Food & Medicine Homology

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Perspective

Food and Medicine Homology Focus in 2026

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The field of food and medicine homology (FMH) is transitioning from traditional empirical knowledge to contemporary scientific methodologies. Commencing in 2026, this evolution will be anchored by a core tenet: fostering trust through scientific rigor, enhancing mechanistic comprehension via systematic analysis, refining health interventions with the concept of precision medicine, and modernizing the entire industrial chain using cutting-edge technologies. The progression within this domain will be underpinned by the scientific expansion of the substance directory and the establishment of an evidence-based standard system, thereby bridging the gap between industry regulations and empirical data. Pertinent research will pursue truths ranging from active component identification to multi-system interaction mechanisms centered around gut microbiota, while also investigating emerging biological processes such as phase separation and immunometabolic reprogramming. Applications are poised to evolve towards dynamic health management, leveraging multidimensional personal data and artificial intelligence for tailored solutions addressing challenges like chronic diseases and aging demographics. Concurrently, future transformations are expected to prioritize value enhancement through advancements in synthetic biology, intelligent delivery systems, and eco-friendly manufacturing, fostering a transparent and sustainable industrial ecosystem. This perspective highlights the key areas of focus in FMH as anticipated for 2026 (Fig. 1).

1 Cornerstone: Standard specification, security system, and evidence-based medicine practice

Advancing scientific progress in the FMH industry requires establishing a logical framework that begins with foundational principles and culminates in rule formulation. Initially, the enlargement of the list of substances and refinement of the theoretical background provide the requisite resources and knowledge foundation for the new developments. The establishment of full standards and safety management systems throughout the entire supply chain then models clear rules for regulated usage. Ultimately, it is the creation and analysis of high-level, evidence-based research that enables us to shift our experience of being effective according to what we see to the level of having scientific evidence. And these three steps make the

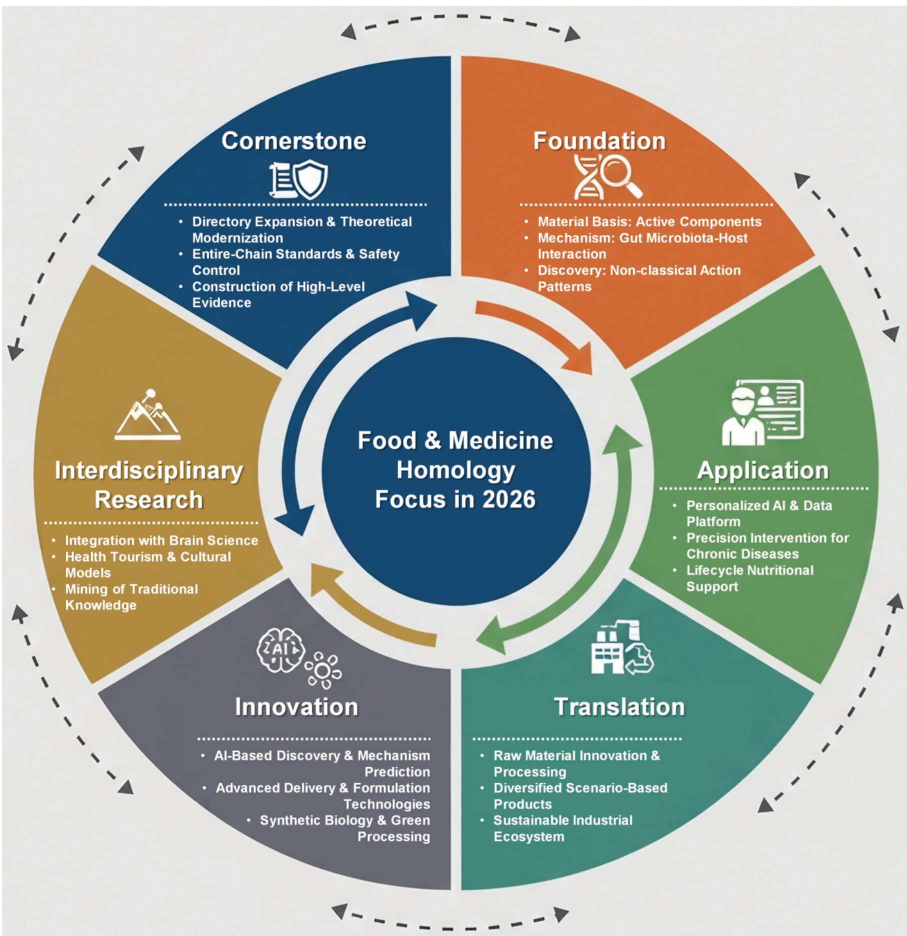

Figure 1 Food and medicine homology focus in 2026.

theory that makes this FMH thing alive and growing (Fig. 2).

1.1 Directory expansion and modernization of theory

The gradual development of the FMH sphere is envisioned through the establishment of two pillars. The one provides a legal and normative material basis, and the other modernizes its theoretical framework. The former mixes the traditional knowledge and the scientific meanings that can be checked and transferred, and the latter establishes a clear array of resources and conditions of entry into the industry's usage. The combination of them creates the required framework for the development of FMH, with the goal to create a complex of cognitive and application structures, which corresponds to the requirements of regulatory regulation and has a significant explanatory power through science.

(1) Scientific expansion of the FMH substance list

The scientific growth of the FMH substance list is a major precondition and a pillar for the sustainable development of the industry. This implies that there is a need to develop a highly rigorous assessment system that integrates both traditional and modern scientific findings related to consumption experiences[1]. To solve the heart of the problem of folk acceptance vs regulatory lag, namely that many highly researched resources are facing innovation and value-creation bottlenecks as they are not listed in formal directories, it is urgent that a systematic research triage methodology be adopted. Firstly, defining historical safety through ancient records and ethnopharmacological tools to understand the consumption line; secondly, defining the current safety by using knowledge on toxicology and population risk assessment in order to circumscribe safety limits; and last but not least, validating the scientific functionality using multi-omics and molecular biology to elucidate active components, structure-activity relations, and mechanisms of action[2]. Indeed, the research in which Sanghuang has advanced in its customs of activating the blood to elaborate a description of the bioactive β-glucans and explain how such compounds can stimulate the immune system through signal delivery. The creation provides one with a complete scientific groundwork to be included in official personages. Hence, this is not only an administrative change, but it is also a total scientific investigation of the ancient resources. This preserves the Chinese medicine history and gives a significant beginning in improving the situation in the industry and special health care. On the international front, as in the case of the EU, the historical evidence of consumption is to be supplemented by the current safety and efficacy data made during the approval of new foods. Similarly, the US applies the same standards to new ingredients used in dietary supplements. Nevertheless, the evaluation systems and specific criteria applied have not yet been standardized.

(2) Modern interpretation of traditional theories

It is important to research the current scientific explanation of the traditional Chinese medicine (TCM) theory in the context of the further development of the FMH theory, as well as the improvement of industrial use of the latter. Its main goal does not only lie in defining terminological parallels; it seeks to generically explain the modern principles of biological and matter science, which form the basis of the empirical descriptions of antiquity. For example, studies may determine how the chilling-heat qualities of herbs are connected to systemic energy metabolism, immune-inflammatory interactions, and the makeup of intestinal microbial communities. In addition, correlations could also be analyzed on the theory of meridian tropism with the pattern of target organ distribution or particular signaling pathway regulations that active compounds provoke[3]. Taking the example of Cinnamomum cassia, the thermal nature is demonstrated by cinnamaldehyde as an activator of TRPV1 receptors and UCP1 expression change, facilitated by which makes heat, at least in part on a molecular level[4]. This research provides us with certain ideas concerning the ability to warm the channels to dissipate cold. Using systems pharmacology, multi-omics technologies, and evidence-based clinical research processes, it is possible to develop a complete association chart that links the conventional efficacy, molecular target, biological network, and health outcome. It enables the translation of concepts, like tonifying Qi or nourishing Yin, into groups of biomarkers. Such an approach will not only affirm the cultural heritages on scientific lines but also establish a platform on which precise dieting and incorporation of TCM dietary information into global health modalities can occur.

1.2 Chain-wide standard and security control

Once a matter-based and theoretical foundation has been

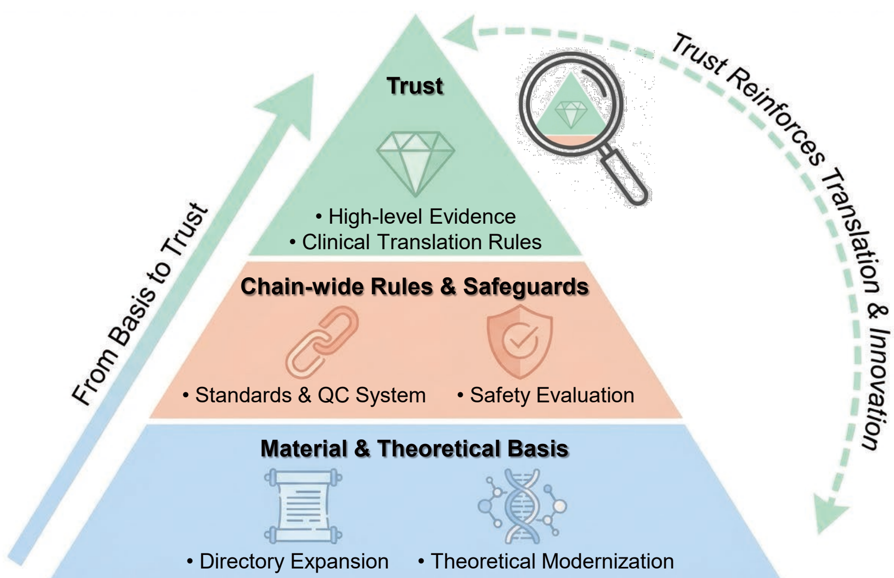

Figure 2 Theoretical basis of food and medicine homology.

established, the need to enhance a universal system of safety controls must be developed, which would fully cover the research and development, production, and consumption spectrum. This system is aimed at outlining the application boundaries, providing quality consistency, and anticipatively the risks. This model is supported by three fundamental pillars, namely application regulations and labeling standards, all-round quality management, and a set of safety assessments. Collectively, they ensure that medicinal food homologous products provide their health benefits to their benefit in a scientific, standard, and safe manner.

