



Perspective

Modernisation of Chinese medicinal cuisine: A paradigm shift from empirical heritage to systems science

Ke Yang¹, Wen-Bo Guo², Rui-Li Pan³, Cong-Nan Cen⁴, Li Yu⁵, Jun-Hua Yang⁶, Kun-Lin Li⁷, Tian-Yi Xin⁸, Wan-Lu Liu⁹, Qiang Li¹⁰, Qi-Ming Zhao¹¹, Zhao Chen¹², Ling-Hang Qu¹³, Rui-Qin Han¹⁴, Sui-Sui Jiang¹⁵, Gui-Fen Wu¹⁶, Hai-Ming Chen¹⁷, Hong Li¹⁸, Yong-Guo Dai¹⁹, Yan Gao²⁰, Xiao-Li Wu²¹, Liang Jin²², Jia-Lin Meng²³, Xian-Tao Yan²⁴, Juan-Juan Li²⁵, Hong-Wei Xue²⁶, Bo-Ying Wang²⁷, Guo-Liang Zheng²⁸, Yang Ye²⁹, Tian-Zhu Guan³⁰, Xin-Pei Zeng³¹, Chang-Wei Zhang³², Wen-Jun Li³³, Ping Zheng³⁴, Xiu-Zhang Li³⁵, Nan-Qu Huang³⁶, Juan Huang³⁷, Xiao-Yuan Ma³⁸, Hai-Ming Hu³⁹, Tao He⁴⁰, Yan-Qi Dang⁴¹, Chen Liang⁴², Dong-Wei Wei⁴³, Bo Sun⁴⁴, Li-Yue Sun⁴⁵, Peng-Hui Feng⁴⁶, Qing-Bin Cui⁴⁷, Yun-Zhou Fan⁴⁸, Yi-Zhou You⁴⁹, Wen-Li Wang⁵⁰, Wen-Yi Kang⁵¹ (✉), Xiao-Hui Fan⁵² (✉), Hong-Jun Yang⁵³ (✉)

- ¹ Key Laboratory of Microbiological Metrology, Measurement & Bio-product Quality Security, State Administration for Market Regulation, College of Life Sciences, China Jiliang University, Hangzhou 310018, China
- ² Zhejiang Key Laboratory of Chinese Medicine Modernization, Innovation Center of Yangtze River Delta, Zhejiang University, Jiaxing 314100, China
- ³ Institute of Food Nutrition and Quality Safety, College of Life Sciences, China Jiliang University, Hangzhou 310018, China
- ⁴ Key Laboratory of Microbiological Metrology, Measurement & Bio-product Quality Security, State Administration for Market Regulation, College of Life Sciences, China Jiliang University, Hangzhou 310018, China
- ⁵ School of Basic Medical Sciences, Zhejiang Chinese Medical University, Hangzhou 310053, China
- ⁶ Department of Anatomy, School of Basic Medical Sciences, Guangdong Pharmaceutical University, Guangzhou 510006, China
- ⁷ Anhui University of Traditional Chinese Medicine, Hefei 230012, China
- ⁸ Institute of Medicinal Plant Development, Chinese Academy of Medical Sciences & Peking Union Medical College, Beijing 100193, China
- ⁹ College of Materials Science and Engineering, Heilongjiang Provincial Key Laboratory of Polymeric Composite materials, Qiqihar University, Qiqihar 161006, China
- ¹⁰ Department of Critical Care Medicine, Beijing Hospital, National Center for Gerontology; National Clinical Research Center for Gerontology; The Key Laboratory of Geriatrics of NHC; Institute of Geriatric Medicine, Chinese Academy of Medical Sciences, Beijing 100730, China
- ¹¹ School of Pharmaceutical Sciences, Fuchun Campus, Zhejiang Chinese Medical University, Hangzhou 311402, China
- ¹² Institute of Basic Research in Clinical Medicine, China Academy of Chinese Medical Sciences, Beijing 100700, China
- ¹³ Hubei University of Chinese Medicine, Wuhan 430065, China
- ¹⁴ State Key Laboratory of Common Mechanism Research for Major Diseases, Institute of Basic Medical Sciences, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing 100005, China
- ¹⁵ Institute of Nutrition and Health, School of Public Health, Qingdao University, Qingdao 266000, China
- ¹⁶ Guangxi Minzu Normal University, Chongzuo 532200, China
- ¹⁷ Guangdong Hospital of Chinese Medicine, Guangzhou 510120, China
- ¹⁸ School of Traditional Chinese Medicine, Southern Medical University, Guangzhou 510515, China
- ¹⁹ Department of Pharmacy, Xiangya Hospital of Central South University; National Clinical Research Center for Geriatric Disease (Xiangya Hospital), Changsha 410008, China
- ²⁰ Biomedical Innovation Center, Beijing Shijitan Hospital, Capital Medical University, Beijing 100038, China
- ²¹ Institute of Medicinal Plant Development, Chinese Academy of Medical Sciences & Peking Union Medical College, Beijing 100193, China
- ²² School of Medical Technology and Information Engineering, Zhejiang Chinese Medical University, Hangzhou 310053, China
- ²³ Department of Urology, The First Affiliated Hospital of Anhui Medical University; Anhui Province Key Laboratory of Urological and Andrological Diseases Research and Medical Transformation, Anhui Medical University, Hefei 230032, China
- ²⁴ Hanshan Normal University School of Life Sciences and Food Engineering, Chaozhou 521041, China
- ²⁵ School of Life and Health Sciences, Hainan Province Key Laboratory of One Health, Collaborative Innovation Center of One Health, Hainan University, Haikou 570228, China
- ²⁶ Bencao Lun Traditional Chinese Medicine Clinic, Nantong 226000, China
- ²⁷ Alpha Health Care Ltd, Auckland 2104, New Zealand
- ²⁸ Department of Gastric Surgery, Cancer Hospital of Dalian University of Technology; Liaoning Cancer Hospital & Institute; No. 44 Xiaohayuan Road, Dadong District, Shenyang 110042, China
- ²⁹ Department of Preventive Medicine and Public Health, Laboratory Science, School of Basic Medical Science and Public Health, Jiangsu University, Zhenjiang 212013, China
- ³⁰ School of Food Science and Engineering, Yangzhou University, Yangzhou 225127, China

© National R&D Center for Edible Fungus Processing Technology 2026. Published by Tsinghua University Press. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Address correspondence to Wen-Yi Kang, kangweny@hotmail.com; Xiao-Hui Fan, fanxh@zju.edu.cn; Hong-Jun Yang, hongjun0420@vip.sina.com

- ³¹ Guangzhou Anyue Health Management Co., Ltd., Guangzhou 510000, China
- ³² Institute of Chemical Industry of Forest Products, Chinese Academy of Forestry, Nanjing 210042, China
- ³³ Institute of Chemical Industry of Forest Products, Chinese Academy of Forestry, Nanjing 210042, China
- ³⁴ Department of Obstetrics and Gynecology, Beijing Chao-Yang Hospital, Capital Medical University, Beijing 100020, China
- ³⁵ State Key Laboratory of Plateau Ecology and Agriculture, Qinghai Academy of Animal and Veterinary Sciences, Qinghai University, Xining 810016, China
- ³⁶ National Drug Clinical Trial Institution, Third Affiliated Hospital of Zunyi Medical University (The First People's Hospital of Zunyi), Zunyi 563000, China
- ³⁷ Key Laboratory of Basic Pharmacology and Joint International Research Laboratory of Ethnomedicine of Ministry of Education, Zunyi Medical University, Zunyi 563000, China
- ³⁸ State Key Laboratory of Food Science and Resources, Jiangnan University, Wuxi 214122, China
- ³⁹ School of Laboratory Medicine, Hubei University of Chinese Medicine, Wuhan 430065, China
- ⁴⁰ College of Pharmaceutical Sciences, Zhejiang Chinese Medical University, Hangzhou 310053, China
- ⁴¹ 7LAB Joint Laboratory, Seventh People's Hospital, Shanghai University of Traditional Chinese Medicine, Shanghai 200137, China
- ⁴² Jiangxi Puzheng Pharmaceutical Joint Stock Co., Ltd., Ji'an 343000, China
- ⁴³ College of Life Sciences, Henan Agricultural University, Zhengzhou 450064, China
- ⁴⁴ Xiangshan Hospital of Traditional Chinese Medicine, Huangpu District, Shanghai 200020, China
- ⁴⁵ Health Management Center, The First Affiliated Hospital of Jinan University, Guangzhou 510630, China
- ⁴⁶ National Clinical Research Center for Women's Health and Obstetric and Gynecologic Diseases, Department of Obstetrics and Gynecology, Peking Union Medical College Hospital, Chinese Academy of Medical Sciences & Peking Union Medical College, Beijing 100730, China
- ⁴⁷ Department of Cell and Cancer Biology, College of Medicine and Life Sciences, The University of Toledo, 3000 Arlington Avenue, Toledo 43614, United States
- ⁴⁸ Department of Physiology and Cell Biology, College of Medicine, Davis Heart and Lung Research Institute, The Ohio State University, Columbus 43210, United States
- ⁴⁹ Key Laboratory of Microbiological Metrology, Measurement & Bio-product Quality Security, State Administration for Market Regulation, College of Life Sciences, China Jiliang University, Hangzhou 310018, China
- ⁵⁰ Department of Food Science & Technology, School of Agriculture & Biology, Shanghai Jiao Tong University, Shanghai 200240, China
- ⁵¹ National R & D Center for Edible Fungus Processing Technology, Henan University, Kaifeng 475004, China
- ⁵² School of Pharmaceutical Sciences, Zhejiang Chinese Medical University, Hangzhou 310053, China
- ⁵³ Beijing Key Laboratory of Traditional Chinese Medicine Basic Research on Prevention and Treatment for Major Diseases, Experimental Research Center, China Academy of Chinese Medical Sciences, Beijing 100700, China

