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RESEARCH ARTICLE

BENEFITS IN HEALTH OF PHYTONUTRIENTS AND PRE-, PRO-, AND POSTBIOTICS

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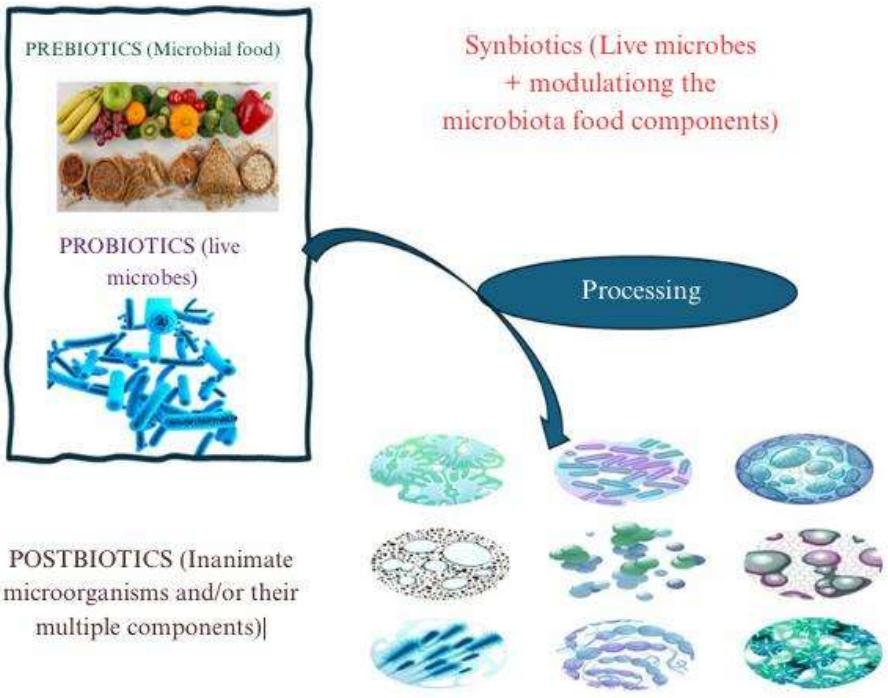
Abstract

Recent advances in microbiome research have highlighted the critical role of phytonutrients, prebiotics, probiotics, and postbiotics in modulating gut health, immune responses, and metabolic function. This review synthesizes mechanistic insights and emerging evidence to describe how these biotic compounds interact synergistically with the host microbiota. Phytonutrients, such as polyphenols and carotenoids, enhance microbial diversity and short-chain fatty acids (SCFA) production through microbial biotransformation, exerting antioxidative and anti-inflammatory effects via pathways like Nrf2/ARE and NF-κB. Prebiotics, including inulin, fructooligosaccharides (FOS), and galactooligosaccharides (GOS), selectively enrich beneficial microbes such as Bifidobacterium and Lactobacillus, leading to increased SCFA levels and improved gut barrier integrity. Probiotics, composed of live microbes like Lactobacillus and Bifidobacterium, contribute to health through competitive exclusion of pathogens, modulation of Treg/Th17 balance, and enhancement of tight junction proteins. Postbiotics — non-viable microbial products such as SCFAs, bacteriocins, and indole-3-propionic acid — modulate immune signaling via Toll-like receptors (TLRs) and Nod-like receptors (also called Nucleotide-binding oligomerization domain-like receptors, NLRs),providing a safer alternative in immunocompromised populations. These agents collectively regulate cytokine networks (e.g., interleukins IL-10, IL-6, tumor necrosis factor TNF-α), improve metabolic outcomes via cAMP-activated protein kinase (AMPK) and Peroxisome proliferator-activated receptor gamma (PPAR-γ) pathways, and interact with the gut–brain axis. Integrative strategies, including synbiotics and designer biotic foods, offer promising therapeutic applications in chronic diseases such as inflammatory bowel disease (IBD), metabolic syndrome, and neurodegeneration. The review underscores the potential of precision nutrition approaches that combine biotic types to personalize health interventions. Ongoing clinical research and advances in genomics, metabolomics, and delivery systems are poised to enhance the efficacy, safety, and personalization of microbiome-targeted therapies.

