

The Mechanism of Fungal Secondary Metabolites in Regulating Intestinal Microecology and Their Health-Sociological Implications

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Abstract: This article aims to explore the multidimensional mechanisms of fungal secondary metabolites in the regulation of gut microbiota and the resulting changes in health concepts. The study adopts a theoretical analysis approach, integrating microbial chemistry, ecological interaction models, and health sociology perspectives to systematically sort out how the chemical diversity of fungal metabolites selectively perturbs the microbial community structure, thereby affecting the host's immune, metabolic, and neuroendocrine functions. Analysis shows that these metabolites are not primarily used for sterilization, but rather guide the evolution of microecology towards a high resilience state through low-intensity, multi-target chemical signals, and reshape health as a dynamic balance rather than a static disease-free cognitive framework in this process. Further research reveals that the discourse of micro ecological intervention has penetrated into the fields of consumption, policy, and daily practice, repositioning individuals as active managers of the body's ecology, thereby promoting the formation of a new health ethics centered on symbiosis, collaboration, and self-regulation. This theoretical construction expands the understanding of the tripartite interaction between fungi, microbiota, and host, providing a sociological entry point for reflecting on responsibility allocation and knowledge power in contemporary health governance.

Keywords: Fungal secondary metabolites; Gut microbiota; Host physiological regulation; Sociology of Health; Symbiotic concept

1. Introduction

At the intersection of contemporary life sciences and health research, gut microbiota is increasingly regarded as a key hub connecting the environment, metabolism, and immune system [1]. Its structural stability and functional dynamism not only affect an individual's physiological state, but also play an indispensable role in the occurrence of chronic diseases, mental health, and even the aging process. Traditional research often focuses on the composition and function of bacterial communities, while fungi, as a small but functionally significant member of the gut microbiome, have long been marginalized in their role [2]. With the development of metagenomics and metabolomics technologies, fungal secondary metabolites have gradually entered the research field and become a new entry point for understanding the host-microbe interaction mechanism [3]. These low molecular weight compounds synthesized by filamentous fungi or yeast in the non-growth stage cover various chemical types such as polyketones, terpenes, alkaloids, cyclic peptides, and sphingolipids [4]. They have a wide range of biological activities such as antibacterial, anti-inflammatory, and immune regulation, which may indirectly affect host health by regulating the structure of the microbiota [5]. Some fungal metabolites, such as ceramide precursors or short chain fatty acid derivatives, have been shown to participate in the regulation of host cell signaling pathways, thereby affecting metabolic homeostasis and neuroendocrine function.

The current research on fungal secondary metabolites mainly remains at the level of drug development or in vitro activity verification, lacking a systematic theoretical construction of their dynamic mechanisms of action in complex microecological systems [6]. Especially in the highly heterogeneous and dynamically balanced microenvironment of the intestine, there is no unified explanatory framework for how fungal metabolites form a multi-level interaction network with bacteria, archaea, and host cells [7]. This knowledge gap limits the precision of micro ecological intervention strategies and hinders the possibility of re-understanding the concept of "health" from a socio-cultural perspective. The perspective of health sociology emphasizes that the evolution of medical knowledge often accompanies the social construction process of health concepts. When microecological

intervention shifts from sterilization to bacterial regulation, from a single target to system balance, the public's understanding of disease causes, treatment methods, and even bodily autonomy is also reconstructed. Fungal secondary metabolites, as potential microecological regulators, are quietly driving the formation of a new health discourse centered on symbiosis, synergy, and ecological resilience through their scientific narrative.

This article aims to go beyond the traditional pharmacological paradigm and construct an integrated theoretical framework from four dimensions: chemical diversity, microecological response mechanisms, host regulatory pathways, and social construction logic. To reveal the deep role of fungal secondary metabolites in the regulation of intestinal microbiota and explore their sociological implications in the transformation of health concepts. This attempt helps bridge the gap between theory and practice, providing a conceptual foundation for the ethical design and public communication of future microecological intervention policies.

2. Chemical diversity and biological activity basis of fungal secondary metabolites

Fungal secondary metabolites originate from their complex secondary metabolic network, with highly diverse chemical structures, mainly including polyketones, non ribosomal peptides, terpenes, alkaloids, and hybrid natural products. These compounds are not essential for fungal growth, but play a crucial role in environmental adaptation, interspecific competition, and the establishment of symbiotic relationships. Its structural complexity endows it with a wide spectrum of biological activities, such as antimicrobial, anti-tumor, immune regulation, and signal transduction regulation functions [8]. Partial metabolites can mediate chemical communication between microorganisms at low concentrations, thereby affecting the composition and functional pattern of the entire microbial community. This chemical diversity forms the material basis for the interaction between fungi and gut microbiota, providing a potential molecular toolbox for subsequent regulation of host physiology.

