IOSR Journal of Biotechnology and Biochemistry (IOSR-JBB)
ISSN: 2455-264X, Volume 11, Issue 1 Series 1 (Jan. – Feb. 2025), PP 01-08
www.iosrjournals.org

A Review On Beautiful Synchronization Of Microbiomes: Microbial Symphony

V.R.S.L. Asritha Kukunuri, Sirisha Kudulla, Meenakshi Devi Mudunuri, Akshay Kumar Voosala, Nagaraju Yalampati, Dr. Y.B. Manju Latha, Dr. V. Bhaskara Raju

Student, Bachelor Of Pharmacy, Sri Vasavi Institute Of Pharmaceutical Sciences, Pedatadepalli, Andhra Pradesh, India.
Professor & Hod For Dept. Of Biotechnology, Bachelor Of Pharmacy, Sri Vasavi Institute Of Pharmaceutical Sciences, Pedatadepalli, Andhra Pradesh, India.
Principal, Bachelor Of Pharmacy, Sri Vasavi Institute Of Pharmaceutical Sciences, Pedatadepalli, Andhra Pradesh, India.

Abstract:
Microbial symphonies, which reflect the complex relationships and harmonious functioning of microbial communities, have drawn a lot of attention due to their applications in biotechnology, environmental sustainability, and human health. Microbial symphonies are thoroughly examined in this review, which distinguishes them from the more general notion of the microbiome by highlighting the coordinated, group-based behaviours and interactions that occur within these communities. Nutrient cycling, immunological modulation, illness prevention, and metabolic regulation are just a few of the essential roles that microbial symphonies play in hosts and surroundings. Growing awareness of these microbial dynamics has sparked interest in their therapeutic uses, such as probiotics, faecal microbiota transplantation (FMT), and medications that modulate the microbiome. These treatments have the potential to improve cancer immunotherapy and treat metabolic and gastrointestinal disorders.
In conclusion, tremendous scientific, ethical, and legal obstacles limit the practical implementation of microbial symphonies, despite the fact that they present revolutionary opportunities in environmental research and medicine. The safe, efficient, and egalitarian application of microbial medicines and interventions depends on resolving these problems. A comprehensive review of the state of knowledge, applications, difficulties, and potential future paths in the study of microbial symphony is provided in this article.
Keywords: *Microbial symphony, Microbiome, Nutrient cycling, therapeutic use, faecal microbiota transplantation (FMT), applications.*

Date of Submission: 29-01-2025 Date of Acceptance: 09-02-2025

I. Introduction To Microbial Symphony:

A group of microorganisms coexisting is frequently referred to as a microbial community. More precisely, multi-species assemblages where microorganisms interact with one another in a shared habitat are known as microbial communities[1].

Microbes, the unseen architects of life, govern species, create ecosystems, and speed up biological processes in a complex, interconnected environment[2]. The "microbial symphony" refers to the vast network of interactions between different microbial species, their habitats, and other animals, which frequently lead to symbiotic relationships that are crucial to ecological balance and evolutionary processes[3].

Symbiosis, whether parasitic, commensal, or mutualistic, is the fundamental component of this microbial community[4]. Some instances for these interactions include the significance of the gut microbiota for human health[5]; nitrogen-fixing bacteria that sustain plant life[6]; marine microbiomes that influence global carbon cycles[7]; and microbial consortia in hostile environments that push the boundaries of life[8].

Modern developments in microbiology, metagenomics, and bioinformatics have expanded our knowledge of microbial communities and exposed the intricate ways that microbes interact, cooperate, and compete[9]. From biotechnology[10] to climate change mitigation[11], from agriculture[12] to medicine[13], these discoveries provide insight into how microbial networks affect ecosystem function.

Symbiotic Relationships: The Heart of the Symphony

Symbiotic alliances, which take several forms, are at the core of microbial interactions.

1. **Mutualism:** In the gut microbiota of humans, microbes aid in digestion, vitamin synthesis, and pathogen protection while getting nutrition and a stable habitat[14].
2. **Commensalism:** One organism benefits without causing harm to another, as observed in skin microbiota that reside on human surfaces[15].
3. **Parasitism:** When one organism gains at the expense of another, such as pathogenic microorganisms that infect hosts and cause diseases[16].

Microbial Communication and Cooperation:

Quorum sensing is one of the complex chemical signalling mechanisms that microorganisms employ for communication. Through this process, populations of bacteria can coordinate their behaviour based on their density[17]. In order to create biofilms—groups of microbial cells that function as a single unit and sometimes show enhanced resistance to external pressures like antibiotics[18] this communication is necessary.

Coevolution can be driven by symbiotic connections, when the evolution of one species influences the evolution of another[19].

Human Health and Biotechnology:

The gastrointestinal system, skin, saliva, oral mucosa, and conjunctiva are among the interior and external surfaces of the human body where microbes are primarily found. The human microbiome is dominated by bacteria, which are two to three orders of magnitude more numerous than eukaryotes and archaea[20-21]. Microbial community are connected to a variety of illnesses, such as obesity, autoimmune diseases, and neurodegenerative disorders[22].