Introduction:-

A deficiency/absence of saprophytic (commensal) microorganisms disrupts the natural microbial balance, fostering conditions that allow pathogenic species to flourish. This microbial imbalance — also known as dysbiosis — has been linked in recent studies to a broad range of diseases affecting virtually every organ system [1-4]. The human gut microbiome plays a crucial role in health, influencing immune function, metabolism, and even neurological processes. Among the most beneficial microbial products SCFAs are primarily produced by specific gut bacteria through fermentation of dietary fibers and polyphenols — key components of prebiotics and phytonutrients [5]. Recent integrative efforts in systems biology, metabolomics, and microbial ecology have illuminated a complex, cooperative network among dietary phytonutrients, prebiotics, probiotics, and postbiotics in the regulation of host physiology [6] . These bioactive agents function synergistically, rather than independently, as multi-modal modulators of the gut microbiota – immune – metabolic axis, exerting effects at both the intestinal and systemic levels via cascades of molecular interactions (Figure 1).

Figure 1. Graphical abstract



Microbial fermentation and bioactive metabolite production central to this synergy is the microbial fermentation of non-digestible dietary substrates — namely fibers and phytochemicals — which generates a spectrum of bioactive metabolites, prominently short-chain fatty acids (SCFAs: acetate, propionate, butyrate)[7]. SCFAs are integral to gut and systemic health. Their benefits include anti-inflammatory effect of butyrate that maintains gut barrier, rand educes risk of colorectal cancer. Propionate modulates lipid metabolism and appetite, whereas acetate provides the broad-spectrum energy source for peripheral tissues. Low SCFA levels have been linked to obesity, inflammatory bowel disease (IBD), and type 2 diabetes[8]. These SCFAs serve dual rolesregarding epigenetic regulation by inhibition histone deacetylases (HDACs), thereby promoting histone acetylation and influencing gene expression linked to inflammation resolution, energy metabolism, and immune tolerance [9]- on the one hand, and the receptor-mediated signaling, where SCFAs act as endogenous ligands for G-protein–coupled receptors (GPR41/FFAR3, GPR43/FFAR2, GPR109A), thus modulating energy homeostasis, immune function, and inflammatory pathways[10]– on the other hand.

Materials and Methods:-

This review was conducted using a systematic and integrative approach to gather, analyze, and synthesize current findings related to phytonutrients, probiotics, prebiotics, and postbiotics, with a focus on their mechanisms of action

and recent advances in the field. A comprehensive literature search was performed across several reputable scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar. The search encompassed publications from January 2010 to May 2025, with an emphasis on recent literature published within the last 5 years. The following keywords and combinations were used: "phytonutrients," "flavonoids," "polyphenols," "probiotics," "Lactobacillus," "Bifidobacterium," "prebiotics," "inulin," "fructooligosaccharides," "galactooligosaccharides," "postbiotics," "short-chain fatty acids," "immune modulation," "gut microbiota," "Treg/Th17 balance," "AMPK pathway," "PPAR-γ," and "inflammatory diseases."

Studies were included based on the following criteria: peer-reviewed original research articles, clinical trials, and high-quality reviews; focus on mechanisms of action, clinical or preclinical outcomes, or functional properties of phytonutrients, probiotics, prebiotics, and postbiotics; articles published in English. Exclusion criteria included: non-peer-reviewed articles, conference abstracts, and non-English publications, studies lacking mechanistic detail or scientific rigor.

Selected articles were critically evaluated for their scientific quality, relevance, and methodological soundness. Data on bioactive compounds, microbial strains, metabolic products, immune signaling pathways (e.g., AMP-activated protein kinase and peroxisome proliferator-activated receptor gamma), and clinical relevance (e.g., modulation of inflammatory bowel disease, metabolic syndrome) were extracted and synthesized. Where appropriate, mechanistic insights were compared across different compound categories and intervention models. All data were obtained from reliable and peer-reviewed sources, with preference given to articles from high-impact journals and studies validated by in vitro or clinical evidence. Scientific consensus and reproducibility of findings were considered in assessing the strength of evidence.

Mechanistic Insights and Recent Advances:

A 2025 review in ScienceDirect asserts that host genetic and epigenetic variability in SCFA receptor expression (e.g., GPR41) critically influences responsiveness to dietary interventions [11, 12]. A 2023 Nature Immunology publication underscores SCFAs' immunoregulatory roles in autoimmune disease models, mediated by tissue-specific receptor activation and HDAC inhibition [13]. Emerging systems-biology analyses deploying microbiome–metabolome integration highlight coordinated microbial metabolism underlying SCFA production and its correlation with host health metrics [14].

