Research Progress in AI-assisted Characteristic Pattern Analysis and Quality Evaluation Methods for Authentic Medicinal Materials

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Abstract

Artificial intelligence technology is rapidly advancing, and research on the application of AI technology in the fields of quality identification and characteristic spectrum analysis of authentic medicinal materials is gaining increasing attention. Using deep learning, image recognition, chemical fingerprinting, and near-infrared spectroscopy, AI can efficiently and accurately analyze and evaluate the quality of traditional Chinese medicines. This review summarizes recent progress in the application of AI technology in the field of traditional Chinese medicine quality management, focusing on innovative applications of AI in areas such as medicinal material classification, fingerprint recognition, origin identification, and chemical composition analysis. AI technology has significantly improved the accuracy of medicinal material quality evaluation, implementing multidimensional fusion analysis of multi-source data , and enhancing the accuracy and efficiency of traditional Chinese medicine quality testing. Through the combination of artificial intelligence and data science, traditional Chinese medicine quality control has achieved a leap forward in standardization and automation, injecting new vitality into the modernization of traditional Chinese medicine. Drawing on recent literature research, this article summarizes the current status of AI application in the quality assessment of traditional Chinese herbal medicines, the challenges it faces, and future evolution trends.

Keywords Artificial Intelligence; Authentic Medicinal Materials; Characteristic Spectrum Analysis; Quality Evaluation; Deep Learning; Chemical Fingerprint; Near-infrared Spectroscopy

1 Introduction

Authentic medicinal materials are the core cornerstone of Traditional Chinese Medicine (TCM) theory and have always occupied a central position in TCM research and practice. These ancient medicinal materials, proven through long-term clinical validation and screening, originate from specific regions and possess remarkable therapeutic effects. Authenticity transcends regional limitations and encompasses the reliability of the medicinal materials' bioactive ingredients, efficacy, and clinical effectiveness. Analyzing scientific approaches to the quality assessment of authentic medicinal materials is a key topic in the modernization of TCM.

Through the passage of time, traditional methods for evaluating authentic medicinal materials persist, relying excessively on empirical verification and failing to align with the modern TCM trend towards standardization, precision, and large-scale quality testing. These limitations are becoming increasingly apparent. Traditional methods are clearly insufficient in key areas such as traceability of medicinal materials' origin, component analysis, and comprehensive quality assessment. Rapid technological advancements, particularly the widespread application of AI technology in the medical and pharmaceutical fields, have enabled breakthroughs in medicinal material quality evaluation research. The application of deep learning, image recognition, chemical fingerprint analysis, and spectroscopy technologies in the analysis of medicinal material characteristics is particularly crucial, significantly improving the efficiency and accuracy of authentic medicinal material quality identification. Leveraging big data, AI can automatically analyze multiple medicinal material attributes, including morphology, chemical composition, olfaction, and taste, enabling more comprehensive and objective quality assessments. Image recognition and chemical fingerprint analysis have demonstrated outstanding performance. AI can accurately identify medicinal material species, sources, and quality attributes, enabling efficient non-destructive testing and high-throughput testing, significantly enhancing the intelligent level of quality control.

This article reviews the progress in the application of AI technologies in the analysis and quality assessment of authentic medicinal material characteristics, focusing on innovative implementation paths for deep learning, image recognition, and spectroscopy. It also examines the practical achievements and challenges of medicinal material quality assessment and systematically summarizes existing research literature. This effort aims to promote the advancement of intelligent quality assessment technology for authentic medicinal materials and provide theoretical support and practical reference.

2 Overview of the Characteristic Patterns of Authentic Medicinal Materials

The quality assessment of traditional Chinese medicines (TCMs) generally utilizes modern testing technologies. Comprehensive datasets of medicinal materials are collected and, using pattern recognition techniques, characteristic data is mined to define the medicinal material's quality attributes. Given the diversity of signal sources, characteristic spectra vary in type. Typical characteristic spectra encompass morphological, chemical, and spectral fingerprints. These various characteristic spectra reveal the diversity of medicinal material quality and form the core foundation for quality assessment.

Table 1 summarizes various characteristic spectra, their detection technologies, and measurement parameters. Digital imaging technology captures the appearance attributes of medicinal materials, such as morphology, color, and texture, enabling efficient and immediate identification of a wide range of medicinal materials. Chromatographic analysis (including high-performance liquid chromatography, thin-layer chromatography, and gas chromatography) performs chemical fingerprinting, analyzing the peak states and relative proportions of components, presenting the full spectrum of the chemical composition of the medicinal material. This is a core approach to medicinal material quality control. Spectral analysis utilizes near-infrared, Raman, and infrared wavelengths to identify absorption spectrum peaks and spectral line patterns, enabling non-destructive and rapid analysis of the medicinal material's molecular structure and chemical composition. Electronic tongue and electronic nose technologies mimic the human sense of taste and smell, utilizing sensory data to generate characteristic maps with reliable repeatability.

