Review

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Unveiling Roles of Beneficial Gut Bacteria and Optimal Diets for Health: A Comprehensive Review

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Abstract: The gut, often referred to as the "second brain," has significant contributions in the maintaining of the good bacteria contribute enormous role such as digestion, produce essential vitamins, support the immune system, and protect against harmful bacteria. The beneficial flora including *Akkermansia muciniphila, Adlercreutzia equolifasciens, Barnesiella, Christensenella minuta*, and *Oxalobacter formigenes*, along with their derived bioactive metabolites emerged as a key player in maintaining host metabolic and immune health. Dietary choices such as blending of prebiotic, fermented, symbiotic, anti-inflammatory foods, and secondary metabolites from a wide variety of plants and fruits promotes the diversity, composition, and stability of beneficial intestinal microbes. The colourful plant foods rich in phytochemicals bioactive compounds such as carotenoids, flavonoids, polyphenols, alkaloids, anthocyanins, and capsaicin offer a wide array of unique properties such as analgesics, antioxidants, anti-inflammatory, antimicrobials effect and promoting the abundance of beneficial gut bacteria and their bioactive metabolites confer numerous health-promoting effects. Here, we present knowledge about most beneficial gut bacteria and their derived metabolites in terms of their sources and health benefits. Finally, we discuss best foods that skew towards promoting healthy intestinal microbes.

Keywords: healthy gut bacteria; phytochemicals; prebiotic foods; & probiotic foods

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INTRODUCTION

The human gut is a fascinating ecosystem that harbours trillions of microorganisms collectively known as gut microbiota that play a crucial role in several physiological functions through their derived metabolites such as nutrient metabolism, immune system regulation, vitamin production, mental health, and brain function that contribute to overall maintaining of health. There is a wide distribution of microbes in the gut which is essential for better health (Figure 1). Some of the key gut bacteria, including *Akkermansia muciniphila, Adlercreutzia equolifasciens, Barnesiella, Christensenella minuta, and Oxalobacter formigenes, Lactobacillus, Bifidobacterium, Faecalibacterium prausnitzii, Roseburia spp.* contribute to unusual health benefits such as improved gut barrier function, better glucose metabolism, reduced inflammation, weight management, and prevention of kidney stone formation (Anhe 2016, Maruo 2008, Ubeda 2013, Ang 2023, Kaufman 2008).

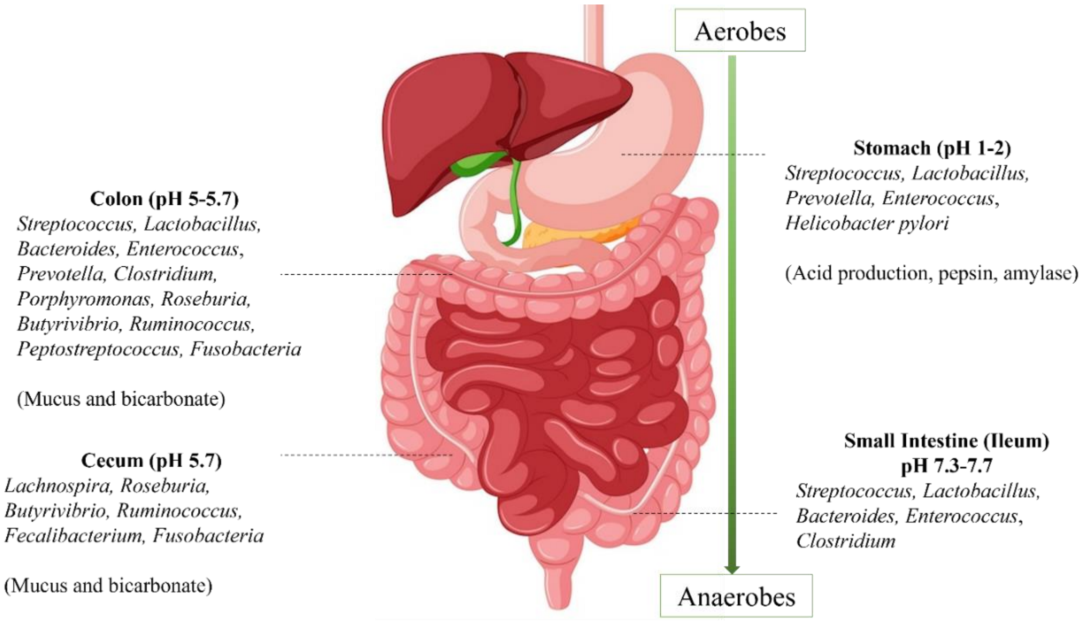

Figure 1. Distribution of gut microbiota.