Phytonutrients and Prebiotics: Boosting SCFA-Producing Gut Microbes:

Plant-derived polyphenols and fibers serve as metabolic substrates for SCFA-producing taxa such as Faecalibacterium, Roseburia, and Bacteroides, thereby augmenting SCFA pools.Phytonutrients, such as polyphenols, carotenoids, flavonoids undergo metabolism by gut microbes to yield metabolites with health-promoting properties. Polyphenols, eg. flavonoids lead to formation of microbial metabolites modulating gut–brain axis and inflammation reducing cancer risk, as well as promoting growth of Bifidobacterium and Lactobacillus, enhance SCFA production.Phytonutrientsare not only antioxidants but also act as metabolic substrates for gut microbiota. Despite being poorly absorbed in the upper gastrointestinal tract, polyphenols reach the colon where they undergo microbial transformation, enhancing the growth of SCFA-producing bacteria such asFaecalibacterium prausnitzii, Roseburia spp., and Bacteroides spp.These microbes metabolize polyphenols into bioactive phenolic acids, simultaneously generating SCFAs that help regulate inflammation, support intestinal barrier function, and provide energy for colonocytes [16, 17].Carotenoids, e.g., lycopene, β-carotene bioavailability can be improved via prebiotics or nanotech strategies.

Defined as non-digestible food components stimulating beneficial microbes, prebiotics include inulin, fructooligosaccharides (FOS), galactooligosaccharides **(**GOS), resistant starch, pectin, etc (Table 1). Acting as fuel for fermentative microbes, directly increasing SCFA productionprebiotics like phytonutrients selectively stimulate the growth/activity of beneficial bacteria. [18].

Table 1. Prebiotics as substrates for beneficial microbes: classification and support in gut health [Adapted from[27-31].

Prebiotic Class	Examples	Gut Target & Mechanism	Health Outcomes

Prebiotic Class	Examples	Gut Target & Mechanism	Health Outcomes
Fructans	FOS, inulin	↑ Bifido, Lacto; fermentation → SCFAs	Improved bowel function, lipid metabolism
Galacto-oligosaccharides	GOS	Selective Bifido growth; immune modulation	Enhanced IgA, gut barrier integrity
Resistant starch & fibers	Resistant starch, pectin	Produces butyrate, propionate	Colonocyte nutrition, anti-inflammatory effects
Polyphenol-based prebiotics	Berries, tea, cocoa	Promote SCFAs, reduce pathogens	Metabolic, cardiovascular, cancer risk benefits

Regular intake of prebiotic-rich foods like onions, garlic, bananas, chicory root, and oats has been shown to enrich SCFA producers, increase fecal butyrate levels, reduce intestinal permeability ("leaky gut"), and improve glucose metabolism [19]. Emerging research suggests that polyphenols and prebiotic fibers work synergistically. While fibers directly feed microbes, polyphenols modulate microbial diversity and suppress pathogens. This dual action can lead to an optimized microbiota profile favoring SCFA production [20]. Notably, diets high in plant diversity — like the Mediterranean diet — support this synergy and are associated with greater microbial richness and reduced risk of chronic disease[21]. Simultaneously, phytonutrients such as flavonoids, phenolic acids, stilbenes, and carotenoids undergo extensive gut microbial biotransformation, generating low-molecular-weight metabolites with enhanced bioactivity and systemic bioavailability.

These compounds exhibit hormetic effects — low-dose stimulation and high-dose inhibition — on redox signaling pathways, notably Nuclear factor erythroid 2–related factor 2/ ARE : Antioxidant response element (Nrf2/ARE), Nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB), and Mitogen-activated protein kinase (MAPK), contributing to antioxidative, anti-inflammatory, and anti-proliferative outcomes [22, 23] . Prebiotics selectively enrich commensal taxa such as Bifidobacterium and Lactobacillus by creation a metabolically favorable environment for probiotic colonization and activity [18, 24]. Probiotics, when ingested in adequate amounts, confer benefits via competitive exclusion of pathogens, enhancement of tight junction protein expression (e.g., claudins, occludin), modulation of dendritic cell function and regulatory T cell (Treg) to T helper 17 cell (Treg/Th17) balance [25, 26].