Table 1. Types of characteristic spectra of authentic medicinal materials

Fingerprint type	Detection Technology	Measurement content	Advantages	refer to
Morphological fingerprint	Digital image acquisition	shape, color, texture	Fast and intuitive, suitable for large-scale recognition	CNN recognition
Chemical fingerprint	Chromatographic techniques such as HPLC, TLC, and GC	Component peak shape and relative content	Reflects overall composition and is suitable for quality control	Fingerprint Analysis Overview
Spectral fingerprint	Near infrared, Raman, and infrared spectroscopy	Absorption peaks and spectral line patterns	Lossless, fast, and reflects overall quality	Near-infrared research
Taste/olfactory fingerprints	Electronic tongue, electronic nose	Solution taste and odor	Simulate human senses and have good objective repeatability	AI sensory technology
genetic fingerprint	DNA barcodes, gene chips	Gene fragment sequence differences	Can accurately distinguish species, suitable for difficult-to-identify species	Fingerprint Analysis Overview

Traditional chromatographic fingerprinting uses only a few components as key parameters for quality control, making it difficult to fully demonstrate the overall efficacy of a medicinal material. Fingerprinting technology comprehensively identifies the entire chemical spectrum of the medicinal material, summarizing common patterns to determine its quality. In addition to chemical fingerprinting, near-infrared spectroscopy technology can also generate a fingerprint information set that comprehensively reflects the quality of the sample, allowing non-destructive testing, rapid operation, and simplified processing. The electronic tongue and electronic nose of this technology mimic the human sense of taste and smell. They are composed of a sensor group, a signal collection device, and a pattern recognition unit. They collect taste and odor data and generate fingerprints. Recent research has used DNA barcoding and machine learning technology to identify medicinal materials with similar sources or difficult to identify. Comprehensively analyze various characteristic spectra and use pattern recognition tools to accurately identify the quality of medicinal materials, as well as their categories, origins, and quality grades. This technology has significantly improved the efficiency and accuracy of medicinal material quality identification, and the quality control of Chinese medicinal materials has entered a new stage of modernization.

3 AI-assisted Feature Map Analysis Method

We strive to improve the level of identification and evaluation of the quality of traditional Chinese medicine. With the continuous advancement of modern technology, many advanced technical means have emerged, transitioning from image recognition technology to chemical feature analysis, and then extending to the field of genetic barcoding. With the help of AI and machine learning, the field of Chinese medicine quality supervision is undergoing innovative changes, especially deep learning technology in image recognition. With its ability to automatically extract image features, it has become the core means in the field of medicinal material identification, greatly promoting the efficiency and accuracy of identification. We will conduct in-depth exploration of these core technologies. The technologies discussed in this section include convolutional neural network image recognition, near-infrared spectroscopy technology, artificial intelligence sensing technology, chemical fingerprint technology and genetic barcoding technology.

3.1 Deep Learning Image Recognition

CNNs play a central role in this field. Image recognition technology automatically extracts characteristic attributes from medicinal herb images, significantly improving recognition efficiency and reducing the subjectivity and limitations of manual feature extraction. The medicinal herb identification process often relies on the identification skills of experienced experts and manual screening steps. This method is time-consuming and labor-intensive, susceptible to subjective errors, and results in low recognition quality. Deep learning technologies, particularly convolutional neural networks, utilize a multi-layered network architecture to automatically mine primary and advanced features from images, significantly enhancing the accuracy and effectiveness of image classification and recognition.

Deep learning technology continues to advance. The amount of image data collected for TCMs continues to increase during model training. This technology is being put to use, allowing computers to independently grasp the appearance of medicinal materials, such as their morphology, color, and texture, and then identify their species and quality attributes. Wang Ganhong's team's research results serve as an example. They collected 276,767 images from 163 types of TCMs and trained them using deep learning models such as EfficientNet_B0 and ResNet50. In the validation set, the EfficientNet_B0 model achieved an accuracy of nearly 99.0% and an AUC of 0.9942, demonstrating the immense value of deep learning in TCM image recognition.

