SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2025, 22(4), 1048.
https://doi.org/10.62617/mcb1048

Article

Identification of common Chinese medicinal materials based on micro-morphological characteristics in traditional Chinese medicine pharmacies

Yaling Gao

Department of Pharmaceutical Engineering, Hebei Chemical & Pharmaceutical College, Shijiazhuang 050026, China; zhiyaoxi319361@163.com

CITATION

Gao Y. Identification of common Chinese medicinal materials based on micro-morphological characteristics in traditional Chinese medicine pharmacies. Molecular & Cellular Biomechanics. 2025; 22(4): 1048. https://doi.org/10.62617/mcb1048

ARTICLE INFO

Received: 9 December 2024
Accepted: 25 February 2025
Available online: 4 March 2025

Abstract: This study systematically investigated the identification methods of traditional Chinese medicinal materials through microscopic morphological analysis combined with biomechanical principles. Firstly, select medicinal samples and clean the surface, observing the samples with different background colors and angles to reveal their microscopic morphological characteristics. In the process of observation and shooting, the parameters of microscope and camera were adjusted, and multiple images were synthesized using the Extended Field (EDF) technology to obtain high-resolution images and clearly present the microstructure of the medicinal materials. Then, FCSnap image processing software is used to enhance, adjust contrast, and perform hierarchical synthesis on the collected images to highlight key structural features of the medicinal herbs, such as cell wall patterns, oil chamber distribution, and fiber arrangement. After image processing, key microscopic features such as oil chambers and fibers were quantified through precise measurement of microstructure dimensions, which are directly related to the biomechanical properties of medicinal materials. For example, the distribution and density of oil chambers may be closely related to the mechanical strength, compressive strength, and volatile oil content of medicinal herbs. By comparing and analyzing the microscopic morphological characteristics of different medicinal herbs, this study reveals the relationship between structural features and biomechanical properties, providing a scientific basis for quality control and biomechanical research of traditional Chinese medicine.

Keywords: biomechanical; micro-morphological characteristics; Chinese medicinal materials; identification; counterfeit; pharmacy operations; traditional Chinese medicine

1. Introduction

Traditional Chinese medicine (TCM) has a long-standing history of application in the treatment and prevention of diseases, forming a cornerstone of medical practice in China and other parts of Asia for thousands of years. The safety and efficacy of TCM largely depend on the quality of the medicinal materials used in its preparation [1–3]. Ensuring the authenticity and quality of these materials is therefore essential, as counterfeit or substandard products can lead to ineffective treatments, adverse effects, and the undermining of the trust in this invaluable system of medicine. This challenge is compounded by the increasing demand for Chinese medicinal materials, leading to a greater market for adulterated, counterfeit, or misidentified products. In this context, the need for precise, reliable, and efficient methods of identification has never been more pressing [4,5].

Historically, the identification of Chinese medicinal materials has relied heavily on traditional methods such as visual inspection, olfactory examination, tactile sensing, and organoleptic tests. While these techniques are widely used in pharmacy practice, they suffer from inherent limitations. First, the human eye can miss subtle morphological features, particularly when examining complex plant or animal tissues. Second, these methods are often subjective and dependent on the experience of the pharmacist or technician conducting the identification, which can introduce variability and potential for error [6,7]. Additionally, the rise of counterfeits and adulterants, which can mimic the external appearance of authentic materials, has further complicated the task of distinguishing genuine medicinal materials from inferior or harmful substitutes.

In response to these challenges, more advanced techniques have emerged, such as physicochemical analysis, chromatographic methods, and molecular biology approaches. While highly accurate, these methods require specialized equipment, considerable expertise, and often time-consuming procedures that are not always suitable for frontline pharmacy operations [8]. Moreover, they can be prohibitively expensive and require controlled laboratory conditions, which makes them less practical for routine identification in daily pharmaceutical practice. Thus, there is a clear need for alternative methods that are both efficient and accessible for use in real-world pharmacy settings.