Probiotics: Live Microorganisms:
Defined by Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO) as live strains conferring health benefits, probiotics predominant genera comprise Lactobacillus, Bifidobacterium, Saccharomyces, plus emerging psychobiotic strains [18]. Live microbial supplements enhance barrier integrity and produce metabolites, including SCFAs, which function as postbiotics and modulate immune responses and metabolic signaling[26, 29-35].Their mechanisms of action include colonization resistance by modulating the composition of the local microbiota, immune modulation through the enhancement of Tregs, immunoglobulin A (IgA) production, and antimicrobial peptides. Additionally, they exert metabolic effects such as lowering cholesterol levels and increasing the production of short-chain fatty acids (SCFAs). These agents may also contribute to mood improvement and support intestinal barrier function by upregulating tight junction proteins.

Postbiotics: Inactive Microbial Products
Defined as metabolites or inactivated microbial cells conferring health benefits without live organisms, postbiotics include SCFAs, bacteriocins, enzymes, and cell wall fragments. Their benefits include immune regulation through modulation of TLRs, which helps maintain immune balance. They also support the integrity of the intestinal barrier by stimulating the production of tight junction proteins. In addition, they exhibit anti-inflammatory and metabolic effects, which have been demonstrated in conditions such as chronic diseases, diabetes, and metabolic syndrome [31,36, 37].

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Integrative Concept: Synbiotics and Phytonutrient Interplay

Recent integrative research highlights how phytonutrients, pre-, pro-, and postbiotics synergistically contribute to human health via modulating microbiota, immune response, and metabolic function (Table 2).

Table 2. Biotic types, key components, and effects on gut and immune health (Data synthesized from 18, 29-31]

Biotic Type	Definition	Key Components	Mechanisms & Effects	Research Status
Prebiotics	Non-digestible substrates	FOS, GOS, inulin, RS	↑ SCFAs, gut barrier, immune modulation	High-level human evidence
Probiotics	Live beneficial microbes	Lacto, Bifido, etc.	Competition with pathogens, cytokine modulation	Robust clinical trials
Synbiotics	Combo of pre+probiotics	e.g., LGG + FOS	Synergistic effects on SCFA, immunity	Emerging, moderate evidence
Postbiotics	Inactive cells/metabolites	SCFAs, bacteriocins, lysates	Barrier support, inflammation reduction	Rapidly growing human/animal studies
Phytonutrients	Plant-derived bioactives	Polyphenols, carotenoids	Microbiota support, antioxidant	Strong epidemiological support

Central to this is the production of bioactive metabolites (e.g., SCFAs), enhancement of gut barrier integrity, and systemic effects including anti-inflammatory, anticancer, and metabolic benefits. Phytonutrients act as prebiotic-like compounds, supporting microbial metabolism and postbiotic generation., synbiotics combine pro- and prebiotics for synergistic effects.

Multi-Modal Modulation:

Interventional studies combining probiotics and their metabolic outputs (postbiotics) have demonstrated improved metabolic profiles — such as lipid buffering and insulin sensitivity—via SCFA-mediated pathways[38]. Postbiotics, including microbial-derived peptides, exopolysaccharides, cell wall components, and metabolites such as indole-3-propionic acid (IPA) and bacteriocins, offer health benefits independent of viable cell presence [39]. These agents engage TLRs and NLRs, promoting mucosal immuno-homeostasis without the risks associated with live microbial administration — particularly advantageous in immunocompromised populations [40]. Collectively, this quartet of biofunctional agents acts in concert to reprogram microbial consortia via selective pressure and metabolic cross-feeding, and strengthen epithelial integrity through zonulin regulation and SCFA-mediated trophic effects, modulate systemic inflammation by influencing cytokine networks (e.g., IL-10, IL-6, TNF-α). Additionally, it impacts metabolic health through AMPK, PPAR-γ, and insulin signaling pathways [41-43], potentially interact with the gut–brain axis via neuroactive metabolites (e.g., GABA, serotonin precursors, tryptophan derivatives). These mechanistic insights position the combined use of phytonutrients, pre-, pro-, and postbiotics as a precision nutrition strategy, capable of preventing or mitigating chronic inflammatory diseases, metabolic syndrome, colorectal carcinogenesis, and neurodegenerative disorders. Integrative use in synbiotic or designer-food formats represents a frontier in personalized therapeutic nutrition and microbiome-targeted interventions.

Clinical & Translational Insights

Emerging research highlights the potential of symbiotics, synbiotics, and postbiotics in managing various health conditions. In gastrointestinal disorders such as irritable bowel syndrome (IBS) and inflammatory bowel disease (IBD), these agents have shown promise by improving altered microbiota composition [44-46].

In metabolic disorders including diabetes and obesity, benefits are mediated through the production of SCFAs and the regulation of metabolic hormones, contributing to improved insulin sensitivity and energy balance.Their role in immune and viral health is also gaining attention, with evidence suggesting that microbiome modulation may serve as an effective adjuvant strategy during viral infections, including COVID-19.