Remarkably, the base of datasets continues to grow, and deep learning performance has significantly improved. Using transfer learning techniques, researchers are able to train superior models even with limited sample data. Data augmentation techniques can mitigate overfitting caused by insufficient sample size. Technological advances have led to the expansion of deep learning applications in multimodal learning, combining image data with other feature data (such as chemical fingerprints and spectral data) to significantly improve the accuracy of medicinal material identification.

The ongoing development of image recognition technology for traditional Chinese medicines has expanded its application beyond medicinal material identification to include quality control, origin identification, and new drug development. By integrating more intensive image data sources, advanced deep learning techniques, and efficient computing environments, image recognition technology holds broad prospects for application in the quality control and modernization of traditional Chinese medicines.

3.2 Near-Infrared Spectroscopy and Chemometrics

Non-invasive, fast-response near-infrared spectroscopy has become an indispensable testing method for the quality identification of traditional Chinese medicines. Compared to conventional chemical testing techniques, near-infrared spectroscopy offers a unique advantage in rapidly analyzing herbal ingredients. It effectively prevents sample damage and preserves their original properties undisturbed. By examining the absorption characteristics of medicinal materials in the near-infrared spectral region (750-2500 nm), near-infrared spectroscopy reveals key elements such as their chemical composition, molecular structure, and water content.

Its notable features are high efficiency, non-destructiveness, and rapidity, making it an ideal tool for quality testing of traditional Chinese medicines. It utilizes chemometric techniques, including representative algorithms such as principal component analysis, partial least squares, and support vector machines, to extract core attributes from spectral data, enabling classification, quantitative measurement, and quality assessment of the herbs. Dimensionality reduction is performed on near-infrared spectral data, and principal component analysis is used to accurately identify differences between herbs and perform unsupervised classification. Supervised learning algorithms such as PLS and SVM are employed to successfully construct high-precision regression prediction models for assessing herbal quality parameters.

The integration of near-infrared spectroscopy with wavelet transforms and SVM techniques has demonstrated significant success in identifying the origins of five varieties of Gastrodia elata, effectively distinguishing the differences in properties between Gastrodia elata from different origins. By implementing near-infrared spectroscopy testing of herbs and employing models such as support vector machines and partial least squares, origin identification and quality assessment can be accomplished within minutes, significantly improving the efficiency and accuracy of quality assessment.

Driven by technological advancements, multispectral analysis methods, such as Raman and UV spectroscopy, are increasingly being integrated and applied. This integration allows researchers to fully reveal the chemical structure and composition of medicinal materials, enabling precise quality assessment. Near-infrared spectroscopy is now widely used in the production of TCMs. Real-time monitoring and early warning mechanisms have been integrated into TCM quality management, enabling immediate quality control.

Infrared spectroscopy, aided by chemometrics, enables efficient, non-destructive, and rapid analysis for TCM quality assessment. This technology will play an increasingly central role in key areas such as TCM quality control, origin traceability, and process control.

3.3 Artificial Intelligence Sensory Technology

Intelligent identification technology, primarily using the electronic tongue and electronic nose, is a key technology supporting the quality assessment of traditional Chinese medicines. Traditional sensory evaluation methods rely on artificial taste and smell, which are subject to significant subjective bias and are easily influenced by personal experience and emotional fluctuations. This leads to significant instability and errors in the evaluation results. Electronic tongues and electronic noses have emerged as a promising technology, replicating human taste and smell responses and demonstrating a high degree of objectivity, stability, and repeatability, providing a solid technical foundation for quality control of traditional Chinese medicines.

The sensor array-based taste replicator mimics the human tongue's taste recognition patterns, analyzing sour, sweet, and bitter taste components in herbal solutions. The device relies on sensing electrical impulses induced by various chemical substances and employs pattern recognition algorithms to analyze taste signals, generating a distribution map of herbal flavor characteristics. The electronic nose, powered by a gas sensor array, mimics the human olfactory mechanism, quickly and accurately analyzing herbal aroma components, thereby assessing herbal quality and processing techniques. The electronic nose collects gases emitted by the herbal ingredients and employs pattern recognition strategies to analyze their odor characteristics. These are then matched against a database template to analyze the herbal ingredients' origin, quality, and level of processing.

Using electronic tongue and electronic nose technology, Liu Ruixin's research team uses electronic tongues to analyze the sour, sweet, and bitter flavors of traditional Chinese medicine decoctions, achieving an accuracy of 88.2%. This technology significantly overcomes the subjectivity inherent in traditional sensory evaluation, enhancing the accuracy and consistency of taste profile detection. Researchers have conducted in-depth quality analysis of traditional Chinese medicines from multiple manufacturers using electronic nose technology. The electronic nose accurately distinguishes between different medicinal material manufacturers and precisely identifies the processing stage and quality grade of each medicinal material.