3. The response mechanism of gut microbiota structure to fungal metabolites

The response mechanism of gut microbiota structure to fungal secondary metabolites is reflected in a multi-level and dynamic interaction process. The core lies in how metabolites disrupt the balance of the original microbial community through chemical signals and induce functional recombination. Fungal metabolites do not act on the gut microbiota in a broad-spectrum bactericidal manner, but rather selectively inhibit or activate specific bacterial groups, thereby altering the topology and metabolic output of the microbial network [9]. Partial fungal derived sphingolipid molecules can be recognized by host intestinal epithelial cells, triggering immune regulatory pathways and further feedback to the microbiota structure, forming a tripartite loop of metabolites, microbiota, and host. The response of gut microbiota to fungal metabolites is highly individual dependent, shaped by factors such as host genetic background, dietary structure, and past antibiotic exposure. Under steady-state conditions, low concentrations of metabolites may only cause brief functional fluctuations; In a state of dysbiosis, the same substance may trigger significant ecological niche rearrangement and even facilitate the establishment of a new steady state.

The impact of fungal metabolites on microecology is not unidirectional, but rather guides the system towards a more resilient state through multi-target, low-intensity sustained disturbances. The regulatory tendencies and potential pathways of four typical fungal secondary metabolites on key gut microbiota groups are summarized in Table 1.

Table 1 Regulatory Tendencies of Fungal Metabolites on Gut Microbiota (Source: Adapted from [6])

Metabolite Category	Targeted Microbial Groups (Genus Level)	Regulatory Direction	Potential Mechanism of Action
Polyketide Derivatives	Escherichia, Klebsiella	Inhibition	Disrupting cell membrane integrity, reducing LPS synthesis
Non-ribosomal Cyclic Peptides	Bifidobacterium	Promotion	Providing nitrogen source precursors, enhancing glycolytic activity
Sesquiterpene Lactones	Clostridium cluster XIVa	Promotion	Activating butyrate synthase gene expression
Sphingosine Base Analogues	Akkermansia	Bidirectional Regulation	Feedback mechanism mediated by host IL-22 levels

4. The regulatory pathway of metabolite microbiota interaction on host physiological functions

The regulatory pathway of metabolite microbiota interaction on host physiological functions is not a non-linear causal chain, but a dynamic network woven together by chemical signals, microbial metabolic outputs, and host receptor systems. Fungal secondary metabolites first act on bacterial communities in the intestinal lumen, altering their metabolic profile and indirectly affecting core physiological processes such as host immunity, neuroendocrine, and energy metabolism. For example, when a certain type of polyketide derivative inhibits Gram negative bacteria that produce lipopolysaccharides (LPS), the endotoxin load in the circulatory system decreases, which can alleviate the chronic activation state of Kupffer cells in the liver and improve insulin sensitivity. At the same time, the promoted butyrate producing bacteria enhance the expression of tight junction proteins in the intestinal epithelium, not only improving barrier function, but also stimulating the differentiation of regulatory T cells, forming a local immune tolerance microenvironment. Some fungal metabolites can directly cross the intestinal epithelium or be taken up by M cells, bind to nuclear receptors in host cells, and regulate the transcription levels of detoxifying enzymes and inflammatory factors. This dual mechanism of direct and indirect action makes fungal metabolites a key mediator connecting exogenous chemical signals and maintaining internal homeostasis. Metabolites of the microbiota, such as short chain fatty acids, secondary bile acids, and tryptophan derivatives, undergo changes in concentration and proportion under the intervention of fungal metabolites, which further act on the central nervous system through the vagus nerve or blood circulation, affecting emotional and cognitive functions.

Table 2 Host Physiological Responses to Metabolite-Microbiota Interactions (Source: Adapted from [8])

Interaction Pattern	Host Response Indicators	Change Trend	Potential Molecular Mediators
Polyketide inhibition of LPS-producing bacteria	Serum TNF- α , IL-6 levels	Decrease	Reduced TLR4/NF- κ B pathway activity
Cyclic peptide promotion of butyrate-producing bacteria proliferation	Colonic Foxp3 ⁺ Treg proportion	Increase	HDAC inhibition and GPR109A activation
Sphingolipid analogue regulation of Akkermansia abundance	Plasma BDNF, 5-HIAA concentrations	Fluctuating Increase	Enhanced vagus nerve afferent activity and tryptophan hydroxylase activity

The response characteristics and potential molecular mediators of host key physiological indicators under three typical interaction modes are shown in Table 2. Fungal metabolites can systematically regulate the host's metabolic homeostasis, immune tension, and neurochemical environment by reshaping the functional output of the microbiota. The intensity and duration of their effects depend on the initial microbiota configuration and host genetic background. The complexity of this regulatory pathway suggests that future micro ecological intervention strategies need to go beyond single component supplementation and shift towards precise guidance of the overall dynamics of metabolic networks.