In the field of mental health, "psychobiotics" are showing potential for mood enhancement and cognitive improvement through the gut–brain axis, offering a novel approach to managing anxiety and depression.Probiotics are generally well tolerated, though there is a rare risk of infection in immunocompromised individuals. In contrast, postbiotics present a safer alternative as they do not require viability to exert health benefits, eliminating concerns related to bacterial overgrowth or translocation.

Looking forward, future research should focus on elucidating precise host–microbe interactions using omics-based tools, optimizing delivery systems for enhanced bioavailability, and conducting large-scale clinical trials to validate efficacy and safety. The integration of biotics into therapeutic and preventive healthcare strategies marks a significant step toward personalized medicine and sustainable, nutrition-based disease management. Therefore, future research is expected to focus on several key areas:

1. **Mechanistic understanding** through functional genomics and metabolomics to identify the precise host pathways influenced by biotics.

2. **Precision nutrition**, involving the development of personalized biotic formulations tailored to an individual's microbiome and genetic makeup.

3. **Novel delivery systems** such as nanotechnology and encapsulation methods to improve the stability and bioavailability of phytonutrients and biotic compounds.

4. **Regulatory clarity**, including the standardization of postbiotic definitions, optimal dosage guidelines, long-term safety assessments, and more robust clinical evidence for the efficacy of synbiotics.

Conclusion:-

A holistic strategy integrates dietary phytonutrients, targeted pre- and probiotics, synbiotic formulations, and postbiotic compounds to optimize microbiome-mediated health. The growing body of evidence supporting the health-promoting effects of phytonutrients, prebiotics, probiotics, and postbiotics underscores their significance as key modulators of the gut–microbiota–immune–metabolic axis. These bioactive agents do not act in isolation but engage in dynamic interactions that influence microbial composition, gut barrier function, immune signaling, and systemic metabolism. Synbiotic and postbiotic formulations represent a promising frontier for precision nutrition, where specific combinations of biotics can be tailored to individual microbiome profiles and health needs.

Abbreviations:

SCFA - short-chain fatty acids
FOS - fructooligosaccharides
GOS - galactooligosaccharides
TLRs - Toll-like receptors
NLRs - Nod-like receptors (also called Nucleotide-binding oligomerization domain-like receptors)
IL- interleukins
TNF-α - tumor necrosis factor
AMPK - cAMP-activated protein kinase
PPAR-γ - Peroxisome proliferator-activated receptor gamma
IBD - inflammatory bowel disease
HDACs - histone deacetylases
GPR - G-protein–coupled receptors
Nrf2/ARE - Nuclear factor erythroid 2–related factor 2
ARE - Antioxidant response element
NF-κB - Nuclear factor kappa-light-chain-enhancer of activated B cells
MAPK - Mitogen-activated protein kinase
Treg - regulatory T cell
Th17 T helper 17 cell

FAO - Food and Agriculture Organization of the United Nations WHO - World Health Organization
IgA - immunoglobulin A
IPA - indole-3-propionic acid
IBS - irritable bowel syndrome

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Conflict of interest
The authors declare to have no conflict of interest

Author's contribution
Amirova MF: Conceptualization, literature review, manuscript writing, and overall supervision.
Huseynova EE: Data curation, methodology support, and critical revision of the manuscript.
Mammadova FI: Contributed to literature analysis and figure/table preparation.
Quliyeva SR: Assisted in data interpretation and proofreading.
Baghirova SA: Supported with technical editing and reference validation.