(1) Application rules and claiming norms

Establishing application rules and efficacy claim regulations for active ingredients in FMH products is a fundamental institutional design to ensure the scientific development of the industry and protect consumer rights. With the increasing use of components such as probiotics, dietary fibers, and plant polyphenols, the market has witnessed a proliferation of health claims lacking solid scientific substantiation. For instance, while clinical studies on specific probiotic strains have confirmed their role in modulating gut microbiota and immune function[5], many products still feature claims disconnected from evidence, which not only mislead consumers but also undermine industry credibility. Particularly for specialized foods such as infant complementary foods, although the addition of plant bioactive compounds may theoretically support long-term health, it faces translational hurdles such as unclear effective dosage, insufficient clinical data, and formulation instability[6]. Therefore, it is imperative to establish a science-based evaluation system centered on “evidence-dose-claim,” rigorously validating the efficacy, safe dose-response relationships, and suitable target populations for each ingredient. Only through such an approach can FMH products make a transition from traditional experience-based practices to precise intervention, which provides fundamental support for industry standardization and innovation. It is also interesting to mention the regulatory approach taken by the US FDA to the dietary supplement claims, which clearly shows the correlation between the level of evidence and the strength of claims. This is a significant reference material for China when establishing its own personal evidence-dose-claim program.

(2) Chain-wide quality control system

To realize the standardization and scalable growth in the FMH industry, the introduction of a complete quality control system, including the entire supply chain from growing and cultivation to the consumption stage, is key to stabilizing the industry. In the raw materials, manufacture, and the final products, standardization is favored. Raw material safety and quality tests should be related to source control by using pesticide residues, heavy metals, and active ingredient content. Best practices in pharmaceutical production are supposed to be followed, particularly when handling high-risk product key process phases. Rather than imposing the same requirement across all the products, use a risk-based standardized production, operations, and packaging control strategy. In a final item, a safety, quality, and stability testing system and a one-item, one-code traceability system are required to be used in the full-process tracking and recalling[7]. Adoption of cross-regional standards minimizes entry barriers to the market, enhances localism in services within the country, and minimizes repetitive exams. It renders institutions, which empower industries, cooperative and prosperous. Development and enhancement of this system matter in ensuring good products, security of what people purchase, and assurance of others in what we produce[8].

(3) Systematic safety evaluation

To guarantee the long-term safety of FMH products produced based on the same material, it is necessary to design an integrity system of safety assessment based on modern toxicology and evidence-based medicine. This process systematically assesses risks as a result of long-term or high dosages, compatibility of substances, and interactions of drugs. While traditional knowledge has identified numerous compatibility contraindications, the scientific mechanisms underlying these remain largely unclear. Current research has revealed significant interaction cases. For example, radish seeds can speed up the excretion of ginsenosides, and licorice combined with seaweed increases the chance of kidney damage[9]. Also, there are worries about how it interacts with other medicines. For example, glycyrrhizic acid can worsen the gastric mucosa injury caused by aspirin and reduce the effect of hypoglycemic drugs. And also, anthraquinones contained in aloe and rhubarb could inhibit liver drug-metabolizing enzymes, causing the accumulation of some pharmaceuticals. Moreover, long-term or high-dose intake is not risk-free. For example, the negative effects of too much ginseng and the dangers of capsaicin in some cases need to be considered carefully. But most of the current warnings do not have causative evidence at the population level[10].

Consequently, it is essential to conduct forward-looking toxicological studies and epidemiological surveillance to develop a scientifically grounded risk classification and early-warning system. The creation of this system should incorporate practical classification strategies and a phased implementation approach. Priority in evaluation resources should be given to novel substances that have been recently included in the directory, and end products resulting from new procedures, new formulas, or ones designed for specific groups such as expectant mothers and babies. For traditional raw materials that have a long history of consumption and simple formulations, we can do a risk assessment by looking at all the information that has already been written down about them and watching what happens after they are used by people. A level of differentiation of the intensity of the evaluation of various risk levels in order to have a standard of safety without limiting industrial innovation. It provides a scientific rationale for why people should use these commodities properly, promoting healthy industry growth in the long run.

1.3 Construction and translation of high-level evidence-based medicine proof

Traditional wisdom has to be transformed into a modern scientific system that can participate in international discussion. It requires a transformation of one thing to the next concerning credibility and then accessibility. Two steps are necessary to achieve this transformation. To begin with, verifiable molecular and clinical levels of mechanisms of action must be developed through an accurate measure of the efficacy relationship. This step inquires why someone takes a credible approach. Second, high-level evidence should be included in the practices of diagnostic and treatment methods and the systems of healthcare reimbursement. Such a combination renders tested interventions a significant part of community health programs such as the prevention of chronic illnesses. The first step is to enhance the scientific foundation of the field, and the second step is to build the social value that determines the way toward encompassing it into the global health management structures.

(1) Quantitative research about function and efficiency

Quantitative research on efficacy relationships represents a pivotal link in advancing FMH from traditional empirical knowledge to modern evidence-based science. Its core lies in constructing a dynamic quantitative model of "components-targets-efficacy" to scientifically address the fundamental questions of "why it works" and "to what extent it works." This requires integrating a multidisciplinary research paradigm: initially employing modern analytical technologies to identify key functional component groups; subsequently utilizing network pharmacology and artificial intelligence to analyze their multi-target interaction networks[11]; and ultimately, through rigorous dose-response clinical studies, dynamically quantifying the continuous causal chain from component exposure and biomarker modulation to improvement in clinical endpoints[12]. This research essentially involves mapping precise "mechanistic maps" and "effect equations" for FMH interventions, thereby transforming macroscopic empirical knowledge into modern scientific evidence characterized by a clear material basis, well-defined pathways of action, and precise dose-effect relationships. This approach is not only crucial for fundamentally establishing scientific credibility, but also serves as the cornerstone for achieving product standardization, precise quality control, and even broader international recognition. It genuinely paves the way for translating "empirically effective" practices into "evidence-based credible" applications.

(2) Application and translation of clinical evidence

Because so many chronic diseases are on the rise, and medical resources available do not meet the existing demand, there is a need to restructure dietary and medicinal interventions not only as a potentially viable alternative but indeed as a practical and implementable component of clinical care to realize all the potential in its contribution to community health. Numerous randomized controlled trials (RCTs) have confirmed that the high content of active compounds in plant products, based on their Mediterranean diet, decreases the risk of cardiovascular disease[13]. RCTs also work with microbial-targeted therapies such as probiotics and prebiotics. These examples indicate that food-related interventions have the ability to control illnesses. Nevertheless, we need to address certain scientific concerns in respect to clinical evidence to popularize additional Chinese-style and bigger methods of dietary-medicinal incorporation. To start with, it is difficult to standardize research subjects. FMH substances are often more complicated natural mixtures; thus, re-randomized and high-quality controlled trials require that both groups receive identical elements. Second, the absence of scientific rigor in the trial design is a solution to a major issue. It is hard to develop a sensorially matched functional food placebo. Lastly, it may be hard to stick to the intervention, which could lead to bias when assessing its effectiveness.

In order to enhance the development of evidence, we need a systematic model of innovation. The study design can no longer be limited to the common RCTs, but rather it should proactively apply the patient-centered and pragmatic clinical trial models that are more representative of real-world settings. These setups require wearable devices and biomarkers to engage in objective monitoring. Regarding the area of research, large-scale and multiple-center RCTs and real-world studies should be conducted, particularly in the case of large chronic diseases, such as cardiovascular and cerebrovascular diseases and diabetes. The hard endpoints and comprehensive health economic evaluations based on these studies should be applied[14]. In this project, there is a need for regulatory science, industrial technology, and clinical medicine that will offer evaluation criteria of complex FMH commodities. Lastly, the FMH approach could then make it through the development of end-to-end evidence chains and application of foreign experience to improve clinical consensus and payment policy to become a stable aspect of the routine therapy system. This would bring empirical inheritance to be turned into evidence-based support, bringing the value of public health and industrial development together.

2 Foundation: Material basis, mechanism, and cutting-edge discoveries

After establishing the standards and evidence base for industrial development, it is crucial to transition the concept of FMH from empirical understanding to precision science. This necessitates a systematic deconstruction of the material entities that contribute to its health effects, and an elucidation of their underlying mechanisms of action. Such a process forms an essential foundation for the construction of a modern scientific explanatory framework. The aim is to have a full-scale annotation system that will be a combination of microscopic, macroscopic, static, and dynamic views. This technology is now centered on the precise entity analysis of material. Achieving this methodological chemicals an attempt to provide the basic answer to the question of whether chemicals do have real effects by examining items on the microscopic level. Three synergistic approaches to this end include the identification of the major bioactive portions, many-sided systematic analyzing methodologies, and the exploration of new useful substances (**Fig. 3**).

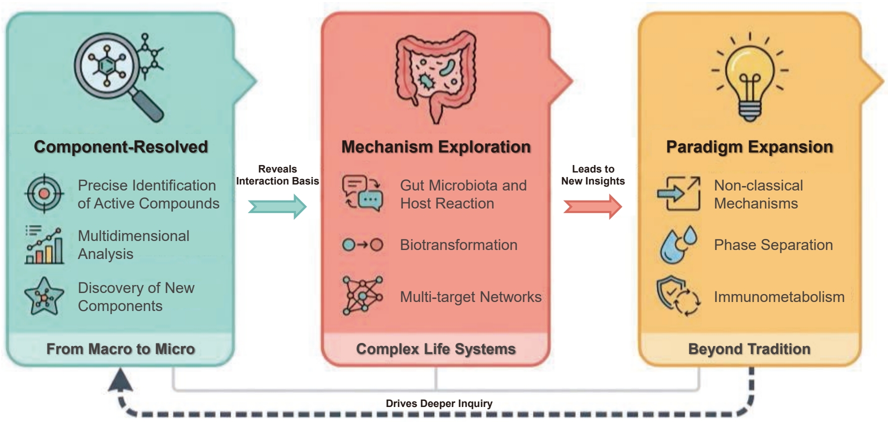

Figure 3 Component exploration and mechanism research.