The dietary sources such as polyphenols, alkaloids, capsaicin, and polysaccharides are essential constituents that support the growth of these beneficial bacteria, leading to improved digestive health and overall well-being (Chenbo 2022, Othman 2019). The metabolites are small molecules that produced by the gut microbiota as byproducts can target directly as well as indirectly both the bacteria themselves and the host, regulating the composition and function of the gut microbiota (Liu et al 2022, Jandhyala et al 2015). In recent years, the significance of gut microbiota and their metabolites in influencing human health has garnered significant attention.

Several studies have focused on elucidating the specific functions and mechanisms of these microorganisms in relation to various diseases (Lavelle & Sokol 2020, Parada et al 2019, Liu et al 2022). There is currently a lack of a comprehensive summarization regarding the most beneficial gut bacteria, their derived metabolites, and their dietary sources that contribute to maintaining overall health. In this review, we provide the potential role of microbiota in human health. We also discuss the essential gut bacteria and emphasize the derived metabolites of these gut bacteria especially the functions of regulating the local and systemic immune system, energy metabolism, and neural activity. Finally, we discuss how dietary approaches impacts the gut microbial ecology, and foods that promote healthier and more resilient intestinal gut bacteria.

Impact of Microbiota on Human Health

The microbial balance in the intestine is closely related to human diseases and wellness. Extensive research has been conducted to uncover the crucial link between gut bacteria and basic human biological functions. Because of the varied metabolic genes that give separate distinct enzymes and biochemical pathways, microbiota play critical roles in energy and nutrition extraction from food (Hou et al., 2022). Furthermore, the creation of bioactive compounds including vitamins, amino acids, and lipids is heavily reliant on the gut bacteria (Roberfroid et al., 2009). The human microbiota not only protects the host from external pathogens by creating antimicrobial compounds, but it also plays an important role in the development of intestinal mucosa and the immune system. The gut microbiota demonstrates stability, resilience, and symbiotic relationships with the host in healthy environments. Furthermore, the gut microbiota differs in different anatomical sections of the GI tract. *A.muniniphila*, for example, lives in the mucus layer of the large intestine and is involved in maintaining intestinal integrity. *A.equolifasciens* is commonly found in the colon. *Barnesiella* has been discovered in many sections of the gastrointestinal tract, including the cecum, colon, and feces (Afzaal et al., 2022). Such discrepancies are primarily attributable to differences in settings. The small intestine has a quick transit time and a high bile content, whereas the colon has slower flow rates and a gentler pH, as well as larger microbial communities, particularly anaerobic types (Afzaal et al., 2022). Aside from regional variation, gut microbiota varies with age. In general, microbial diversity increases between childhood and adulthood and declines with age (beyond 70).

Role of Microbiota in Disease Induction

The intestinal mucosal barrier, which consists of physical, chemical, microbial, and immunological components, is one of the major body defensive barriers. It defends the body from bacterial invasion, the entry of foreign antigens and poisons into the circulation, and water and nutrient loss. It controls molecular exchange as well as the coexistence and colonization of gut bacteria. Even little changes in the composition of the gut microbiota have significant repercussions and influence the development of major diseases in the future (Figure 2).