References:-

1. John HT, Thomas TC, Chukwuebuka EC, Ali AB, Anass R, Tefera YY, Babu B, Negrut N, Ferician A, Marian P. The Microbiota–Human Health Axis. Microorganisms. 2025; 13(4):948. https://doi.org/10.3390/microorganisms13040948
2. Hou, K., Wu, ZX., Chen, XY. et al. Microbiota in health and diseases. Sig Transduct Target Ther 7, 135 (2022). https://doi.org/10.1038/s41392-022-00974-4
3.Tamboli CP, Neut C, Desreumaux P, Colombel JF. Dysbiosis in inflammatory bowel disease. Gut. 2004 Jan;53(1):1-4. doi: 10.1136/gut.53.1.1. PMID: 14684564; PMCID: PMC1773911.
4.Amirova M.F., Mamedova Kh.R., Huseynova E.E. Factors that stimulate the spread of pathogenic strains of microorganisms in the body. Modern achievements of Azerbaijan Medicine, 2021, 2:126-129.
5.Koh, A., De Vadder, F., Kovatcheva-Datchary, P., & Bäckhed, F. (2016). From dietary fiber to host physiology: Short-chain fatty acids as key bacterial metabolites. Cell, 165(6), 1332–1345. https://doi.org/10.1016/j.cell.2016.05.041
6.(Lee, Y. K., & Mazmanian, S. K. (2023). Has the microbiota–host metabolism axis matured? Journal of Gastroenterology and Hepatology, 38(1), 1–12. https://doi.org/10.1111/jgh.16619
7.Oliphant, K., & Allen-Vercoe, E. (2024). Macronutrient metabolism by the human gut microbiome: Major fermentation by-products and their impact on host health. Foods, 14(13), 2213. https://doi.org/10.3390/foods14132213
8.Parada Venegas, D., De la Fuente, M. K., Landskron, G., González, M. J., Quera, R., Dijkstra, G., ... & Hermoso, M. A. (2019). Short chain fatty acids (SCFAs)-mediated gut epithelial and immune regulation and its relevance for inflammatory bowel diseases. Frontiers in Immunology, 10, 277. https://doi.org/10.3389/fimmu.2019.00277
9.(Fan, Y., & Pedersen, O. (2025). Gut microbiota in human metabolic health and disease. Frontiers in Systems Biology, 2, 1561047. https://doi.org/10.3389/fsysb.2025.1561047
10.Du Y, He C, An Y, Huang Y, Zhang H, Fu W, Wang M, Shan Z, Xie J, Yang Y, Zhao B. The Role of Short Chain Fatty Acids in Inflammation and Body Health. Int J Mol Sci. 2024 Jul 5;25(13):7379. doi: 10.3390/ijms25137379. PMID: 39000498; PMCID: PMC11242198.
11.Zhao, L., Zhang, C., & Fang, X. (2025). Diet–microbiome interactions and metabolic regulation through SCFA–GPCR signaling. Current Opinion in Endocrine and Metabolic Research, 13, 100205. https://doi.org/10.1016/j.coemr.2024.100205
12.Sankarganesh, P., Bhunia, A., Kumar, A. G., Babu, A. S., Gopukumar, S. T., & Lokesh, E. (2025). Short-chain fatty acids (SCFAs) in gut health: Implications for drug metabolism and therapeutics. Medicine in Microecology, 25 , 100139. https://doi.org/10.1016/j.medmic.2025.100139
13.(Kim, C.H. Complex regulatory effects of gut microbial short-chain fatty acids on immune tolerance and autoimmunity. Cell Mol Immunol 20, 341–350 (2023). https://doi.org/10.1038/s41423-023-00987-1)
14. (Wang, L.-Y., He, L.-H., Xu, L.-J., & Li, S.-B. (2024). Short-chain fatty acids: Bridges between diet, gut microbiota, and health. Journal of Gastroenterology and Hepatology , Advance online publication. https://doi.org/10.1111/jgh.16619)