2.1 Research on the material basis from macro to micro

The new scientific discoveries in the research of FMH substances date back to the careful dismantling of the material basis. The contemporary main aim and indicator of interest is to shift the macroscopic empirical descriptions to microscopic entity analysis, consciously answering the underlying question. Which chemicals are indeed curative? Further advancement relies on the combined development of three technical directions: the possibility to identify the most important active factors, which requires the foundation of standardized investigation; the multiple-sided systematic analytical technologies, which are needed to explain the complex systems of interactions; and the exploration of new functional substances, which marks the higher level of knowledge extension. They constitute an entire cognitive chain that leads to the realization of what triggers things, thus leading to the emergence of a molecular scientific age where all is simple and easy.

(1) Precise identification of active components and decoding the structure-activity relationship

The study concerning FMH has drifted away from empirical formulation to accurate constituents, whose major objective is to discover, acknowledge, and analyze the structure-activity correlation and describe how precisely the key bioactive constituent work. Conventional means are sluggish and ineffective in determining working components of huge blended masses. The active parts that adsorb some spots have, however, been reported to be caught by ligand fishing methods[15]. Molecular networking accelerates the identification of unknown compounds when processed using high-resolution mass spectrometry. The future research should have many targets using network pharmacology and multi-omics technology. Such an approach will indicate that active constituents control numerous types of biological networks and therefore demonstrate their many targets. We should also learn how to relate the chemical structure and biological activity. As an example, curcumin has the phenolic hydroxyl group and methoxy group that are vital pharmacophores contributing to its antioxidant activity, and the glycosidic framework of ginsenosides influences its immunomodulatory activity[16]. Future research should apply structure-activity relationships to scientifically describe traditional concepts such as taste tropism and the roles of king, minister, assistant, and guide. This approach will encourage the similarity of food and medicine by integrating molecular accuracy and general fine-tuning.

(2) Multi-dimensional analyzing technological applications

To learn to work with FMH substances in the context of complex living organisms, we must make use of a multitude of multiple sciences together: multi-omics, AI, and computer models. Conventional single-method solutions cannot address this multitude of synergistic purposes and directions[17]. Instead, network pharmacology, molecular docking, and various omics technologies help reveal the main active compounds and targets. Curcumin and gingerol research using this paradigm is becoming more popular in a mechanistic manner[18]. AI and deep learning algorithms make the analysis of immense data faster and better and contribute to the discovery of targets and pathways. Molecular dynamics and molecular docking help in the interactions between atoms. This combination of techniques enhances scientific research by allowing us to predict outcomes and create personalized products and services.

(3) Exploring emergent categories of functional matter

To bring the borders of the matter science in FMH forward, we must take a systematic step past merely viewing the classic active ingredients and broaden our research to cover different types of useful materials like plant exosomes, antibacterial peptides, and bioactive peptides. Plant exosomes are natural nanocarriers that can be used to transport active ingredients to different species and regulate gut microbiota and host immunity. The system of next-gen delivery is targeted. However, they can be exploited only on a large scale, provided that we are able to produce large quantities of them with the same quality and functionality. Growth conditions should be strictly regulated to get high-quality, batch-stable plant exosomes[19]. Concurrently, it is possible to investigate the composition of substances and their activities with the help of such methods as metabolomics, thereby providing the base of the standardization[20,21]. The antimicrobial peptides that disrupt membranes create innovative ones that resist bacterial resistance. They also cause numerous effects (including the immune system regulation and protection of the brain) due to their ability to regulate pathways[22]. The new classes of substances that have been discovered enhance the depth of scientific bases and material foundation of FMH and offer an alternative basis to address contemporary health problems, such as metabolic diseases and infections. It is a big plus to know something as simple as compared to being on the side of the most up-to-date research.

2.2 Exploration of the mechanisms within complicated systems and interaction networks

To get a complete picture of the health effects of FMH substances, we cannot stick to the easy one-component-one-target perspective. We should not only think about them separately but also describe their interaction in our bodies as a complex system. This constrained a radical change of research: cease to study short-term effects and begin to examine all the levels on which biology functions as well as the way different components communicate with each other at more than one size. The key question is how these substances make their way into your entire body to accumulate in great numbers and position in such diverse ways to cause you to feel ill or well? This metamorphosis means a shift from the exact opinions concerning the functioning of things to a wider one.

(1) Mechanism of gut microbiota-host core interaction

The gut microbiota serves as a central regulatory hub through which FMH substances exert their biological effects, playing the dual roles of a "biotransformer" and a "therapeutic target." The microbiota is a biotransformer, helping the enzymes to carry out functions such as breaking down, removing methyl groups, and chopping off sugar components of large and complex natural molecules. It converts them into smaller, more convenient secondary metabolites, which are more effective, long-lasting, or have novel mechanisms of action within us[23]. Being direct mediators of effects, they change physiological functions, such as the immune system and redox balance. FMH components are also selective in their ability to stimulate positive bacteria, inhibit harmful bacteria, and reorganize the ecological structure and functionality of the microbiota and can serve as a therapeutic target. This ecological re-creation enhances the environment of the intestine and aids microorganisms in generating SCFAs and secondary bile acids. These compounds are capable of triggering the signals of our bodies using G protein-coupled receptors, nuclear receptors, and other detectors. These cues are subsequently relayed via larger pathways to the brain, liver, and immune tolerance so that remote brain inflammation, gut-liver, and gut-immune can be conducted[24]. Thus, the in vivo effect of

FMH substances cannot be a one-target phenomenon, as it occurs due to a complex and multi-layered interaction network mediated by the gut microbiota, which involves biotransformation, metabolic signaling, and inter-organ communication. Understanding this complex system can help individuals make appropriate eating decisions that promote harmony in their health.

2.3 Discovery of novel mechanisms beyond classical paradigms

The FMH substance research is changing to the basic physical and chemical processes that are present in life rather than the way they work. The new industry focuses on finding non-traditional ways for these systems to function across different size scales. The goal is to abandon traditional testing methods that rely on individual initiative in exploring new ways for living organisms to function. This approach aims to build on established scientific foundations and develop new mechanisms to enable innovative treatments for illnesses in the future.

(1) Discovery of non-classical and disruptive action patterns

In FMH research, the perspective of the world is shifting; people are no longer satisfied to simply describe large effects but instead attempt to discover minute components and chemicals that cause the large effects to occur. This study is revolutionary, as it introduces in a systematic manner new mechanisms of action other than the anti-inflammatory/antioxidant ones. We are learning the basics of biological activity on the molecular biophysics level. As an example, forsythoside B controls the α-synuclein liquid-liquid phase separation and prevents pathogenic condensates. It gives a fresh approach to neurodegenerative disease management[25]. The networks of interacting subcellular organelles enable certain elements to select certain centers of signaling, including endoplasmic reticulum membranes, which are mitochondrion-associated, to modify the cell response towards stress. They can function as organelle communication and homeostatic network modulators. Immunometabolic control studies have demonstrated that certain specific active compounds can be used as "metabolic switches" in the course of reprogramming. These switches have the potential to alter the functional phenotype of immune cells by modifying cells' metabolic pathways, including glycolysis, that influence the immune microenvironment[26]. The regulation of new changes through histone acetylation and the capacity to establish genomic memory through the reconfiguration of the DNA methylation and non-coding RNA networks have also been revealed by epigenetic and spatial-temporal studies. This can bring the generations along in terms of health benefits. These new non-classical methods are usually different because the conventional methodologies tend to fight swelling and inhibit oxidation. Classical and non-classical mechanisms are different in the aspects of cognitive dimension, intervention rationale, and research paradigm. Classical mechanisms are experimentally available, dose-response, and quantity directed towards biological targets and pathways. But this tactic is not able to elucidate all the outcomes of combining many chemicals and attacking many targets of foods and medicines. Non-classical mechanisms are those that center around biological physical processes, cellular system regulation, and cross-level epigenetic landscapes. The power of these processes is that they give us new ideas and methods of understanding how things animate and work and make us do good to our bodies that endure, which is perhaps many families. Such mechanisms are, however, difficult to study thanks to the complexity of the technologies and the chains of events that are long-term causes of macroscopic health effects. In achieving a proper understanding of the science of food-medicine synergy, there is a need to have an understanding and integration of classical and non-classical mechanisms.

3 Application: Personalized nutrition interventions and dynamic health management

A more detailed study on the mechanism of complex systems may allow exploring the concept of FMH to make advances beyond banal macroscales and start a new epoch of precise healthcare. The people focus on their data and manipulations with their topical wishes in such an epoch. The advancements demonstrate the importance of this research for healthcare improvement. The problem with this issue of FMH is that it needs to expand and specialize, which has a negative impact on the general view of health care and depends on the time. This change is necessary to deal with contemporary health problems and reach FMH. The way is through a successively elaborated practice of transition, of method development, scenario application, and population customization. And, above all, the individualization requirement of such evolution is the progressive development of basic technical capabilities. The primary challenge of the contemporary research and industry is how to make it personal. To develop a smart platform, we apply artificial intelligence algorithms, multi-omics, and new technologies to products. This platform will explore the ability of analyzing individual differences specifically and developing and enhancing the intervention plans in a dynamic manner. This is the technical basis of theory application and the driving success of the field. It assists in the elimination of uncritical, one-size-fits-all health care and personal care, where an individual receives tailor-made care (Fig. 4).

3.1 Construction of personalized data, algorithm, and product platform

Personalized health management will be realized when an integrated data and product platform is developed, which will analyze the individual differences and provide customized solutions. Basic personalized implementation issues on this platform are solved by means of multidimensional data, complex algorithms, and novel manufacturing technologies. The current development cornerstones of the platform are a multi-dimensional individual evaluation system, adaptive interventions and feedback systems, AI-powered smart formulation, and design. The first pillar lays the foundation of scientific assessment and tries to identify the goal of the intervention correctly. The second pillar includes a translational hub that tailors solutions. The third pillar assures continuous development on the basis of real-time physical data. These works constitute a complete technology that encompasses precise checking, intelligent designing, and real-time modifications. It is the most important structure that promotes health care integration to provide quality FMH service.