This technology's notable feature is its ability to mimic the sensitivity of human senses, ensuring highly objective results and removing the uncertainty inherent in manual sensory evaluation. The combined use of electronic tongue and electronic nose technologies deepens the multidimensional data collection required for traditional Chinese medicine quality assessment, providing a more comprehensive understanding of the quality, efficacy, and properties of medicinal materials.

Driven by technological innovation and the continuous optimization of sensors, the accuracy and stability of electronic tongues and electronic noses will achieve significant breakthroughs due to technological advancements. This strategy will promote the quality identification, process control, and standardized production of traditional Chinese medicines, achieving precision technical support and ushering in a new stage of modernized quality control of traditional Chinese medicines.

3.4 Chemical Fingerprinting and Machine Learning

By interpreting the chemical composition spectrum of medicinal materials, researchers can use technology to identify the variety, source, and quality grade of medicinal materials. Conventional chemical analysis typically uses chromatographic techniques (such as high-performance liquid chromatography (HPLC), gas chromatography (GC), and thin-layer chromatography (TLC)) to separate the main active ingredients of medicinal materials. The quality of medicinal materials is then assessed based on key indicators such as chromatographic peak shape and relative content. However, analysis often focuses on a single component, making it difficult to fully reveal the overall quality of the medicinal material. The integration of machine learning and chemical fingerprinting technology is becoming a key development focus in the field of traditional Chinese medicine quality control.

By meticulously analyzing the chemical components of medicinal materials and constructing complete chemical maps, we present a comprehensive chemical spectrum of the medicinal materials. By incorporating machine learning into data collected through chromatography and spectroscopy, we efficiently process complex chemical data, enabling variety identification, quality assessment, and origin traceability. We employ HPLC and PCA fusion technology to analyze the quality of Salvia miltiorrhiza from multiple sources. Machine learning is employed to analyze and process chemical fingerprint data, accurately revealing subtle differences between medicinal materials and demonstrating exceptionally high accuracy in identifying their variety and quality.

Continuous advancements in multi-platform testing technology, including the use of high-end instruments such as LC-MS and GC-MS for data integration and processing, have enabled comprehensive optimization of medicinal material quality analysis. Multi-dimensional, multi-level in-depth analysis allows for models that accurately capture the complexity and diversity of medicinal materials, improving the accuracy and reliability of quality assessments. Data and intelligent algorithms are simultaneously reaching new heights. By integrating chemical fingerprints with machine learning, the quality monitoring system for traditional Chinese medicines will enter a new stage of intelligence and automation.

3.5 Genetic Fingerprinting and Multi-omics Analysis

DNA barcoding, gene chip technology, and other technologies are used to identify and categorize medicinal herbs. Traditional identification relies heavily on the morphology and chemical composition of medicinal herbs. Traditional identification methods are often challenging for herbs with similar morphologies and complex compositions. However, gene sequence analysis has significantly improved the accuracy of identification methods. With the continuous advancement of multidisciplinary technologies in genomics, transcriptomics, and metabolomics, combined with machine learning and data mining, genetic fingerprinting and multi-omics analysis have shown significant potential for the quality assessment of traditional Chinese medicines.

DNA barcoding technology is used to analyze the sequence of specific gene fragments for precise identification of medicinal herbs. By analyzing differences between sequences, genetic fingerprinting technology demonstrates unique effectiveness in distinguishing between medicinal herbs with similar morphology and chemical composition, even for herbs that are difficult to identify using traditional methods. Genetic sequence differences provide a precise basis for genetic fingerprinting to identify medicinal herbs. By combining transcriptomics and metabolomics data sources, genetic fingerprinting technology provides more comprehensive data support for variety identification, source tracing, and quality assessment of medicinal herbs.

By integrating multi-omics data, the research team conducts a full-angle analysis of medicinal materials, identifying the varieties and categories of medicinal materials, and carefully studying the medicinal materials' effective components, quality changes, and production control key points. The technology enables standardized management and quality assurance of authentic medicinal materials.

4 Research Progress Diagram

Figures 1, 2, and 3 below reveal the distribution estimates of various AI methods in the field of Chinese herbal medicine quality assessment , the typical accuracy of each method, and the cumulative research volume in the literature.