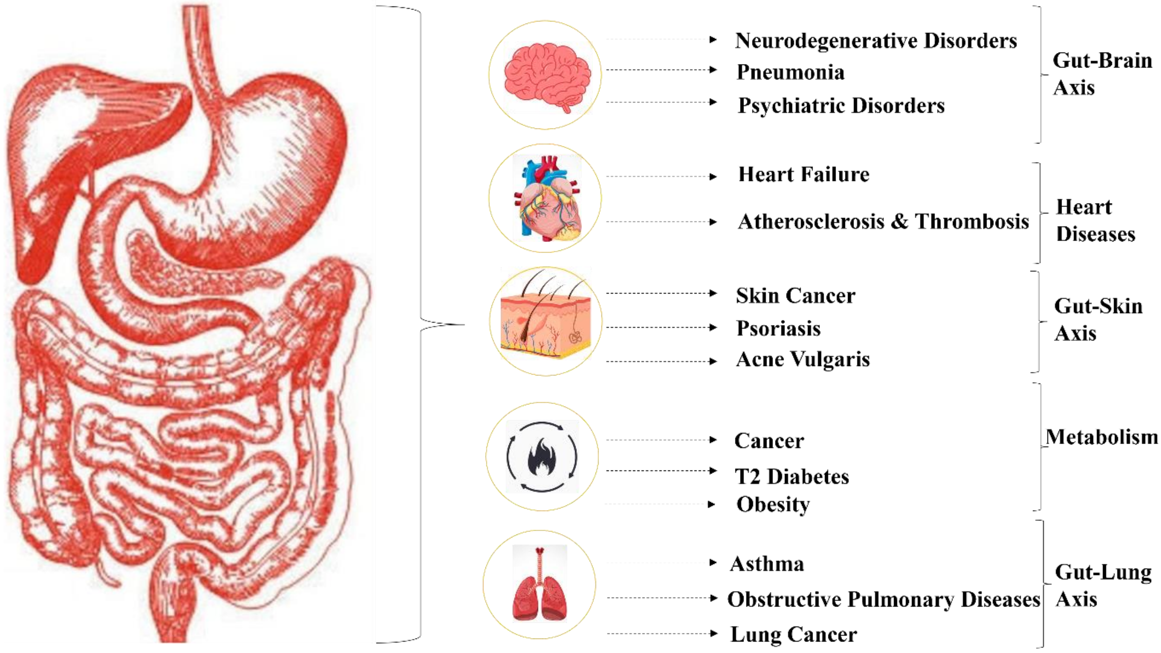

Figure 2. Dysbiosis of the Human Microbiota.

Much research has recently suggested that COVID-19 has a strong gut-lung axis. The gut microbiota was found to upregulate the synthesis of ACE2 in laboratory animals' guts. COVID-19 drew attention to the benefits of excellent eating, and the suggested diet for the disease includes probiotics, vitamins, and trace elements (Wang et al., 2023). Nutraceuticals, such as polyphenols, may have a role in preventing COVID-19 pathways. Similarly, inflammatory bowel disease (IBD) is regarded as a disease caused by both genetic and environmental factors, with the host genome potentially playing a major role in the makeup of the gut microbiota. Several studies have established that nutrition and bacteria have a direct association in IBD patients. It is believed that IBD patients' digestive tract mucus layers are weakened, allowing luminal bacteria to penetrate intraepithelial cells and trigger proliferative and inflammatory processes (Parekh et al., 2015).

Furthermore, the gut microbiota is important in the creation and progression of metabolic diseases such as obesity and Type 2 Diabetes (T2D). Obesity and type 2 diabetes (T2D) are two traditional risk factors for the progression of cardiovascular disease (CVD). The ability of the microbiota from obese people to ferment food and extract energy from the diet is boosted. Obese individuals have a high Firmicutes to *Bacteroides/Prevotella* ratio, which elevates the microbial genes involved in polysaccharide breakdown and raises the level of SCFAs. As a result, microbial digestion of dietary choline and carnitine, which constitute most of the Western diet, has been shown to raise the risk of CVD. In type 2 diabetes, the body either produces insufficient amounts of insulin or is unable to adequately metabolize glucose in spite of this production. Low insulin receptor titers and/or insulin resistance are its defining features. Host genetics and lifestyle factors may both have an impact on the composition of the gut microbiota and, subsequently, the risk of type 2 diabetes. In contrast to healthy people, those with diabetes had a larger proliferation of several phyla, including *Proteobacteria, Bacteroidetes, and Firmicutes* (Muscogiuri et al., 2017).

Recent epidemiological, pharmacological, and omics-based investigations, supported by cellular and animal tests, have shown that intestinal microbiota play an important role in both health and disease.

Essential Gut-Friendly Bacteria and their Byproducts

A. muciniphila

A. muciniphila is an anaerobic gram-negative anti-obesity bacterium that grows singly or in pairs in mucin-rich medium (Liu et al 2022). *Akkermansia muciniphila* has garnered significant attention due to its ability to degrade mucus that considers a protective layer that lines the gut and maintains a healthy balance that serves as a barrier against harmful microorganisms as excessive mucus production can lead to a range of health issues, including inflammatory bowel disease (IBD) and obesity (Geerlings et 2018, Kim et al 2021). Mucin layer is primarily made up of gelatinous mucins secreted by goblet cells and also consist of a peptide backbone modified by O-linked glycans. The presence of proline and threonine in the peptide backbone contributes to the unique properties of mucin, including its gel-like consistency and protective function (Pelaseyed et al 2014). Further, the production of butyrate, a short-chain fatty acid by *Akkermansia muciniphila* not only provides an energy source for the cells lining the colon but also contributes to reducing inflammation and improving gut barrier function (Portincasa et al 2022). Another metabolite produced by *Akkermansia muciniphila* is propionate, which also has anti-inflammatory effects and regulate glucose metabolism. It also stimulates the production of molecules that promote the growth of beneficial bacteria in the gut, leading to a more diverse and balanced gut microbiota (Rodrigues et al 2022).