Received: 14 July 2026 / **Revised:** 20 July 2026 / **Accepted:** 20 July 2026

1 Introduction

Over the past two decades, suboptimal diets have been confirmed by extensive epidemiological studies to contribute substantially to type 2 diabetes, obesity, cardiovascular disease, and other non-communicable diseases, and also to shape chronic inflammatory states. In North America and parts of Europe, Food Is Medicine initiatives have moved from lifestyle advocacy towards testable interventions and policy implementation^[1]. Chinese medicinal cuisine, or “yao shan”, could occupy a related but distinct space as sustained, food-based support for early cardiometabolic risk, sub-health conditions, age-related needs, and recovery rehabilitation.

Within East Asia, two alternative modernisation paths further sharpen the contrast. Japan's ishoku-dougen heritage has been channelled into regulated product categories—Foods for Specified Health Uses (FOSHU, licensed individually) and Foods with Function Claims (FFC, notification-based with an evidence dossier)—which anchor evidence requirements at the level of each product but leave little room for formula-level, pattern-based reasoning. South Korea's sikchi tradition has developed alongside institutionalised medical-nutrition meal services and a ginseng-centred health-functional food category. These paths represent, respectively, regulatory productisation and service institutionalisation; China's challenge is distinctive in seeking to preserve formula-level theory while building evidence at both the product and the service level.

Chinese dietary-therapy culture extends over more than two

millennia. Its roots reach the pre-Qin and Han periods: the Rites of Zhou: Offices of Heaven described the “food physician” (shi yi), an early role in dietary regulation; the *Huangdi Neijing* (Yellow Emperor's Inner Canon) linked dietary nourishment to the viscera, yin and yang, qi, and blood; and the *Shennong Bencao Jing* (Divine Farmer's Classic of Materia Medica) classified substances into three grades and recorded their properties and flavours. This lineage was further elaborated in successive dynasties and long predates contemporary wellness markets. This long tradition provides the conceptual foundation, but contemporary medicinal cuisine now faces the challenge of translating historical insights into evidence-based practice.

Beyond these foundational works, later texts placed dietary therapy more explicitly within clinical reasoning. Zhang Zhongjing recorded Danggui Shengjiang Yangrou Tang in the *Jin Gui Yao Lue* (Essential Prescriptions from the Golden Cabinet), a surviving part of the *Shanghan Zabing Lun* (Treatise on Cold Damage and Miscellaneous Diseases). Sun Simiao's *Beiji Qianjin Yaofang* (Essential Prescriptions Worth a Thousand Gold Pieces for Emergencies) prioritised dietary therapy before medication when appropriate. Chen Zhi's *Yanglao Fengqin Shu* (Book for the Care of the Elderly) systematised dietary care for older adults, and Hu Sihui's *Yinshan Zhengyao* (Principles of Correct Diet) further integrated properties and flavours, meridian tropism, and multi-ethnic dietary practices. Li Shizhen's *Bencao Gangmu* (Compendium of Materia Medica) consolidated information on compatibility and contraindications. These texts establish historical continuity and conceptual organisation, not the safety,

mechanism, or clinical effectiveness of contemporary formulations^[2].

The historical tradition defines yao shan as more than adding medicinal materials to food. Formulation draws on properties and flavours, meridian tropism, ascending-descending and floating-sinking tendencies, cold-heat distinctions, and the viscera and channels. The sovereign-minister-assistant-courier hierarchy assigns principal, supportive, moderating, and coordinating roles within a preparation. These constructs generate historically grounded hypotheses about classification, compatibility, and context; they do not establish molecular mechanisms or clinical efficacy.

Traditional experience is therefore a source of hypotheses, not a substitute for evidence. Although yao shan is used for health maintenance and early risk management, many interventions remain poorly defined. Their material basis is often unclear, human exposure is seldom traced, mechanisms are inferred from association, efficacy is weakly graded, and safety boundaries remain incomplete. These limitations impede international appraisal and a defensible transition from general health practice to structured nutritional support.

Modernisation requires a translational chain rather than a broader restatement of tradition. The chain should progress from resource identity and finished-product definition to constituent characterisation, *in vivo* transformation, causal testing, efficacy assessment, safety governance, product translation, and real-world services. We examine five connected domains: Material basis and mechanism; quality and safety; clinical settings and precision nutrition; industrial and digital translation; and public and international communication. We then propose a staged research agenda and ten questions designed to falsify, refine, or delimit the field's central assumptions (Fig. 1).

How this framework was developed. This Perspective synthesises two inputs: (1) a narrative review of the literature on

medicinal cuisine, food matrices, microbiome causality, clinical nutrition, toxicology, and regulation; and (2) structured expert consultation within the author consortium, which spans traditional Chinese medicine (TCM), food science and engineering, clinical medicine, nutrition, toxicology, pharmacy, regulatory science, and industry. Candidate constructs and priority questions were proposed by the writing group and then challenged through three rounds of written internal review, in which contributors were asked to identify unsupported claims, missing evidence, and foreseeable failure modes; the ten questions in Section 9.3 are the survivors of that process. We present the result as a consensus-informed expert framework, not the product of a formal Delphi procedure or a systematic prioritisation survey; the transparency we can offer is disclosure of these sources and reasoning.

2 Definition and scope

Terminology. Throughout this article, “yao shan” is the single primary term; “medicinal cuisine” without qualification refers to the same intervention class. We avoid “medicated diet”, which conflates the intervention with medically prescribed diets and with foods for special medical purposes—statutory categories governed by distinct rules.

Here, yao shan denotes a complex dietary intervention—embodying the food–medicine homology principle, whereby certain substances traditionally serve as both food and medicine—made from legally permitted ingredients and edible parts at plausible dietary doses, and oriented primarily to maintaining good health, with risk-marker management and standardised nutritional support as secondary, evidence-dependent roles. TCM dietary-therapy theory is the primary—but not the exclusive—framework guiding ingredient selection, compatibility, processing, and consumption; preparations grounded in documented folk

