

Perspective

Key factors, challenges, and recommendations for science and technology innovation in traditional Chinese medicine



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Abstract

China has made remarkable achievements in the science and technology innovation of traditional Chinese medicine (TCM) since the 18th National Congress of the Communist Party of China. The modernization of TCM is advancing steadily, contributing significantly to public health and well-being, while accumulating valuable experience for the development of TCM in the new era. Based on the current research status of TCM modernization in the new era, this study systematically identifies key factors influencing the achievements in TCM innovation, and puts forward targeted recommendations to address existing challenges, aiming to provide novel insights for optimizing the mechanism of heritage-driven innovation and development in TCM, offer theoretical foundations and decision-making support for the national science and technology deployment in the TCM sector, and promote high-quality development of TCM driven by scientific and technological innovation.

Keywords: TCM modernization, Science and technology innovation, Experience, Strategic study

1 Introduction

Science and technology innovation serves as a crucial underpinning for the high-quality development of China's public health service system, while also constituting the pathway for traditional Chinese medicine (TCM) to accelerate modernization and radiate renewed brilliance in contemporary settings. The modernization of TCM is, in

essence, a scientific and technological reconstruction of its life-cognition system. It represents a deep integration of traditional techniques with modern technology, evolving in accordance with the principle of "preserving its essence while innovating", thereby ensuring its enduring vitality in modern society^[1]. The modern development of TCM should be driven by innovation and oriented toward high-quality development as the goal. This entails

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conducting TCM research to elucidate and strengthen its scientific foundations and clinical efficacy through modern technology, thereby strengthening theoretical frameworks, guiding clinical practice, propelling industrial advancement, and deploying scientific achievements for tangible problem-solving, all while continuously adapting to and catalyzing TCM's evolution in modern society.

With the advancement of modernization of TCM, the ability of science and technology innovation in TCM has been rapidly improved, accelerating the translation of scientific achievements into practice. Groundbreaking advances constantly emerge in preventing, diagnosing and treating major diseases that affect people's health, rendering more tangible outcomes accessible, beneficial and usable by the public^[2,3]. At present, the frontier and disruptive technologies in life science are reshaping the paradigm of scientific research and the pathway of technological innovation. While facing threats and challenges, TCM is also provided with strategic development opportunities for cross-fertilization and systemic integration with modern science and technology for innovation^[4]. Therefore, it is imperative to further strengthen the science and technology innovation system to spearhead TCM's revitalization and development. This perspective proposes the driving role of science and technology innovation in TCM modernization, identifies key factors influencing TCM scientific output based on the authors' practical experience and analysis of achievements, and proposes recommendations to advance TCM modernization in response to existing challenges.

2 Analysis of Scientific and Technological Innovation Achievements and Key Factors in TCM

2.1 Overview of Science and Technology Innovation Achievements in TCM

In recent years, continuous breakthroughs have been made in the science and technology innovation of TCM, and resources have continued to gather for innovation under national strategic deployment. Investment in TCM projects in the national science and technology plans has been gradually increased, and the network of TCM science and technology innovation platforms has basically taken shape, including 2 national TCM clinical research centers, 40 national TCM clinical research bases (approved for construction), and 7 national key laboratories in fields such as new TCM drug development, Chinese herbal medicine processing, and TCM industrialization, alongside several national TCM technical innovation centers. TCM researchers, represented by TU Youyou, winner of the

Nobel Prize in Physiology or Medicine, have received 58 national science and technology awards, including 1 State Preeminent Science and Technology Award, 7 First Prizes of the State Scientific and Technological Progress Awards, 44 Second Prizes of the State Scientific and Technological Progress Awards, 2 Second Prizes of the State Natural Science Award and 4 Second Prizes of the State Technological Invention Awards^[5].