Adlercreutzia equolifasciens

Adlercreutzia equolifasciens is a Gram-positive bacterium that thrives in an anaerobic environment, slightly acidic pH range of 6.0 to 6.5 by using culture medium, such as Reinforced Clostridial Medium (RCM). This bacterium is of particular interest due to its ability to produce equol, a metabolite of the soy isoflavone daidzein, which is found in soy products and other legumes. Research has shown that equol has estrogenic and antioxidant properties, which may help alleviate symptoms associated with hormonal imbalances, such as menopause, hot flashes and night sweats (Mayo et al 2019). Further equol have anti-inflammatory and anti-cancer effects. Individuals who consume a diet rich in soy products are more likely to have a higher abundance of *Adlercreutzia equolifasciens* in their gut (Tuli et al 2022).

Barnesiella

Barnesiella is an obligate anaerobic bacterium that can be cultivated under both anaerobic and microaerophilic conditions at a temperature range of 37-42°C in nutrient-rich media, such as brain-heart infusion (BHI) or tryptic soy broth (TSB), supplemented with appropriate carbon and nitrogen sources (Ubeda et al 2013). *Barnesiella* is a commensal bacterium that found reasonably low level in the gastrointestinal tract of humans help in the breakdown of complex carbohydrates, production of SCFAs, modulation of immune responses, facilitate the clearance of intestinal VRE colonization and prevent the spread of highly antibiotic-resistant bacteria. (Tao et al 2021, Ubeda et al 2013, Aindelis & Chlichlia 2020).

Christensenella minuta

Christensenella minuta is an obligate anaerobe that could be grow optimally under mesophilic conditions, between 30°C to 37°C by using a suitable culture medium, such as a nutrient-rich broth, to support its growth (Kropp 2021, Ang 2023). One of the unique metabolic features of *Christensenella minuta* is its ability to produce butyrate, a short-chain fatty acid linked with various health benefits, including anti-inflammatory and anti-cancer properties. Studies suggest that individuals with higher levels of *Christensenella minuta* may have a lower risk of type 2 diabetes, inflammatory bowel disease and obesity which sparked interest in the use in the development of probiotics and prebiotics (Mazier et al 2021, Ang 2023). In addition, this bacterium can influence the host's response to certain medications, such as antidiabetic drugs and suggested that it may contribute to inter-individual differences in drug response and could potentially be targeted for personalized medicine approaches.

Oxalobacter formigenes

Oxalobacter formigenes is a unique bacterium that can be grow in anaerobic environment by using Oxalate-Minimal Medium, which consists of oxalate, mineral salts, vitamins and buffer system (Duncan et al 2002, Daniel et al 2021). This bacterium resides in the human gastrointestinal tract known for its unique ability to break down and metabolize oxalate, a compound that can form kidney stones in some individuals. Studies have shown that individuals with a higher abundance of *Oxalobacter formigenes* in their gut have a lower risk of developing kidney stones (Chmiel et al 2022). This bacterium produces an enzyme called oxalyl-CoA decarboxylase, which converts oxalate into a less harmful compound called formate (Karamad et al 2022).

Optimal Foods for Nurturing the Growth of Gut-Friendly Bacteria

Research has consistently shown that our dietary choices have a direct impact on the health and resilience of our gut microbiome (Singh et al 2017, Su & Liu 2021). The incorporation of prebiotic rich foods, fermented foods, and a wide variety of plants and fruits promote the thriving of these gut microbiome as detailed in Table 1 (Nambiar et al 2023, Leeuwendaal et al 2022). The colourful plant foods are not only visually appealing, but they also provide a wide range of health benefits for the microbiome and metabolism. One of the key benefits of colourful foods is their high content of phytochemicals bioactive compounds such as carotenoids, flavonoids, and anthocyanins that have been shown to have numerous health-promoting effects (Samtiya et al 2017, Khoo et al 2017).

The microbiome is a living dynamic environment where the relative abundance of species may fluctuate daily, weekly, and monthly depending on diet, medication, exercise, and a host of other environmental exposures.

Table 1. Various dietary sources that produce and nourish good gut bacteria.

S. No.	Beneficial bacteria	Substances	Sources	References
11 1.	Akkermansia muciniphila	Polyphenols	Caffeic acid, chlorogenic acid, salvianolic acid A, ferulic, Concord grape polyphenols, puerarin, resveratrol,	Zhou et al 2017 Visioli et al 2003 Anhe et al 2014

			epigallocatechin gallate, black tea, red wine, grape juice, aronia juice, canarium album extract, arctic berries, flavonoids	Roopchand et al 2015 Kajla et al. 2015 Chenbo et al 2022
		Alkaloids	Berberine, curcumin caffeine, chlorogenic acid and betaine	
		Capsaicin	Chili peppers	
		Plant-derived carbohydrates	Nonfermentable fiber, wheat dietary fiber, konjac glucomannan, bran, fiber-rich common beans, oligofructose, Inulin-type fructan, stachyose, polysaccharides from spirulina platensis, lycium barbarum polysaccharide and fucoidan	
		Others	Oily fish, walnuts bamboo shoots, rhubarb extract and flaxseed	
2.	Adlercreutzia equolifasciens	Isoflavone diet	Tofu, tempeh, and soy milk	Jensen et al 2021