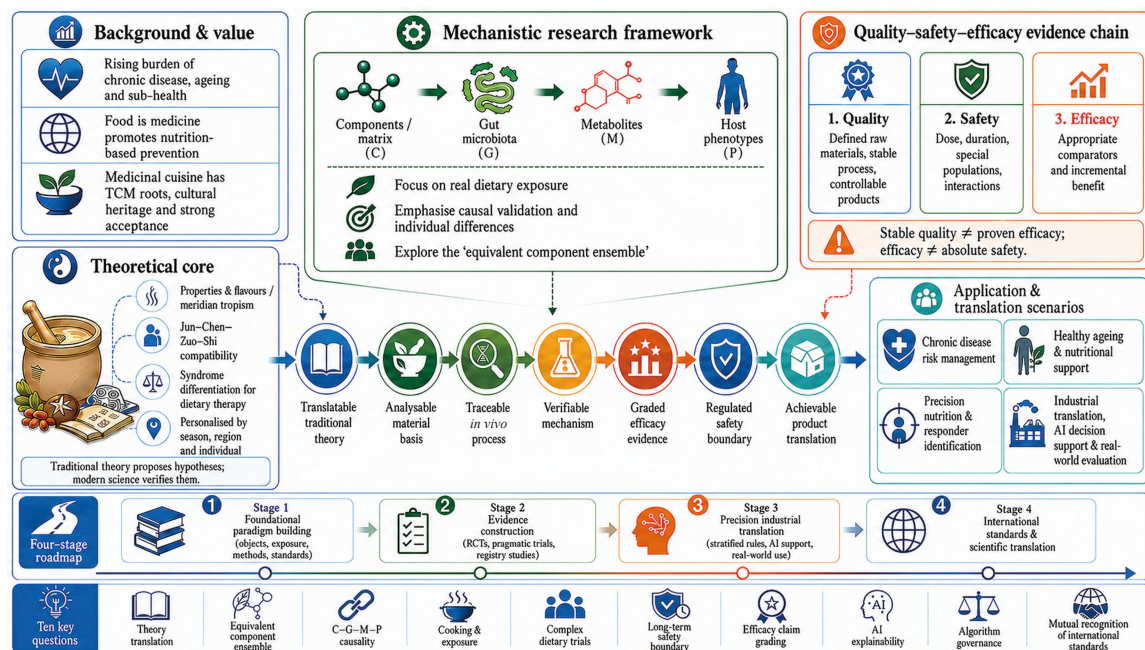


Figure 1 A systematic framework for the modernisation of yao shan. Reading from left to right, the framework begins with the historical corpus and current regulatory boundaries (Sections 1–3), which define what yao shan is and what its traditional constructs may legitimately claim. It proceeds to the evidence core (Section 4): A standardised finished product, staged exposure characterisation, causal testing along defined chains, and graded human evidence. Quality, safety, and efficacy governance (Section 5) form parallel guardrails that constrain every downstream step. The framework then moves to application settings (Section 6), industrial and digital translation (Section 7), and public and international communication (Section 8), before converging on the milestone-gated roadmap and ten priority questions (Section 9). The figure is intended as a map of dependencies rather than a catalogue of topics: Each block names the failure mode it is designed to prevent.

food-therapy practice or in contemporary nutrition science that meet the ingredient and dose criteria above are included as boundary cases and are flagged as such. The intervention retains a complete food matrix, and its identity depends on the interaction among theory, compatibility, processing, matrix, intake context, and target population. Highly purified single-component supplements, disease-treating herbal formulas, and arbitrary food combinations without any documented theoretical or empirical rationale fall outside this definition.

Yao shan, as defined here, differs from: Dietary therapy, a broader practice that includes clinician-directed diets without TCM formulation logic; functional foods and health foods, statutory product categories assessed by ingredient- or function-level evidence; foods for special medical purposes, nutritionally complete or targeted products intended for patients under medical supervision; herbal formulas, medicinal products intended to treat disease; and Food Is Medicine interventions, medically tailored meals or produce prescriptions embedded in health-system financing rather than in TCM theory. These categories overlap in practice but not in regulatory identity, and conflating them is a frequent source of overclaiming.

The designation yao shan does not create a statutory product category in China. Each product remains subject to the requirements governing its actual category, ingredients, intended use, labelling, and claims. Article 38 of the *Food Safety Law of the People's Republic of China* (2025 revision) prohibits adding medicines to foods, except substances officially catalogued as both foods and Chinese medicinal materials^[3]. The catalogue is maintained by the National Health Commission and the State Administration for Market Regulation under dedicated management provisions and is expanded only by formal announcement—for example, Announcement No. 9 of 2023 added nine substances, including *Codonopsis pilosula* (Dangshen), *Dendrobium officinale* (Tiepishihu), *Astragalus membranaceus* (Huangqi), and *Ganoderma* (Lingzhi). Ordinary foods, health foods, foods for special medical purposes, and medicinal products follow distinct rules for market access, claims, and risk management. Catalogue inclusion is entry-specific: It does not authorise unlisted plant parts, unrestricted doses or combinations, use in all populations, or any health claim.

3 Principles for translating medicinal-cuisine theory

Modernisation should preserve the internal structure of medicinal-cuisine theory without shielding it from scrutiny. Properties and flavours, meridian tropism, the sovereign-minister-assistant-courier hierarchy, TCM pattern-differentiated dietary prescription, and adaptation to season, locality, and individual distinguish yao shan from conventional functional foods. Two reductions must be avoided: Recasting yao shan as 'food containing bioactive compounds' by selecting only concepts that map readily onto biomedicine, and treating traditional theory as self-validating. A defensible approach uses TCM theory to generate hypotheses about classification, compatibility, and context, while modern research defines the objects, doses, populations, and outcomes for which those hypotheses hold.

Translation should satisfy three conditions. First, semantic fidelity requires a modern variable to reflect the meaning of a traditional concept in a specified text and practice. 'Cold-heat', for example, should not be reduced to inflammatory intensity, and meridian tropism should not be equated with organ targeting.

Second, operationalisation requires investigators to report who assessed body constitution or pattern differentiation, when assessment occurred, which instruments and decision rules were used, and the resulting inter-rater agreement. Third, falsifiability requires protocols to define in advance which findings would support, weaken, or refute a hypothesis.

A boundary clarification: Properties, flavours, and meridian tropism apply to foods as well as to drugs. Classical food-therapy literature (e.g., *Shiliao Bencao*; *Yinshan Zhengyao*) assigns natures, flavours, and tropisms to ordinary foods, typically with weaker intensity and effects framed over habitual, long-term consumption rather than acute dosing. In this article's translation matrix, food-level assignments are treated the same way as drug-level ones—as prior hypotheses to be encoded with inter-rater reliability and tested prospectively—not as exempt descriptions. Where a food carries no classical assignment, the cell is recorded as 'unassigned' rather than inferred.

A translation matrix could link traditional propositions to operational variables and validation levels. Properties and flavours might inform priors for ingredient selection and compatibility; meridian tropism might nominate candidate functional systems; and the sovereign-minister-assistant-courier hierarchy might generate competing hypotheses about primary effects, synergy, constraint, and matrix modulation. TCM body-constitution categories could be tested as stratification variables alongside age, sex, disease status, background diet, and medication use. Concepts that cannot be mapped reliably to a single indicator should remain frameworks for clinical reasoning or cultural interpretation rather than being declared 'proven' by one molecular pathway.

4 Material basis, candidate mechanisms, and evidence

4.1 Actual dietary exposure

Many studies isolate polysaccharides, flavonoids, saponins, phenolic acids, or volatile constituents from raw materials and infer the effect of a complete cuisine from *in vitro* antioxidant activity, enzyme inhibition, or cellular responses. Such studies can identify candidate constituents but poorly represent actual intake. Soaking, decoction, steaming, stewing, fermentation, and storage alter dissolution and degradation. Proteins, lipids, starch, and dietary fibre modify release, absorption, and colonic delivery, while meal timing, energy distribution, and co-consumed foods further shape responses^[4]. The study object should therefore be defined by formula, process, matrix, dose, and intake schedule—not by ingredient name alone.

Research should begin with a standardised finished product and a staged exposure workflow. Investigators should characterise constituents before and after processing, quantify bioaccessible fractions after simulated digestion, and identify products of colonic fermentation. Where feasible, studies should measure systemic or tissue exposure and relate exposure to host phenotypes. Consensus digestion models improve interlaboratory comparability but cannot replace human exposure studies. Minimum reporting should include species and anatomical part, origin and batch, ingredient ratios, pretreatment, temperature-time profile, product yield, serving size, energy and macronutrient composition, ranges of key constituents, and storage conditions. Without these data, mechanistic findings remain difficult to reproduce or translate, regardless of statistical significance.

4.2 Microbiota-mediated causal pathways

Some polysaccharides, dietary fibres, and polyphenols are transformed by gut microorganisms into short-chain fatty acids, bile-acid derivatives, tryptophan metabolites, and phenolic acids. These products may affect defined measures of epithelial barrier function, immune regulation, and glucose or lipid handling. Microbial transformation offers one plausible route for system-level effects but is not an obligatory mediator. Absorbable small molecules, nutrient substitution, energy restriction, food texture, and sensory experience may act independently. Treating every microbiota shift as an efficacy mechanism confuses association with causation^[5].