Micro-morphological identification, a technique that examines the fine structure of medicinal materials under magnification, presents an elegant solution to these problems. By leveraging sophisticated imaging systems, such as stereomicroscopes and high-resolution cameras, micro-morphological identification allows for the visualization and analysis of intricate tissue structures that are invisible to the naked eye. This technique has the potential to reveal unique characteristics of medicinal materials, such as the arrangement of cells, the distribution of oil glands, and the organization of fibers, which can serve as reliable markers for distinguishing between species or identifying high-quality materials. Importantly, this method is cost-effective, relatively simple to implement, and provides intuitive results that can be easily interpreted by pharmacy staff, even with limited training [9].

From a biomechanical perspective, micro-morphological identification ties into the field of biomechanics by examining the structural properties and mechanical characteristics of plant and animal tissues at a microscopic level. Biomechanics focuses on understanding how biological structures function, including how forces are distributed through tissues and how material properties, such as strength, elasticity, and toughness, influence the overall function of an organism. In the context of medicinal materials, the biomechanical properties of plant cells, fibers, and other tissues play a critical role in the material's effectiveness as a therapeutic agent [9]. For example, the cell wall structure of medicinal plants determines their resilience and response to external forces, which can impact the release and absorption of active compounds in the body. By studying these microstructural features, we can gain deeper insights into the quality and potential therapeutic value of computerized maintenance management systems (CMMS) [10].

Furthermore, the application of biomechanical principles in micro-morphological identification allows for a deeper understanding of how medicinal materials behave at the cellular and tissue level. For example, the distribution and density of oil chambers, which are often a key feature for identifying high-quality medicinal slices like Aurantii Fructus, are indicative of the plant's capacity for oil storage and secretion. This biomechanical characteristic correlates with the material's medicinal potency, as higher oil content generally translates to more potent bioactive compounds. By quantifying and analyzing these micro-morphological features, pharmacists and researchers can rapidly assess the quality of medicinal materials and their suitability for clinical use.

2. Materials

2.1. Main instruments

The precision and reliability of micro-morphological identification rely heavily on the use of advanced instruments. In this study, the following equipment was employed to ensure accurate observation and analysis of the micro-morphological characteristics of medicinal materials:

Equipped with a high-resolution zoom capability, this microscope facilitated the observation of intricate details of the medicinal material surfaces at varying magnifications. The adjustable zoom body (SZX-ZB7) allowed for seamless transitions between magnification levels, ensuring optimal visualization of microstructures.

This high-quality lens provided superior optical performance, allowing for the detailed capture of tissue structures critical for identifying subtle differences between authentic and counterfeit medicinal materials.

This system captured high-definition images of the micro-morphological features, ensuring that the fine details were preserved for documentation and analysis.

The software enabled the processing and enhancement of images, including operations like maximum contrast adjustment and multi-layer merging, to produce clear and detailed visuals of the microstructures.

Used to observe fluorescence characteristics of specific samples, this tool highlighted biochemical differences, such as oil content or active compound presence, which are key indicators of material quality.

2.2. Source of medicinal materials

To ensure the diversity and representativeness of the study, medicinal material samples were sourced from multiple reputable suppliers and institutions, as shown in **Table 1**. These included:

Known as a prominent trading hub for Chinese medicinal materials, this market provided a variety of samples with broad regional representation. This supplier offered authenticated medicinal material specimens that were verified for quality and consistency. A well-regarded supplier of traditional Chinese medicines, contributing samples that reflect the quality expected in pharmacy practice. Samples from this source added practical relevance, representing materials commonly encountered in everyday pharmacy operations. Experimental medicinal material specimens provided by this institution served as authenticated reference materials, ensuring accuracy in comparative analyses.

The selection of these instruments and materials is underpinned by their biomechanical implications. Micro-morphological features, such as cell wall thickness, oil chamber density, and tissue organization, are not only critical for identification but also reflect the biomechanical properties of the medicinal materials. For instance, the resilience and structural integrity of plant tissues, observable under the stereomicroscope, are directly influenced by their biomechanical composition, such as cellulose and lignin content.

Moreover, the use of ultraviolet analysis highlights fluorescence properties tied to biomechanical stress responses in plants. For example, the density and distribution of oil chambers in Aurantii Fructus are indicative of the plant's ability to store secondary metabolites, which contribute to its therapeutic efficacy. These biomechanical characteristics provide deeper insights into the quality and functional potential of medicinal materials, underscoring the importance of precise instrumentation and diverse sourcing.