The continuous emergence of modern information technologies and biotechnologies such as big data, artificial intelligence (AI) and systems biology has greatly promoted the scientific interpretation of TCM theory, improved TCM clinical efficacy and efficiency, and advanced breakthroughs in breeding of excellent varieties of TCM herbal medicines and research & development (R&D) of new drugs. As a pioneering achievement in digital-intelligent TCM from a national-level TCM hospital, the Guangyi Qizhi Large Model leverages 70 years of expertise from renowned veteran practitioners at Guang'anmen Hospital. It integrates 4.07 million clinical case records to establish a TCM clinical knowledge repository spanning 9 categories with 14 million entries. This multi-scenario service matrix drives high-quality development in TCM through new, quality, and productive forces. With deepening interdisciplinary integration, novel discoveries and achievements continue to emerge in fundamental and applied research of TCM, demonstrating a positive trend of "concurrent growth in both quantity and quality". Technological innovation empowers TCM theoretical advancements, efficacy enhancement, and industrial development across the entire science and technology innovation chain^[6]. The development of scientific and technological innovation in TCM has unique contextual features. The authors contend that, beyond a favorable policy environment and researchers' dedicated efforts, three intrinsic determinants are pivotal for sustaining TCM modernization and generating consistent scientific outputs: Valuable questions, organized research, and commercialization market.

2.2 The Valuable Question as a Fundamental Condition for the Science and Technology Innovation of TCM

Research questions represent not only the "starting point" of TCM science and technology innovation but also the "practical purpose" of scientific and technological results^[7]. In recent years, research addressing key questions in TCM has advanced steadily, with growing international influence. For example, in 2021, Shanghai Jiao Tong University and Science magazine listed the question "Is

there a scientific basis for the Meridian System in TCM” as one of the 125 most pressing scientific questions globally.

The value of research questions in TCM is reflected in three aspects: Key scientific questions without clear conclusions. The first project in acupuncture and moxibustion included in the Basic Research on Acupoint Specificity Based on Clinical Efficacy (973 Program), and the first major TCM project under the National Natural Science Foundation of China were initiated to address the critical question of acupoint existence, a topic pivotal to the development of acupuncture and moxibustion. The findings offered evidence-based answers to the international academic community’s questions regarding the acupoint specificity^[8]. Major practical questions hindering industrial development. In 2016, findings from the “Chinese herbal medicine DNA barcode species identification system” (awarded with the State Scientific and Technological Progress Award) accurately identified the species information of Chinese herbal medicines through DNA barcode identification technology, which solved the practical problem of authenticity identification of Chinese herbal medicines and laid the research foundation for the “1K Herb Genomes Project”^[9–11]. Clinical questions concerning the unmet needs of patients. These include refractory diseases lacking effective treatment, newly emerging infectious diseases, and a lack of medication regimens or treatment protocols during disease progression phases of major chronic diseases. For instance, Huangkui capsules have shown comparable efficacy to irbesartan with additional advantages, establishing a novel therapeutic modality for proteinuria in diabetic kidney disease^[12], and acupuncture treatment has greatly improved the symptoms of patients with moderate-to-severe chronic prostatitis/chronic pelvic pain syndrome (CP/CPPS), filling the gap in long-term efficacy data for acupuncture in treating CP/CPPS^[13].

2.3 “Organized Research” Ensures Science and Technology Innovation in TCM

Organized research emphasizes the systematic, holistic and synergistic nature of scientific research activities, enabling the concentration of superior resources to tackle major scientific and technological challenges. Synergistic integration of multidisciplinary and cross-sectoral resources enhances both research efficiency and quality^[14]. The National Key R&D Program of China is currently China’s highest-level R&D project for developing key core technologies under the new national system, providing continuous support and guidance for the main areas of national economic and social development^[15].