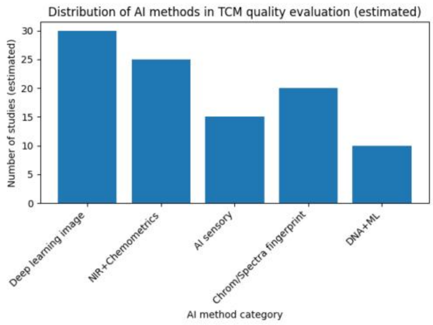

Fig. 1. Distribution of AI methods in TCM quality assessment (estimated)

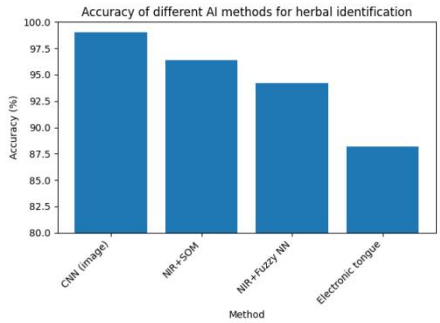

Fig. 2. Accuracy of different AI methods in herbal medicine identification

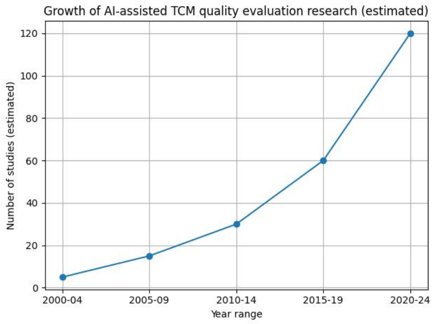

Fig. 3. Growth of AI-assisted traditional chinese medicine quality assessment research (estimated)

5 Quality Evaluation Methods and Indicators

In addition to feature maps, quality identification requires the adoption of reasonable evaluation standards and algorithms. Table 2 summarizes typical artificial intelligence strategies and their characteristics; Table 3 details the main types of fingerprints; Table 4 summarizes common evaluation models and applicable scenarios.

Table 2. AI methods and application characteristics

Method Category	Key Features	Typical algorithms	refer to	advantage	Limitations
Deep Learning Image Recognition	shape, color, texture	CNN, EfficientNet , ResNet	Wang, G. et al.[1]	High accuracy, no need for artificial features	Requires a large amount of labeled data
Near-infrared spectroscopy + chemometrics	Near-infrared diffuse reflectance spectroscopy	PCA+LS － SVM, self-organizing map, fuzzy neural network	Li, W., & Qu, H. et al. [2]	Fast, non-destructive, real-time monitoring	The spectrum is affected by noise
AI sensory technology	Taste/smell fingerprints	Electronic tongue/electronic nose + PCA, SVM	Liu, R. et al.[3]	Simulate senses and be highly objective	Sensor stability and calibration
Chemical fingerprints + machine learning	Chemical composition peak shape	HPLC/TLC/GC + PCA, PLS － DA, SVM	Noviana et al. [4]	Reflects the overall composition	The experimental cycle is long and the instrument cost is high
DNA fingerprinting + machine learning	Gene fragment sequence differences	DNA barcoding, clustering algorithm, SVM	Related reviews[5-6]	Accurate species identification	Requires laboratory and complex sample preparation

Table 3. Characteristic spectrum types and detection technologies

Fingerprint type	Detection Technology	Measurement content	Advantages	Application Examples
Morphological fingerprint	Digital imaging, machine vision	Form, color, texture	Fast and intuitive, suitable for automatic identification	CNN Identification of Chinese Medicinal Herbs
Chemical fingerprint	HPLC, TLC, GC	Component peak shape and relative content	Comprehensive reflection of chemical composition	Fingerprint analysis
Spectral fingerprint	Near infrared, Raman, infrared	Absorption peak, spectral line pattern	Lossless and fast	Near infrared identification of Salvia miltiorrhiza
Taste/olfactory fingerprints	Electronic tongue, electronic nose	Taste/Smell Mode	Simulate sensory perception and objective repetition	Electronic tongue distinguishes sour, sweet and bitter
genetic fingerprint	DNA barcodes, gene chips	Gene sequence differences	Accurate species identification	DNA Methods Review

Table 4. Common quality evaluation models

Evaluation Method	Applicable Scenarios	describe	Features
Similarity evaluation (correlation coefficient, Euclidean distance)	Chromatographic/spectral fingerprint similarity comparison	Calculate the similarity between the sample and the standard fingerprint	Simple and intuitive, suitable for rapid screening
Principal Component Analysis (PCA)	Dimensionality reduction and unsupervised classification	Extracting the main components and reducing the dimensionality can be used to explore the clustering structure	No need to label data, explain variance
Discriminant Analysis (PLS － DA, LDA)	Supervised classification	Modeling to distinguish different categories or origins	Explain classification contribution, suitable for small samples
Support Vector Machine (SVM/LS － SVM)	Classification and regression	Constructing the optimal hyperplane segmentation sample	Suitable for nonlinear and high-dimensional data
Self-Organizing Map (SOM)	Unsupervised pattern recognition	Neural networks map high-dimensional data to a two-dimensional plane	Visualization results are intuitive
Fuzzy Neural Network	Fuzzy Line Classification	Combining fuzzy logic with neural networks for classification	Dealing with fuzzy categories
Deep Learning (CNN, LSTM)	Image and multimodal data analysis	Multi-layer neural network automatic feature extraction	High accuracy, but high training cost

