples contain 100 million bacteria per 240 g, promoting gut health). 2. Watermelon (Watermelon juice contains 108 to 109 CFU per ml). 3. Custard Apple (Custard apples are a good source of fibre and antioxidants, supporting digestive health). 4. Grapefruit (Grapefruit is high in vitamin C and fibre, promoting gut health and supporting digestion.) [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97]. Dairy products are staple sources of probiotics, offering convenient options to incorporate into daily meals. Here are some examples of probiotic-rich cereals and dairy products 1. Yoghurt (Yoghurt contains 90 billion to 500 billion CFU of probiotics per serving, aiding digestion.). 2. Kefir (Kefir is a fermented dairy drink that contains 500 billion CFU of probiotics per cup, supporting gut health and digestion). 3. Buttermilk (Buttermilk contains probiotic bacteria that can help maintain a healthy gut flora balance). 4. Sour Cream (Sour cream contains probiotic bacteria that promote gut health and may improve digestion). 5. Cottage Cheese (Cottage cheese is a good source of probiotics, which can help maintain a healthy balance of gut bacteria). 1. Chia Seeds (Chia seeds contain probiotics that support digestive health and contribute to a healthy gut microbiome). 2. Pistachios (Pistachios are rich in probiotics, aiding digestion and overall

gut health). 3. Flaxseeds (laxseeds are rich in probiotics, containing 3.3 billion CFU of probiotics per 100 g). 4. Kvass (Kvass is a traditional Slavic fermented beverage made from rye bread, rich in probiotics and antioxidants). 5. Soy Sauce (Soy sauce is a fermented condiment made from soybeans, wheat, and salt, containing beneficial probiotics). 6. Kombucha (Kombucha is a fermented tea beverage rich in probiotics, promoting gut health and offering various health benefits). 7. Turshi (Turshi is a Middle Eastern fermented vegetable dish that provides probiotics and a unique tangy flavour) [1, 2, 3-22, 26-34, 53-60, 76, 80, 88, 97].

The use of probiotics has gained significant momentum in terms of advocation for use amongst the global population[1-97-103]. The advent of genetically engineered probiotics may be more effective, have cheaper production costs, and have higher stability and specificity for the treatment of a plethora of human ailments and disorders [3]. However, the application of these GMOs faces significant hurdles, particularly in terms of biosafety considerations upon ingestion by the host. Several clinical trials have been conducted to date[1- 97-103]. However, their effect cannot be guaranteed to achieve their intended effect, which therefore prevents effective deployment[1- 97-103]. With more in-depth understanding into the human microbiome and its relation to disease mechanisms, the safety and endorsement of engineered probiotics, both bacterial and yeast, may gain acceptance for use, particularly when conventional health strategies prove ineffective [1- 97-103]. Additionally, in terms of advances in probiotic production and formulation, significant strides have been made to deliver highly efficacious probiotic treatments for the treatment of several human metabolic disorders[1- 97-103].