3.	Barnesiella	Polyphenols Prebiotics	Cherry juices Black raspberry-rich diet *Ganoderma lucidum* mushroom	Ubeda et al, 2013 Daillère et al, 2016 Gu et al, 2019 Miaoyu et al, 2021
4.	Christensenella minuta	Polyphenols	Red grapes, cranberries, strawberries and blueberries	Mazier et al, 2021 Ang et al, 2023 Waters et al 2019
5.	Oxalobacter formigenes	Prebiotic foods	Prebiotic foods like kimchi, sauerkraut, kefi, spinach, legumes, tea and celery	Kaufman et al, 2008 Chmiel et al, 2022

Carotenoids

Gut microbiota breaks down the carotenoid's rich foods, into various beneficial gut metabolites such as apocarotenoids and SCFAs having anti-inflammatory, antioxidant, and anticancer properties that contribute to decrease the risk of the development of chronic diseases, cardiovascular diseases, type 2 diabetes, obesity, brain-related diseases and certain types of cancer (Rowles et al 2020, Rocha et al 2023, Eroglu et al 2023, Min et al 2023). They also act as antioxidants, protecting the body's cells from damage caused by harmful free radicals. Their ability to protect against lipid peroxidation and damage caused by ROS makes them valuable in maintaining overall health and reducing the risk of chronic diseases ((Lobo et al 2010, Rocha HR et al 2023).

Apo-carotenoids exhibit unique characteristics, including higher aqueous solubility and higher electrophilicity, which make them particularly suitable for targeting transcription factors such as NF-κB, PPARγ, and RAR/RXRs (Eroglu A et al 2023). These compounds hold potential for therapeutic applications in the fields of inflammation, metabolic disorders, and cell differentiation. Studies have found that carotenoids can directly influence the composition of the gut microbiota in a positive manner (Rocha HR et al 2023). Beta-carotene such as carrots and sweet potatoes can increase the abundance of certain beneficial bacteria, such as *Bifidobacteria* and *Lactobacillu* (Rinninella, E et al., 2018, *Zhiguo*, Z et al 2023). Lycopene, found in tomatoes, has been shown to increase the levels of bacteria that produce short-chain fatty acids, which are beneficial for gut health (Eroglu et al, 2023). A. Lutein, found in leafy greens, has been associated with a more diverse gut microbiota (Dinsmoor et al 2019).

Flavonoids

Flavonoid-rich foods including fruits like berries, citrus fruits, vegetables, dark chocolate and tea, can lead to an increase in the diversity and abundance of gut metabolites that break down the flavonoids through fermentation processes into various metabolites compounds that have anti-inflammatory and antioxidant properties and reduce the risk of metabolic disorders such as cardiovascular disease by improving the insulin sensitivity (Joaquim et al., 2023, Wang et al., 2022, Pan et al., 2023). One important group of flavonoids known as flavan-3-ols has been shown to increase the levels of short-chain fatty acids (SCFAs) such as butyrate, which provide energy for the gut epithelial cells and have anti-inflammatory effects (Fotschki et al., 2015). Another bioactive compound flavanols associated with increase the production of urolithins metabolites in the gut that have been shown to have anti-inflammatory, antioxidant, and anticancer properties (Singh R et al., 2023). Further flavonoids have also been found to increase the production phenolic acids, benzoic acid derivatives, and microbial-derived compounds that can influence various physiological processes in the body (Rahman M et al., 2021). Previous research reported that flavonoids have the ability to modulate the relative abundance by increasing the relative abundance *of Bifidobacterium*, Lactobacillus, while decreasing the relative abundance of *Lachnoclostridium* and *Bilophila*, highlights their potential as dietary supplements or functional food ingredients to promote a healthy gut microbiota (Baky et al., 2022, Pan et al., 2023).

Anthocyanins

Anthocyanins that are responsible for bright red, purple, and blue colours to fruits like blueberries, blackberries, purple cabbage and cherries have been shown to have anti-inflammatory and antioxidant effects, as well as potential anti-cancer properties (Khoo et al., 2017, Bahare et al., 2020). They may also help regulate blood sugar levels and improve insulin sensitivity (Fernandes, I. *et al*., 2019). One metabolite that has been extensively studied in relation to Anthocyanins increase nitric oxide (NO) metabolite known as signalling molecule that helps in the regulation of blood flow, neurotransmission, and immune responses (Geum, H.L., et al. (2020). Increased levels of nitric oxide relax and dilate blood vessels, leading to improved blood flow and reduced risk of hypertension, heart disease and diabetes (da Silva et al., 2021, Kumar S et al., 2022). Studies have consistently shown that anthocyanin leads to an increase in the presence of beneficial bacteria such as *Lactobacillus*, *Bifidobacterium*, *Blautia, Faecalibacterium*, *Prevotella*, *Akkermansia* and stimulate the production SCFAs particularly butyrate (Verediano et al., 2021, Zhong et al., 2023, Liang et al., 2023).