By employing advanced tools and sourcing from varied, high-quality origins, this study ensures the robustness of its findings while demonstrating the critical intersection of micro-morphology and biomechanics in evaluating Chinese medicinal materials. This approach not only enhances the identification process but also contributes to a better understanding of how structural and mechanical properties influence the efficacy and quality of traditional Chinese medicine.

Table 1. Sample information table.

No.	**Source of Medicinal Materials**	**Identification Results**	**Remarks**
1a	Anguo Medicinal Materials Market	Aurantii Fructus	Authentic
1b	Henan Dingxin Medicinal Material Specimen	Aurantii Fructus	Authentic
1c	Guoyao Bencao Pharmacy	Aurantii Fructus	Authentic
2a	Henan Dingxin Medicinal Material Specimen	Amomum longiligulare T. L. Wu	Authentic
2b	Henan Dingxin Medicinal Material Specimen	Amomum gagnepainii T. L. Wu & al	Counterfeit
2c	Henan Dingxin Medicinal Material Specimen	Amomum villosum Lour	Authentic
3a	Community Traditional Chinese Medicine Pharmacy in Shijiazhuang	Atractylodis Rhizoma	Authentic
3b	Unknown	Atractylodes japonica Koidz. ex Kitam	Counterfeit
4a	Anguo Medicinal Materials Market	Ziziphi Spinosae Semen	Authentic
4b	Unknown	Vicia lens	Counterfeit
4c	Unknown	Ziziphus mauritiana	Counterfeit
5a	Guoyao Bencao Pharmacy	Carthami Flos	Authentic
5b	Unknown	Weight Gain Carthami Flos	Counterfeit
6	Guoyao Bencao Pharmacy	Plantaginis Semen	Authentic
7	Anguo Medicinal M Fructus Amomi Longiligularis aterials Market	Euodiae Fructus	Authentic
8	Anguo Medicinal Materials Market	Perillae Fructus	Authentic
9	Anguo Medicinal Materials Market	Sinapis Semen	Authentic

3. Methods

3.1. Preparation of medicinal materials

Select medicinal material samples and record the numbers. Clean the surface of the samples with a brush, and choose different colored backgrounds according to the color of the samples. Place the samples at different angles to observe the micro-morphological characteristics of different parts of the surface.

3.2. Observation and photography of medicinal materials

Before conducting observation and photography, ensure proper setup of the camera parameters and adjust the LED light source to achieve optimal illumination. Turn on the microscope and the FCSnap software, and adjust the light source settings for clarity. Carefully focus the microscope to obtain sharp images.

Depending on the sample size, adjust the zoom level of the microscope to magnifications of ×0.8, ×1, ×1.25, ×1.6, or ×2. Use the fine focus knob to fine-tune the field of view, gradually transitioning from blurred to clear and then back to blurred. Capture 5–30 images to gather sufficient data for analysis.

For enhanced imaging, utilize EDF (Extended Depth of Field) technology to synthesize multiple images, creating detailed micro-morphological characteristic diagrams and depth synthesis diagrams of various sample sections. This process ensures high-quality visuals that highlight the subtle structural features essential for accurate identification.

3.3. Image processing

The process of image processing plays a pivotal role in ensuring the accuracy and clarity of micro-morphological identification. Using the FCSnap imaging software, the captured image sets undergo systematic enhancement to highlight fine structural details of medicinal materials. The steps involved include:

The series of images taken under different magnifications and lighting conditions are imported into the FCSnap software. This ensures that all captured details are available for analysis and subsequent merging.

The software is utilized to optimize the contrast of the images. This adjustment enhances the visibility of key micro-morphological features such as cell wall patterns, oil chamber distribution, and fiber arrangements. These details are critical for distinguishing authentic materials from counterfeit ones.

Merging layers with displacement and scaling ensures that images taken at different focal depths and magnifications are accurately aligned. This step reduces visual artifacts and maintains the proportionality of microstructural features, allowing for precise comparisons.

The processed images are combined into a single, clear representation using Extended Depth of Field (EDF) technology. The resultant high-resolution composite image enables detailed examination of the material’s structural properties, ensuring robust identification and quality assessment.