4. Insufficient intake of Natural Probiotics: Health Issues

Insufficient intake of natural probiotics can pose several health risks. Here are some potential health risks associated with not getting enough natural probiotics: Weakened immune system and increased susceptibility to infections [1- 97-103]. An imbalance in gut bacteria leads to inflammation and chronic diseases. Increased risk of skin problems like acne and eczema. Higher likelihood of mood disorders such as anxiety and depression. Impaired nutrient absorption and deficiencies. Elevated risk of antibiotic-associated diarrhoea[1- 97-103]. Natural probiotic deficiency disrupts the gut microbiome balance, causing various health issues, such as: **Digestive Problems**: Individuals lacking natural probiotics may experience digestive issues such as bloating, gas, diarrhoea, or constipation[1- 97-103]. These symptoms indicate an imbalance in the gut microbiota, affecting digestion and nutrient absorption. **Weakened Immune System**: A compromised gut microbiome due to probiotic deficiency can weaken the immune system, making individuals more susceptible to infections, colds, and other illnesses. Frequent infections or prolonged recovery times may indicate a deficiency in beneficial bacteria[1- 97-103]. **Skin Conditions**: Imbalances in the gut microbiome can manifest as skin problems such as acne, eczema, or psoriasis. Skin issues often stem from inflammation and disruptions in the gut-skin axis, highlighting the importance of gut health for skin wellness[1- 97-103]. **Mood Disorders**: The gut-brain connection plays a crucial role in mental health, and probiotic deficiency may contribute to mood disorders such as anxiety, depression, or mood swings. Restoring gut balance with probiotics can potentially alleviate symptoms and improve overall well-being[1- 97-103]. **Food Intolerances**: Natural probiotics aid in the breakdown of food and the absorption of nutrient Deficiencies in beneficial bacteria may lead to food intolerances or sensitivities, causing discomfort, bloating, or other gastrointestinal symptoms after eating certain foods[1- 97-103]. **Chronic Fatigue**: A disrupted gut microbiome can affect energy levels and contribute to feelings of fatigue or lethargy. Individuals experiencing persistent fatigue despite adequate rest and nutrition may benefit from addressing potential probiotic deficiencies[1- 97-103].

5. Health Benefits of Natural Probiotic Rich Foods

Integrating natural, probiotic-rich foods into our daily meals can yield many health advantages, fostering gut wellness and overall vitality[1- 97-103]. These foods are abundant in beneficial bacteria that can positively impact various facets of health [1- 97-103]. Some of compelling benefits that natural probiotic-rich foods offer: Enhanced Immune Function: A balanced gut microbiome is essential for a strong immune system, and probiotics play a crucial role in supporting immune function and preventing infections [1-97-103-112]. Improved Digestion and Nutrient Absorption: Probiotics promote a healthy gut environment and aid in the efficient digestion and absorption of food and essential nutrients. Protection Against Hostile Bacteria: Probiotics compete with harmful bacteria for resources in the gut, helping to prevent the growth of pathogenic microbes and reduce the risk of infections[1- 97-103]. Reduced Inflammation: Probiotics have anti-inflammatory properties that can help reduce inflammation in the gut and throughout the body, lowering the risk of inflammatory conditions[1- 97-112]. Improved Intestinal Health: Natural probiotics contribute to a balanced gut microbiome, promoting intestinal health and reducing digestive issues such as bloating and constipation. Enhanced Ability to Fight Infections: Probiotics help strengthen the body's natural defences, making it more resilient against infections caused by harmful pathogens[1- 97-103-112]. Improved Bowel Movements: Probiotics can help regulate bowel movements and alleviate gastrointestinal disorders such as irritable

bowel syndrome (IBS) symptoms. Decreased Harmful Bacteria: Consumption of probiotic-rich foods can lead to a reduction in the population of harmful bacteria in the gut, creating a healthier microbial balance[1- 97-103]. Enhanced Vitamin Production and Mineral Absorption: Certain strains of probiotics can produce vitamins and enhance the body's ability to absorb minerals from food, contributing to overall health and well-being[1- 97-103-112].