For interventions with plausible microbial mediation, a component/matrix-gut microbiota-metabolite-host phenotype (C-G-M-P) chain can organise causal testing. C denotes components and matrix features; G, microbial structure and function; M, metabolites jointly produced by microbes and the host; and P, clinical or physiological phenotypes. Each link requires evidence approximating an appropriate counterfactual. Depletion and add-back experiments can test component necessity; antibiotics, germ-free animals, defined communities, or faecal microbiota transplantation can test microbial mediation; stable-isotope tracing can establish metabolite origin; and receptor blockade or genetic models can test host pathways. Causal language requires convergent evidence from intervention, temporal ordering, and, where feasible, rescue. Experimental causality does not establish a human mechanism without corresponding exposure and mediation evidence.

The C-G-M-P chain builds on established diet-microbiome-metabolite-host frameworks and does not claim to replace them. Its intended contribution is twofold. First, the C node is defined as components together with matrix and process, not as isolated constituents, reflecting that medicinal cuisine is consumed as a finished food. Second, the chain is embedded alongside competing non-microbial routes, requiring investigators to estimate the microbial contribution rather than assume it.

Recognising this evidentiary bar, we acknowledge that for most yao shan, microbiota-mediated causality is likely to be partial rather than exclusive. We therefore treat the C-G-M-P chain as one route among several. Parallel pathways include: (1) direct absorption of small molecules acting on host targets; (2) nutrient displacement and energy-density effects, whereby the cuisine changes total intake of energy, sodium, fat, or protein rather than acting through any unique constituent; (3) sensory-neural pathways, whereby taste, aroma, texture, and temperature engage cephalic-phase, vagal, and reward circuits; and (4) behavioural pathways, whereby preparing and consuming the cuisine changes meal timing, eating rate, and subsequent food choices. These routes are not mutually exclusive and may interact. An effect that survives gut-microbiota depletion argues for non-microbial mediation; an effect abolished by depletion and restored by defined communities or metabolite add-back supports—but still does not prove—the human C-G-M-P route.

Interindividual variation should be partitioned into measurement error, intervention variability, adherence, confounding, and reproducible effect modification. The same food can elicit different postprandial glycaemic, lipidaemic, and microbial responses, and clinical, lifestyle, and microbiome variables may improve response prediction. Medicinal-cuisine studies should prespecify analyses of responders, non-responders, and people at elevated risk, then test whether TCM body constitution, background diet, age, medication use, microbiota, or

metabolic phenotype adds predictive value beyond conventional variables^[6].

4.3 The 'equivalent component ensemble' as a falsifiable working hypothesis

A single chemical marker can support identification or batch release but rarely establishes consistency of the overall effect. We use 'equivalent component ensemble' (ECE) as a provisional term for a defined subset of constituents—identified through integrated chemical, bioactivity, and network-based screening—that, at human-achievable exposures and within a specified matrix, process, dose, and population, reproduces the effect of the complete cuisine on a prespecified endpoint (whether clinical or a validated surrogate) through additive or synergistic relations. 'Equivalence' here is functional, not chemical: It denotes the effect on that endpoint—judged, where the reference cuisine has a reliable, clinically meaningful effect (e.g., based on prior systematic reviews or established minimal clinically important differences), against a prespecified non-inferiority margin—and it implies nothing about compositional identity, mechanism, safety, palatability, or any other endpoint. This functional equivalence is not to be confused with regulatory bioequivalence as defined in pharmacokinetic studies. The construct differs from a quality-control marker panel, which may establish identity or consistency without reproducing biological effects. The ensemble remains unvalidated, and its utility for any specific cuisine requires empirical demonstration.

The ECE likewise overlaps with, but is not identical to, existing constructs. Quality markers establish identity, consistency, or processing traceability without requiring reproduction of a biological endpoint; active-component groups and mixture-pharmacology approaches identify bioactive combinations but are typically validated at cellular or animal exposures rather than human-achievable dietary exposures; and food-matrix research documents matrix effects without demanding endpoint-specific equivalence. What distinguishes the ECE is its acceptance-rejection rule, rather than the terminology itself—the criteria below operationalise that rule.

A candidate ensemble should meet four criteria. Its components should have traceable origins, defined structures, and measurable between-batch abundance. The combination should reproduce prespecified effects of the complete cuisine, and removal of core components should attenuate those effects. Additivity or synergy should be demonstrated at human-achievable exposures, not inferred from network pharmacology. Exposure or downstream-response markers should correlate reproducibly with batch-level or individual variation; local intestinal readouts may be more informative than systemic exposure for gut-restricted effects. Discovery may combine top-down fractionation and composition-effect modelling with traditional compatibility hypotheses, mixture designs, and add-back experiments, but validation must return to the complete food matrix.

Equivalence is endpoint-specific. A combination may approximate a cuisine's effect on postprandial glucose yet differ in safety, palatability, microbiota response, or long-term adherence. If the reference cuisine has a reliable, clinically meaningful effect, a non-inferiority design may be appropriate; otherwise, superiority or mechanistic-equivalence testing is more defensible. Failure of a minimal combination to reproduce the prespecified effect should lead to rejection of the hypothesis and prompt tests of food

structure, processing products, nutrient displacement, or behavioural factors.

4.4 Reproducible human evidence beyond multi-omics associations

Multi-omics should reduce mechanistic uncertainty, not maximise measurement. Studies should begin with a causal diagram that prespecifies exposures, mediators, outcomes, confounders, and sampling times. Investigators can then determine whether metabolomics, transcriptomics, proteomics, single-cell methods, or spatial technologies are necessary. Independent screening of each omics layer followed by *post hoc* pathway assembly produces data-rich but often unfalsifiable narratives. A stronger sequence moves from high-dimensional discovery to targeted validation in independent samples and then to human dose-exposure-effect models or responder identification.

Mechanistic readouts cannot substitute for efficacy. Human studies should separate primary clinical or functional outcomes from mechanistic and exploratory measures. Prediabetes studies may use glycated haemoglobin, postprandial glucose, or continuous-glucose-monitoring metrics; hypertension-risk studies may use ambulatory blood pressure; and ageing studies may prioritise muscle strength, gait speed, cognition, and quality of life. Epigenetic age, composite omics scores, and microbial health indices remain exploratory until their reproducibility and clinical meaning are established.

Complete blinding is often infeasible because medicinal-cuisine interventions differ in taste, appearance, and individual adjustment. Replicating drug-trial procedures may therefore create the appearance rather than the substance of rigour. A fit-for-purpose evidence portfolio could combine standardised randomised trials for baseline efficacy, pragmatic randomised trials for routine delivery, N-of-1 trials for stable participants and rapidly reversible outcomes, and prospective registries for durability and safety. The Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework can assess certainty. Study design should match the question, comparator, and intended strength of inference^[7].

Evidence should not be collapsed into one score. Quality, safety, and efficacy require separate but connected chains. Quality evidence establishes intervention consistency; safety evidence defines acceptable exposures and populations; and efficacy evidence determines incremental benefit over an appropriate comparator. Stable quality does not prove efficacy, and statistical benefit cannot offset serious risk. Decisions should report the certainty, applicability, and principal uncertainties of each chain.

5 Standards, safety and evidence governance

5.1 Ingredient eligibility and quality control

Safety and efficacy depend on an authentic, stable, and reproducible intervention. Ingredient eligibility should specify taxonomic identity, edible part, provenance, harvesting and processing, traditional context, intended dose, contamination risks, and resource sustainability—not perceived naturalness or local custom. The food-medicine catalogue is dynamic, and inclusion does not authorise every part, dose, or combination. Taxonomic confusion, use of the wrong plant part, and concentration beyond traditional intake can each alter risk.

The quality chain should cover ingredient identity, critical

process parameters, compositional fingerprints or function-related markers, microbial and contaminant control, packaging, storage, and shelf life. Fingerprint similarity shows analytical resemblance, not equivalent human exposure or effect. A useful quality marker should have a defined source, robust measurement, processing sensitivity, *in vivo* traceability, and relevance to function or risk. When a few markers are insufficient, control may combine multi-index fingerprints, critical process parameters, and effect-based assays.

Quality standards must include the food matrix. The same ingredient can produce different release kinetics and exposure in soup, porridge, a solid meal, fermented food, or concentrate; extract standards cannot be transferred directly to the finished cuisine. Yao shan should therefore be treated as a process-defined intervention. Process optimisation should balance bioaccessibility, nutritional composition, sensory acceptability, contamination risk, and realistic intake rather than maximise one constituent.