5. Changes of health concept and social construction logic from the perspective of microecological intervention

The rise of microecological intervention not only marks the deep transformation of biomedical paradigm, but also reflects the reconstruction process of health concept in contemporary society. Traditional medicine has long regarded microorganisms as pathogens, emphasizing the logic of confrontation between clearance and defense. However, the microecological perspective turns to symbiosis, balance and system resilience, and advocates maintaining health through regulation rather than elimination. As a potential regulator in this new paradigm, the scientific narrative of fungal secondary metabolites is quietly pushing the public's understanding of body, disease and treatment to shift. Health is no longer regarded as a static disease-free state, but a dynamic ecological coordination ability. This concept change is embedded in a wider social and cultural context and has become the core issue of health sociology. With the help of consumer market and media discourse, intestinal health has gradually evolved from a technical term to a symbol of daily practice, and probiotics, metazoans and natural metabolites have been given moral colors, such as purity, naturalness and self-control. This

discourse construction reshapes the individual's health responsibility ethics, and also blurs the boundary between medical intervention and lifestyle choice. The popularization of microecological knowledge is not evenly distributed, and its acceptance is deeply influenced by education level, media contact habits and cultural cognitive framework, which leads to the hidden generation of new health inequality.

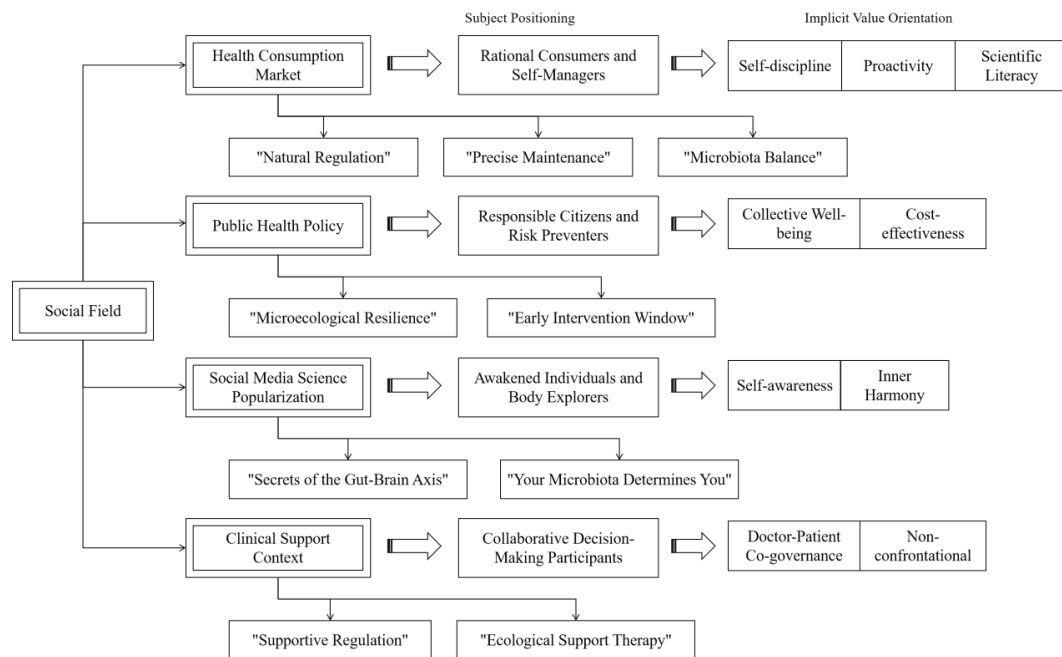


Figure 1 Social Representation of Microecological Health Discourse

The presentation characteristics of micro-ecological intervention discourse in different social fields and its corresponding subject positioning strategy are shown in Figure 1. Micro-ecological health concept internalizes health governance into a daily ethical practice by metaphor of the body as an ecosystem, endowing individuals with the role of gardeners and emphasizing the responsibility of continuous care and fine regulation. This kind of construction logic not only releases individual initiative, but also may aggravate the moral responsibility of the unbalanced person. Therefore, the microecological intervention path represented by fungal metabolites is far beyond the technical level, and it is actually a deep consultation on body sovereignty, scientific authority and social norms.