6 Research Progress and Case Analysis

6.1 Morphological Recognition

Deep learning has achieved remarkable results in the field of Chinese herbal medicine image recognition. A Chinese herbal medicine image recognition system based on CNN has been introduced in Chinese academic journals. With the help of the EfficientNet_B0 model, 163 kinds of herbal medicine images were classified, with a validation set accuracy of 99.0% and an AUC value of 0.9942. The study used a large image data set and conducted a comprehensive analysis of the model's performance in terms of accuracy, sensitivity, specificity and F1 score. This type of model is good at dealing with the problem of identifying similar herbs, and a large amount of data annotation and image acquisition standards are indispensable [7].

6.2 Spectral Fingerprints and Chemometrics

Fast and non-destructive near-infrared spectroscopy technology has been widely used in the field of medicinal material identification, especially in the identification of varieties, origins and production processes. Through near-infrared spectroscopy, convolution transformation and fingerprint similarity coefficient analysis, the subtle differences between the five varieties of Fritillaria were significantly highlighted, revealing their similarity differences [8]. For the identification of the authenticity of medicinal materials, researchers used LS-SVM technology to build a Danshen origin identification system. In near-infrared spectroscopy identification, the accuracy of the self-organizing neural network was as high as 96.4%. For injections of different manufacturers, the fuzzy neural network identification effect was 94.2% [9]. Empirical analysis shows that with the help of near-infrared spectroscopy and AI algorithms, the overall quality assessment of medicinal materials can be quickly achieved, and online monitoring of the production stage can also be implemented.

6.3 Artificial Intelligence Sensory Technology

Taste and smell electronic simulation devices, electronic tongue and electronic nose, sensor arrays collect data on flavor and gaseous signals, and analyze sample patterns with pattern recognition algorithms. The electronic tongue system is composed of three modules: taste sensing element, signal collection device and pattern recognition module, and outputs sample feature maps; the electronic nose is a combination of sensor array and pattern recognition system, which performs complex gas pattern analysis [10]. The study used electronic tongue technology to model the sour, sweet and bitter tastes of Chinese medicine decoctions, with an overall discrimination accuracy of 88.2% [11]. This technology is also used in the evaluation of processing technology and the study of taste masking effects . AI sensory technology has shown extraordinary significance in the quality supervision of Chinese medicine [12].

6.4 Chemical Fingerprints and Machine Learning

One of the key methods for quality control of traditional Chinese medicine is chemical fingerprint analysis, which is an alternative to single marker detection. It is a comprehensive identification of chemical composition and evaluates quality based on the similarity between the sample and the standard fingerprint spectrum [13] . Conventional techniques include chromatographic fingerprint analysis (such as HPLC, TLC, GC) and analytical methods such as PCA, PLS-DA, and correlation coefficient analysis. A global review reveals that this technology is good at verifying authenticity, identifying origin, and assessing quality. After integrating multiple detection platforms (such as LC-MS, GC-MS, CE), it can provide primary, secondary, and tertiary fingerprint data [14] . As the data dimension increases, the use of algorithms such as SVM and random forest to build classification models has significantly enhanced the efficiency of fingerprint data processing [15] .

6.5 Multi-omics and Genetic Fingerprinting

The combination of DNA barcoding and multi-omics technology has created an innovative identification technology path for organisms that are difficult to identify based on appearance and chemical characteristics. Literature review shows that the use of DNA technology can be used to identify plant varieties and effectively solve the problem of species confusion. Research trends will focus on the integration of transcriptomes, metabolomes , and machine learning to form a comprehensive evaluation system [16] . The challenges faced by this method are mainly reflected in the high standards required for sample extraction and experimental conditions. Its accuracy has laid a scientific foundation for the standardization of authentic medicinal materials [18] .