Supply sustainability is also a quality concern. Wild-resource dependence, shifts in production regions, germplasm variation, and substitute species can alter composition and increase adulteration. Standardised production should document cultivation, germplasm, harvest period, and supply-chain changes, and assess whether expansion creates unsustainable demand. Modernisation should neither deplete scarce resources for premium products nor use 'geo-authenticity' to obscure sustainable cultivation and equitable access.

5.2 Safety boundaries: Dose, duration, vulnerability and interactions

Safety is conditional: For whom, at what dose, and for how long is risk acceptable? Traditional consumption provides context but does not establish the safety of new combinations, concentrated processing, continuous intake, vulnerable populations, or concomitant medication. Assessment should cover intrinsic toxicants; pesticide and veterinary-drug residues; heavy metals; mycotoxins; microbial contamination; allergens; illegal additives; cumulative exposure; hepatic and renal function; and interactions involving metabolic enzymes or transporters.

Safety assessment should consider total exposure, not the amount in one product. A food-medicine substance may be consumed in home-prepared meals, prepackaged foods, health foods, and herbal prescriptions, producing combined intake above historical levels. Risk assessment should distinguish average from high consumers and account for body weight, frequency, duration, seasonality, and multiple sources. Data from typical adults cannot be extrapolated directly to older adults, people with multimorbidity, pregnant or lactating women, children, or people with hepatic or renal impairment. Conclusions should specify plant part, daily intake, duration, contraindications, interaction risks, and monitoring requirements.

Evidence for food-drug interactions also requires grading. *In vitro* enzyme inhibition and network predictions can flag risk, but clinical relevance depends on human-achievable concentrations, the drug's therapeutic window, case signals, and clinical studies. Risk communication should neither dismiss an unconfirmed interaction nor convert every prediction into an absolute contraindication. Advice could be classified as 'avoid concomitant use', 'use with monitoring', or 'insufficient evidence', with categories updated as real-world signals accumulate.

5.3 Efficacy claims, failed formulas and publication bias

Efficacy asks whether a defined intervention provides

meaningful incremental benefit over an appropriate comparator. Traditional theory, *in vitro* experiments, and animal studies generate hypotheses; they do not support disease-treatment claims to consumers. Ordinary foods, health foods, foods for special medical purposes, and medicinal products have different claim boundaries that cultural terminology cannot override. New claims or restricted-access pathways require a legal basis, technical review, and post-market surveillance. Policy proposals should be identified as proposals, not current regulation^[3].

Human studies should report effect sizes, confidence intervals, minimal clinically important differences, adherence, heterogeneity, and adverse events—not statistical significance alone. Comparators should test benefit beyond an optimised healthy diet rather than only beyond no intervention. Controls may include standard dietary guidance, isoenergetic and nutrient-matched meals, or formulas without a prespecified compatibility component. When meals differ visibly or sensorially, blinded outcome assessment, expectation measurement, and standardised contact can reduce bias.

Negative trials, non-responsive subgroups, intolerance, and failed formulas indicate where an intervention does not work and are as informative as positive studies. Controlled trials of yao shan published in China have historically reported positive results far more frequently than trials published elsewhere, and methodological quality has been variable. No verified estimate exists for medicinal-cuisine studies specifically, but the field inherits the same structural risks of publication and selective-reporting bias, and the burden of disproof lies with transparent reporting rather than with assumed innocence. Transparent, multilingual reviews should compare registered protocols, completed studies, and published outcomes. Selective publication inflates apparent efficacy and safety and encourages mechanistic narratives that have not survived replication.

Safety failures illustrate distinct failure classes rather than a single lesson. (1) Botanical misidentification and species substitution: *Gynura segetum* (syn. *Gynura japonica*) (Ju San Qi), which contains hepatotoxic pyrrolizidine alkaloids, may be confused with *Panax notoginseng* and has caused hepatic sinusoidal obstruction syndrome in case series and reviews. (2) Part- and category-specific rules: The authorised food-medicine source of ginkgo is the dried mature seed of *Ginkgo biloba* L.; ginkgo leaf is regulated differently and is not an authorised ordinary-food ingredient. (3) Excessive or prolonged intake of otherwise permitted substances: Long-term liquorice intake can cause pseudoaldosteronism, hypokalaemia, hypertension, and oedema through glycyrrhizin-mediated inhibition of 11 β -hydroxysteroid dehydrogenase type 2. *Polygonum multiflorum* (syn. *Fallopia multiflora*) preparations—associated with herb-induced liver injury in clinical case series and regulatory surveillance—are medicinal products, not catalogue-listed foods, and their appearance in foods constitutes illegal addition rather than culinary use. (4) Food–drug interactions: Concentrated turmeric/curcumin supplements or natural health products, this should not be extrapolated directly to culinary turmeric doses; liquorice may compound diuretic-induced hypokalaemia; and grapefruit juice raises plasma concentrations of nifedipine and felodipine by inhibiting intestinal CYP3A4, illustrating the human pharmacokinetic evidence required before a predicted interaction is treated as clinically actionable. Only classes (3) and (4) involve substances legitimately used in medicinal cuisine as defined in Section 2; classes (1) and (2) are boundary violations, but surveillance must nonetheless detect

them because consumers encounter them under the same vernacular umbrella.

Trial registration, public protocols, locked primary outcomes, and complete reporting are essential. Negative evidence should revise compatibility rules, doses, target populations, and stopping criteria rather than be treated as rejection of traditional knowledge. A field that accepts only confirmation cannot distinguish durable knowledge from selective memory.

5.4 End-to-end safety governance

Safety governance should extend from pre-use identification through in-use control to post-use surveillance. Before use, investigators should define taxonomic source, edible part, process, total exposure, and high-risk populations. During use, records should capture batch, serving size, duration, co-consumption, and medication changes. After use, registries, adverse-event reporting, and signal detection should update contraindications, limits, and monitoring requirements. A minimum database should connect contaminants, intrinsic toxicants, allergens, enzyme and transporter effects, food-drug interactions, and real-world outcomes to define permitted use, conflicts, and stopping conditions.

Failed cases should also shape research priority. Ineffective trials, subgroups that do not reach a minimal clinically important difference, intolerance, declining adherence, and unexpected interactions require formal evaluation. Protocol registration, locked outcomes, complete adverse-event reporting, and cross-institutional replication should be routine. Formulas with persistently uncertain benefit-risk profiles, effects confined to selected samples, or dependence on uncontrollable processing conditions should receive lower translational priority. Safety governance should guide upstream selection rather than operate only after commercialisation.

6 Clinical settings, vulnerable populations and precision nutrition

6.1 Chronic-disease risk management and incremental benefit

Evidence status. No finished yao shan, as defined in Section 2, has yet been tested in adequately powered randomised trials with prespecified clinical endpoints. Existing human evidence is preliminary, small-scale, or derived from isolated constituents and related dietary patterns. Guidance documents—including the national dietary-nourishment guidelines for adults with dyslipidaemia, hypertension, and diabetes (2023) and for hyperuricaemia and gout (2024)—incorporate food-medicine substances into dietary patterns but do not grade the evidence for complete cuisines. The settings discussed below are therefore presented as prioritised research settings, justified by plausibility, feasibility, and public-health need, not as established applications.

Yao shan is most plausible where interventions must be moderate, sustained, and compatible with daily life. It is less suited to acute or severe disease or conditions requiring precise pharmacological dosing. Prediabetes, central obesity, mild dyslipidaemia, and elevated blood pressure may be priorities only after energy intake, salt, fat, and overall dietary quality are addressed. The intervention must then show incremental benefit over national dietary guidance for hypertension, diabetes, dyslipidaemia, or hyperuricaemia.

Trials should specify the target metabolic phenotype, finished product, dose, duration, and primary endpoint. Glucose studies should distinguish impaired fasting glucose from impaired glucose tolerance; blood-pressure studies should record sodium intake and antihypertensive use; and lipid studies should control for weight change and background diet. Evidence from isolated compounds, extracts, or animals cannot substitute for effects of the complete cuisine under realistic dietary conditions.

Endpoints must match intervention intensity and duration. Studies lasting weeks may assess postprandial responses, blood pressure, sleep, or gastrointestinal function but cannot support claims about long-term disease events. Studies lasting months may assess glucose and lipid metabolism, body weight, and body composition yet remain inadequate for cognition, fractures, or cardiovascular events. Each trial should designate one clinically interpretable primary endpoint; mechanistic measures should explain, not replace, that endpoint.