The national key R&D programs (Key Programs) of Study on Modernization of TCM (during the 13th Five-Year Plan period) and Modernization of TCM (during the 14th Five-Year Plan period), as the primary forms of organized research in TCM, have forcefully propelled the inheritance, innovation and development of TCM. Their deployment has predominantly embodied the following three key characteristics: Mobilizing national scientific research resources for large-sample studies. For example, China Stroke Registry for Patients With Traditional Chinese Medicine (CASES-TCM), supported by the Key Programs, is the first and largest stroke registry study with TCM in China, including 20,000 hospitalized patients for intervention and observation, standardizing and optimizing intervention measures for stroke prevention and treatment with TCM^[16], and the China Rheumatoid Arthritis Registry of Patients with Chinese Medicine (CERTAIN), supported by the Key Programs, has collected and recorded important data on demographics, characteristics, complications, treatment, adverse events of the disease through long-term follow-up of 11,764 registered patients^[17]. Whole-chain design and integrated research. Following the main line of modernization of TCM, the Key Programs focus on the advantageous fields of TCM and the major needs of the country, and deploy the whole-chain design and integrated research from the frontier basic research and major common key technologies to clinical applications. In the design of each project, the theoretical inheritance and innovation, breakthrough of key technologies, preparation of clinical protocols, modernization and upgrading of service, and promotion of industrial development are comprehensively planned and coordinated for step-by-step implementation, to open up the research paths from “laboratory” to “production line” and from “field” to “bedside in ward”. Multidisciplinary cross integration for joint R&D with combined wisdom. The Key Programs focus on guiding the integration of research resources in different disciplines and fields, forming a joint force for joint studies on the modernization of TCM, with the characteristics particularly highlighted in the guidelines for project application each year. For example, in the 2022 guideline “Herbal Archaeological Research on Origin of Genuine Medicinal Materials”, the requirement was “to integrate multidisciplinary research methodologies-such as textual research on materia medica and herbal archaeology-to ascertain the botanical origin of drugs in corresponding historical periods and trace the provenance of genuine producing regions”. And in the 2023 guideline “Integrated Research on Prevention and Treatment of Major Emerging Diseases with Traditional Chinese Medicine”, the requirement was “to conduct the

dynamic studies on the evolution law of syndromes of major emerging diseases in multiple regions and seasons, using the methods from meteorology, epidemiology, AI and other disciplines”. Introducing the methods from IT, biotechnology, archaeological technology, and meteorological technology into TCM research will help break technical bottlenecks and promote the transformation and application of scientific and technological results.

2.4 The “Commercialization Market” as a Power Source of Science and Technology Innovation of TCM

Scientific and technological results can realize their application value only after market validation and acceptance, which not only tests capabilities for commercialization, engineering, and industrialization of scientific and technological achievements but also demonstrates the ability to bring products and services to the market and obtain economic benefits. Driven by science and technology innovation, the integration of TCM and science/technology has given birth to new business forms. The R&D of new Chinese herbal medicines, secondary development of Chinese patent medicines, digital services, and intelligent TCM diagnosis and treatment have attracted substantial capital investment, which has not only fueled the sustained advancement of science and technology innovation of TCM, but also accelerated the rapid development of the TCM industry, creating a virtuous circle that provides robust momentum for science and technology innovation in TCM.

The market scale continues to expand, generating high demand for research results. The production system of commonly used Chinese herbal medicines in China has been basically established, and the number of major varieties of Chinese traditional medicines with annual sales exceeding 100 million CNY has increased to more than 500^[18]. In 2023, the business income of Chinese medicine industry reached 709.52 billion CNY. While major economic indicators in the pharmaceutical industry contracted year-on-year, revenue and profits in the Chinese herbal decoction pieces sector sustained double-digit growth^[19]. The TCM health industry market has expanded to over 480 billion CNY, with the food-medicine homology sector growing at 22.3% year-on-year, indicating substantial growth potential. The dietotherapy and nourishing products are urgently needed in the consumer market, with the market scale expanding rapidly, and the nutritional health food industry in China is projected to exceed 800 billion CNY in market size by 2027^[20]. Science and technology innovation empowerment can greatly increase product value. The research results of multi-component