6. Probiotic Bacteria

Probiotics are emerging as a fascinating field in health. Thus, efforts should be made to increase awareness among the chemists to encourage the implementation of the concept, "probiotic rather than medicine[1- 97-103-112]. *Lactobacilli* are known to play an important role in the maintenance of human health by stimulating the natural immunity and contributing to the balance of microflora, mainly through competitive exclusion and antimicrobial activity against pathogenic bacteria[1- 97-103]. Several species of obligately homofermentative, facultatively heterofermentative, and obligately heterofermentative lactobacilli have been found in the oral cavity, with *Lactobacillus gasseri*, *Lactobacillus salivarius, Lactobacillus plantarum, Lactobacillus rhamnosus,* and *Lactobacillus fermentum* being the most prevalent[1- 97-103]. *Lactobacilli* are widely used for the manufacture of fermented foodstuffs and, as such, have been consumed for centuries[1- 97-103]. During recent decades, lactobacilli have gained importance as probiotics, i.e. "live microorganisms which when administered confer a health benefit on the host." Consumption of products containing probiotic lactobacilli has been shown to reduce caries risk and oral carriage of mutans streptococci[1- 97-103]. *L. rhamnosus* strain GG (LGG) was the first probiotic to have received the most clinical attention to date. It was discovered in 1985 by developing a list of ideal qualities for probiotics. LGG has been found to have beneficial effects on intestinal immunity[1- 97-103]. It increases the number of IgA and other immunoglobulin secreting cells in the intestinal mucosa, stimulates the local release of interferons, and facilitates antigen transport to underlying lymphoid cells, which serves to increase antigen uptake in Peyer's patches[1- 97-103]. In order to assess whether naturally occurring oral lactobacilli have probiotic properties, lactobacilli were isolated from the saliva and plaque of children and adolescents, with or without caries lesions. Twenty-three Lactobacillus spp. completely inhibited the growth of all mutans streptococci tested. Species with maximum interference capacity against mutans streptococci included *Lactobacillus paracasei, L. plantarum,* and *L. rhamnosus*[1- 97-112].

Bifidobacteria produce antimicrobial substances that are effective against many harmful gram-positive and gram-negative bacteria[1- 97-103]. In fact, some species of *bifidobacteria* (including *Bifidobacterium infantis, Bifidobacterium breve,* and *Bifidobacterium longum*) bind to the intestinal mucosa and prevent attachment of pathogenic coliform bacteria[1- 97-103]. In the gut microflora of newborn, breastfed children, *bifidobacteria* represent one of the predominant groups of intestinal bacteria[1- 97-112].

7. Probiotics Production Strategies: Delivery methods

Probiotics are typically produced in stirred tank bioreactors, and growth conditions must be optimized per strain to achieve high-cell-density cultivations [1- 97-103-112]. Conventional yeast production requires a cultivation medium that typically contains carbon, nitrogen, vitamins, and trace metals [30, 31]. As the growth medium for probiotic production is a major consideration in process development, other non-conventional fer- mentation feedstocks are being considered to produce probiotics to minimize production costs. Agro-industrial residues, such as molasses, have been used for the cultivation of yeast probiotics [1- 97-103]. Molasses is a viscous, sugar-rich nutrient source that contains ~34% sucrose, glucose, fructose, and other minerals. In sugar-producing countries, such as India, Brazil and South Africa, ~10 million tons of sugar cane molasses is discharge making it a suitable nutrient feedstock for the large-scale production and manufacturing of probiotics[1- 97-103]. Furthermore, the food waste that is accumulated is rich in proteins, carbohydrates, and lipids, and therefore, it can be used as a suitable substrate to cultivate microorganisms[1- 97-103-112]. A key component of successfully commercializing a probiotic is the access to suitable manufacturing expertise, particularly in developing countries. Infrastructure requirements are capital intense and are limited in availability. Probiotic technologies require a production-scale pipeline that facilitates technology development from the small scale to manufacturing scale[1- 97-103]. Large enterprises that have shown efficient production competencies have skills and infrastructure that are currently producing a wide variety of products. Furthermore, the use of *CRISPR-Cas9* technology has been employed in demonstrating the enhanced probiotic potential of S. boulardii targeting various therapeutic functions. The practice of using probiotics has become widely accepted as a natural means to stimulate health for humans. Today, probiotics are used as health supplements in food, as pharmaceuticals, or chemical supplements [30, 31]. If a probiotic is classified as pharmaceutical or drug for the treatment of a disease or disorder, stricter requirements are necessary to substantiate the claims stated by the manufacturer[30, 31].