The importance of these steps is underscored by their biomechanical implications. Structural properties, such as fiber thickness and cellular organization, are intricately tied to the mechanical behavior of medicinal materials. Proper image processing ensures that these characteristics are preserved and accurately represented for further analysis.

3.4. Sample measurement

The accurate measurement of microstructural dimensions is essential for a comprehensive understanding of the biomechanical properties of medicinal materials. The following steps outline the procedure:

The sample is carefully positioned under the microscope objective lens to ensure stability and optimal visualization of the target area. The microscope zoom body is adjusted to achieve the desired magnification level (e.g., ×0.8, ×1, ×1.25, ×1.6, ×2).

The fine focus knob is utilized to achieve sharpness and clarity of the observed field. This step ensures that the micro-morphological features are distinctly visible, minimizing distortions or blurring.

The software’s measuring ruler tool is employed to quantify the length, width, and other dimensions of microstructural features, such as oil chambers, fibers, or cellular arrangements.

High-resolution images are captured at each magnification level, recording detailed measurements of the sample’s micro-morphological characteristics for documentation and comparison.

From a biomechanical perspective, these measurements provide insights into the material’s structural integrity and mechanical behavior. For instance, the dimensions of oil chambers and fibers can be correlated with the plant’s ability to withstand environmental stress or its effectiveness in releasing bioactive compounds. Understanding these parameters aids in the evaluation of material quality and therapeutic potential.

3.5. Micro-morphological identification

The final step involves the comprehensive analysis and documentation of the micro-morphological characteristics observed during imaging and measurement. This process is critical for distinguishing authentic medicinal materials from counterfeits or low-quality specimens.

The unique microstructural features of each sample are described in detail. For example, in Aurantii Fructus, the density and distribution of oil chambers near the outer edge serve as key distinguishing factors. Similarly, in Amomum villosum Lour, the shape and arrangement of the fruit’s surface cells are indicative of its quality and authenticity.

Key features are summarized and compared against reference data from authenticated samples. This step ensures that any deviations, such as abnormal cell structures or irregular oil chamber distributions, are identified and documented.

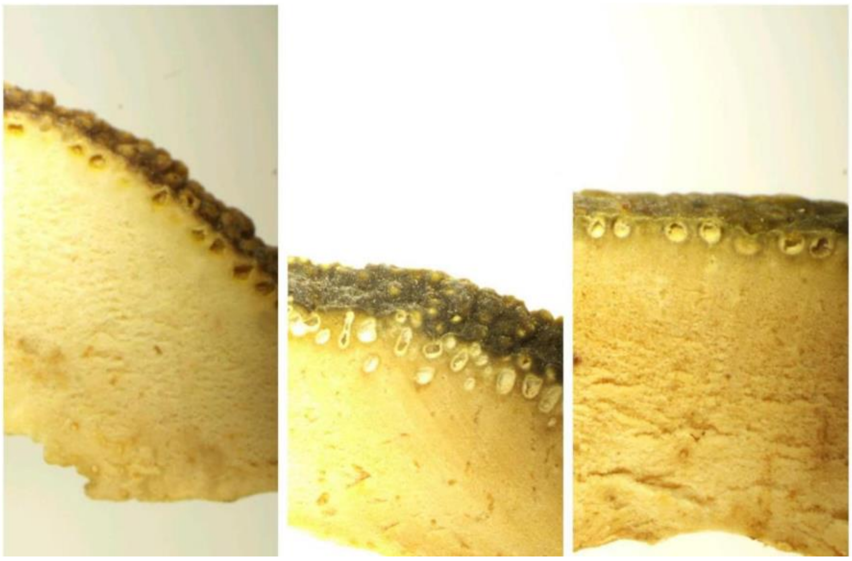
The identified features are analyzed in the context of their biomechanical significance. For instance, a denser arrangement of oil chambers may indicate higher volatile oil content, which is directly linked to the material’s therapeutic efficacy. Similarly, thicker cell walls or well-organized fibers may reflect greater structural integrity, which could influence the material’s extraction and absorption properties.