There are several uses for microbial symbiosis in biotechnology, including:

- **Agriculture**: By generating biofertilizers and biopesticides, beneficial microbes can increase soil fertility and crop resilience[23].
- **Industrial applications**: bioremediation[24], waste remediation, and biofuel production using microbial consortia.
- **Synthetic biology**: The practice of altering microbial communities to do certain tasks, such as producing drugs or breaking down contaminants[25].

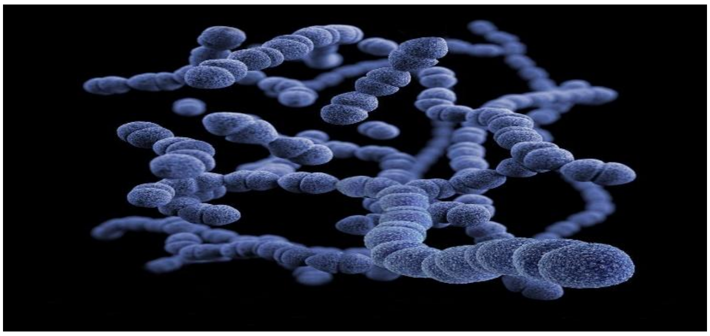


FIG 1: MICROBIAL SYMPHONY (BACTERIA)

Background and History of Microbial Symbiosis:

As scientific understanding of microorganisms grew over decades, it became increasingly evident that these organisms are essential to the formation of life on Earth[26]. In ecology, evolution, and biogeochemistry, microbial symbiosis is becoming more widely acknowledged as a fundamental phenomenon with important implications for agriculture, human health, and environmental sustainability[27].

Early Discoveries and Observations:

The history of microbial symbiosis began with the discovery of microorganisms themselves. In the late 17th century, **Antonie van Leeuwenhoek** created the microscope and was the first to investigate bacteria and other microorganisms, which he called "animalcules"[28]**.**

In 1879, **Heinrich Anton De Bary** coined the term "symbiosis" in his monograph, which he used to refer to "the living together of unlike organisms" as a comprehensive term to describe a broad range of relationships[29].

Microbes in Nitrogen Fixation and Plant Symbiosis:

In the late 19th and early 20th centuries, scientists first identified the crucial functions that bacteria play in biogeochemical cycles. The link between nitrogen-fixing bacteria like *Rhizobium* and leguminous plants became a hot topic in agriculture, which was one significant finding. It was demonstrated by **Hermann Hellriegel** and **Hermann Wilfarth** in 1886 that the bacteria in the nodules in legume roots could transform nitrogen from the air into ammonia, which plants could then absorb and use for growth[30].

The Birth of Germ Theory and Pathogenic Symbiosis:

The development of germ theory, led by pioneers like Louis Pasteur and Robert Koch, in the late 19th century made pathogenic microorganisms—those that cause disease—the focus of microbiology. The germ hypothesis of disease was beginning to overtake the miasma idea by the end of that decade[31].

Advances in Human Microbiome Research:

Projects like The Human Microbiome Project (HMP) have demonstrated since the early 2000s that a number of human diseases are linked to the diversity of microbes in particular body habitats, which is reflected in the variety and abundance of different organisms, low gut diversity has been linked to inflammatory bowel disease and obesity[32-33].

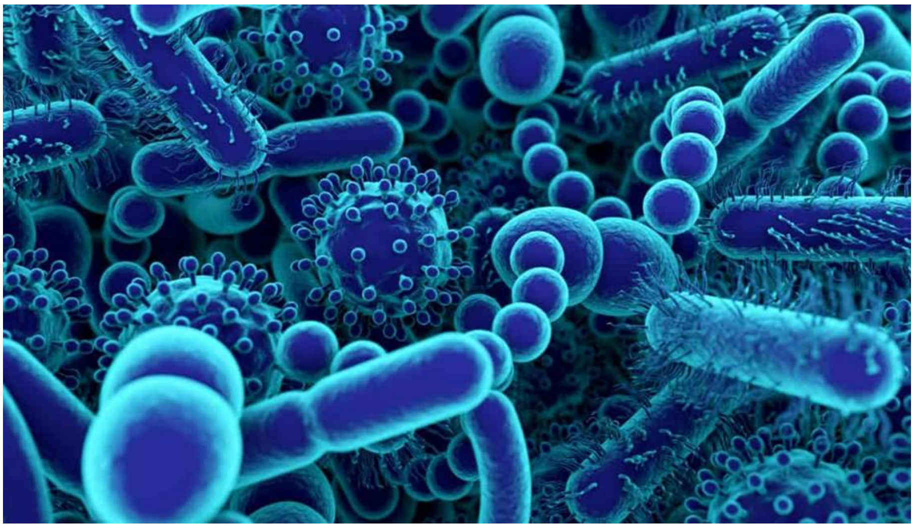


FIG 2: MICROBIOME

Modern Tools: Genomics and Metagenomics:

In the late 20th and early 21st centuries, the study of microbial symbiosis was transformed by the introduction of genomic technologies[34].