(1) Multi-dimensional individual evaluation systems

The multi-dimensional individual assessment system is the major scientific background for achieving the right and personalized nutritional intervention. The combination of data dimensions, including TCM composition recognition, gene assays, metabolome profiles, and gut bacteria analysis, is essential. Such an incorporation creates a comprehensive perspective of the

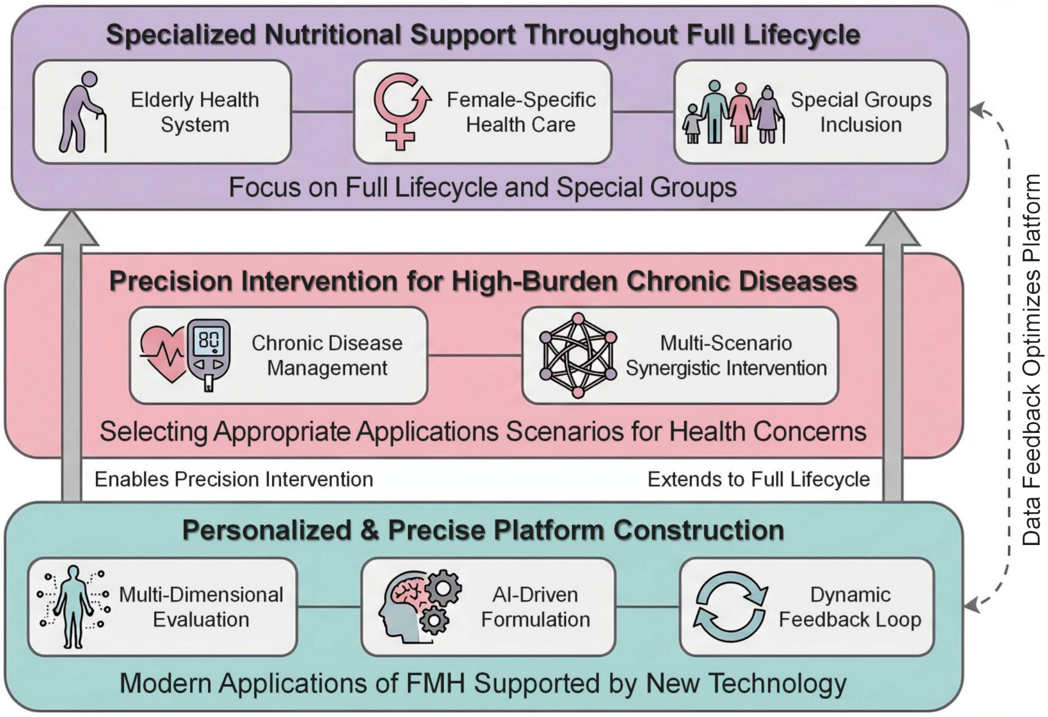

Figure 4 FMH application: From personalized platform to full lifecycle care.

complex health of an individual in a statistical way. The biochemical evidence supports this concept, linking the type of TCM constitution to the gut microbial shapes and metabolism patterns. It encourages the control of chronic diseases. The non-alcoholic fatty liver disease is an example; the interactional approach to examining the formation and genetic indicators, along with metabolic characteristics, could possibly assist in distinguishing the different types of this illness, hence allowing early and customized intervention[27]. Besides that, regarding the prevention of osteoporosis, it boosts the accuracy in the determination of risks, which results in customized diets[28]. The given system can be viewed as a point of entry to the world of health care and a smart point of convergence that can productively join the individuals with complex needs to the available expanse of food-medicine options. This will provide the most valued solution to the most crucial question: Who should use it? This system aims to enable informed decisions regarding knowledge-specific interventions.

(2) AI-driven intelligent formulation design

The basic technology that facilitates the development of individualized nutrition is an AI-driven intelligent formulation and design system. The approach creates a smart system grounded in general algorithms of artificial intelligence and machine learning to change the general formulations to the dynamic precision design. The change is done by integrating and analyzing multidimensional individual health data. This system has technical foundation algorithms based on population datasets and ingredient databases. It is a scientific optimization of the percentage and dose, as well as the network of the synergistic effects of the formulation components[29]. Second, 3D printing, microencapsulation, and smart hydrogel are employed in the implementation of engineering. They transform precise formulas into items that satisfy specific body requirements and life circumstances, resolving issues that people have with considering the special care plans[30]. Therefore, it connects personal data and health products, which compels the FMH business to use mass-produced products instead of specific health services.

(3) Dynamic intervention and feedback mechanism

Actual personalization of health management can be achieved without requiring a completely new system of intelligent intervention; instead, it can be based on the ability to provide continuous self-reconstruction through dynamic adjustments to the health status of each individual. The fundamental assumptions in this system were seamless synergies of three key technologies: sustained non-invasive monitoring technologies (wearable monitoring, microbiome evaluation), which will provide real-time data streams[31]; smart algorithms to analyze the data and provide optimal prescriptions; and a responsive delivery service, e.g., pH-responsive microcapsules, to release the microdrugs precisely within space and time. Its device can modify the rate at which the compounds, such as ferulic acid, release depending on real-time blood sugar variations or the administration plan of prebiotics, polyphenols, and gut bacteria. The technological path that transforms the inanimate nutrition recommendations into real-time services is the dynamic interventions and feedback. This development provides new long-term care solutions for chronic illnesses based on the assumption that medicine and food are similar, and it also highlights the emergence of intelligent and adaptive health care.

3.2 Precise dietary intervention strategies for high-burden chronic illnesses

To tackle this costly burden of chronic disease, capacity building in the area of FMH needs to be addressed simultaneously at two key fronts. First, the need for the development of disease-specific precision approaches to pathology intervention, and an effective collaborative deployment vehicle that can be productively utilized. The former aims at key diseases such as cardiovascular and metabolic diseases, controlling key functions of pathology through systems biology-based daily intervention methods. The second area is an ecological intervention network that is a prescription to a lifestyle and that incorporates hospitals, community, schools, and online platforms. Precision protocols give the scientific basis on which the working-together approach is used in real life, and precision protocols make precision protocols easier to apply. When combined, they change the way we look at body care, which is not merely encompassing the cure of all diseases but rather, regarding all the parts as a whole.

(1) Cardiovascular, cerebrovascular, and metabolic disorder management

There is a massive transformation in the management paradigm of cardiovascular and metabolic diseases. The emerging management of health ecosystems revolves around the concept of dietary control and deals with all disease mechanisms. This shift stresses the investigation into the interaction of various factors of what we consume with our bodies and tiny living organisms inside the gut, instead of considering functional foods as an addition. This method is based on the all-inclusive regulatory concept of FMH[1]. In this way, the study stopped determining the effect of each active element separately and started to examine the overall effect of complex food combinations and regulatory network mechanisms. The multi-component-multi-target food-based and medicine-based therapies involving theory change (this is considerable progress in understanding and comprehending clinical conditions) are useful in this paradigm change. Hawthorn flavonoids mediate the intestinal flora-bile acid metabolism pathway in order to influence the hepatic cholesterol metabolism that influences atherosclerosis. The antioxidant and anti-inflammatory activity of curcumin enhances the functions of the endothelium. These studies can explain how food-derived substances have a macroscopic effect on metabolic-inflammation pathways and immune homeostasis by using various omics techniques and demonstrate the exact materials and methods of preparation[32]. The main problem ahead is turning such mechanistic findings into evidence-based eating plans for particular disease types, giving exact amounts and mixes, and looking into how they might work well with current standard treatments. The main purpose is to create personal diets that fit into everyday life without much effort, changing how people deal with sickness from just reacting when sick to stopping it before it starts and taking care of themselves all the way through getting better. This task is mainly dependent on the combination of nutrition science, modern pharmacology, food engineering, and data science to scientifically verify and improve the notion of FMH in the management of contemporary chronic illnesses.

(2) Synergistic intervention for several health concerns

Precision dietary interventions for chronic diseases with a heavy burden, such as obesity and diabetes, have shifted from one-size-fits-all suggestions to a multi-scenario cooperative intervention system based on danger stratification and actual-life situations. The scientific basis for this approach is evidence-based, comprehensive diet patterns such as the Mediterranean and DASH diets that have been proven to lower cardiometabolic risks via the combined effect of various nutrients[33]. This approach can succeed if there is a unified structure involving hospitals, communities, schools, and digital platforms. Hospitals are responsible for providing prescription-based dietary plans via nutrition clinics and standardized clinical pathways. Communities and workplaces are encouraged to promote standardized, healthy meals with less salt and oil. Schooling institutions are also working on the prevention of childhood obesity by increasing the nutritional content of school meals and restricting the consumption of sugary beverages. Online technologies enable individuals to receive long-term and intimate care and receptiveness by taking advantage of such items as wearable devices and apps to monitor their diets. The sugary beverage tax in Mexico, the Singaporean label of Healthier Choice, and the Chinese program of Internet Plus Hypertension/Diabetes Follow-up proves that policies, environmental conditions, and human habits should be combined in the system to transform scientific feeding habits into chronic disease prevention and control measures on the national level. The combination of global methods with national research of the Internet and the health management model displays that different situations collaborating may transform food science into health and wellness[34]. Integrating these foreign experiences with our country's quest to find the Internet Plus model for health management indicates that multi-scenario collaboration is a favorable way to transform scientific dietary models into national health policy.

3.3 Specialized nutritional support throughout the entire life cycle

The level of FMH can be improved considerably with the creation of an accurate system of nutritional support, which includes the life cycle. The result is a significant shift in the industry, where generic products have been abandoned for proactive and targeted interventions. Mechanistic studies are of highest priority for life cycle health promotion and this approach includes the following three pathways to develop mechanistically based guidelines: “Intervention Cascade”, which target comorbidities between older persons; “Precision Substitution,” which targets physiological vulnerabilities of females; and “Proactive Planning,” which targets maternal and occupational populations. Effects, on their part, safeguard health along the arc of life from conception to senescence. The above are just some examples that are the logical next step in moving medicine and nutrition into an era of precision medicine to best optimize individual health outcomes.