By integrating detailed observation, precise measurement, and biomechanical analysis, the micro-morphological identification method provides a comprehensive approach to evaluating Chinese medicinal materials. This methodology not only enhances the accuracy of identification but also establishes a scientific basis for understanding the relationship between structural features and therapeutic potential, thereby contributing to the broader field of traditional Chinese medicine research.

4. Results

4.1. Identification of Aurantii Fructus

Aurantii Fructus is the dried immature fruit of Aurantii Fructus L. and its cultivated varieties in the Rutaceae family. Aurantii Fructus slices are irregularly arc-shaped thin slices, with 1–2 rows of punctate oil chambers near the outer edge [4]. Observe the edge oil chambers of Aurantii Fructus at 0.8 magnification, and it can be seen that 1a has sparse oil chambers, 3a is the next, both are 1 row, and 2b has dense oil chambers, 2 rows. Combined with the fluorescence identification results, comparing the three types of Aurantii Fructus, the more oil chambers, the more obvious the fluorescence, indicating more volatile oil, better quality, and rapid identification of the quality grade of Aurantii Fructus. See **Figures 1** and **2** for details.



(a) **(b)** **(c)**

Figure 1. Micro-morphological identification characteristics of Aurantii Fructus ×0.8: **(a)** Anguo medicinal materials market; **(b)** Henan dingxin medicinal material specimen; **(c)** Guoyao bencao pharmacy.

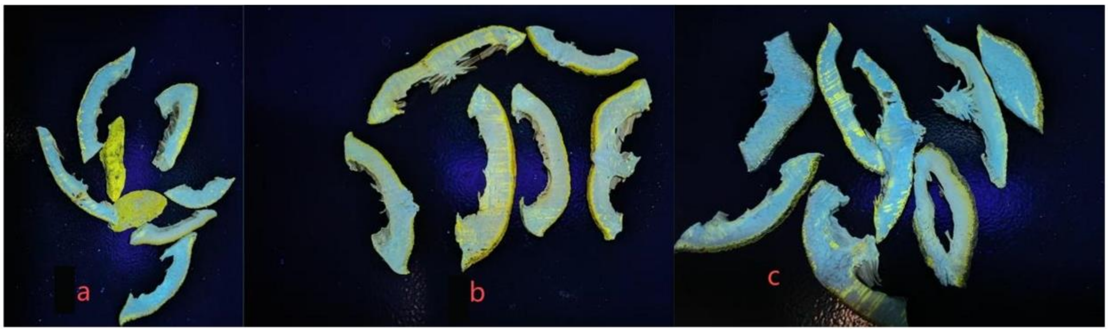


Figure 2. Ultraviolet analyzer observation of Aurantii Fructus (365 nm): **(a)** Amomum longiligulare T. L. Wu; **(b)** Amomum gagnepainii T. L. Wu & al; **(c)** Amomum villosum Lour.

4.2. Identification of Amomum villosum Lour

Amomum villosum Lour, belonging to the Zingiberaceae family, is the dried mature fruit of *Amomum villosum Lour*, *Amomum villosum Lour var. xanthioides* T.L. Wu et Senjen, or *Amomum longiligulare* T.L. Wu. Due to the existence of numerous varieties of *Amomum villosum Lour* and the prevalence of counterfeit products, accurate identification becomes critical. This study analyzes three varieties: Hainan *Amomum villosum Lour*, Long sequence *Amomum villosum Lour*, and Yangchun *Amomum villosum Lour*. Among these, Yangchun *Amomum villosum Lour* is generally considered to have better quality, while Long sequence *Amomum villosum Lour* is often confused with it.