6.6 Development Trends and Challenges

In the field of authentic medicinal material quality evaluation, AI-assisted feature map analysis has enabled innovation in research methods, but several challenges remain:

Insufficient data standardization and sharing: There are large differences in sampling techniques and equipment parameters among studies, and there is no unified image, spectral and chemical fingerprint database. The establishment of a multimodal public database and the formulation of a standardized process will help improve the generalization efficiency of the model [18] .

Label quality and sample size limitations: The development of deep learning models is closely linked to a large amount of high-quality annotated data . The stock of medicinal material images and spectral data is relatively low, the labels are mismatched, and the performance is disturbed. Future data quality improvements will rely on expert consensus and semi-supervised learning technology [19-21] .

Model interpretability and traceability: Deep learning AI models have limitations in interpretability. Visualization and interpretable machine learning methods are used to clarify the basis for model decision-making and form a traceable quality evaluation mechanism [22-24] .

Multimodal fusion and systematic evaluation: In the future, the evaluation of authentic medicinal materials will abandon the reliance on a single map. Instead, it should integrate multimodal information such as morphology, chemistry, spectroscopy, sensory and genetics, and combine it with clinical efficacy feedback to form a systematic evaluation standard for the transformation from "excellent shape" to "high quality" and "excellent efficacy" [25-26] .

7 Conclusion

This article summarizes research on the application of artificial intelligence in the analysis of characteristic patterns and quality evaluation of authentic Chinese medicinal materials. AI technology has a significant impact on improving the accuracy and efficiency of quality control for traditional Chinese medicines. As AI technology continues to advance, the application of AI will enable a qualitative leap in the quality control of traditional Chinese medicines, particularly in data integration, sensor technology deployment, and machine learning model optimization. The promotion of AI applications in TCM faces multiple challenges, including data standardization, model interpretability, and a lack of industry standards. Future research should focus on overcoming the challenges of standardization in data collection and processing, improving the transparency and reliability of AI models, and promoting the in-depth application of AI in the field of traditional Chinese medicine through multidisciplinary integration. This will enable intelligent and precise quality evaluation technology innovations, providing solid technical support for the modernization and internationalization of TCM.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

1. Wang, G., Zhang, Z., Xi, M., Xia, K., Zhou, Y., & Chen, J. (2025). Establishment of artificial intelligence model and application for automatic identification of traditional Chinese medicine based on convolutional neural network. Chinese Journal of General Practice, 28(9), 1128-1136. https://doi.org/10.12114/j.issn.1007-9572.2024.0394
2. Li, W., & Qu, H. (2017). Research progress in the application of near-infrared spectroscopy in quality control and production process monitoring of traditional Chinese medicine. Journal of Zhejiang University (Medical Sciences), 46(1), 80–88. https://doi.org/10.3785/j.issn.1008-9292.2017.02.12
3. Liu, R., Chen, S., Li, X., Wu, Y., Yang, M., Chen, X., Zhang, C., Wang, S., & Li, Y. (2017). Artificial intelligence sensory technology: a new technology in pharmaceutical field. Journal of Pharmaceutical Analysis, 37(4), 559–567. https://doi.org/10.16155/j.0254-1793.2017.04.017
4. Noviana, E., Indrayanto, G., & Rohman, A. (2022). Advances in fingerprint analysis for standardization and qu ality control of herbal medicines. Frontiers in Pharmacology, 13, 853023. https://doi.org/10.3389/fphar.2022.85 3023
5. Yuan, Y., & Huang, L. (2025). Inheritance and innovation of the evaluation theory of authentic medicinal materials: three advantages. China Journal of Traditional Chinese Medicine, 1-8.