Understanding the vast variety of microorganisms present in the soil environment, producing new compounds with therapeutic value, advancing biotechnology, and promoting sustainable agriculture can all be aided by metagenomics[35].

Symbiosis in Extreme Environments:

Microbiological symbiosis by showing that these kinds of connections are not just found in "typical" habitats but are necessary for survival even in the most hostile settings. Microbes that live in extreme environmental habitats are called extremophiles, and they have special qualities that allow them to flourish and endure in such a wide range of conditions[36].

Differences between microbial symphony and microbiome:

Aspect	Microbial Symphony	Microbiome
Definition	The complex interactions between bacteria and their activities in ecosystems are described metaphorically[37].	Assemblage of microbes in a particular setting[38].
Focus	Relationships, ecological results, and processes[39].	Microbes and their genetic material[40].
Processes vs. Entities	analyses the behaviour and interactions of microbes[41].	Describes the actual community of microbes[42].
Conceptual vs. Biological	A theoretical basis for understanding the behaviour of microorganisms[43].	A biological term that defines a microbial community[44].

Application	Encompasses signaling, competition, and symbiosis[45].	Particularly focused in investigating microorganisms in a specific habitat (gut, soil, etc.)[46].

Importance Of Microbial Symphony And Microbiome:

Area of Impact	Importance of Microbial Symphony and Microbiome
Human Health	Vital role in immunity, illness prevention, digestion, and the potential for treatments like probiotics[47,48].
Agriculture	Improves plant growth, disease resistance, soil health, and sustainable farming[49,50].
Environmental Sustainability	Essential for preventing climate change, disinfecting environmental pollutants (bioremediation), and cycling nutrients[51].
Biotechnology and Synthetic Biology	Progress in industrial processes, biosensors, and biofuel production[52].
Evolution and Ecology	Gives information about ecological stability, biodiversity, and co-evolution[53].
Public Health	Essential for developing immunotherapies, decreasing antibiotic resistance, and managing infections[54].

Diseases:

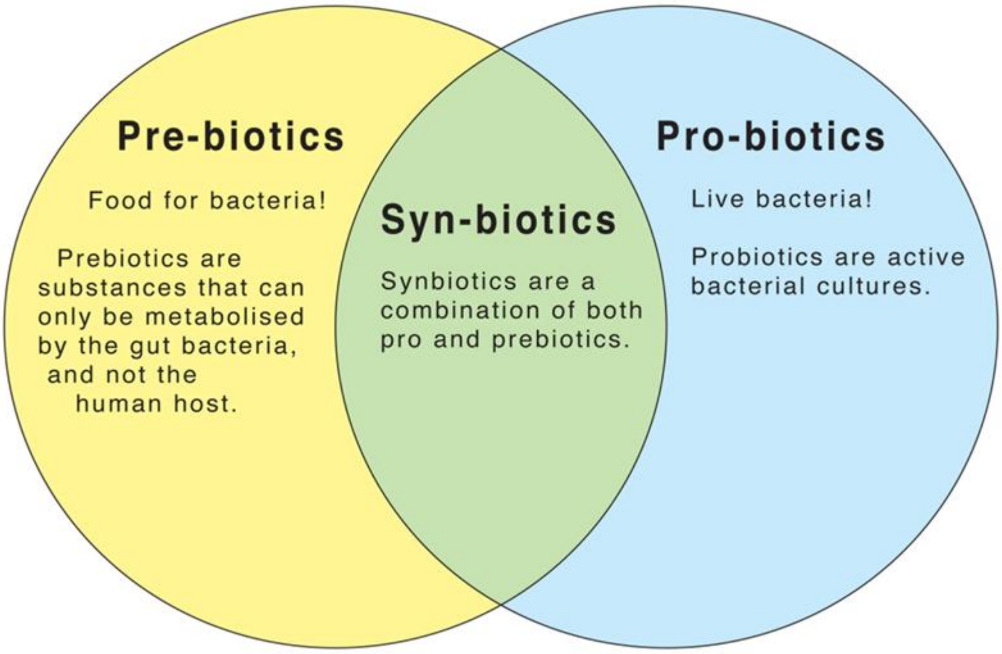
Disease Type	Microbial Connection
Gastrointestinal Diseases	The imbalance in the gut microbiome has been associated to inflammatory bowel disease (IBD), irritable bowel syndrome (IBS), Clostridium difficile infection (CDI), and colorectal cancer[55].
Metabolic Diseases	Chronic inflammation and energy metabolism alterations brought on by the microbiota have an impact on obesity, type 2 diabetes, and non-alcoholic fatty liver disease (NAFLD)[57].
Allergic and Autoimmune Diseases	Immune dysregulation can be triggered by microbiome imbalances linked to rheumatoid arthritis (RA), multiple sclerosis (MS), asthma, and dermatitis[58].
Neurological and Psychiatric Disorders	As microbial imbalances impact neurodevelopment and mental health, disorders such as depression, anxiety, autism spectrum disorder (ASD), Parkinson's disease (PD), and Alzheimer's disease (AD) are associated with the gut-brain axis[59].
Cardiovascular Diseases	Metabolite generated from the microbiome, such as trimethylamine N-oxide (TMAO), affects vascular health and is implicated in atherosclerosis, hypertension, and heart failure[60].
Cancer	malignancies such as stomach, liver, and oral cancer are linked to microbial imbalance, where chronic inflammation and microbial metabolites are involved[61].