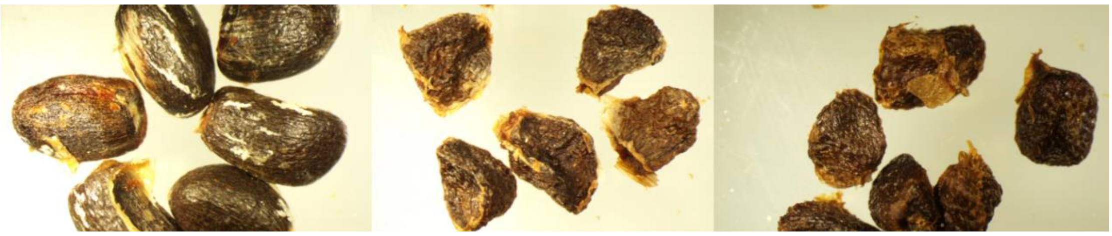
1) Morphological features:
   - Color: The outer skin of all three varieties is brown, showing no significant color difference.
   - Shape: Hainan *Amomum villosum Lour* and Long sequence *Amomum villosum Lour* are longer and mostly oval, whereas Yangchun *Amomum villosum Lour* is predominantly oval.
   - Ridges: Hainan *Amomum villosum Lour* has three distinct ridges, while Yangchun and Long sequence *Amomum villosum Lour* exhibit less prominent, blunt ridges.
2) Microscopic observations:
   - Surface Features: Under a stereomicroscope, Yangchun *Amomum villosum Lour* and Long sequence *Amomum villosum Lour* show evenly arranged fine longitudinal protrusions, which are not as pronounced in Hainan *Amomum villosum Lour*. The surface of Yangchun *Amomum villosum Lour* is densely covered with sharp, spiny protrusions, whereas Long sequence *Amomum villosum Lour* displays sparse spines, and Hainan *Amomum villosum Lour* has larger, flat, recumbent spines.
   - Seeds: The seeds of all three varieties are brown, with Hainan *Amomum villosum Lour* occasionally exhibiting a reddish-brown hue. The seed surface of Hainan *Amomum villosum Lour* is oval with subtle undulating protrusions and obvious longitudinal stripes. In contrast, the seeds of Long sequence *Amomum villosum Lour* and Yangchun *Amomum villosum Lour* are irregular polyhedra with more prominent undulating textures, covered by light brown membranous pseudo-pericarps.

3) Sensory characteristics:
   - Aroma and Taste: Yangchun *Amomum villosum Lour* has a strong aromatic fragrance, a spicy and cool taste, and a slight bitterness. On the other hand, Hainan *Amomum villosum Lour* and Long sequence *Amomum villosum Lour* have a mild aroma and light flavor.

   For detailed observations, please refer to **Figures 3** and **4**.

(a) **(b)** **(c)**

Figure 3. Micro-morphological identification characteristics of Amomum villosum Lour ×0.8: **(a)** Hainan Amomum villosum Lour; **(b)** Long sequence Amomum villosum Lour; **(c)** Yangchun Amomum villosum Lour.



(a) **(b)** **(c)**

Figure 4. Micro-morphological identification characteristics of Amomum villosum Lour seeds ×1: **(a)** Hainan Amomum villosum Lour; **(b)** Long sequence Amomum villosum Lour; **(c)** Yangchun Amomum villosum Lour.

4.3. Identification of Rhizoma Atractylodis

In the Asteraceae family, Atractylodis Rhizoma is the dried rhizome of either Atractylodes japonica Koidz. ex Kitam (DC.) Koidz. or Atractylodis Rhizoma (Thunb.) DC. The common imitation of Atractylodis Rhizoma is Atractylodes japonica Koidz. ex Kitam, which has a grayish-white surface, fewer cinnabar spots than Atractylodis Rhizoma, inconspicuous oil chambers, and light brown edges. Atractylodis Rhizoma has a yellowish-white surface, numerous red-brown oil chamber centers, orange-red edges, and a characteristic aromatic odor. Details are shown in **Figure 5**.

(a) **(b)**

Figure 5. Micro-morphological identification characteristics of Atractylodis Rhizoma ×0.8: **(a)** Atractylodis Rhizoma; **(b)** Atractylodes japonica Koidz. ex Kitam.

4.4. Identification of Ziziphi Spinosae Semen

Ziziphi Spinosae Semen is the dried mature seed of Ziziphus jujuba Mill. var. spinosa (Bunge) Hu ex H. F. Chou in the Rhamnaceae family. Ziziphi Spinosae Semen appears flat and round or flat oval, with both sides bulging, one side has a raised longitudinal line in the middle, the other side is slightly protruding, the surface is smooth and shiny, and is purplish-brown; the processed product of Vicia lens is flat and round, without end points, flat, one side is slightly bulging, the skin is wrinkled, the overall shape is flatter, reddish-brown or brown, the color is uneven, some can see color halos left after dyeing; Ziziphus mauritiana is flat and round, one end is flat, one end is pointed, one side is bulging, one side is flat, the color is mottled with red-brown spots. See **Figure 6** for details.