Polyphenols

Polyphenols are a group of compounds that are naturally found in many plant-based foods and beverage that undergo various transformations by the gut bacteria and converted into a wide range of metabolites having antioxidant and anti-inflammatory properties (Gizem, C et al., 2020, Bertelli, A et al., 2021). Studies have shown that certain polyphenols, such as those found in green tea, berries, and cocoa, can increase the production of short-chain fatty acids (SCFAs) and branched-chain amino acids (BCAAs) and could be useful in the treatment and prevention of various gastrointestinal disorders (Manach C et al., 2004). Kumar Singh et al., 2019, Lippolis et al., 2023). Furthermore, polyphenols have been shown to modulate the composition of the gut microbiota, promoting the growth of beneficial bacteria like *Lactobacillus*, *Lactiplantibacillus* and *Bifidobacterium* while hindering the proliferation of pathogenic strains like *Clostridium* and *Fusobacterium* (Corrêa, T A.F. et al 2019, Wang X et al., 2022, Lippolis et al., 2023).

Alkaloids

Alkaloids have been known to possess various biological activities and have been used in traditional medicine for centuries (Heinrich, M. et al., 2021). Studies have shown that certain alkaloids promote the growth of beneficial bacteria that leads to an increase in the production of short-chain fatty acids, such as butyrate, which have numerous health benefits (Feng, W et al., 2018, Dehau, T et al., 2023 Furthermore, alkaloids found in coffee, such as caffeine and chlorogenic acid, have been shown to increase the production of certain bile acids in the gut (Iriondo-DeHond, A et al., 2020, Chen, L et al 2023). Bile acids are important for the digestion and absorption of dietary fats and also have regulatory roles in lipid and glucose metabolism (González-Regueiro, JA et al., 2017). Research has shown that berberine has antimicrobial properties, specifically targeting harmful bacteria like Escherichia coli (E. coli) and Clostridium difficile (C. difficile), while promoting the growth of beneficial bacteria like Bifidobacterium and Lactobacillus (Cheng et al., 2022, Zhang et al., 2022, Peng et al., 2019).

Capsaicin

Research has shown that capsaicin can stimulate the production of certain gut metabolites such as SCFAs known to have various beneficial effects, such as reducing inflammation and improving insulin sensitivity (Song, JX et al., 2017, Kang, C et al., 2017). Furthermore, capsaicin has been shown to enhance the activity of certain enzymes such as enzyme lipase, which is responsible for breaking down dietary fat (Liu, S. J et al., 2021). This increased enzyme activity can lead to a more efficient digestion and utilization of nutrients, ultimately affecting the production of gut metabolites (Menden A et al 2022, Chandra P et al 2020). In addition to its direct effects on gut metabolites, capsaicin has alsobeen found to influence the composition of the gut microbiota and increase the abundance of *Akkermansia muciniphila* (Li et al 2022).

Prebiotic-Rich Foods

Prebiotics can be found in a variety of foods, including fruits, vegetables, whole grains, and legumes. Some common examples of prebiotic fibers include inulin, fructooligosaccharides (FOS), and galactooligosaccharides (GOS) (Lockyer & Stanner, 2019). The primary benefits of prebiotics are their ability to selectively stimulate the growth of beneficial bacteria, such as *Bifidobacteria, Lactobacilli* and enhance the production of beneficial metabolites like short-chain fatty acids (Markowiak & Śliżewska, 2017, Davani-Davari et al., 2019). Prebioticb rich foods such as Chicory root and Jerusalem Artichokes are excellent sources of inulin, a fiber that serves as a fuel for the beneficial gut bacteria (Carlson et al., 2018). Similarly, the content of pectin in apples and resistant starch in bananas acts as nourishment for good bacteria (Englyst and Cummings, 1986, Leonel & Alvarez-Leite, 2012).

Other prebiotic foods like oats, barley, and quinoa promote healthy gut bacteria by providing good source of prebiotic fibers (Slavin et al 2013). Legumes foods, including lentils, chickpeas, and beans, are known for their high nutritional value and are an excellent source of prebiotics that promote the growth of beneficial bacteria in the gut (Kadyan et al., 2022). The content of fructooligosaccharides (FOS) in garlic and onions, and inulin and oligofructose in asparagus vegetables act as prebiotics by stimulating the growth of beneficial gut bacteria (Zhang et al., 2013, Guillamón et al., 2021).