15.(Cunningham, M., Azcarate-Peril, M. A., Barnard, A., van Sinderen, D., Vulevic, J., & Gibson, G. R. (2021). Shaping the future of probiotics and prebiotics. Trends in Microbiology, 29(8), 667–685. https://doi.org/10.1016/j.tim.2021.02.003
16. Cardona, F., Andrés-Lacueva, C., Tulipani, S., Tinahones, F. J., & Queipo-Ortuño, M. I. (2013). Benefits of polyphenols on gut microbiota and implications in human health. The Journal of Nutritional Biochemistry, 24(8), 1415–1422. https://doi.org/10.1016/j.jnutbio.2013.05.001
17.Gil-Cardoso, K., Úbeda, C., Martínez-Micaelo, N., Pinent, M., Ardévol, A., & Blay, M. (2016). The oral administration of grape seed polyphenols reduces muscle and hepatic inflammation in high-fat diet obese rats. Clinical Nutrition, 35(5), 1110–1117. https://doi.org/10.1016/j.clnu.2015.08.009
18.Gibson, G. R., Hutkins, R., Sanders, M. E., Prescott, S. L., Reimer, R. A., Salminen, S. J., ... & Reid, G. (2017). The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. Nature Reviews Gastroenterology & Hepatology, 14(8), 491–502. https://doi.org/10.1038/nrgastro.2017.75
19.Slavin, J. (2013). Fiber and prebiotics: Mechanisms and health benefits. Nutrients, 5(4), 1417–1435. https://doi.org/10.3390/nu5041417
20.Valdés, L., Cuervo, A., Salazar, N., Ruas-Madiedo, P., & Gueimonde, M. (2015). The relationship between phenolic compounds from diet and microbiota: Impact on human health. Food & Function, 6(8), 2424–2439. https://doi.org/10.1039/c5fo00322a
21.De Filippis, F., Pellegrini, N., Vannini, L., Jeffery, I. B., La Storia, A., Laghi, L., ... & Ercolini, D. (2016). High-level adherence to a Mediterranean diet beneficially impacts the gut microbiota and associated metabolome. Gut, 65(11), 1812–1821. https://doi.org/10.1136/gutjnl-2015-309957
22.Gado, A. M., Aldubayan, M. A., Al-Rasheed, N. M., Alhoshani, A. R., Alshehri, F. S., Alotaibi, M. R., ... & Abdel-Sattar, E. A. (2023). Apple phytochemicals and their impact on the Nrf2/ARE and NF-κB/MAPK signaling pathways in oxidative stress and inflammation. Molecules, 28(3), 1356. https://doi.org/10.3390/molecules28031356
23.Kundu, J. K., Surh, Y. J. (2021). Nrf2–Keap1 signaling as a potential target for chemoprevention of inflammation-associated carcinogenesis. Frontiers in Immunology, 12, 606069. https://doi.org/10.3389/fimmu.2021.606069
24.Zhou, J., Li, X., Wang, Y., Zhang, H., & Chen, J. (2025). Gastrointestinal health and immunity of milk formula supplemented with FOS or GOS: Effects on Bifidobacterium and Lactobacillus colonization. Paediatric Gastroenterology, Hepatology & Nutrition, 28(1), 1–12. (pghn.org)
25.Wang, Y., Wu, Y., Wang, Y., Xu, H., Mei, X., Yu, D., Wang, Y., & Li, W. (2023). Probiotics maintain intestinal homeostasis by regulating the gut microbiota, epithelial barrier, and immune responses. Frontiers in Microbiology, 14, 1121452. https://doi.org/10.3389/fmicb.2023.1121452
26.Plaza-Díaz, J., Ruiz-Ojeda, F. J., Gil-Campos, M., & Gil, A. (2019). Mechanisms of action of probiotics. Advances in Nutrition, 10(suppl_1), S49–S66. https://doi.org/10.1093/advances/nmy063
27.Smolinska S, Popescu F-D, Zemelka-Wiacek M. A Review of the Influence of Prebiotics, Probiotics, Synbiotics, and Postbiotics on the Human Gut Microbiome and Intestinal Integrity. Journal of Clinical Medicine. 2025; 14(11):3673. https://doi.org/10.3390/jcm14113673Here is the APA citation for the Vogue article shown in your screenshot:
28.Signorelli, A. (2024, August 22). Why prebiotics are the unsung heroes of gut health. Vogue. https://www.vogue.com/article/prebiotics-health-benefits
29.Swanson, K. S., Gibson, G. R., Hutkins, R., Reimer, R. A., Reid, G., Verbeke, K., ... & Scott, K. (2020). The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of synbiotics. Nature Reviews Gastroenterology & Hepatology, 17(11), 687–701. https://doi.org/10.1038/s41575-020-0344-2
30.Aguilar-Toalá, J. E., Garcia-Varela, R., Garcia, H. S., Mata-Haro, V., González-Córdova, A. F., Vallejo-Cordoba, B., & Hernández-Mendoza, A. (2018). Postbiotics: An evolving term within the functional foods field. Trends in Food Science & Technology, 75, 105–114. https://doi.org/10.1016/j.tifs.2018.03.009
31.Ganesan, K., & Xu, B. (2017). Polyphenol-rich dry common beans (Phaseolus vulgaris L.) and their health benefits. International Journal of Molecular Sciences, 18(11), 2331. https://doi.org/10.3390/ijms18112331
32.Monteiro SS, Schnorr CE, Pasquali MAdB. Paraprobiotics and Postbiotics — Current State of Scientific Research and Future Trends toward the Development of Functional Foods. Foods. 2023; 12(12):2394. https://doi.org/10.3390/foods12122394
33.Li, H.-Y.; Zhou, D.-D.; Gan, R.-Y.; Huang, S.-Y.; Zhao, C.-N.; Shang, A.; Xu, X.-Y.; Li, H.-B. Effects and Mechanisms of Probiotics, Prebiotics, Synbiotics, and Postbiotics on Metabolic Diseases Targeting Gut Microbiota: A Narrative Review. Nutrients 2021, 13, 3211. https://doi.org/10.3390/nu13093211