With regards to nutraceuticals, these are known as pharmaceutical alternatives that exert physiological benefits, are used to promote health, and support the structure or function of the human body [1-60-102]. Nutraceuticals are regarded as safe and less likely to have side effects; for example, probiotics are generally classified as nutraceuticals. The safety of probiotics is apparent due to the absence of toxicity in their populations. Additionally, most probiotics form part of the natural microbiome of the human host and therefore are applied back to a known environment [30, 31].

The most common delivery of probiotics is oral administration. This infers that the final step in the probiotic production process is the formulation and packaging of a probiotic into a delivery system that will be able to maintain the functionality of the probiotic through the harsh gastric environment[30, 31]. Conventionally used delivery systems include tablets, capsules, hydrogels, granules, and others [30, 31]. Another simple and effective methods to deliver probiotics into the dermis to regulate local dermal tissue are lacking [30, 31-112]. Yeast organisms, such as *S. boulardii*, have been used to treat skin ailments, such as acne, due to its anti-inflammatory properties. However, in this instance, the probiotic product was administered dermally, as one would expect, rather than as an oral supplement[30, 31-100]. Upon ingestion, the anti-inflammatory effects of the organisms are exerted towards the skin. S. boulardii demonstrated the ability to produce acetic acid, which is known to exert antifungal and antimicrobial effects. It is known that the most common and effective delivery route for probiotics is orally, as the intended destination for the product is the GI tract of the host [1-68-99]. However, during the processing of pharmaceutical products in general, such as tablets, high processing temperatures may be used to obtain aesthetically pleasing final products, which may kill the probiotic microorganisms of interest Fermented foods derived from animals and plants play an important role in human diets, as they contain beneficial microorganisms and compounds, including organic acids, ethanol, or antimicrobial compounds 1-[69-86]. These fermented foods are termed functional foods, which are foods that offer benefits that are more than their nutritional value and are divided into dairy and non-dairy options[30, 31].

Probiotics administered orally transit through the mouth, stomach, small intestine, and the colon, where they are subjected to saliva, acidic conditions, pancreatic juices, bile acids, and digestive enzymes as well as competition with host microbiota for nutrients and adhesion sites [1-85]. As a result, these probiotics are shown to lose viability upon transit[30, 31]. This is attributed to their high sensitivity to gastrointestinal conditions, extrinsic factors such as processing techniques and storage conditions, and intrinsic factors, which include water activity, antimicrobial components, and redox potential in the product matrix [1-86]. As stated above, a probiotic must maintain its viable activity to confer a therapeutic effect on the host. Typically, the intended viable population is targeted to be within the range of ~1.0 × 106 as a minimum up to a maximum of ~1.0 × 109 CFU·mL^{-1} viable cells to be considered effectively[30, 31]. Immobilization has been shown to be an effective method for the preservation of yeasts. It is typically used as a method of the entrapment of bioactive materials in protective matrices, and several reports have indicated its suitability to enhance the viability of many probiotic bacterial [30, 31] and yeast cultures [1-96]. However, in some instances, yeast probiotics cells were found to be not entirely protected, as a small percentage of the immobilized. material is still exposed to the external environment at the surface of the carrier and may as a consequence be deemed inefficient[30, 31].

Encapsulation is one of the most utilized methods for the protection of probiotics from harsh conditions and is defined as a process that involves the packaging of live probiotic cells in a food-grade material, such as polymers, proteins, and fats [30, 31-80]. In general, encapsulation is carried out in three steps[30, 31-70]. The initial step involves the incorporation of the microbial cells into a solid or liquid matrix. The second step includes spraying and the dispersion of the solid and liquid matrix, respectively[30, 31]. In the third phase, the stabilization of the system is carried out either through physical (evaporation, solidification, and coalescence) or chemical (polymerization) and gelation processes[30, 31-100]. Alginate, starch, k-carrageenan, chitosan, xanthan gum and cellulose acetate phthalate, gelatin, and milk proteins are some of the known polymers used in the encapsulation of probiotics to date [1-101–103]. The encapsulating materials are selected based on their ability to stabilize the final product, non-toxicity, and protective effect to the cells and because they possess a control release mechanism of the bioactive material in the intestinal tract [1-99,100]. Extrusion, spray drying, coacervation, liposomes, and emulsions are encapsulation techniques that are conventionally used in the food industry[30, 31].