(a) **(b)** **(c)**

Figure 6. Micro-morphological identification characteristics of Ziziphi Spinosae Semen ×1: **(a)** Ziziphi Spinosae Semen; **(b)** processed Vicia lens; **(c)** Ziziphus mauritiana.

4.5. Identification of Carthami Flos

Carthami Flos is the dried flower of Carthami Flos L. in the Asteraceae family. Common adulterants of Carthami Flos are extracted to increase weight; normal Carthami Flos is tubular, with a surface of red-yellow or red, a slender corolla tube, and the flower is relatively complete, with yellow pollen granules attached on top. Adulterated and Weight Gain Carthami Flos is broken and incomplete; the corolla and stamen are not distinct, and they are bonded into clusters with the weight-increasing material. See **Figure 7** for details.

Figure 7. Micro-morphological identification characteristics of Carthami Flos ×1: **(a)** Carthami Flos; **(b)** adulterated and weight gain Carthami Flos.

4.6. Identification of several common small seed medicinal materials

4.6.1. Identification of Plantaginis Semen

This product is composed of the dry mature seeds of Plantaginis Semen. or Plantago depressa Willd. before Plantago. The plantain seeds are irregularly oblong or triangular oblong, slightly flattened, approximately 2 mm in length and 1 mm in width. The surface features fine wrinkles, ranging from yellowish brown to blackish brown. When magnified, it can be observed that the surface has a grainy texture, and on one side, there is a grayish white concave spot, which is the seed umbilical. For details, see **Figure 8**.

Figure 8. Micro-morphological identification characteristics of Plantago asiatica: **(a)** ×1.25; **(b)** ×2.5.

4.6.2. Identification of Euodiae Fructus

Fructus Euodiae (Juss.) Woolly Evodia, Euodiae Fructus (Juss.), or Benth. var. officinalis (Dode) Huang Euodiae Fructus (Juss.) Benth. var. bodinieri (Dode) Huang’s dry, almost ripe fruit. Pentagonal oblate spherical in shape, the product has a diameter of 2 to 5 mm, a concave top, noticeable pentagonal star cracks, an uneven surface, a fold that resembles the small intestine, punctate protrusions or concave oil spots, and a yellowish green to brown fruit. The base is still a fruit stalk, and the fruit stalk has a yellow villus. It has a rich perfume and a bitter, spicy flavor. Details are shown in **Figure 9**.

(a) (b) (c)

Figure 9. Micro-morphological identification characteristics of Euodiae Fructus: **(a)** ×1; **(b)** ×2.5; **(c)** ×1.6 (showing residual fruit stalk).

4.6.3. Identification of Perilla frutescens (L.) Britt

Perilla frutescens (L.) Britt. is the dried mature fruit of Perilla frutescens (L.) Britt. (L.) Britt. in the Lamiaceae family. This product is oval or spherical, about 1.5 mm in diameter; the surface is gray-brown, with obvious dark purple reticulations; the reticulations are slightly raised, forming irregular polygonal grids; the base of the fruit is slightly pointed, with a gray-white dotted fruit stalk mark; the outer circle is white and round, and the center is gray-black. The fruit skin is thin and brittle; some are cracked, revealing the yellow-white kernel inside. Crushing it releases a fragrant aroma, with a slightly spicy taste. See **Figure 10** for details.

(a) (b) (c)

Figure 10. Micro-morphological identification characteristics of Perilla frutescens (L.) Britt: **(a)** ×1.25; **(b)** ×2; **(c)** ×2 (showing fruit stalk mark).

4.7. Identification of Sinapis alba

Sinapis alba is the dried mature seed of Sinapis alba L. or Brassica juncea (L.) Czern. et Coss. in the Brassicaceae family. The former is commonly known as “white Sinapis Semen”, and the latter as “yellow Sinapis Semen”. This product is white Sinapis Semen, spherical, light yellow, with a diameter of 1.5–2.5 mm. The surface has fine reticulations, with an orange peel-like dotted texture, a distinct point-like hilum, surrounded by white fluff. The aroma is slight, and the taste is pungent. See **Figure 11** for details.