Functions:

Function	Microbial Role
Nutrient Cycling	Utilise carbon, nitrogen, sulphur, and phosphorus to break down organic materials[62].
Decomposition	Organic matter decomposition and nutrient recycling[63].
Detoxification & Bioremediation	Hazardous chemicals are detoxified and contaminants are broken down by microbes[64].
Host Protection	To prevent infections, resist against infections and alter the immune system[65].
Biofilm Formation	create protective communities on surfaces in clinical and environmental instances[66].
Communication (Quorum Sensing)	Through chemical signals, group activities and interactions between species can be synchronized[67].
Development and Homeostasis	support the growth of host tissues and preserve homeostasis in host systems[68].

Therapeutic Applications:

Application	Description
Probiotics	Used for immunological regulation and intestinal health[69].
Fecal Microbiota Transplantation	Gut microbiota is restored for recurring C. difficile infections[70].
Microbiome-Based Therapies	Contains postbiotics, synbiotics, and prebiotics to promote gut health[71].
Cancer Immunotherapy	Improves response to cancer treatments by modifying the microbiome[72].
Antibiotic Development	Antimicrobial peptides and bacteriophage treatment development[73].
Mental Health	Psychobiotics for neurological disease management and mental health enhancement[74].
Agricultural Applications	Biopesticides and fertilisers for sustainable agriculture[75].
Bioremediation	Repairing ecosystems through microbial degradation of harmful contaminants[76].
Synthetic Biology	Modifying bacteria to produce enzymes, medicines, and biofuels[77].
Vaccination	Mucosal immunity-boosting techniques and microbial vaccines[78].



Advantages And Disadvantages Of Microbial Symphony:

Advantages	Disadvantages
1. Health Benefits	**1. Complexity of Microbial Communities**
- Probiotics can help with digestion and intestinal health[79].	- In varied microbial communities, it might be difficult to predict interactions and effects[82].
- Immune responses may be modulated by microbial treatments[79].	- Individual variations may impact the efficiency of treatment[82].
2. Disease Treatment and Prevention	**2. Standardization Issues**
- Recurrent infections are successfully treated by faecal microbiota transplantation (FMT)[68].	- Treatment efficacy and quality may vary due to a lack of standard techniques[83].
- Modification of the microbiome may be used to treat metabolic diseases and some types of cancer[80].	- Ensuring hygiene is essential to preventing contamination and adverse effects[83].
3. Environmental Sustainability	**3. Regulatory Challenges**
- Microbial bioremediation aids in the removal of environmental contaminants[75].	- The special difficulties related to microbial treatments may not be sufficiently addressed by legislation as they exist[84].
4. Biotechnological Innovations	**4. Limited Understanding of Mechanisms**
- Enzymes, medications, and biofuels can all be produced by engineered bacteria[81].	- Inadequate mechanisms can make it more difficult for physicians to effectively adjust treatments[85].

Limitations Of Microbial Symphony:

Limitation	Description
1. Complexity of Interactions	- The complex interactions among microbial communities make it challenging to pinpoint the precise impacts of individual microorganisms or their combinations on environmental or health outcomes[86].
	- Microbe interactions which are antagonistic or synergistic might make predictions and interpretations more difficult[86].
2. Limited Understanding of Mechanisms	- The capacity to develop targeted therapies or actions is hindered by the frequently inadequate understanding of the mechanisms by which microbial symphonies produce their effects, whether beneficial or hazardous[85].
3. Risk of pathogen transmition	- Inadequate screening of donors increases the risk of spreading harmful microorganisms during procedures like faecal microbiota transplantation (FMT)[87].
	- For patient safety, it is crucial to understand the possibility of opportunistic infections[87].
4. Long-Term Effects Unknown	- To evaluate long-term effects and safety, monitoring and follow-up inquiry are required[88].

Acknowledgements:

The authors would like to express their gratitude to Name(s) or Organization(s) for their insightful conversations and insightful observations of the intricate interactions that occur within microbial communities. We express our special gratitude to certain people or organisations for their knowledge and recommendations, which enhanced the viewpoints offered in this review.

The authors also thank their reviewers and colleagues for their helpful criticism, which improved our comprehension and illustration of the dynamic interactions within the microbiome.