Fermented Foods

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Fermented foods provide a natural and delicious way to support a healthy gut microbiome. With their probiotic properties, they offer numerous benefits, including improved digestive health, enhanced immune function, increased nutrient availability, and potential mental well-being (Leeuwendaal et al., 2022). Yogurt is a widely consumed fermented dairy product that augments beneficial bacteria, such as *Lactobacillus* and *Bifidobacterium* (Lisko et al., 2017). Kimchi is mainly produced by fermented vegetables, including cabbage, radishes, and garlic that contains *Lactobacillus* bacteria, which are known to promote gut health and improve digestion (Dimidi et al., 2019).

Another fermented food known as Kombucha made from fermented tea beverage that rich in bioactive compounds and a variety of beneficial acetic acid bacteria and yeasts, contributing to a healthy gut microbiome (Kitwetcharoen et al., 2023). A previous study conducted on rats revealed that tempeh, a fermented soybean product, has the potential to enhance the production of immunoglobulin A (IgA) and modulate the composition of gut microbiota. In addition to the study on rats, research involving supplementation of tempeh in humans for 16-days led to a significant increase in the abundance of beneficial gut bacteria like *Akkermansia muciniphila* (Stephanie et al., 2017).

Synbiotic Foods

Synbiotic foods provide a convenient and effective way to support a healthy gut microbiome (Jiang et al., 2022). By combining prebiotics and probiotics, these foods offer numerous health benefits, including improved digestion, enhanced immune function, increased nutrient absorption, and reduced inflammation (Yadav et al., 2022). Incorporating synbiotic foods into a balanced diet can be a valuable strategy for promoting overall health and well-being (Pandey et al., 2015). Synbiotic food having a combination of arabinose, lactulose and *Lactobacillus plantarum*, have gained attention for their potential to effectively regulate blood glucose, blood lipid, and body weight in patients with Type 2 Diabetes Mellitus (T2DM) (Jiang et al., 2022). Another preparation known as banana smoothie made with kefir or yogurt is a delicious and nutritious beverage that hat maximizes the benefits for gut bacteria. Stir-fry made with tempeh, asparagus, garlic, and leeks prompts, you can actively healthy gut microbiome. The combination of yogurt and fruits such as blueberries creates a synbiotic effect, where the probiotics from yogurt and the prebiotics from blueberries work together to promote the growth and activity of healthy gut bacteria (Fernandez et al., 2017).

Anti-Inflammatory Foods

Anti-inflammatory foods such as fatty fish, fruits, vegetables, whole grains, and spices have long been recognized for their potential health benefits by supporting a diverse and balanced gut microbiome, reducing inflammation and promoting overall gut health (Bagheri et al., 2022). Fish like salmon, sardines, and anchovies in diet can have a positive impact on gut health. Their omega-3 fatty acids and ability to increase healthy gut bacteria make them a valuable addition to an anti-inflammatory diet (Costantini et al., 2017). Flax seeds are rich in dietary fiber, including both soluble and insoluble fiber that act as prebiotics and provide nourishment for the beneficial bacteria in the gut (Kajla et al., 2015, Mueed et al., 2022). When the gut bacteria ferment the fiber from flax seeds, they produce short-chain fatty acids (SCFAs), such as butyrate that help in maintaining a healthy gut environment (Arora et al., 2019).

Impact of Diet on Microbial Ecology in the Gut

Diet has a significant impact on the composition, variety, and richness of the gut microbiota. Different dietary components shape gut bacterial communities in a time-dependent manner. Long-term dietary patterns, notably protein and animal fat intake against carbohydrates or plant-based diets, cause a major variation in the host intestinal environment. A comparison of the gut microbiota from rural and urban groups revealed that nutrition has a significant impact on the microbiome (De Filippo et al., 2010). Microbiota-accessible carbohydrates (MACs) are dietary fiber. These carbohydrates are made up of monosaccharides linked together by various forms of glycosidic connections. Any major differences in their chemical makeup, solubility, and size classify these carbohydrates into a wide range of biological niches. Dietary fibers are crucial sources of energy for the bacteria that live in the colon and cecum. In addition to reducing microbial diversity and short chain fatty acid (SCFA) production, a low intake of dietary fiber causes the gut microbial metabolism to shift toward the use of less advantageous substrates. The mucus barrier is harmed by a protracted absence of dietary fibers, which is also linked to an increase in the number of bacteria that break down mucins, like *Akkermansia muciniphila* (Makki et al., 2018).