(1) Elderly health support system

In addressing the complex challenge of multiple comorbidities such as sarcopenia, cognitive impairment, and metabolic syndrome within the context of global population aging, modern elderly health management urgently requires a transition towards multi-target, systemic intervention paradigms. FMH substances, owing to their inherent “multi-component, multi-target” synergistic properties and high safety profile, serve as an ideal scientific resource for constructing such integrated intervention strategies. Their value has been substantiated by cutting-edge evidence-based research: for instance, ginsenosides can delay the progression of diabetes-associated cognitive decline by precisely regulating key signaling pathways such as STAT5-PPARγ and PI3K/Akt, and for the widespread issue of metabolic dysregulation, various components including lotus seed polyphenols, diosgenin, and Lycium barbarum polysaccharides exert comprehensive regulatory effects through multidimensional mechanisms such as activating the Nrf2 antioxidant pathway, modulating the AMPK energy metabolism hub, and optimizing gut microbiota structure[35]. These studies not only elucidate the mechanistic principles of FMH at the molecular level but also provide core evidence for its transition from traditional empirical knowledge to modern “precision nutrition.” Therefore, systematically elucidating and utilizing this resource constitutes a strategic pathway for scientifically designing evidence-based dietary regimens, developing compound formulations, and ultimately establishing an effective, distinctive healthy aging support system with Chinese characteristics[36].

(2) Management of female-specific health cycles

The marked decrease in estrogen levels after menopause greatly increases the risk of osteoporosis, cardiovascular and cerebrovascular diseases, and metabolic disorders. So we need to take care of those dangers so that we can do special health work inside FMH things. Traditional estrogen replacement therapy has a major problem because it causes a higher chance of getting cancer, which means we need to find safer ways to use plant-based estrogen (phytoestrogens) from medicines and foods instead. The scientific challenge is the systematic finding of new types of commercially satiating phytoestrogen constituents other than soy isoflavones, including isoflavonoids and coumarins. These may potentially be selective estrogen receptor modulators, which mimic the favorable physiological outcomes without the usual risks[37]. The current research addresses several challenges, including the poor oral bioavailability of existing drugs, the application of modern technologies to discover new dominant compounds with improved pharmacokinetics, and the enhancement of their efficacy through innovative delivery systems. The research involves is dealing with important issues of social health and contributes to the development of high-value pharmaceutical and nutritional chemicals based on their functional validation. The positive outcomes will be a statement of the necessity to continuously increase the number of materials to encompass resources that have their own activities, which will transform the industry into a medical system of precision nutrition grounded on solid evidence[38].

(3) Other life stages and special groups

Creating a full-life-cycle nutritional support system is an important expansion of the FMH concept, intended to fully leverage its public health advantages. It primarily involves transforming traditional knowledge into innovative dietary plans that provide targeted nutritional needs for individuals at different life stages and across diverse population groups, with its scientific basis rooted in the theory of "early-life nutritional programming." That's when what you eat as a baby can affect how your body works when you grow up because of tiny changes in your genes and the good guys and bad guys living in your tummy[39]. Creating palatable nutrient delivery systems containing functional ingredients such as human milk oligosaccharides and prebiotics for infants and young children is necessary to promote a healthy gut microbiota[40]. For those adults facing many difficulties, FMH resources become the base for developing functional foods to solve energy metabolism and oxidative stress problems, with dynamic and personal assistance provided by wearable tech and AI. Incorporating FMH components into food designed for specific medical purposes may significantly enhance the effectiveness of nutritional therapy, particularly in pre-surgery support and for patients with dysphagia. Innovative solutions for a broad variety of product lines, such as maternity and infant nutrition and clinical patient care, are encouraged, implying that the FMH sector is increasingly integrated into preventive and clinical care. The intake of accurate materials, specific forms, and computer tools assists in preplanning and staying healthy in life.

4 Translation: High value products innovation and whole industry chain transformation

There is a complete process to turn scientifically sound application plans into practical industrial products that benefit people, starting with the generation of new ideas and culminating in real-world application. Since the era of academic research, improvements in market value and social benefits have been remarkable. High-value scientific research findings in FMH-related substance fields must follow a gradual path to value realization before they can be industrialized. "Origin optimization, core innovation, and system support"—this approach forms the strategy for building a modern industrial ecosystem. Currently, it is about building a complete closed-loop system from high-quality supply to precise demand satisfaction, and setting up a sustainable support system. Raw material and processing technology innovations form the basis for creating value, providing new "ingredients" and "methods" for industrial progress. Value realization is essentially about varied, scenario-based product innovation, translating science into marketable goods. At the same time, building a modern industrial ecosystem and forming a strong supply chain are important for increasing the value, aiming to create a large-scale, good quality, and sustainable operation system for the whole system. The three parts move up one after another, depend on each other, and together make a single plan for thinking and growing. It helps substances used in both medicine and food transition from scientific study to production in factories, ultimately creating a large, healthy environment where everything fits perfectly together (Fig. 5).

4.1 Raw material innovation, intensive processing and cross-border integration

Industry transformation to high-value output is based on

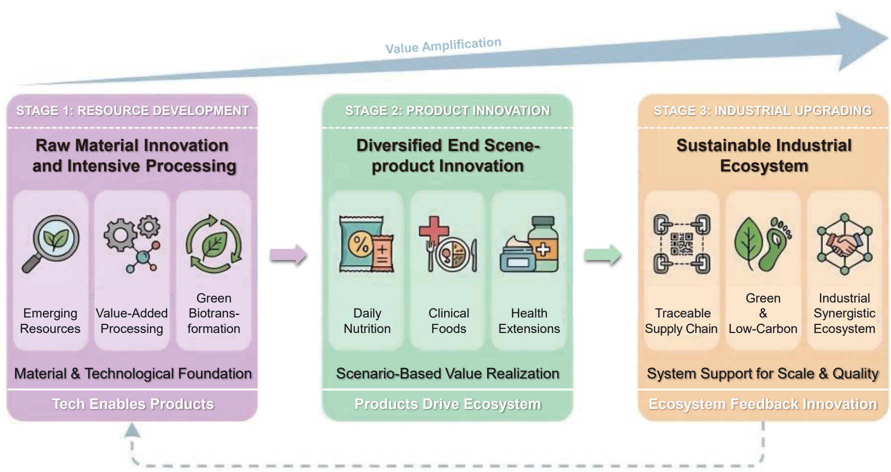

Figure 5 High value products innovation and whole industry chain transformation.

innovative source materials and processing technologies. The industrial development today is powered by systematic technical innovation to break the shackles of the old models of resources and processing and produce high-value-added products in the first place. The paradigm is reflected in three interconnected strategic directions, namely, cross-sectoral integration of new resources, where the goal is both to extend the spatial and functional limits of exploited resources and to use every part of the material, as a result of which the value of the existing resources is fully obtained; precision deep processing of the material; and biotransformation technologies, according to which the raw materials acquire new functions through environmentally friendly procedures. These factors create a comprehensive innovation chain that spans resource expansion, efficiency improvement, and functional transformation, all supported by a robust material and technical foundation for developing disruptive products.

(1) Emerging resources mining and cross-border integration

The further scientific integration of marine and land-based FMH resources is also a significant direction to expand the resource base of the industry and ensure high-value innovations. This is an attempt to do more than assemble things together in a physical manner to find out in-depth how specific ocean life objects (say, fucoidan and carotenoids) and land plants work together, what they do, and how their bodies create new objects. As an example, one can consider co-encapsulation of astaxanthin of marine origin and terrestrial dihydroartemisinin in the PLGA nanoparticles, which makes possible intervention in atherosclerosis through synergistic control of lipid metabolism and the immune microenvironment[41]. Algal DHA, which consists of Ginkgo biloba extract, is what forms a new way of enhancing your brain in numerous ways. The aim of such cross-boundary integration on the basis of mechanistic knowledge is to produce next-generation core ingredients that have higher impacts and new emotions. And so it opens up the possibility to break out of the sameness of products and make a new value chain for the industry[42].

(2) Intensive processing and value enhancement

Deep processing and value-added improvement of FMH resources need to change the industrial model fundamentally. It means moving away from the old way of just taking out single parts that work well by themselves (like long sugar chains and plant pigments), and instead using all the parts together so nothing gets wasted. Even though there are many studies today, they are still quite limited to just one part[43]. This leads to a waste of other active ingredients in the residue of separation and does not realize that multi-component synergistic systems such as protein-polysaccharide hydrogel and polysaccharide-polyphenol complex can have functions greater than the sum of their parts, 1+1>2. Therefore, the essence of industrial progress is the creation of a precise technology system covering the whole "testing-design-manufacturing-evaluation" chain. Non-destructive testing methods, such as near-infrared spectroscopy and green extraction techniques, such as ultrasound-assisted extraction, are included at the raw material level. In the middle stage, it is about making smart products with AI and big data and creating steady ways to give things, like little round balls made of fat. Downstream it will focus on explaining complicated working together rules between different parts by looking at how they fit together (molecular docking) and using lots of different types of information (multi-omics)[44]. Lastly, a conventional assessment practice comparing raw materials to custom products may cause the corporation to shift between mass production, scientific planning, and precise invention. This change will guarantee that we utilize our resources in a maximum way and make the sector expand in a sustainable manner.

(3) Application of biotransformation technology

Another eco-friendly solution that strategically involves FMH resources to add value through value enrichment and diversification is biotransformation technologies such as microbial fermentation. Microbial enzyme systems like 2-glucosidases and esterases are used to hydrolyze and change bound components in materials. This process achieves three main goals. Firstly, the bioavailability and bioactivity are considerably enhanced, with hesperidin effectively being transformed into a more active hesperetin; secondly, new functional molecules absent in the raw materials are produced under mild and environmentally friendly conditions, and so it adheres to the principles of green manufacturing[45]. It is through this methodology that the organization of biorefining and the enhancement of FMH molecules can be carried out to a greater extent than the conventional extraction methods. It hugely broadens the scientific reach and material limitations of these substances and develops a normative and inventive basic procedure for producing subsequent-generation health products that have high activity and novel functions[46,47].