8. Human Gastrointestinal (GI) tract: Role of Probiotics

According to Thursby and Juge [17, 30, 31], the human gastrointestinal (GI) tract (Figure 1, 2) represents one of the largest interfaces (250–400 m^2) between the host, environmental factors, and antigens in the human body[1-100]. In an average lifetime, around 60 tons of food pass through the human GI tract along with an abundance of microorganisms from the environment, which impose a huge threat on gut integrity [17-100]. The digestive process starts after the ingestion of food in the mouth, where the food is grinded by teeth into smaller particles, which are then emptied into

the mouth [17-103]. Due to the harsh environment in the stomach, the microbial community that exists is at a low concentration of ~102 cells[1-100]. Once food is passed from the stomach, the contents called chyme are emptied slowly into the small intestine[1-100]. In the small intestine, the duodenum, jejunum, and ileum are added; food is mixed with digestive juices from the pancreas, liver, and intestine, and the mixture is pushed forward for further digestion. In the small intestine, the microbial community can reach between 104 to 106 cells [17, 30, 31].Thereafter, all non-absorbed nutrients and waste matter that were not absorbed or used are passed into the colon, where there are between 1012 and 1014 cells[17, 30, 31]. Microorganisms (bacteria, archaea, and eukarya) that colonize the GI tract may exert several benefits to the host through a range of physiological functions[17, 30, 31]. These may include but are not limited to improving gut integrity or shaping the intestinal epithelium, har- vesting energy, protecting against pathogens, and regulating host immunity[17, 30, 31]. However, there is potential for these mechanisms to be disrupted as a result of an altered microbial composition known as dysbiosis [17, 30, 31-112]. Hursby and Juge [17, 30, 31-100] also added that the role of gut microbiota in human health has gained increasing attention[17, 30, 31-112] Several studies found that the human gut is colonized by diverse groups of bacteria species whose composition is strongly linked to every person's individual GI health[17, 30, 31-112]. There is also growing evidence that the administration of probiotics contributes to the microbial ecosystem, which exerts a variety of health benefits, including the prevention and/or treatment of diseases [17, 30, 31-112].