II. Conclusion:

The investigation of microbial symphony reveals the vital functions that microbes perform in human health, ecology, and biotechnological development. Even while there are many advantages to comprehending these intricate relationships, from better health outcomes through probiotics to increased agricultural sustainability, it is impossible to ignore the difficulties, such as the intricacy of microbial interactions and the dangers of pathogen transmission. To overcome these restrictions and guarantee the safe and efficient use of microbial technology, more research is necessary. We can use the potential of microbial symbiosis to promote a healthier and more sustainable future by resolving these complications.

References:

[1] Konopka A. What Is Microbial Community Ecology?. The ISME Journal. 2009 Nov;3(11):1223-30.
[2] Pantigoso HA, Newberger D, Vivanco JM. The Rhizosphere Microbiome: Plant–Microbial Interactions For Resource Acquisition. Journal Of Applied Microbiology. 2022 Nov 1;133(5):2864-76.
[3] Falkowski PG, Fenchel T, Delong EF. The Microbial Engines That Drive Earth's Biogeochemical Cycles. Science. 2008 May 23;320(5879):1034-9.
[4] Raina JB, Eme L, Pollock FJ, Spang A, Archibald JM, Williams TA. Symbiosis In The Microbial World: From Ecology To Genome Evolution. Biology Open. 2018 Feb 15;7(2):Bio032524.
[5] Sender R, Fuchs S, Milo R. Are We Really Vastly Outnumbered? Revisiting The Ratio Of Bacterial To Host Cells In Humans. Cell. 2016 Jan 28;164(3):337-40.
[6] Pajares S, Bohannan BJ. Ecology Of Nitrogen Fixing, Nitrifying, And Denitrifying Microorganisms In Tropical Forest Soils. Frontiers In Microbiology. 2016 Jul 5;7:1045.
[7] Karl DM. Microbial Oceanography: Paradigms, Processes And Promise. Nature Reviews Microbiology. 2007 Oct;5(10):759-69.
[8] Shu WS, Huang LN. Microbial Diversity In Extreme Environments. Nature Reviews Microbiology. 2022 Apr;20(4):219-35.
[9] Zhang Q, Wu J, Yang F, Lei Y, Zhang Q, Cheng X. Alterations In Soil Microbial Community Composition And Biomass Following Agricultural Land Use Change. Scientific Reports. 2016 Nov 4;6(1):36587.
[10] Handelsman J. Metagenomics: Application Of Genomics To Uncultured Microorganisms. Microbiology And Molecular Biology Reviews. 2004 Dec;68(4):669-85.
[11] American Society For Microbiology. Microbes And Climate Change-Science, People & Impacts: Report On An American Academy Of Microbiology Virtual Colloquium Held On Nov. 5, 2021.
[12] Pérez-Jaramillo JE, De Hollander M, Ramírez CA, Mendes R, Raaijmakers JM, Carrión VJ. Deciphering Rhizosphere Microbiome Assembly Of Wild And Modern Common Bean (Phaseolus Vulgaris) In Native And Agricultural Soils From Colombia. Microbiome. 2019 Dec;7:1-6.
[13] Aggarwal N, Kitano S, Puah GR, Kittelmann S, Hwang IY, Chang MW. Microbiome And Human Health: Current Understanding, Engineering, And Enabling Technologies. Chemical Reviews. 2022 Nov 1;123(1):31-72.
[14] Clemente JC, Ursell LK, Parfrey LW, Knight R. The Impact Of The Gut Microbiota On Human Health: An Integrative View. Cell. 2012 Mar 16;148(6):1258-70.
[15] Grice EA, Segre JA. The Human Microbiome: Our Second Genome. Annual Review Of Genomics And Human Genetics. 2012 Sep 22;13(1):151-70.
[16] Goebel W. From The Beginning To The Present State Of Molecular Microbial Pathogenesis—A Tribute To Pascale Cossart. Molecular Microbiology. 2020 Mar;113(3):538-40.
[17] Miller MB, Bassler BL. Quorum Sensing In Bacteria. Annual Reviews In Microbiology. 2001 Oct;55(1):165-99.
[18] Stoodley P, Sauer K, Davies DG, Costerton JW. Biofilms As Complex Differentiated Communities. Annual Reviews In Microbiology. 2002 Oct;56(1):187-209.
[19] Thompson JN. The Geographic Mosaic Of Coevolution. University Of Chicago Press; 2019 Dec 31.
[20] Qin J, Li R, Raes J, Arumugam M, Burgdorf KS, Manichanh C, Nielsen T, Pons N, Levenez F, Yamada T, Mende DR. A Human Gut Microbial Gene Catalogue Established By Metagenomic Sequencing. Nature. 2010 Mar 4;464(7285):59-65.
[21] Yatsunenko T, Rey FE, Manary MJ, Trehan I, Dominguez-Bello MG, Contreras M, Magris M, Hidalgo G, Baldassano RN, Anokhin AP, Heath AC. Human Gut Microbiome Viewed Across Age And Geography. Nature. 2012 Jun 14;486(7402):222-7.
[22] Ridaura VK, Faith JJ, Rey FE, Cheng J, Duncan AE, Kau AL, Griffin NW, Lombard V, Henrissat B, Bain JR, Muehlbauer MJ. Gut Microbiota From Twins Discordant For Obesity Modulate Metabolism In Mice. Science. 2013 Sep 6;341(6150):1241214.
[23] Bashan Y, De-Bashan LE. How The Plant Growth-Promoting Bacterium Azospirillum Promotes Plant Growth—A Critical Assessment. Advances In Agronomy. 2010 Jan 1;108:77-136.
[24] Singh A, Ward OP, Editors. Biodegradation And Bioremediation. Springer Science & Business Media; 2004 Jun 21.
[25] Zhou J, Deng Y, Luo F, He Z, Tu Q, Zhi X. Functional Molecular Ecological Networks. Mbio. 2010 Oct 29;1(4):10-128.
[26] Falkowski PG, Fenchel T, Delong EF. The Microbial Engines That Drive Earth's Biogeochemical Cycles. Science. 2008 May 23;320(5879):1034-9.
[27] Bastida F, Eldridge DJ, García C, Kenny Png G, Bardgett RD, Delgado-Baquerizo M. Soil Microbial Diversity–Biomass Relationships Are Driven By Soil Carbon Content Across Global Biomes. The ISME Journal. 2021 Jul;15(7):2081-91.
[28] Gest H. The Discovery Of Microorganisms By Robert Hooke And Antoni Van Leeuwenhoek, Fellows Of The Royal Society. Notes And Records Of The Royal Society Of London. 2004 May 22;58(2):187-201.
[29] De Bary A. Die Erscheinung Der Symbiose.
[30] Mokhele B, Zhan X, Yang G, Zhang X. Nitrogen Assimilation In Crop Plants And Its Affecting Factors. Canadian Journal Of Plant Science. 2012 May;92(3):399-405.
[31] Susser M, Stein Z. Eras In Epidemiology: The Evolution Of Ideas. Oxford University Press; 2009 Aug 13.
[32] Turnbaugh PJ, Hamady M, Yatsunenko T, Cantarel BL, Duncan A, Ley RE, Sogin ML, Jones WJ, Roe BA, Affourtit JP, Egholm M. A Core Gut Microbiome In Obese And Lean Twins. Nature. 2009 Jan 22;457(7228):480-4.
[33] Qin J, Li R, Raes J, Arumugam M, Burgdorf KS, Manichanh C, Nielsen T, Pons N, Levenez F, Yamada T, Mende DR. A Human Gut Microbial Gene Catalogue Established By Metagenomic Sequencing. Nature. 2010 Mar 4;464(7285):59-65.
[34] Bäckhed F, Ding H, Wang T, Hooper LV, Koh GY, Nagy A, Semenkovich CF, Gordon JI. The Gut Microbiota As An Environmental Factor That Regulates Fat Storage. Proceedings Of The National Academy Of Sciences. 2004 Nov 2;101(44):15718-23.