4.2 Diversified end scene-product innovation

End products, which are based on various scenarios, represent a diverse array of uses that leverage the intrinsic value of innovations in raw materials and processes. The industry is strategically undergoing innovation in its product line on three levels, namely, its high-frequency daily situations, the medical needs of professionals, and special health extensions. The aim is to bring scientific evidence into real-life, easy-to-comprehend health solutions. The three areas bring about industrial value. Its convenient daily nutritional products serve as an effective tool for consumer education, encouraging regular consumption by aligning with modern daily lifestyles. Special clinical and therapeutic nutrition products are developed to incorporate dietary interventions into the existing health care systems. Cross-sectoral integration serves as a conduit for new value creation efforts, manifested in the form of distinctive, comprehensive health extensions. This situation-oriented and multi-layered innovation model indicates how the industry is responding quickly to consumer demands to have an improved product and scientific value.

(1) Convenient daily nutritional product

The scientific transformation of FMH efficacy into high-frequency, convenient daily consumer goods represents a key strategy for its integration into modern life and the amplification of industrial value. The core of this innovation lies in conducting targeted formulation design and modern food engineering conversion based on evidence from quantitative research on efficacy relationships, rather than simply turning herbs into food[48]. To precisely address the core demands of modern consumers for efficiency, convenience, and palatability, and systematically overcome the experiential barriers of traditional wellness practices. Take ready-to-eat snacks that include wolfberry and chrysanthemum, for example, these could be made for the "late-night scenario," and portable drinks that have astragalus and ginseng could be created for "office fatigue," or standardized and cold-chain technologies can be used to turn classic medicinal cuisine into pre-prepared meals[49]. This approach significantly expands consumption scenarios and user groups. As these products become an integral part of daily life, they gradually enhance public acceptance of Traditional Chinese Medicine (TCM) through consistent exposure. Therefore, it constantly drives the improvement of the industrial chain, promoting the "soft" revival and deep integration of traditional culture into the modern era.

(2) Special clinical and dietary foods

Advancement of special clinical and therapeutic food based on FMH is one of the important means to change the way from general health care to precision medicine[50]. This emerging field aims to deliver "prescription-equivalent nutritional solutions" tailored to specific diseases (e.g., diabetes and kidney disorders), age groups (e.g., pediatric and geriatric populations), and extreme environmental conditions (being way up high in the mountains or going to space)[51]. The scope of this field consists of medical foods developed to deal with specific metabolic traits related to diseases, clinical nutrition items that offer assistance throughout treatment intervals, and hospital-based medicinal diets that make it possible for exact dietary therapy via TCM syndrome differentiation. Product innovation has to be very flexible to different uses, such as making gels for people who have trouble swallowing, chewy jellies for kids, and easy-to-carry food with lots of nutrients. Future progressions in this area are expected to incorporate the complete integration of dynamic biomarker monitoring with AI to create closed-loop personal nutritional intervention systems that can be adjusted in real time. This improvement will help bring the FMH industry more into modern precision health management systems that combine preventing illness, treating it, and helping people get better.

(3) Specialized health products extension

Shifting FMH resources to special wellness goods is a relevant strategy that should be adopted by the business to enhance the multiplication of the value and contribute to collaboration among various areas. Two novel procedures, based on a unified mechanism analysis of polyphenols and saponins, power its operations. First, it creates useful items that do beneficial jobs, such as keeping off old age or getting ill when climbing high mountains[52]. Second, it offers another way to use plants' inherent biological activities—such as their ability to resist damage from air or fire (antioxidant properties) or reduce pain (anti-inflammatory effects)—to produce expensive skincare products like serums and masks[53]. It is a systematic expansion of the value chain of a single resource with internal consumption to external care that meets the demand on the market of natural and multi-purpose products and demonstrates how the industry is creating a new health system through interdisciplinary innovation.

4.3 Industrial ecology modernization and sustainable supply chain construction

Three interrelated industrial pillars, or areas, need to be created to guarantee a stable supply of innovative products: a combined traceable supply chain to provide quality transparency, a sustainable development system to create ecological responsibility, and an industrial synergy ecosystem to provide innovation. These pillars generate essential skills, competitive strength, and innovations that would help the medicine and food industries adopt a new medical concept characterized by high quality, durability, and productivity.

(1) Traceable supply chain integration

Developing an integrated and traceable supply chain, which reaches from the fields to the consumer, is a core infrastructure towards large-scale, high-quality, and sustainable development of the FMH industry. The key aspect in this case would be to implement technology such as Internet of Things, block-chain or big data that enables moving and aggregating all data along the whole supply chain, from real production and homogeneous treatment up to cold chain logistics until turning it into a one-way digital twin. This way, detailed transparency and complete control of the process could be facilitated[54]. Quality traceability is just the beginning of this project, which will change how we produce our products. For instance, Hema Fresh employs direct sourcing and QR code traceability, while Tesla and BYD leverage digital supply chain platforms to ensure quality amid rapid expansion. Each new medicine to be added to the expanded list is assigned a life-cycle data passport by this system in FMH. The key lies in transforming available resources into market-trusted reliable products, which serves as the foundation for modern, intensive management[55].

(2) Green, low-carbon, and sustainable development

The move towards a green, low-carbon, and sustainable development system in the entire chain of the industry is a strategic pillar and source of competitive advantage to the FMH sector in the future, with the global dual carbon goals driving the move. This framework should effectively incorporate ecological advantages into the industrial standards in a systematic manner, and the hub of this framework is to provide comprehensive regulation of carbon footprints throughout their life cycles and attain fundamental innovation in three significant phases. During the cultivation phase, we would have to advance ecological agriculture with the application of technologies like the biochar-based fertilizer, because only in this case will we be able to perform the carbon fixation ourselves and enhance the quality thereof. Green practices, resource reuse, and low-carbon drying should be part of the processing to save the consumption of energy[56]. Lastly, they have to employ digital tracking and new technologies of encapsulation in the circulation aimed at enhancing efficiency and waste reduction. To this modification, the substance list science should progress. Any new addition of resources in the future would involve demonstration of safety and efficiency and the complete data of the green life cycle, which comprises the entire steps of growing to eating[57]. This will be the new standard of industry sustainability, where all newly created materials must be beneficial in terms of the environment. This will drive the industry's transition from scale-oriented expansion to a modern health industry model that is ecologically resilient, economically viable, and socially responsible. Furthermore, to promote the green transition, we should take into account industrial entity differences. Building a life-cycle carbon footprint database, investing in closed-loop supply chains and zero-waste facilities, and becoming a technical and standard setter should be encouraged in large corporations. Modular and cost-effective green processing equipment utilization, as well as an active role in platforms for utilizing waste resources within local ecological agriculture cooperatives or industrial clusters, are the additional priorities of small and medium-sized enterprises. The financial support and policies must be geared towards such a scenario so as to generate a benchmark leading to a step-by-step industrial improvement strategy.

(3) Construction of industrial synergistic ecosystem

Enhancing systematic competitiveness in the FMH industry requires a deeply interconnected system of collaborative innovation. This ecosystem is supported by three key pillars that comprise standards, data, and technical platforms. They connect laboratory research to large-scale production and consumption.

Unified technical standards are an approximation of industrial cooperation: a language of quality standards. Comprehensive data flows are also valuable infrastructure for decisions[58]. Moreover, research and development (R&D) and engineering physical platforms also act as facilitators to transform demands into technical solutions[59]. Furthermore, these components serve as efficient channels for collaborative innovation. It provides firm institutional promotion; thus, all things that are discovered by science and become included in the FMH raw material list can be easily and confidently altered into something customers desire to purchase; this forms the foundation of organizations expanding indefinitely.

5 Innovation: Emerging technology-driven and intelligent fusion innovation

The systematic integration and disruptive innovation of the newest technologies are the main propelling force of the further evolution of the whole chain of these applications and transformations. The above integration and innovation are spread across various levels, from the pre-research and development phase, through the product development phase, to the actual product, being the driving force behind transforming the industry into a new vision. This development follows a detailed rational sequence that includes intelligent design, precise manufacturing, and green production that involves advanced scientific innovations as an accelerant to reinvent the whole chain of industry, from the beginning of R&D upstream to the end products downstream. At this point, the focus on change is centered around three complementary innovative frontiers that together represent the pillars of the industrial improvement philosophy: First, an AI-inspired data-driven system of R&D allows a shift in the existing paradigm of trial and error toward the predictability and individually tailored flexibility of the intelligent design. Second, enhanced formulation and production methods are being elaborated, including smart nano-delivery systems and synergies to resolve issues in the desired delivery of bioactive compounds through intelligent production. Thirdly, with the help of synthetic biology and environmentally friendly, low-carbon processes, technology improvements in raw material production and processing aim to create a green production mode from the outset, enabling the industry to become sustainable. These three trajectories together create the basic technical framework for the medicinal food industry moving towards a more efficient, precise, and sustainable future (**Fig. 6**).

5.1 Data-driven research, evaluation, and service innovation

Data-driven R&D innovation is becoming more prominent in FMH as a new paradigm emerges. It relies on a complete digital closed-loop system with smart forecasting, accurate planning, and dependable distribution. This research model tackles the efficiency obstacles within traditional R&D procedures, making it easier to move away from experience-based methods towards ones based on algorithms and facts. A closed loop system starts off with AI-enhanced bioactivity discovery that uses computation to rebuild the knowledge about "the component-bioactivity" relationship so that new things can be created. Next, it tries to find particular translations from molecule form to each product via intelligent formulation engineering. At last, it closes for quality, reliability, and governance all along the chain with digital tools and improved regulations. The union between them is one of the main pillars of smart upgrades to R&D systems.