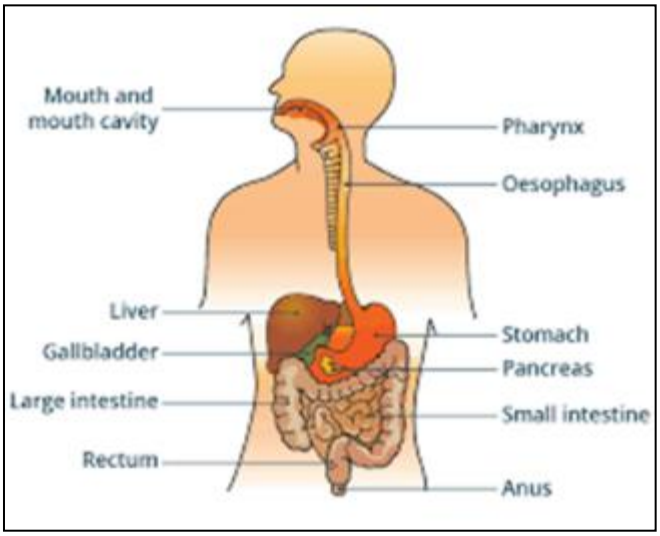

Figure 1 Digestive system

Microbial colonization of the GI tract mucosal tissue starts from infancy; these early life events have a long-standing consequence to the development of the human body and how it responds to diseases[17, 30, 31-100]. During development from infancy, the developing microbiome is responsible for facilitating tolerance to environmental exposures or contributing to the development of diseases, including inflammatory bowel disease, allergies, and asthma[17, 30, 31-100]. Recent studies have begun to define a critical period during early development in which the disruption of optimal host–commensal interactions can lead to persistent and in some cases irreversible defects in the development and training of specific immune subsets [17, 30, 31-112]. The role of the microorganisms that form the microbiome is to facilitate metabolism, such as breaking down indigestible complex polysaccharides into essential nutrients, such as vitamin K and B12, butyrate, and propionate [17, 30, 31-112]. The latter has been found to have a positive effect on the epithelial barrier integrity, which plays a crucial role in protecting microbiota from pathogenic microorganisms and avoiding inflammation in the gut[17, 30, 31-112].

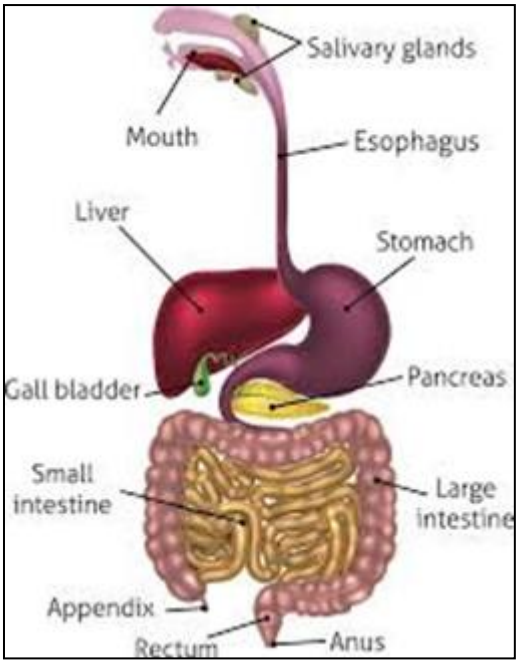

Figure 2 Detailed view of Digestive system

Researchers that focus on the composition of the human microbiome have found that the most abundant genera of fungi in the human gut are *Saccharomyces, Malassezia,* and *Candida* in descending order of abundance [1-100], with 8 out of 15 genera comprising ascomycetes and Saccharomyces comprising approximately 5–65% of the observed fungi. Saccharomyces strains have been observed up to 96.8% of samples in recent myco- biome studies [1-100]. Since fungi are harboured in the gut environment, it follows that some resident species might provide a symbiotic benefit to the human host [1-100].

9. Conclusion

Probiotics are living microorganisms, principally bacteria, and yeasts that are safe for human consumption and, when ingested in sufficient quantities, have beneficial effects on human health, beyond basic nutrition. Probiotics are emerging as a fascinating field in health. Thus, efforts should be made to increase awareness among the chemists to encourage the implementation of the concept, "probiotic rather than medicine. Microorganisms that are considered to be probiotics mainly belong to the genera *Saccharomyces boulardii, Lactobacillus* and *Bifidobacterium. Lactobacilli* and *bifidobacteria* are "friendly" bacteria, and *Saccharomyces boulardii* which means that they normally occur in the human gastrointestinal and genitourinary tracts and thus play an important roles in promoting overall health. The microbiome of a healthy individual consists of balanced populations of both beneficial and harmful microorganisms. These play a major role in providing the host with physiological, metabolic, and immune functions that are useful in warding off pathogens, and any imbalance results in increased levels of harmful microbes. Nutraceuticals are regarded as safe and less likely to have side effects; for example, probiotics are generally classified as nutraceuticals. The safety of probiotics is apparent due to the absence of toxicity in their populations. Additionally, most probiotics form part of the natural microbiome of the human host and therefore, are applied back to a known environment. Probiotics have always been an integral part of Indian cuisine and *Ayurvedic* texts and western-style dairy products. The probiotic industry in India is experiencing strong growth, fuelled by increasing consumer awareness of gut health and a rising demand for functional foods. Indian consumers are increasingly incorporating probiotics into daily diets in the form of functional foods and drinks.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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