[35] Goel R, Suyal DC, Narayan, Dash B, Soni R. Soil Metagenomics: A Tool For Sustainable Agriculture. Mining Of Microbial Wealth And Metagenomics. 2017:217-25.
[36] Uzilday RO, Ganie SA. Extremophiles: Tolerance Mechanisms And Use In Crop Improvement. Frontiers In Plant Science. 2023 Jun 20;14:1233202.
[37] Dobrovol'Skaya TG, Zvyagintsev DG, Chernov IY, Golovchenko AV, Zenova GM, Lysak LV, Manucharova NA, Marfenina OE, Polyanskaya LM, Stepanov AL, Umarov MM. The Role Of Microorganisms In The Ecological Functions Of Soils. Eurasian Soil Science. 2015 Sep;48:959-67.
[38] Turnbaugh PJ, Ley RE, Hamady M, Fraser-Liggett CM, Knight R, Gordon JI. The Human Microbiome Project. Nature. 2007 Oct 18;449(7164):804-10.
[39] Falkowski PG, Barber RT, Smetacek V. Biogeochemical Controls And Feedbacks On Ocean Primary Production. Science. 1998 Jul 10;281(5374):200-6.
[40] Lloyd-Price J, Mahurkar A, Rahnavard G, Crabtree J, Orvis J, Hall AB, Brady A, Creasy HH, Mccracken C, Giglio MG, Mcdonald D. Strains, Functions And Dynamics In The Expanded Human Microbiome Project. Nature. 2017 Oct 5;550(7674):61-6.
[41] Boon E, Meehan CJ, Whidden C, Wong DH, Langille MG, Beiko RG. Interactions In The Microbiome: Communities Of Organisms And Communities Of Genes. FEMS Microbiology Reviews. 2014 Jan 1;38(1):90-118.
[42] Pillay S, Calderón-Franco D, Urhan A, Abeel T. Metagenomic-Based Surveillance Systems For Antibiotic Resistance In Non-Clinical Settings. Frontiers In Microbiology. 2022 Dec 2;13:1066995.
[43] Brock TD. Biology Of Microorganisms.
[44] Turnbaugh PJ, Ley RE, Hamady M, Fraser-Liggett CM, Knight R, Gordon JI. The Human Microbiome Project. Nature. 2007 Oct 18;449(7164):804-10.
[45] Mcfall-Ngai M, Hadfield MG, Bosch TC, Carey HV, Domazet-Lošo T, Douglas AE, Dubilier N, Eberl G, Fukami T, Gilbert SF, Hentschel U. Animals In A Bacterial World, A New Imperative For The Life Sciences. Proceedings Of The National Academy Of Sciences. 2013 Feb 26;110(9):3229-36.
[46] Fierer N, Jackson RB. The Diversity And Biogeography Of Soil Bacterial Communities. Proceedings Of The National Academy Of Sciences. 2006 Jan 17;103(3):626-31.
[47] Round JL, Mazmanian SK. The Gut Microbiota Shapes Intestinal Immune Responses During Health And Disease. Nat Rev Immunol. 2009 May;9(5):313-23.
[48] Belkaid Y, Hand TW. Role Of The Microbiota In Immunity And Inflammation. Cell. 2014 Mar 27;157(1):121-41.
[49] Lugtenberg B, Kamilova F. Plant-Growth-Promoting Rhizobacteria. Annual Review Of Microbiology. 2009 Oct 13;63(1):541-56.
[50] Bulgarelli D, Garrido-Oter R, Münch PC, Weiman A, Dröge J, Pan Y, Mchardy AC, Schulze-Lefert P. Structure And Function Of The Bacterial Root Microbiota In Wild And Domesticated Barley. Cell Host & Microbe. 2015 Mar 11;17(3):392-403.
[51] Glick BR. Plant Growth-Promoting Bacteria: Mechanisms And Applications. Scientifica. 2012;2012(1):963401.
[52] Lehmann J, Kleber M. The Contentious Nature Of Soil Organic Matter. Nature. 2015 Dec 3;528(7580):60-8.
[53] Loreau M, Naeem S, Inchausti P, Editors. Biodiversity And Ecosystem Functioning: Synthesis And Perspectives. OUP Oxford; 2002.
[54] Olive AJ, Sassetti CM. Metabolic Crosstalk Between Host And Pathogen: Sensing, Adapting And Competing. Nature Reviews Microbiology. 2016 Apr;14(4):221-34.
[55] Sartor RB. Microbial Influences In Inflammatory Bowel Diseases. Gastroenterology. 2008 Feb 1;134(2):577-94.