Chinese medicines have been applied to the creation of major national new drugs and the secondary development of major varieties of Chinese patent medicines, expanding the number of TCM patent medicines with annual sales exceeding 100 million CNY from 48 to more than 500, including more than 60 with sales surpassing 1 billion CNY, significantly enhancing the scientific sophistication, economic impact and social benefits of these major varieties of Chinese traditional medicines; and findings from studies on systemic intervention in the cardiovascular continuum using venation and Ying-Wei theory were published in *Journal of the American Medical Association* and other international authoritative journals^[21–23], which verified the safety and effectiveness of marketed Chinese patent medicines, with extensive social and economic values for improving clinical efficacy and prognosis. Policy support and guidance provide important support for the transformation of results. Authorities at all levels have formulated policies and provided financial support, creating a favorable environment and conditions for the transformation of the scientific and technological results of TCM. The National Administration of Traditional Chinese Medicine revised the *Measures for the Registration of Scientific and Technological Results of Traditional Chinese Medicine* to promote the transformation and application of scientific and technological results of TCM with standardized results management. The National Medical Products Administration issued the *Implementation Opinions on Facilitating the Inheritance, Innovation and Development of Traditional Chinese Medicine* for top-level design and overall planning of reform and improvement of the review and approval mechanism of TCM, to strengthen the regular and standard R&D of new TCM drugs, and improve the efficiency and success rate of R&D^[24–25].

3 The Current Challenges in the Development of TCM

3.1 Weak Spot in Innovation System: The Deficiency in Overall Planning for the Construction of the TCM Science and Technology Innovation Platform and Investment Guarantee Mechanism Restricts the Effective Implementation of Innovation in TCM

Insufficient national R&D funding allocation. During the “14th Five-Year Plan” period among the 14 key projects in biomedicine set up by the National Key R&D Program of China, only one was designated for TCM. In 2024, there were 661 TCM projects supported by the General Program of the National Natural Science Foundation of China, accounting for 14% of the total 4,684 projects of the Department of

Health Sciences, with a funding rate stagnating at 7.36%. Inadequate national scientific innovation support platform for TCM. National laboratories represent the national level strategic scientific and technological force, and the development of TCM has risen to a national strategy, but currently, no national laboratories dedicated to TCM have been established. National key laboratories are an important carrier of the national science and technology innovation base, but there are only 7 national key laboratories in TCM. National clinical medical research centers are the core force of clinical medical research in China, and 50 national clinical medical research centers have been built in China by 2024, but in contrast, there are only 2 clinical medical research centers of TCM. Insufficient cross integration with modern science and cutting-edge technology. It is reflected in the fact that no breakthrough has been made in interpreting the principles of TCM and solving the problem of “unclear and inexplicable” mechanism of action. Bio-manufacturing technology has not been widely used, and the sustainable development of TCM resources is hindered. The conflict between the ambiguity of TCM syndrome differentiation and the precision of AI algorithms is the main technical bottlenecks that limit the deep integration of AI+ and TCM, which restricts the digital, intelligent and standard upgrading of the TCM industry. For example, digital standards for pulse diagnosis and tongue diagnosis have not yet been standardized, limiting the generalization capabilities of machine learning models.

3.2 Talent Cultivation Predicament: Insufficient Support and Flawed Evaluation Mechanisms Constrain the Development of TCM Talent Teams

Insufficient allocation of national-level talent programs. Take the projects supported by the Youth Program of the National Natural Science Foundation of China as an example, there were 50 projects in Category A supported by the Youth Program in the Department of Health Sciences in 2023, but only 2 in TCM, and 76 projects in Category B, but only 6 in TCM. Lack of TCM-adapted evaluation frameworks. The current evaluation system fails to fully reflect the disciplinary characteristics and application attributes of TCM, and pays insufficient attention to the talent of the clinical advantage, macro-strategy, grassroots practice, industrial specialty type, *etc.* Inadequate interdisciplinary synergy mechanisms and talent cultivation pipelines. At the interdisciplinary level, the deep integration of TCM with modern biomedicine, AI, material science, and other fields is still insufficient, without the support of a systematic technology integration platform. In terms of talent supply, there is a shortage of inter-disciplinary talent who are proficient in both classical TCM theories and

modern scientific research methods, alongside deficient reserves of professionals in emerging cross-disciplinary fields, *e.g.*, R&D of intelligent pharmaceutical equipment, TCM big data analysis, *etc.* Furthermore, the situation is compounded by ambiguous criteria for cross-disciplinary research outputs, which stifles multi-team collaboration incentives.