(1) AI-based component discovery and mechanism prediction

AI, in essence, transforms the FMH research model from an empirical (trial-and-error) approach into an approach built upon substantial knowledge about what works, enabling researchers to make informed predictions for the future outcome. By uniting powerful deep learning capabilities, along with large amounts of different types of data about both living objects and chemicals, AI helps to quickly identify novel bioactive compounds, as well as to best understand their potency and mode of action. The essence of this revolution is that through QSAR modeling combined with generative artificial intelligence one can learn the complicated rules governing bioactivity, and, from them, more successful peptides and small molecules will be designed[60]. A notable example is the AntiFungiPept platform, which has successfully generated novel antifungal peptides by computationally optimizing the amino acid sequences of the most potent and least

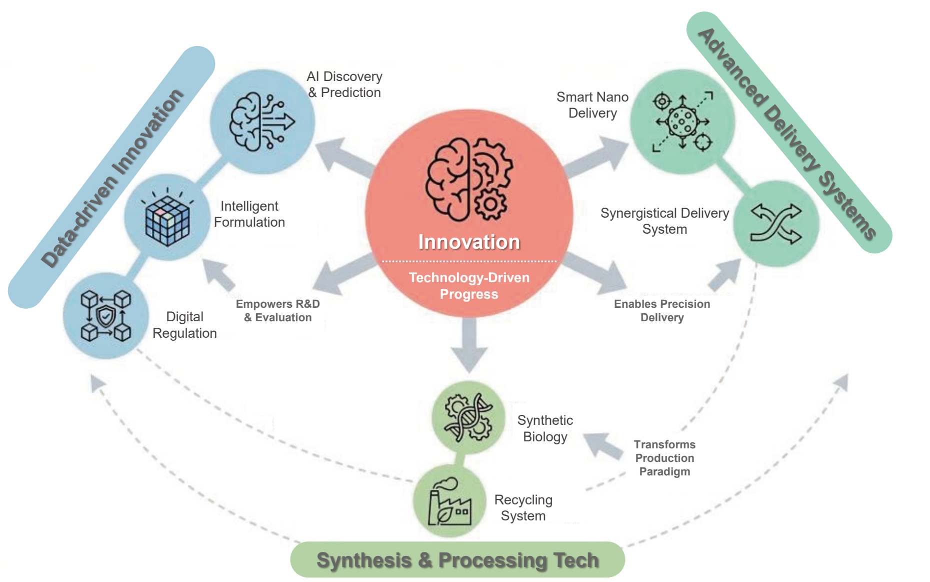

Figure 6 Emerging technology-driven and intelligent fusion innovation.

toxic variants, achieving an experimental success rate of over 80%. AI-based models do not just detect things: they understand difficult-to-comprehend underlying molecular processes, like distinguishing between breaking down cell membranes and halting metabolism, to have safer and more effective medicines[61]. Besides, host microbiomes and personalized nutrition plans with new structures are added. And it is the computational advancement that is making it easier to explore the biological dark matter of nature, and it is forming a smarter self-correcting cycle of coming up with next-gen functional health foods, which brings in a new era of personal health-based therapy.

(2) Intelligence generation and dynamic optimization of individualized formulations

The FMH products that have transitioned from universal to customized offerings are the result of advanced formulation engineering and personalization. The change is centered on the application of AI to recreate the find-make-check of the R&D cycle and transform product creation into a process that is directed by numbers and models instead of simple gut feeling[62]. And the ingredients and dosage and the reaction of people are rather big things, so the multi-omics, the clinical evidence, and the consumer insight can be done simultaneously. Machine learning and generative models are aided by rapid screening of candidate formulations in silico, nomenclature of their efficacy and stability, and then optimizing them with the assistance of digital twins and high-throughput experiments[63]. In practice, certain homemade brands have demonstrated that this approach is a possibility by connecting wearable tools to real-time physiological information to implement dynamic and closed-circle adjustments to the formula underlying products. That is why this enhancement is a technical enhancement, as well as a fundamental change in the manner the business is being conducted. It implies that the profession has left the intuition phase behind and entered into the era of evidence-based and constantly evolving precision, which provides us with a scientific means of managing personal health demand on a mass scale.

(3) Digital platform and smart regulation

The fundamental infrastructure in ensuring the promotion of contemporary governance, as well as the implementation of a full-fledged, trusted system in the FMH sphere, will be the development of an all-in-one digital platform that combines AI with the usage of the consortium blockchain, IoT, and multi-omics information. This platform establishes conditions that support the smart authentication of raw materials through the establishment of a conventional digital sample library. It relies on consortium blockchain and smart contracts to guarantee the unbearable and unshakable quality of the track of the information throughout the entire process, from growing and processing until selling, and to solve issues related to responsibility and origin[64]. Moreover, due to the incorporation of the IoT architecture, one can constantly monitor the environment where production and storage take place, and real-time warnings about risks occur[65]. Simultaneously, the multi-omics evidence inclusion supplies the quality assessment and the threat identification of complex components with high-dimensional molecular fingerprints. Such an overall approach will allow one to make a transition between seeing the finished product of something and observing everything through to the end, as though the latter could think sufficiently to do so themselves. It also redefines the levels of trust people in the business have towards one another. Thus, it offers a robust technology and credibility ground towards the high-quality and sustainable development of the industry.

The integration of AI and multi-omics is extremely promising, and it is challenging to put this technology into practice. To begin with, fundamental issues of data standardization and interoperability have to be resolved when constructing the cross-scale knowledge graphs. Additionally, it is essential to establish connections and mappings between classical Traditional Chinese Medicine (TCM) terms—such as "syndrome" and "constitution"—and modern molecular phenotypic data. Second, continually collecting physiological, metabolic, and gut microbe data for active health tracking and individual recommendations involves a significant amount of personal information. Therefore, we will need to implement a robust data safety system and an ethics examination process. It is not only a technical issue but also a fundamental foundation for gaining the long-term trust of the users and supporting the long-term development of the business.

5.2 Application of advanced delivery systems and formulation technologies

The translation of FMH substances from in vitro activity to effective in vivo applications relies heavily on advanced delivery and formulation technologies. They are technologies that exist with the purpose of eliminating the flaws that appear inherent in active ingredients: low bioavailability and lack of specificity to targets. This communication is critical in resolving the translation gap so as to realize accurate results in therapy. In the literature, the two strategic directions are complementary; one involves the development of smart nanodelivery systems that will enable the modularization of delivery vectors for active valuable components to address concerns about their behavior in the body, while the other focuses on creating more effective delivery systems that will be highly active by emulating and enhancing the behavior of individual medicine combinations. The second approach enhances the total effectiveness of the program since it considers several issues simultaneously. The two strategies provide an elaborate technical approach to the key problem of enhancing the process of delivery as well as the efficacy of the treatments available in their destination.

(1) Intelligent nano delivery systems

To overcome the in vivo application bottlenecks of bioactive components from FMH sources—stemming from their complex physicochemical properties and suboptimal pharmacokinetic profiles—the development of intelligent nanocarrier delivery systems has emerged as a critical breakthrough in formulation technology. This system is engineered to systematically address core challenges such as low solubility, poor stability, non-specific distribution, and lack of controllable release of active ingredients[66]. The technological approach converges on three synergistic levels: firstly, employing nanocarriers like liposomes and polymeric micelles to encapsulate and protect hydrophobic or labile components (e.g., curcumin, baicalin), thereby enhancing their solubility and stability; secondly, guiding carriers to actively recognize and accumulate in pathological tissues through surface modification with targeting ligands (e.g., antibodies, peptides); and ultimately, achieving stimuli-responsive, precise release of active ingredients at target sites by utilizing materials designed to respond to pathological microenvironments (e.g., specific pH, enzymes, or redox levels)[67]. Consequently, intelligent nanocarrier delivery systems essentially construct a bidirectional bridge connecting traditional bioactive substances with the demands of modern precision medicine: they not only significantly unleash the therapeutic potential of the existing library of FMH components but also provide a feasible delivery foundation for the future development of innovative functional products based on well-defined mechanisms. This represents the core technological driver propelling the field toward clinical translation and precision application.

(2) Efficient synergistical delivery system

High-efficiency synergistic delivery systems represent a core technological breakthrough in advancing the formulation of FMH compounds toward engineering and intelligence. Their essence lies in achieving multi-component co-loading, targeted delivery, and controllable release through sophisticated carrier design, systematically addressing the application bottleneck of traditional complex formulas characterized by "multiple components yet low efficiency." These systems rely on engineerable carriers such as liposomes and polymeric nanoparticles to construct "micro-warehouses" capable of simultaneously encapsulating active ingredients with diverse properties[68]. Through surface modifications, they enable intelligent delivery across biological barriers and targeted accumulation in pathological tissues. More importantly, they can be designed with release mechanisms responsive to pH, enzymes, or reactive oxygen species, ensuring the precise release of components at specific sites and achieving multi-dimensional synergistic effects—for instance, combining the antioxidant properties of polyphenols with the immunomodulatory functions of polysaccharides to cooperatively reconstruct pathological microenvironments[69]. Therefore, this system is not only a key technological pathway for enhancing the utility of the existing library of FMH substances but also serves as an advanced tool for scientifically interpreting and modernly realizing traditional formulation theories such as "sovereign, minister, assistant, and envoy." It establishes the core technological foundation for developing next-generation intelligent functional products based on well-defined synergistic mechanisms.

5.3 Innovation on synthesis and processing technology

To ensure a reliable supply of resources and promote the sustainable development of the food and medicine co-production industry, it is essential to focus on fundamental technological innovations in the methods of acquiring and producing raw materials. Such inventions pursue two parallel and complementary strategies: the first one is to exhaust an exhaustive study and evaluation of the existing natural biological resources, and the second one is to deconstruct the limits of traditional resources essentially to design new substances, a new way to make things, and establish a new source of productive potential for the industry. We will discuss the latter strategy in this section. With the three constraints of resources and quality on the one hand, there are two emerging ways of conducting the study in this field today. Synthetic biology production is the first direction; it refers to designing new materials and synthesizing them on a large scale within cell factories to produce a new supply in the origin of sources. The second way emphasizes green and low-carbon processing technologies, which are trying to change the processing paradigm itself by applying the exact and gentle methods of physical processing, thereby causing the maximum effective and safe application of raw material possible. These two alternatives—creating something new and improving the existing one—collectively establish the principal framework for overcoming the issue of old resources and ensuring the industry's successful development in the future.