6. Lou, Q., Xin, T., Song, J., Huang, J., Li, J., Li, T., Zhang, L., Lou, C., & Luo, J. (2020). Application progress of DNA barcoding technology in the whole industry chain of traditional Chinese medicine. Acta Pharmaceutical Sinica, 55(8), 1784-1791. https://doi.org/10.16438/j.0513-4870.2020-0929
7. Hu, X., Huang, C., Li, J., et al. (2024). Integrating artificial intelligence into the modernization of traditional Chinese medicine industry: a review. Frontiers in Pharmacology, 15, e12345.
8. Liu, Y., Zhao, W., Zhang, W., et al. (2023). Progress in the application of hyperspectral imaging technology in quality detection and modernization of Chinese herbal medicines. Chinese Herbal Medicines, 15(3), 301-315.
9. Zhao, J., Yang, C., Li, X., et al. (2023). Application of data fusion in traditional Chinese medicine: a review. Journal of Pharmaceutics and Biopharmaceutics, 8(2), 77-89.
10. Liu, C. X., Li, X. H., Cheng, Z. X., et al. (2022). Innovation theory, technical methods and industrial application of quality marker of traditional Chinese medicine. Chinese Journal of Natural Medicines, 20(6), 449-458.
11. Deng, F., Ma, X., Tang, Y., et al. (2024). Mass spectrometry imaging for unearthing and validating quality markers in traditional Chinese medicines. Chinese Herbal Medicines, 16(1), 1-12.
12. Huang, Z., Liao, Y., Xie, Q., et al. (2023). Chinese herbal medicine recognition network based on knowledge distillation and cross-attention. Scientific Reports, 13(1), 1011-1023.
13. Mao, J., Lyu, Y., He, S., et al. (2021). From traditional medicine to modern medicine: the importance of TCM regulatory science. Regulatory Science of Traditional Chinese Medicine, 3(2), 65-74.
14. Su, M., Wu, Y., Liu, X., et al. (2023). Integration of hyperspectral imaging and deep learning for discrimination of fumigated lilies and prediction of quality indicator contents. Journal of Food Engineering, 356, 111-122.
15. Li, Q., & Wu, D. (2023). AI empowering traditional Chinese medicine? Chemical Science, 14(5), 1124-1134.
16. Yao, H., Li, X., Shen, S., et al. (2022). A novel multidimensional strategy to evaluate Belamcanda chinensis and Iris tectorum based on plant metabolomics, digital reference standard analyzer and biological activities evaluation. Chinese Medicine, 17(1), 1-13.
17. Liu, R., Chen, Y., Zhang, Y., et al. (2023). Plant metabolomics: a new strategy and tool for quality evaluation of Chinese medicinal materials. BMC Plant Biology, 23(1), 245.
18. Jiang, C., Zhao, L., Li, M., et al. (2024). Application of metabolomics in quality control of traditional Chinese medicines: a review. Frontiers in Plant Science, 15, 1162.
19. Yuan, Y., Cheng, Z., Zhao, H., et al. (2023). Rapid identification of medicinal plants via visual feature-based deep learning. BMC Plant Methods, 19(1), 90.
20. Yin, Y., Liu, S., Zhang, Y., et al. (2023). Herbify: an ensemble deep learning framework integrating convolutional neural networks and vision transformers for precise herb identification. BMC Plant Methods, 19(1), 133.
21. Zhao, H., Hu, Y., Zhang, C., et al. (2023). Identification of growth years for Puerariae thomsonii Radix based on hyperspectral imaging technology and deep learning algorithm. Scientific Reports, 13, 1761.
22. Chen, F., Zheng, J., Zhao, J., et al. (2022). Data fusion of electronic noses and electronic tongues aids in botanical origin identification on imbalanced Codonopsis Radix samples. Scientific Reports, 12, 18219.
23. Zeng, Z., Wang, J., Chen, L., et al. (2021). Intra-regional classification of Codonopsis Radix produced in Gansu province by multi-elemental analysis and chemometric tools. Scientific Reports, 11, 4162.
24. Zhou, J., Bai, J., Wu, Y., et al. (2022). Identification of the raw and processed Crataegi Fructus based on the electronic nose coupled with chemometric methods. Scientific Reports, 12, 10929.
25. Guo, Y., Zhu, X., Li, C., et al. (2022). Identification and classification of Coix seed storage years based on hyperspectral imaging technology combined with deep learning. Foods, 11(7), 993.
26. Shen, C., Yu, J., Wang, P., et al. (2024). A dual-technology approach: handheld NIR spectrometer and CNN for Fritillaria spp. quality control. Foods, 13(1), 12

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AI輔助下的道地藥材特徵圖譜分析及品質評價方法的研究進展

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摘要：人工智能技術迅猛進步，道地藥材品質鑑定與特徵圖譜分析領域，AI技術應用研究熱度不斷攀升，採用深度學習、圖像識別、化學指紋及近紅外光譜技術手段，AI能夠對中藥材的質量進行高效、精確的分析與評估，近期AI技術在中藥材品質管理領域的應用進展梳理，重點分析了AI在藥材分類、指紋識別、產地鑑別、化學成分分析等方面的創新應用。AI技術顯著提升藥材品質評價的精確性水平，對多源數據實施多維融合分析，增進中藥材質量檢測的精確度及效能，通過人工智能與數據科學的結合，中藥質量控制實現了標準化與自動化的飛躍，爲中藥現代化注入新活力，本文借鑑近年文獻研究，對AI在中草藥品質評估中的應用現狀、面臨的挑戰及未來演變趨勢進行了總結。

關鍵詞：人工智能；道地藥材；特徵圖譜分析；品質評價；深度學習；化學指紋

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