3.3 Bottleneck in Industrial Transformation: Narrow Pathways for TCM Innovation Hinder Industrial Growth Momentum

TCM innovation activities are not aligned with the actual needs of the industry, and innovation-to-implementation pathways remain suboptimal. Drug evaluation and approval systems inadequately accommodate the distinct characteristics of TCM, impeding the R&D and approval of new TCM drugs. For example, in 2023, over 50 innovative chemical drugs and improved new drugs secured market approval, while fewer than 10 newly developed TCM drugs obtained regulatory approval. The medical insurance payment system fails to reflect the characteristics of TCM, excluding significant portions of characteristic TCM therapies and medications. Furthermore, the “centralized procurement” system creates some disincentives for industrial innovation. Clinical application of Chinese patent medicine faces systemic constraints, including discriminatory classification as “supplementary therapeutics” and reimbursement restrictions misaligned with TCM pattern-based prescription, collectively impeding their broader adoption.

4 Recommendations for the Development of TCM and Its Prospects

4.1 Improve the Science and Technology Innovation System of TCM by Leveraging the Strength of the New System for Mobilizing Resources Nationwide

Enhance strategic coordination and foresight in the science and technology innovation of TCM. Crystallize strategic objectives for inheritance, innovation, and development of TCM by strengthening the top-level design and systematic planning, carrying out key R&D on clinically dominant diseases, industrial technology bottlenecks, *etc.*, overhauling the research project formation mechanism, and manifesting the role of the academic community. To strengthen the organization and implementation mechanism and support of TCM technology projects. Intensify support for science and technology innovation of TCM through National Science and Technology Major Projects, National Key R&D Program of China, National

Natural Science Foundation of China (NSFC), *etc.*, set up special projects dedicated to TCM, increase financial support, and optimize the leading and guiding role of TCM projects, thereby concentrating and coordinating the national superior forces in related fields to form a strong synergy. To strengthen the construction of the TCM science and technology innovation platform system. Focus on strengthening the collaboration between science, education and health authorities, and the collaboration between the central and local governments; speed up the construction of high-level TCM laboratories and research centers; optimize the hierarchical deployment of disciplines, laboratories and research platforms; through functional categorization and integration, construct an open-access, shared-use, and interactive TCM science and technology innovation network; and establish a command system and management mechanism with effective coordination, efficient decision-making, and quick response capabilities to drive scientific breakthroughs in TCM.

4.2 Optimize Talent Evaluation Frameworks to Strengthen the Construction of the TCM Talent Team

Remain solution-oriented, dismantle conceptual and institutional barriers that constrain science and technology innovation, and revolutionize TCM talent evaluation and incentive systems to serve as strategic compasses for resource allocation and professional recognition. Based on TCM's core concepts and thinking patterns, fully consider TCM characteristics when selecting assessors, evaluation criteria, metrics, and evaluation methods. Innovate diversified talent classification and evaluation models, *e.g.*, for basic research, prioritize research quality, originality and practical contribution; for clinical research, emphasize resolving critical clinical challenges and improving clinical efficacy and service quality^[26]; for strategic research, evaluate whether the research drives paradigm-shifting conceptual innovation and breakthroughs, or whether the research is adopted or referenced by relevant policies, plans, departmental regulations and technical principles of government authorities; and for industrial research, consider both market data and user feedback, and emphasize evaluating the transformation and application outcomes.

4.3 Expand Pathways for Industrial Technology and Ignite TCM Innovation Commercialization Momentum

Uphold innovation-driven industrial development, amplify science-driven industrial enablers and unclog critical bottlenecks impeding research-to-market translation.

Crystallize a “product competition-centered, survival-of-the-fittest” policy orientation for the TCM industry; give full play to the key role of various innovation-enabling factors, including national drug registration and supervision, medical insurance bidding and payment for drug purchase, rational drug use and essential drugs^[27]; translate industrial demand and clinical demand into scientific and technological demand and innovation demands; and expand pathways for science and technology innovation of TCM across multiple dimensions-product and service innovation, technical improvement, preparation and improvement of standards, market survival of the fittest-to clear the pathway for translating scientific achievements into tangible productive forces. Propel the deep integration of science and technology innovation and industrial innovation, and establish a multi-tiered science-based financial service system engaging academia, industry, and investment sectors to ignite the dynamism of science and technology innovation of TCM and to promote the high-quality development of the TCM industry.

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Declaration of Competing Interest

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