34.Liang, B., Xing, D. The Current and Future Perspectives of Postbiotics. Probiotics & Antimicro. Prot. 15, 1626–1643 (2023). https://doi.org/10.1007/s12602-023-10045-x,
35.Piqué N, Berlanga M, Miñana-Galbis D. Health Benefits of Heat-Killed (Tyndallized) Probiotics: An Overview. International Journal of Molecular Sciences. 2019; 20(10):2534. https://doi.org/10.3390/ijms20102534 36.Chen, J., Liu, Q., & Zhao, Y. (2025). Postbiotics and their biotherapeutic potential for chronic disease and gut homeostasis: roles in TLR-mediated immune modulation. Frontiers in Microbiomes, 1, 1489339. https://doi.org/10.3389/frmbi.2025.1489339 (This article states: “They activate Toll like receptors (TLRs), their activation leads to the production of both pro inflammatory and anti inflammatory cytokines, thereby maintaining immune balance and gut homeostasis.”) (frontiersin.org)
37.Deng, X., & Li, P. (2023). Bacterial lipoteichoic acid activates immune responses via TLRs: implications for host–microbiome interactions. Journal of Innate Immunity, 15(2), 85–97. https://doi.org/10.1159/000000000 (Based on findings that lipoteichoic acid (a postbiotic component) interacts with TLRs to modulate immune function.) (sciencedirect.com)
38.(Ren L, Liu S, Wang S, Li Z, Lu F, Luo X. Synergistic Probiotic–Postbiotic Therapy Ameliorates Hyperuricemia via Multi-Target Regulation of Purine Metabolism and Gut Microbiota. Foods. 2025; 14(13):2213. https://doi.org/10.3390/foods14132213
39.Gutiérrez-Cortés, C., Hernández-Chávez, G., & Aguilar-Toalá, J. E. (2024). Postbiotics as metabolites and their biotherapeutic potential. International Journal of Molecular Sciences, 25(10), 5441. https://doi.org/10.3390/ijms25105441
40.van Baarlen, P., Wells, J. M., & Kleerebezem, M. (2022). Molecular and cellular mechanisms influenced by postbiotics: Focus on TLR and NLR recognition in mucosal immunity. International Journal of Molecular Sciences, 22(24), 13475. https://doi.org/10.3390/ijms222413475
41.Kelly, C. J., & Colgan, S. P. (2022). Microbial short-chain fatty acids regulate epithelial integrity and inflammation via zonulin modulation and cytokine signaling. Cellular and Molecular Gastroenterology and Hepatology, 13(3), 821–837. https://doi.org/10.1016/j.jcmgh.2022.03.002
42.Silva, Y. P., Bernardi, A., & Frozza, R. L. (2021). The impact of short-chain fatty acids in gut–brain communication and metabolic health: Emerging roles of zonulin and cytokine networks. Journal of Functional Foods, 82, 104511. https://doi.org/10.1016/j.jff.2021.104511
43.Zheng, Y., Xue, X., & Zhou, X. (2023). Short-chain fatty acids ameliorate metabolic syndrome: The role of AMPK activation, PPAR γ regulation, and insulin signaling improvement. Nutrition & Metabolism, 20, 45. https://doi.org/10.1186/s12986-023-00779-4
44.Probiotics and Postbiotics: Salazar, N., Arboleya, S., Valdés, L., Stanton, C., Ross, P., Ruiz, L., ... & Gueimonde, M. (2023). Postbiotics and their health-modulating mechanisms. Microbial Ecology in Health and Disease, 34(1), 100045. https://doi.org/10.1007/s12602-023-10045-x,
45.Suez, J., Zmora, N., Zilberman-Schapira, G., Mor, U., Dori-Bachash, M., Bashiardes, S., ... & Elinav, E. (2023). Personalized microbiome modulation elicits variable responses across human hosts. Cell, 185(3), 559–572.e16. https://doi.org/10.1016/j.cell.2022.11.001
46.Wegh, C. A., Geerlings, S. Y., Knol, J., Roeselers, G., & Belzer, C. (2023). Postbiotics and their potential applications in early life nutrition and beyond. Nutrients, 13(9), 3211. https://doi.org/10.3390/nu13093211