6.2 Healthy ageing and standardised nutritional support

For older adults, the relevant objective is preserved function—not normalisation of one biomarker. Outcomes should include muscle strength, gait speed, cognition, appetite, sleep, and quality of life. Yao shan may provide a palatable, nutrient-dense food vehicle, but formulations must account for polypharmacy, chewing or swallowing difficulty, declining renal function, and undernutrition. Easily consumed porridges or soups may be preferable, whereas hard or sticky ingredients that increase aspiration risk should be avoided.

Bone loss, sarcopenia, and cognitive decline require long observation. Short-term antioxidant or inflammatory changes cannot substitute for function. Bone studies may combine dual-energy X-ray absorptiometry (DXA) with serum alkaline phosphatase (ALP), procollagen type I N-terminal propeptide (PINP), and C-terminal telopeptide of type I collagen (β -CTX). Cognitive studies may use the Mini-Mental State Examination (MMSE) and Montreal Cognitive Assessment (MoCA) within a broader outcome set. Interventions may require at least 12 months to capture slow trajectories, although duration should follow the endpoint.

During cancer rehabilitation, perioperative care, or stable chronic disease, yao shan can support energy and protein intake and symptom management only within clinical-nutrition guidelines and multidisciplinary care. Yao shan cannot replace anticancer, anti-infective, or other standard treatments. Nor should phrases such as 'supporting healthy qi' or 'enhancing immunity' bypass evidential boundaries. Nutritional-risk screening should precede use, with referral for weight loss, inadequate intake, dysphagia, or other high-risk signals.

Oncology requires the narrowest claims. Potential roles include supporting appetite between chemotherapy cycles, managing xerostomia or dysphagia after radiotherapy, and providing nutritional rehabilitation after surgery once the patient is stable. Intestinal obstruction, severe bone-marrow suppression, or periods when ingredients could alter targeted-therapy exposure require specialist assessment and may preclude use. Patient-reported outcomes should be primary for symptom-support roles; tumour markers and radiographic responses are inappropriate efficacy endpoints.

6.3 Responder identification and precision nutrition

Precision yao shan should improve decisions, not merely add omics layers. Before randomisation, protocols should specify how

TCM body constitution, microbiota features, metabolic state, or clinical variables will define stratification and should limit subgroup numbers. *Post hoc* searches for an 'effective constitution' invite false-positive findings. A useful stratification biomarker must replicate independently and add predictive value beyond age, body mass index, background diet, and medication use^[6].

TCM body-constitution classifications are candidate stratifiers only after their inter-rater reliability, longitudinal stability, and cross-regional reproducibility are established. As set out in Section 3, such constructs enter trials as testable priors rather than self-validating theory. Exposure, depletion and add-back, and population-response studies should then support, revise, or reject those hypotheses. A construct that repeatedly fails its falsification criterion should revert to a framework for clinical reasoning or cultural interpretation, not be retained as a validated stratification biomarker. Reliability thresholds should be prespecified before unblinding; instruments, decision rules, assessor qualifications, and inter-rater statistics should be reported with every study that uses these constructs.

Implementation conditions can attenuate efficacy outside trials. Procurement cost, cooking complexity, taste, family support, regional availability, and professional training influence uptake. Clinical and community studies should assess acceptability, reach, sustainability, equity, stopping rules, and adherence. For people with diagnosed disease, yao shan must not affect standard treatment and should support nutritional or lifestyle interventions.

Sleep, fatigue, mood, and gastrointestinal discomfort are especially vulnerable to expectancy effects, natural fluctuation, and concurrent lifestyle change. Validated scales should be paired with objective monitoring where possible. Studies should record caffeine intake, exercise, sleep schedule, and background diet, and prespecify referral or stopping criteria for symptom deterioration, rapid weight loss, abnormal laboratory results, or medication changes. Perceived mildness does not justify lighter monitoring.

7 Translational development and digital enablement

7.1 Traceability as the prerequisite for industrial translation

Industrial translation should follow traceability from raw material to population outcome, not the proliferation of dosage forms or marketing terms^[2]. Ingredient records should cover species, anatomical part, origin, cultivation, and contaminants; manufacturing records should identify parameters affecting component release and safety; product evaluation should address matrix, sensory properties, dose uniformity, and stability; and service records should document recommendation rationale, adherence, outcomes, and adverse events. A shared semantic framework is needed to explain why a batch or service was effective, ineffective, or harmful.

Industrial translation requires a control system designed for the finished food matrix rather than for decoction pieces. At the agricultural end, Good Agricultural Practice (GAP) cultivation, documented germplasm, and harvest-period control stabilise the ingredient base. In manufacturing, Hazard Analysis and Critical Control Points (HACCP) should be mapped to cuisine-specific hazards—microbial load of fresh ingredients, histamine formation in fermented preparations, acrylamide in baked forms—and Quality by Design (QbD) should define a design space linking critical process parameters (decoction temperature-time, solid-to-

liquid ratio, shear during filling) to critical quality attributes of the finished matrix. For soups and porridges, scale-up must preserve extraction and release profiles measured in the finished product, not in the raw material; fingerprint monitoring should be anchored to function-related markers rather than to single index constituents. Traceability platforms should connect cultivation lots, process parameters, and released batches to downstream registries, so that any safety signal can be traced from a population outcome back to field and process.

Beyond conventional process control, emerging technologies offer new possibilities but also introduce new risks that require explicit evaluation. Two distinct tiers of technology are involved. Process technologies—fermentation and convenience processing (e.g., ready-to-eat formats)—reshape the matrix itself and may alter constituent profiles; delivery technologies—microencapsulation and nanodelivery—leave the matrix largely intact but modify release, absorption, and thus internal exposure. Both tiers should therefore address a defined bottleneck and be evaluated in the finished product through exposure, efficacy, and safety testing. Concentration or enhanced delivery requires reassessment of dose, cumulative exposure, and interactions with concomitant medication.

At the scale-up stage, two specific issues require attention. First, process parameters do not transfer directly: Heat transfer, shear, oxygen exposure, and solid-to-liquid ratios can differ between laboratory decoctions and industrial equipment. Second, formulation changes for palatability can undermine the intended effect: Added sugar, salt, or fat may offset the health benefit. Scale-up studies should therefore include quality-risk assessment, design-space confirmation, and clinical-batch bridging. The product tested in humans must be materially comparable to the marketed product.

7.2 AI-assisted product design and dietary recommendation: Decision support under human oversight

Digital tools can improve knowledge integration, risk screening, and feedback but cannot repair weak source data. Knowledge graphs should distinguish classical records, expert experience, *in vitro* studies, animal studies, clinical trials, regulatory information, and adverse events because these sources carry different evidential weight. Recommendation systems should enforce constraints on ingredient and product compliance, dose, contraindications, food-drug interactions, evidence level, and uncertainty. Outputs should state the recommendation, rationale, applicable population, evidential strength, uncertainty, and stopping or referral conditions^[8].

Large language models (LLMs) add three defensible capabilities to this decision-support role. First, corpus-scale mining: Retrieval-grounded models can extract ingredient–formula–indication relations from classical literature and modern trial reports into auditable knowledge graphs, turning hypothesis generation from anecdote into a traceable search. Second, prediction: Trained on composition and outcome data, models can rank candidate formulas for a prespecified endpoint and flag plausible food–drug interactions before laboratory work begins. Third, validation support: LLMs can draft protocol skeletons, pre-screen eligibility against stratification criteria, and monitor incoming real-world data for safety signals. All three uses inherit the same constraints as any other algorithm in this pipeline—outputs must be retrieval-grounded rather than freely generated, uncertainty must be

displayed, and every predicted benefit remains a hypothesis until confirmed in a controlled study. A model that cannot cite its sources or that drifts from validated performance should be retired from the workflow.

Artificial intelligence (AI) should support TCM practitioners, dietitians, and clinical pharmacists rather than issue unsupervised consumer recommendations. *Post hoc* visualisation does not make a black-box model clinically explainable. The constraints listed above should be encoded before model training rather than applied as post-hoc filters, and prospective studies should compare AI with transparent rule-based systems and professional judgement. Evaluation should include health outcomes, adverse events, explanation quality, adherence, cost, and equity—not accuracy on a closed test set alone.