(1) Synthetic biology in producing FMH substances

Synthetic biology is a paradigm shift to address the problem of efficiency and sustainability and is built upon the traditional production of high-value bioactive compounds under FMH sources. The key to this solution is the efficient, environmentally friendly, and scalable production of target compounds through the engineering of metabolic pathways and microbial fermentation. The innovation succeeds in removing the dependency of the supply chain on a few natural resources, the time-consuming growth process, and the traditional way of extracting resources. Some of the notable developments in the field include a biosynthetic pathway to artemisinic acid that has been developed in Saccharomyces cerevisiae, yielding 25 g/L; engineered *E. coli* that has been employed to synthesize curcuminoids and catalyze the formation of allicin; and yeast metabolic engineering that has significantly enhanced the production of valuable ginsenoside aglycones[70]. The technological development at a strategic scale has gone up to the industrialization stage, which can be seen in the invention of a demonstration production line of rare ginsenosides by China so that more than twenty types of high-purity ginsenosides can be manufactured de novo[71]. Therefore, synthetic biology is not merely an alternative technology but a strategic cornerstone for reconstructing a sustainable raw material supply system for food-medicine homology and vastly enriching its inventory of high-value substances, laying a foundation for securing the supply of premium ingredients and creating novel functional components for the future.

(2) Green processing technology and recycling system

To overcome some of the limitations that conventional manufacturing technologies have in terms of high-energy consumption, low efficiency, or even environmental issues, we must develop green, low-carbon production technology; this will be an important development trend in the precise, sustainable development of medical foods. The next technology complex will allow for revolutionary change in primary material processing through the organized application of new and advanced analytical techniques, physical fields, and artificial intelligence. The main maternal implementation plan includes three steps: First, develop a complete database of all types of bioactive substances and harmful substances of all types of medicinal materials; secondly, direct oneself towards the development of non-thermal physical processing processes and synergies above cold plasma and pulsed electric fields. The technologies enable the efficient recovery of bioactive compounds and targeted modification of the compounds at mild conditions and extraction of harmful substances[72]. To conclude, with multi-dimensional analysis and AI algorithms, we can discover how things operate and optimize them to ensure that we can alter various raw materials to ensure that they suit our needs in terms of health[73]. This approach not only outperforms traditional environmentally harmful methods but also represents a significant technological breakthrough that endows raw materials with enhanced functionality while improving their environmental sustainability and safety. It provides valuable strategic technical support to the development of high-quality medical food materials, as well as assures the continuation of industrial development.

6 Interdisciplinary research: Multi-disciplinary fusion and exploration

The final formation and improvement of value at the crossroads of food and medicine must be achieved through a strong resonance and coordination with other disciplines and social systems, which not only means that the field of research and scope is getting larger but also that it is the correct way for the field to develop as a health product, a health culture in the future, eventually a health ecosystem. The three mutually reinforcing fronts, which center on human health, facilitate this shift. In a physical sense, the cross-cutting services of the recent fields that involve brain sciences and neurosciences, enable to offer an in-depth view on regulation processes in complex living systems, and thus, it raises both scientific and intervention precision. Level of application scenario: It can integrate health preservation tourism, sociology, etc., to create experience and service products related to ecosystem health, thus increasing their social value. Resource Foundation Level: It combines the resource strategy of herbal resources and information technology to comprehensively research and analyze traditional resources, thus laying down solid grounds for sustainable development (**Fig. 7**).

6.1 Deep integration into brain science and neuroscience

Current studies seek to know about the role of FMH compounds that promote brain wellness, and it is one of the most significant factors in life science and their contribution to maximizing cognition of higher-order brain operation and central homeostasis. It goes beyond the classic or mono-factorial description of effect, revealing multidimensional integrative regulative architectures between the complex networks of neuroimmune metabolism. The research relates to serious diseases such as decline in cognition or inexplicable depression and rage and the fact that certain regions in the brain cannot execute their function properly.

(1) Brain health and neural mechanisms

Global aging and increasing incidence of neurodegenerative disorders have made FMH resources an important area of focus for research at the intersection of neuroscience and nutrition. Primary mechanism: Microbiota-gut-brain axis connects gut dysbiosis with neuroinflammation, cognitive decline, and other brain health problems via immune, metabolic, and endocrine pathways. Studies show that eating lots of foods that contain plant-based bioactive substances such as polyphenols and flavonoids can help your brain work better and think faster because these things stop your body from getting sick, make your brain cells stronger, and tell your tummy how to talk to your head[74]. Also, gut-derived metabolites such as short chain fatty acids and indole-3-propionic acid also participate in the regulation of neuroinflammation and the expression of neurotrophic factors, they are important signaling molecules that mediate the neuroprotective effect of FMH[75]. Future research needs to explore the mechanisms by which representative components such as polyphenols, polysaccharides, saponins, and bioactive peptides affect the neural circuits via the gut-brain and immune-brain axes. Integration of multi-omics, neuroimaging, and AI will move the field beyond empirical application into a science-driven approach based on mechanisms and precise intervention.

6.2 Integration with health care tourism and social science

Turning the idea of FMH into real-life, service-based healthy living styles and industries means looking at all the groups and places people live in. Transformation refers to the promotion of changing from separate products to ecological solutions including "products + services + scenarios". To explore the untapped potential in the health industry, we need to create practical, replicable integrated models. By making a series of innovations about how to do business and implement projects, it looks for certain ways things can change and how those changes might make money when working with medicines and foods that are similar in social places like keeping healthy and going on trips to learn about culture, etc.

(1) "FMH plus" in health care tourism

The FMH concept, deeply integrated into wellness and cultural tourism, is forming a new kind of development pattern that goes beyond the usual limits of food therapy. This model integrates and restructures the industrial chain by means of scenarios, turning the preventive treatment idea of TCM into something that can be experienced and participated in. Therefore, it creates a full industrial ecosystem covering "health-wellness-tourism." This practice is carried out via actual projects. For example, the wellness town in Qiannan Prefecture combines TCM health care, medicinal cuisine, and herb growing, drawing more than 300,000 visitors each year. Moreover, in Sichuan, the Huomao Rural Garden offers a rich cultural experience through the cultivation of herbs and the offering of educational workshops. Next, Huangshan City in Anhui has developed a comprehensive system that integrates five nourishing wellness practices: medicine, tea, food, exercise, and mental training, all based on the Xinan medical theory. The examples indicate that the homology of food and medicine and the wellness tourism model are not only renewed spawners of the industry's development but also significant paths

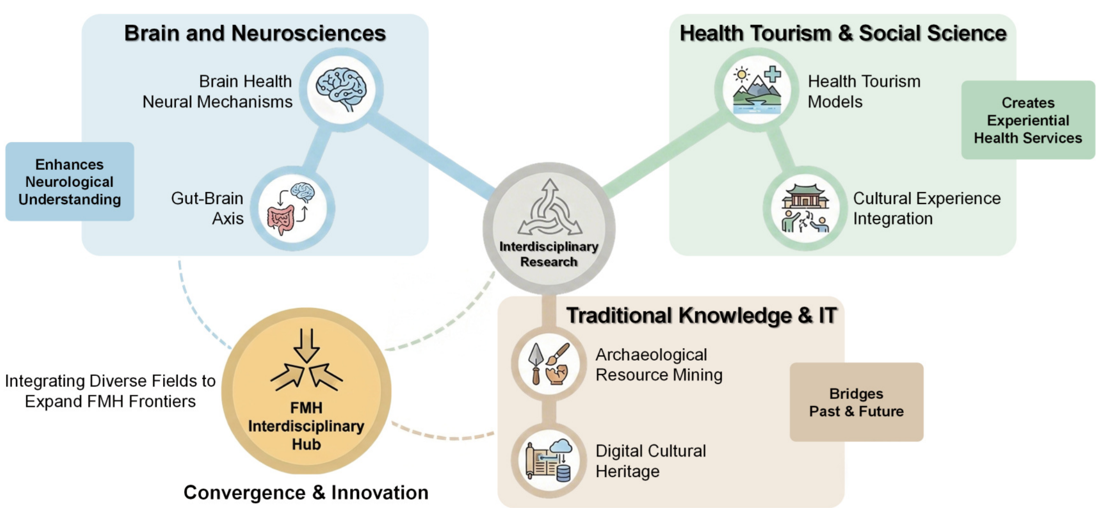

Figure 7 Multi-disciplinary fusion and exploration.

of the creative transformation and innovative development of the TCM culture, which provides enduring support for the development of the region's economy and the revival of villages.

6.3 Combination of traditional knowledge and information technology

To effectively utilize the past and discover things that we were not originally familiar with, we must establish a system of conducting research in which various types of information in various regions can converge together. This approach substantially proves ancient beliefs scientifically through the addition of historical documents and physical objects besides on-site research findings, which make them appropriate in the present era. This goal can be attained by herbal archaeology. They do not only enhance the material base and cultural legacy in FMH but also significantly enhance the rate and precision of locating the resources through technology, which is the foundation of long-term development in the industry.

(1) Resource mining based on archaeological herbal medicine traditional culture

In the systematic exploration of modern FMH resources, the "multiple-evidence approach", which combines traditional pharmacological archaeology, ethnic botany, and multi-omics technologies, has emerged as a crucial method. This approach, through the mutual verification of literature research, scientific analysis of unearthed medicinal relics, ethnographic field surveys, and modern technological means, aims to precisely trace the origin and application history of substances and clarify their scientific implications. For example, the systematic study of the fennel fruits from the Han Dynasty unearthed at the Lao Guanshan Han tomb not only uses physical evidence to trace the history of fennel's use as both food and medicine back to the Han Dynasty but also reveals the potential scale of early large-scale utilization based on the size of the relics[76] The investigation of the "grass soybean" in the Dunhuang documents and the ethnic botany survey of traditional medicinal plants of the Tujia ethnic group together establish a comprehensive evidence chain from history to the present and from the center to the periphery[77]. Therefore, this systematic "root-seeking and origin-tracing" and scientific verification not only provide historical legitimacy and modern scientific validity as dual bases for the scientific expansion of the list of FMH substances but also lay a solid foundation for product development innovation and the dynamic inheritance of cultural heritage.

Conflicts of interest

The authors declare that there are no conflicts of interest in this work. Wenyi Kang is a Chief Editor of Food & Medicine Homology, but was not involved in the processing, peer review or decision making of this article.

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