[56] Villanueva-Millán MJ, Pérez-Matute P, Oteo JA. Gut Microbiota: A Key Player In Health And Disease. A Review Focused On Obesity. Journal Of Physiology And Biochemistry. 2015 Sep;71:509-25.
[57] Round JL, Mazmanian SK. The Gut Microbiota Shapes Intestinal Immune Responses During Health And Disease. Nature Reviews Immunology. 2009 May;9(5):313-23.
[58] Cryan JF, Dinan TG. Mind-Altering Microorganisms: The Impact Of The Gut Microbiota On Brain And Behaviour. Nature Reviews Neuroscience. 2012 Oct;13(10):701-12.
[59] Koeth RA, Wang Z, Levison BS, Buffa JA, Org E, Sheehy BT, Britt EB, Fu X, Wu Y, Li L, Smith JD. Intestinal Microbiota Metabolism Of L-Carnitine, A Nutrient In Red Meat, Promotes Atherosclerosis. Nature Medicine. 2013 May;19(5):576-85.
[60] Garrett WS. Cancer And The Microbiota. Science. 2015 Apr 3;348(6230):80-6.
[61] Paul EA. Soil Microbiology, Ecology, And Biochemistry In Perspective. Insoil Microbiology, Ecology And Biochemistry 2007 Jan 1 (Pp. 3-24). Academic Press.
[62] Swift MJ, Heal OW, Anderson JM, Anderson JM. Decomposition In Terrestrial Ecosystems. Univ Of California Press; 1979.
[63] Rittmann BE, Mccarty PL. Environmental Biotechnology: Principles And Applications. (No Title). 2001.
[64] Round, J. L., & Mazmanian, S. K. (2009). The Gut Microbiota Shapes Intestinal Immune Responses During Health And Disease. Nature Reviews Immunology, 9(5), 313-323.
[65] Donlan RM. Biofilms: Microbial Life On Surfaces. Emerging Infectious Diseases. 2002 Sep;8(9):881.
[66] Miller MB, Bassler BL. Quorum Sensing In Bacteria. Annual Reviews In Microbiology. 2001 Oct;55(1):165-99.
[67] Belkaid Y, Hand TW. Role Of The Microbiota In Immunity And Inflammation. Cell. 2014 Mar 27;157(1):121-41.
[68] Sanders ME, Merenstein DJ, Reid G, Gibson GR, Rastall RA. Probiotics And Prebiotics In Intestinal Health And Disease: From Biology To The Clinic. Nature Reviews Gastroenterology & Hepatology. 2019 Oct;16(10):605-16.
[69] Van Nood E, Vrieze A, Nieuwdorp M, Fuentes S, Zoetendal EG, De Vos WM, Visser CE, Kuijper EJ, Bartelsman JF, Tijssen JG, Speelman P. Duodenal Infusion Of Donor Feces For Recurrent Clostridium Difficile. New England Journal Of Medicine. 2013 Jan 31;368(5):407-15.
[70] Roberfroid M. Prebiotics: The Concept Revisited1. The Journal Of Nutrition. 2007 Mar 1;137(3):830S-7S.
[71] Gopalakrishnan V, Spencer CN, Nezi L, Reuben A, Andrews MC, Karpinets TV, Prieto PA, Vicente D, Hoffman K, Wei SC, Cogdill AP. Gut Microbiome Modulates Response To Anti–PD-1 Immunotherapy In Melanoma Patients. Science. 2018 Jan 5;359(6371):97-103.
[72] Zasloff M. Antimicrobial Peptides Of Multicellular Organisms. Nature. 2002 Jan 24;415(6870):389-95.
[73] Dinan TG, Cryan JF. The Microbiome-Gut-Brain Axis In Health And Disease. Gastroenterology Clinics. 2017 Mar 1;46(1):77-89.
[74] Zilhao NR, Olthof MC, Smit DJ, Cath DC, Ligthart L, Mathews CA, Delucchi K, Boomsma DI, Dolan CV. Heritability Of Tic Disorders: A Twin-Family Study. Psychological Medicine. 2017 Apr;47(6):1085-96.
[75] Vidali M. Bioremediation. An Overview. Pure And Applied Chemistry. 2001 Jul 1;73(7):1163-72.
[76] Nielsen AA, Der BS, Shin J, Vaidyanathan P, Paralanov V, Strychalski EA, Ross D, Densmore D, Voigt CA. Genetic Circuit Design Automation. Science. 2016 Apr 1;352(6281):Aac7341.
[77] Pavot V, Rochereau N, Genin C, Verrier B, Paul S. New Insights In Mucosal Vaccine Development. Vaccine. 2012 Jan 5;30(2):142-54.