For constitution- and medication-based recommendation specifically, the minimum dataset should be limited to variables shown to alter recommendations (constitution class, current medications, documented allergies, and renal or hepatic status where relevant), and every automated output should name the compatibility rule and the evidence tier on which it rests. Platforms need documented provenance, version control, model-drift monitoring, and auditable logs. Regulatory changes or new safety signals should trigger identification and retrospective review of affected recommendations. High-risk populations, complex medication regimens, low-confidence outputs, and abnormal monitoring signals require human review.

7.3 Real-world evaluation, regulatory experimentation and health economics

Real-world data can assess long-term adherence, heterogeneity, safety signals, and implementation but cannot alone establish causal efficacy. A prospective registry should link standardised product batches, recommendation rules, background diet, medication use, primary outcomes, and adverse events under prespecified analyses. Such registries can test external validity and guide product refinement if confounding and missingness are addressed transparently.

A time-limited research or policy pilot could be considered only within an expressly authorised regulatory framework and without implying general market approval. Entry criteria should include compliance with an existing product category, adequate safety assessment, restricted claims, predefined evidence obligations, active surveillance, and enforceable withdrawal conditions. For AI services, accountability should be allocated among the platform, developer, professional reviewer, and user according to control over decisions, with mechanisms for human intervention and termination.

Whether any form of time-limited, evidence-conditional market access could ever be appropriate for traditional dietary interventions remains an open question for regulatory-science research. We do not propose such a pathway here. Under current Chinese law, ordinary foods, health foods, foods for special medical purposes, and medicinal products each carry defined pre-market evidence obligations, which real-world evidence may complement but cannot replace. Any future exploration would require an explicit legal basis, defined minimum pre-market evidence, permitted claims, surveillance obligations, and enforceable withdrawal criteria—none of which currently exist for a “medicinal cuisine” category.

Public-health or clinical-nutrition adoption also requires evidence of value for money. Economic evaluations should compare yao shan with standard dietary education and with the

dietary-pattern recommendations of the 2023/2024 national dietary-nourishment guidelines, costing product, delivery, professional service, adherence, and adverse events. Chinese evaluations can adapt this framework to local primary care^[9], delivery costs, supply chains, and diagnosis-related group (DRG) or diagnosis-intervention packet (DIP) payment reforms, interpreting any saving within these payment systems. Any contextual advantages require testing.

8 Public communication, lifestyle integration and service models

8.1 From efficacy promotion to benefit-risk communication

Public communication should correct two misconceptions: That yao shan is only a tonic for middle-aged or older adults and that natural products suit everyone. Communication should state product classification, evidence level, target population, serving size, contraindications, interaction risks, and stopping conditions rather than list putative ingredient functions. Traditional terms may be retained but should not become promises of disease treatment. When evidence is uncertain, traditional-use information, mechanistic hypotheses, and human evidence should be labelled separately.

Communication should itself be evaluated. Page views and sales do not demonstrate health literacy. Relevant outcomes include whether consumers can identify the product category, understand limits of use, avoid stopping prescribed medicines or consuming excessive doses, and seek care when warning signs arise. For younger users, digital and scenario-based delivery may broaden access, but entertainment-oriented narratives must not displace risk information.

8.2 Integrated medical and elder care with risk-tiered dietary services

Medicinal-cuisine services require complementary expertise. Within local professional regulations, TCM practitioners may contribute body-constitution and pattern assessment and articulate compatibility logic; dietitians may evaluate the whole diet, energy intake, and nutrient adequacy; and pharmacists may assess medication-related risks and potential interactions. Institutional governance should define responsibility for ingredient compliance, product classification, documentation, and escalation. Service quality should be judged by safety, functional outcomes, adherence, cost, and feasibility—not the number of formulas or degree of personalisation.

Professional intensity should increase with risk. Healthy adults may receive food-based guidance consistent with public dietary recommendations; people at cardiometabolic risk require standardised assessment and follow-up; and people with multimorbidity or polypharmacy, pregnant or lactating women, children, and those with hepatic or renal impairment require multidisciplinary review. Personalisation does not remove the need for standardisation or accountability; each adjustment and outcome should be documented.

8.3 Cross-cultural adaptation: Scientific translation, not cultural export

The East Asian food-medicine continuum and the Western

Food Is Medicine movement both address diet in health and risk management, but their theories, service structures, and regulatory contexts differ. International communication should neither collapse the concepts nor erase TCM theory by forcing it into one biomedical vocabulary. A three-layer strategy is more defensible: Retain historical context and explicit non-equivalences at the theoretical level; standardise ingredients, doses, processes, data, and outcomes at the technical level; and follow the target market's food and health-claim rules at the product level. Scientific comparability should precede product circulation.

Cross-cultural research must also test acceptability and equity. Flavour, cooking time, and ingredient availability affect adherence. Standardisation that serves only high-income consumers would turn a potential public-health intervention into a premium commodity. International collaborations should evaluate cultural adaptation, cost, supply-chain sustainability, locally available substitutes, and biological efficacy.

Modernisation of yao shan is also an act of cultural stewardship. Every validated formula, every transparent standard, and every honestly reported negative result converts an element of China's outstanding traditional culture from a private inheritance into a shareable public good—one that can be examined, used, and built upon across borders. Scientific translation is therefore not a retreat from cultural confidence but its most durable form: When the theory survives international scrutiny, the culture travels with it. International cooperation should accordingly be framed as mutual learning, in which Chinese dietary-therapy knowledge and the evidential methods of partner countries refine each other, and in which standards recognition serves both health and intercultural exchange.

9 Outlook: A milestone-gated development roadmap and ten scientific questions

Modernisation should proceed through prerequisites rather than accumulate technologies. Undefined interventions and exposures make population trials irreproducible; unclear quality and safety boundaries allow industrial expansion to amplify risk; and standards without cross-population validation remain limited to terminology and analytical methods. We therefore organise the agenda into four connected stages. The dates are planning horizons, not policy commitments, and progression should depend on milestones.

9.1 Four stages of development

Stage 1: Establish the foundation. Priorities are a shared vocabulary and reproducible intervention definitions. Core tasks include verifying taxonomic origin, edible parts, and historical use; establishing minimum reporting standards for finished products; standardising digestion-fermentation-exposure workflows; validating instruments for body constitution and pattern differentiation; and selecting representative formulas for intervention at key C-G-M-P nodes. Progress should be judged by cross-institutional reproducibility, traceable exposure, and falsifiable traditional propositions—not database size.

Stage 2: Build evidence. Once quality is controlled and candidate pathways are explicit, multicentre randomised trials, pragmatic trials, and prospective registries should establish core outcomes, efficacy-certainty grades, and safety-monitoring rules for priority settings. The aim is to test incremental benefit, not to expand an indication list. Negative findings and adverse events must be reportable. Progression should require directionally

consistent effects in independent populations, interpretable effect sizes, and defined risk boundaries for a small set of standardised products.

Stage 3: Translate with precision. Validated formulas, processes, and stratification rules should become traceable products and services. Priorities include function-related quality standards, exposure bridging across matrices, responder identification, registries, auditable AI support, and health-economic evaluation. Market entry should depend jointly on quality, safety, efficacy, and implementation value. Success requires links among product batches, recommendation rules, and population outcomes, with acceptable effectiveness and safety in routine care.

Stage 4: Coordinate international standards and validation. Once the domestic evidence system is mature, international work should address terminology, ingredients, processing, quality, safety, and data standards alongside validation across countries and populations. Internationalisation should neither export unexplained traditional terms nor treat standardisation as evidence of efficacy. Defined products must show reproducible safety and incremental benefit in specified contexts. The World Health Organization (WHO) Global Traditional Medicine Strategy 2025–2034 provides broad policy context for evidence generation, safety, regulation, and appropriate health-system integration; it does not validate yao shan or any product category^[10].

9.2 Scenario-based progression and stage governance

The roadmap is exposed to technological, policy, funding, and collaboration uncertainty. Under an accelerated scenario, standardised methods, replication, and multicentre trials mature rapidly, enabling earlier industrial and international validation. Under a baseline scenario, each stage advances as prerequisites are met. Under a constrained scenario, resources prioritise ingredient identity, quality, safety, and core evidence platforms while deferring costly omics, complex AI, and international expansion. Scenario analysis should expose assumptions and fallback pathways, not create false precision about dates or budgets.