6. Conclusions

The role of fungal secondary metabolites in intestinal microecological regulation is far from being covered by traditional pharmacology, and its significance lies in opening a life intervention logic with ecological relationship as the core. Through theoretical integration, this paper shows that these natural compounds with diverse structures indirectly shape the immune homeostasis, metabolic efficiency and neurochemical environment of the host by selectively regulating the abundance and functional output of bacterial groups, forming a nonlinear regulation path of chemical signals, bacterial recombination and physiological response. This mechanism emphasizes the integrity and dynamic adaptability of the system, and challenges the antagonistic medical paradigm characterized by single target and powerful inhibition.

The far-reaching influence is reflected in the social and cultural level. With the spread of microecological knowledge, health is gradually constructed as an ecological balance state that needs to be maintained continuously, rather than a pathological absence defined only by the medical system. Individuals are endowed with the role of body gardener, and assume the responsibility of fine-tuning the internal flora through diet, supplements and lifestyle. This concept is commercialized as a symbol of self-discipline and scientific literacy in the consumer market, transformed into a cost-benefit logic of giving priority to prevention in the context of public health, and evolved into a narrative of self-exploration and internal harmony in social media. However, this empowerment is accompanied by hidden risks-when health is regarded as an optimized ecosystem, those groups that are difficult to implement "precise conservation" due to social structural restrictions may face new moral accusations and health inequality. Therefore, the real value of the microecological intervention path represented by

fungal metabolites lies not only in the biological activity itself, but also in prompting the society to rethink the responsibility boundary of health, the degree of democratization of scientific knowledge and the ethical connotation of the symbiotic relationship between people and microorganisms.

References

- [1] Li Minghui, Wang Mingming, Yin Pengkai. Isolation of intestinal-derived fungi from *Pleuronichthys cornutus* and screening of antimicrobial and antitumor activities of their secondary metabolites [J]. *Chinese Journal of Antibiotics*, 2023, 48(08): 885-893. DOI: 10.13461/j.cnki.cja.007553.
- [2] Miao Jingnan, Wang Yong, Yang Liu. Research progress on the regulation of gut microbiota by polysaccharides from edible and medicinal fungi [J]. *Journal of Food Safety & Quality*, 2021, 12(13): 5341-5348. DOI: 10.19812/j.cnki.jfsq11-5956/ts.2021.13.036.
- [3] Zhang Suping, Lin Xiaoying, Xu Mingchao. Biological characteristics and probiotic effects of *Lactobacillus coryniformis* Lc7 [J]. *Acta Microbiologica Sinica*, 2023, 63(01): 319-332. DOI: 10.13343/j.cnki.wsx.20220318.
- [4] Dou Liyuan, Huang Juan, Ye Sen. Treatment burden status and influencing factors in elderly patients with chronic disease coexistence in the community [J]. *Chinese General Practice*, 2021, 24(13): 1671-1675.
- [5] Zhong Jiawen, Jiang Bo, Zhang Wenyan. Liuwei Dihuang pill regulates intestinal microbiome balance and inhibits oxidative stress in mice with premature ovarian failure [J]. *Chinese Journal of Tissue Engineering Research*, 2025, 29(11): 2285-2293.
- [6] Wu Fang, Ma Rui, Ma Guobiao. Co-evolutionary culture and diversity analysis of probiotic complex microbiota [J]. *Journal of Chinese Institute of Food Science and Technology*, 2025, 25(09): 302-314. DOI: 10.16429/j.1009-7848.2025.09.025.
- [7] Luo Wei, Song Yuefan. Absorption characteristics of phenolic compounds and their effects on gut microbiota [J]. *Journal of Food Safety & Quality*, 2020, 11(03): 701-707. DOI: 10.19812/j.cnki.jfsq11-5956/ts.2020.03.008.
- [8] Chu Siyuan, Qian Lisheng, Chen Haimin. Research progress on the regulatory effect of tea components on gut microbiota and their health benefits [J]. *Natural Product Research and Development*, 2024, 36(02): 357-367. DOI: 10.16333/j.1001-6880.2024.2.018.
- [9] Ren Caijun, Wu Liming, Wang Kai. Research progress on the effects of dietary polyphenols on gut microbiota [J]. *Science and Technology of Food Industry*, 2022, 43(01): 400-409. DOI: 10.13386/j.issn1002-0306.2020090112.