As a result, a lack of dietary fibre and an increase in sugar and fat in human diets may lead to the extinction of particular bacterial species. These changes may lead to dysfunctions, which could exacerbate existing conditions like IBD, allergies, colorectal cancer, autoimmune illnesses, obesity, etc. A diet high in fiber helps to maintain a healthy gut microbiota that is more diverse and performs activities like producing short-chain fatty acids (SCFAs) (Figure 3). Low fiber intake, a diet high in protein and sugar, and an industrialized diet all contribute to altered gut bacterial function, including a significant decrease in their capacity to produce SCFAs, which is linked to the emergence of chronic inflammatory diseases (Makki et al., 2018).

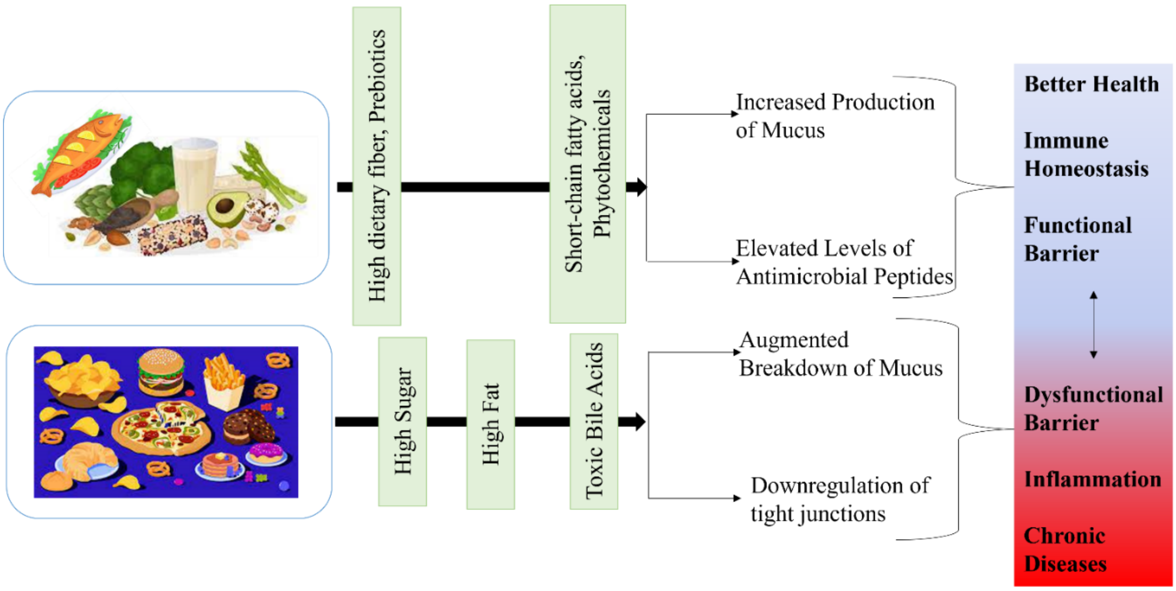

Figure 3. Effect of high and low fiber diet on gut microbiota.

Conclusion

The study of the human gut microbiota has grown significantly in recent years. The host's metabolism, physiology, and immune system are affected by the gut microbiota. Numerous variables, including nutrition, host genetics, age, medicines, and way of life, have an impact on the gut microbiota's makeup. Human health is directly impacted by changes in the composition and operation of the gut microbiota, which also play a significant role in the development of numerous diseases. Finally, a deeper comprehension of the interplay between diet and microbiota will aid in the development of a tailored nutrition strategy that will target and more effectively lower the prevalence of chronic inflammatory disorders.

The emerging evidence from various studies highlights the crucial role of plant foods rich in phytochemicals and other specific foods in promoting the growth and maintenance of beneficial gut bacteria. Various challenges related to absorption, bioavailability, dietary interactions, and individual variations in metabolism can limit the effectiveness of phytochemicals found in plant-based food in promoting a healthy gut microbial community. Standardization, individual variability, bioavailability and absorption, processing and preparation, and long-term maintenance are among the key challenges with specific foods. Additionally, the composition of the gut microbiota is highly dynamic and subject to change based on various environmental factors. Further research is crucial to address the existing obstacles and fully harness the potential benefits of phytochemicals and specific foods on gut bacteria. In this comprehensive review, we are uncovering the intricate roles of beneficial gut bacteria and the significant impact of optimal diets on human health. Our findings suggest that personalized nutrition, customized to individual microbiota profiles, has the potential to revolutionize healthcare. By leveraging the symbiotic relationship between gut bacteria and dietary patterns, we can explore targeted interventions and preventive strategies. However, we must acknowledge the challenges ahead. Implementing personalized dietary recommendations on a large scale requires a paradigm shift in healthcare systems towards individualized care. Moreover, ethical concerns related to privacy and data usage in precision medicine present formidable obstacles. To fully realize the potential of our insights into the microbiota's role in health and diet optimization, it is crucial to combine scientific knowledge with ethical frameworks as we navigate this path of discovery.

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