Stage transitions should use a continue-revise-stop rule. Continue when standardised samples reproduce across institutions, human exposure is traceable, primary outcomes meet prespecified thresholds, and risk is acceptable. Revise when mechanistic direction is consistent but effect size is inadequate, benefit is confined to a defined population, or implementation is weak. Stop when a key hypothesis repeatedly fails, risk cannot be controlled through dose or population restrictions, or cost and complexity greatly exceed incremental benefit. These rules prevent a calendar-driven technology list.

9.3 Ten priority scientific questions

The following questions form an interdependent sequence from theory and intervention definition to mechanism, evidence, and translation. The questions should not become a menu from which only technically convenient topics are selected.

(1) Which dimensions of properties and flavours, meridian tropism, TCM body constitution, and compatibility yield stable biological or behavioural phenotypes with predictive value beyond conventional variables? Which should remain frameworks for clinical reasoning or cultural interpretation?

(2) How should an 'equivalent component ensemble' be defined and invalidated? Studies should specify the minimal functional unit, human-achievable exposure, depletion and add-back logic,

synergy criteria, and, where justified, a non-inferiority margin, then test robustness across batches, processes, matrices, and populations.

(3) How can direction and relative contribution within the C-G-M-P chain be established? Time-series designs, stable-isotope tracing, germ-free or defined-microbiota models, mediator blockade, and human exposure studies should be integrated without assuming that all effects depend on the microbiota.

(4) How do cooking, fermentation, storage, and co-consumption alter exposure and function? Models of release, transformation, and degradation should determine whether soups, porridges, solid meals, fermented foods, and concentrates are materially comparable.

(5) How should trials of complex dietary interventions be designed? Core problems include background-diet confounding, incomplete blinding, comparator selection, individual adjustment, adherence, long-term follow-up, and core outcome sets.

(6) How can safety boundaries be established for long-term, low-dose exposure, multiple sources, and vulnerable populations? Evaluation should integrate cumulative intake, processing-related compositional change, allergy, hepatic and renal function, enzymes and transporters, concomitant medication, and real-world adverse events into dynamic, tiered warnings.

(7) How should claims align with evidence and product classification? Traditional-use information, nutritional attributes, general health functions, specified functions, and disease-related claims must remain distinct, as must the legal boundaries among ordinary foods, health foods, foods for special medical purposes, and clinical-nutrition services.

(8) How can AI-assisted product design and dietary recommendation be explainable, beneficial, and safe? Compliance, dose, contraindications, the sovereign-minister-assistant-courier prior, and food-drug interactions should be encoded prospectively. Prospective studies should compare AI with transparent rules and professional judgement.

(9) How should algorithmic bias, privacy, model drift, and accountability be governed? Data provenance should be audited; negative results and adverse reactions should be represented; validation should be extended across regions and populations; logs should be made traceable; and responsibility should be assigned according to control over decisions.

(10) How can terminology, cross-population validation, and mutual recognition of standards advance internationally? Operational definitions should first be harmonised for taxonomy, anatomical part, dose, process, quality, risk, data, and outcomes, while TCM theory is explained in parallel. Standards can improve comparability, quality, and safety but cannot confer clinical efficacy or validate traditional theory.

These questions are not of equal priority, and their dependencies matter for sequencing. Questions (1–2) are foundational: Until the intervention can be reproducibly defined (Q2) and the measurable, translatable content of traditional constructs is established (Q1), downstream studies risk measuring unreproducible objects. Questions (3–4) build directly on that foundation by addressing mechanism and exposure and should proceed in parallel for priority formulas. Questions (5–6), trial design and safety boundaries, become productive once interventions are defined and candidate pathways exist. Questions (7–9)—claims, AI support, and governance—presuppose at least interim answers to Q1–Q6. Question (10), international harmonisation, is the most advanced and should follow, not precede, domestic validation. Early-career researchers and funding

agencies seeking the highest marginal value should therefore prioritise Q1 and Q2; investment in Q7–Q10 before the foundations are answered risks building regulatory and digital infrastructure for interventions that cannot yet be reproducibly specified.

10 Conclusions

The central challenge is not a shortage of traditional resources, functional concepts, or technical tools, but whether the field can build a translational chain without conceptual inflation or selective positive evidence. The chain begins by preserving the historical context of TCM dietary theory while defining modern regulatory boundaries. It then requires a process- and matrix-specific intervention, traceable human exposure, causal testing, and analysis of population heterogeneity. Real-world use must be constrained jointly by quality, safety, efficacy, cost, and accessibility.

Five questions, complementary to the ten priority questions in Section 9.3, should discipline internationally credible research. What product was studied? What reached the human body? Did the proposed causal chain survive counterfactual testing? Who benefited, and who carried risk? Was the evidence sufficient for the corresponding claim, service, or standard? Yao shan can develop into a systems science for chronic-disease risk management, healthy ageing, and precision nutrition only if mechanisms are interpretable, evidence is assessable, safety is bounded, manufacturing is reproducible, services are traceable, and comparisons are internationally meaningful.

The objective is not to make tradition explain modernity or modernity explain tradition; each should constrain the other. TCM theory can generate historically continuous questions about classification, compatibility, and context, while modern science tests where those questions retain predictive or practical value. Supported experience should refine traditional knowledge, whereas negative findings and safety signals should revise contraindications, doses, and population boundaries. Yao shan can remain a living knowledge system only if preservation, translation, revision, and abandonment are all permissible outcomes.

Data availability

Not applicable.

Conflicts of interest

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

Acknowledgements

We are grateful to all authors for their valuable insights and materials.

Funding

This work was granted by Key project at central government level: The ability establishment of sustainable use for valuable Chinese medicine resources (2060302).

Author contribution statement

Ke Yang organised and wrote the manuscript. The three corresponding authors provided the conceptual framework and revised the manuscript. The other authors contributed arguments to the manuscript.

Informed consent

Not applicable.

Ethics statement

Not applicable.

Use of AI statement

During the preparation of this work, The authors used Kimi to polish the full text and to construct the initial sketch for Figure 1. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the content of the publication.

References

- [1] Mozaffarian, D., Aspry, K. E., Garfield, K., et al. "Food Is Medicine" strategies for nutrition security and cardiometabolic health equity: JACC State-of-the-Art Review. *Journal of the American College of Cardiology*, **2024**, 83: 843–864. <https://doi.org/10.1016/j.jacc.2023.12.023>
- [2] Huang, L. Q., He, C. N., Ma, P., et al. Strategic thinking on the development of the food-medicine industry (in Chinese, with English abstract). *Strategic Study of CAE*, **2022**, 24: 81–87.
- [3] Standing Committee of the National People's Congress. *Food Safety Law of the People's Republic of China (2025 Amendment)*: Article 38. 2025.
- [4] Aguilera, J. M. The food matrix: Implications in processing, nutrition and health. *Critical Reviews in Food Science and Nutrition*, **2019**, 59: 3612–3629. <https://doi.org/10.1080/10408398.2018.1502743>
- [5] Wastyk, H. C., Fragiadakis, G. K., Perelman, D., et al. Gut-microbiota-targeted diets modulate human immune status. *Cell*, **2021**, 184: 4137–4153.e14. <https://doi.org/10.1016/j.cell.2021.06.019>
- [6] Berry, S. E., Valdes, A. M., Drew, D. A., et al. Human postprandial responses to food and potential for precision nutrition. *Nature Medicine*, **2020**, 26: 964–973. <https://doi.org/10.1038/s41591-020-0934-0>
- [7] Schünemann, H. J., Brennan, S., Akl, E. A., et al. The development methods of official GRADE articles and requirements for claiming the use of GRADE: A statement by the GRADE Guidance Group. *Journal of Clinical Epidemiology*, **2023**, 159: 79–84. <https://doi.org/10.1016/j.jclinepi.2023.05.010>
- [8] Han, C., Yang, G., Li, H., et al. Tuning and clinical application of large language models in traditional Chinese medicine: Scoping review. *Chinese Medicine*, **2026**, 21: 71. <https://doi.org/10.1186/s13020-026-01346-8>
- [9] Wang, L., Cudhea, F., Deng, S., et al. Health and economic impact and cost-effectiveness of produce prescriptions for diabetes in 50 U.S. states: A microsimulation study. *Diabetes Care*, **2025**, 48: 1783–1793. <https://doi.org/10.2337/dc25-0144>
- [10] Wang, X., Li, H., Jiang, S., et al. International standards and good practice guidelines in traditional, complementary and integrative medicine: A scoping review. *Frontiers in Pharmacology*, **2026**, 17: 1742400. <https://doi.org/10.3389/fphar.2026.1742400>