[78] Sanders ME, Merenstein DJ, Reid G, Gibson GR, Rastall RA. Probiotics And Prebiotics In Intestinal Health And Disease: From Biology To The Clinic. Nature Reviews Gastroenterology & Hepatology. 2019 Oct;16(10):605-16.

[79] Round JL, Mazmanian SK. The Gut Microbiota Shapes Intestinal Immune Responses During Health And Disease. Nature Reviews Immunology. 2009 May;9(5):313-23.

[80] Gopalakrishnan V, Spencer CN, Nezi L, Reuben A, Andrews MC, Karpinets TV, Prieto PA, Vicente D, Hoffman K, Wei SC, Cogdill AP. Gut Microbiome Modulates Response To Anti–PD-1 Immunotherapy In Melanoma Patients. Science. 2018 Jan 5;359(6371):97-103.

[81] Nielsen AA, Der BS, Shin J, Vaidyanathan P, Paralanov V, Strychalski EA, Ross D, Densmore D, Voigt CA. Genetic Circuit Design Automation. Science. 2016 Apr 1;352(6281):Aac7341.

[82] Faust K, Raes J. Microbial Interactions: From Networks To Models. Nature Reviews Microbiology. 2012 Aug;10(8):538-50.

[83] Biazzo M, Deidda G. Fecal Microbiota Transplantation As New Therapeutic Avenue For Human Diseases. Journal Of Clinical Medicine. 2022 Jul 15;11(14):4119.

[84] Cherbuy C, Bellet D, Robert V, Mayeur C, Schwiertz A, Langella P. Modulation Of The Caecal Gut Microbiota Of Mice By Dietary Supplement Containing Resistant Starch: Impact Is Donor-Dependent. Frontiers In Microbiology. 2019 Jun 6;10:1234.

[85] Dinan TG, Cryan JF. The Microbiome-Gut-Brain Axis In Health And Disease. Gastroenterology Clinics. 2017 Mar 1;46(1):77-89.

[86] Faust K, Raes J. Microbial Interactions: From Networks To Models. Nature Reviews Microbiology. 2012 Aug;10(8):538-50.

[87] Biazzo M, Deidda G. Fecal Microbiota Transplantation As New Therapeutic Avenue For Human Diseases. Journal Of Clinical Medicine. 2022 Jul 15;11(14):4119.

[88] Youngster I, Sauk J, Pindar C, Wilson RG, Kaplan JL, Smith MB, Alm EJ, Gevers D, Russell GH, Hohmann EL. Fecal Microbiota Transplant For Relapsing Clostridium Difficile Infection Using A Frozen Inoculum From Unrelated Donors: A Randomized, Open-Label, Controlled Pilot Study. Clinical Infectious Diseases. 2014 Jun 1;58(11):1515-22.