(a) (b) (c)

Figure 11. Micro-morphological identification characteristics of Sinapis alba: **(a)** ×1.25; **(b)** ×2; **(c)** showing hilum.

5. Discussion

This study highlights the application of micro-morphological identification methods in the quality control of traditional Chinese medicinal (TCM) materials, with a focus on its significance in enhancing accuracy, efficiency, and reliability. By combining advanced imaging technology and biomechanical insights, this method offers a robust approach to overcoming challenges in TCM identification.

5.1. Significance of micro-morphological characteristics in biomechanics

Micro-morphological characteristics reflect the intrinsic biomechanical properties of medicinal materials. Features such as cell wall thickness, fiber arrangements, and oil chamber density provide insights into the material's structural integrity and functionality [11]. For example:

In materials like Aurantii Fructus, the density and size of oil chambers are indicative of the volatile oil content, which directly correlates with the material's therapeutic efficacy. Biomechanically, these chambers represent storage adaptations that influence the material's response to external stress and its ability to preserve active compounds.

The arrangement and thickness of fibers in plant-based materials, such as Atractylodes Rhizome, determine their mechanical strength and resilience. These properties affect the material's grindability, extractability, and pharmacological activity.

The study's ability to capture and analyze these features through advanced microscopy and image processing underscores the importance of integrating biomechanical principles into TCM quality control.

5.2. Practical implications for TCM pharmacies

The findings demonstrate the practicality of using micro-morphological identification methods in pharmacy settings. Traditional identification methods rely heavily on subjective evaluations, such as visual inspection and sensory testing, which are prone to errors and require significant expertise. Advanced chemical and chromatographic techniques, while accurate, are often impractical for frontline operations due to their complexity and cost [12,13].

In contrast, the micro-morphological method is economical, user-friendly, and time-efficient, making it highly suitable for routine use in TCM pharmacies. By enabling rapid and reliable identification of medicinal materials, this approach enhances the accuracy of procurement, acceptance, and dispensing processes. Furthermore, the use of standardized imaging and measurement tools ensures reproducibility and consistency, addressing a critical need in the field.

5.3. Challenges and limitations

Despite its advantages, the micro-morphological method has certain limitations:

While high-magnification imaging reveals detailed features, some microscopic characteristics may still be difficult to discern, especially in highly degraded or adulterated samples.

The method relies on comprehensive reference databases for comparison, which may not be available for all medicinal materials or regional variants [13,14].

Although simpler than chromatographic techniques, the method requires trained personnel to operate the instruments and interpret the results accurately.

Future research should address these challenges by enhancing imaging resolution, expanding reference libraries, and developing automated identification algorithms based on artificial intelligence.

5.4. Integration with biomechanical analysis

The intersection of micro-morphology and biomechanics offers opportunities for deeper insights into the functional properties of medicinal materials. For example, the study's analysis of fiber thickness and oil chamber density provides not only identification data but also clues about the mechanical and chemical behavior of the material during processing and use [15].

The biomechanical properties revealed through micro-morphological features can be linked to the material's pharmacodynamics, offering a more holistic understanding of its therapeutic potential.

Biomechanical insights can guide the optimization of grinding, extraction, and storage processes, ensuring maximum retention of active compounds and structural integrity [16–18].

Availability of data and materials: The data used to support the findings of this study are available from the corresponding author upon request.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

References

1. Yang D. Application of Micro-morphological Identification Method in the Quality Evaluation of Chinese Medicine (Chinese). Special Economic Animals and Plants. 2024; 27(2): 167–171+174.
2. Zhang L, Lou Z, Zhu X, et al. Application of Micro-morphological Identification Method in the Quality Acceptance of Chinese Medicinal Slices in Medical Institutions (Chinese). Chinese Pharmacist. 2024; 27(8): 1309–1319.
3. Zhou J, Yang Q. Chinese Medicinal Micro-morphological Identification Method (Chinese). Journal of Anhui University of Chinese Medicine. 2011; 30(1): 66–68.
4. National Pharmacopoeia Commission. Chinese Pharmacopoeia 2020 Edition Part I (Chinese). China Medical Science and Technology Press; 2020.
5. Li F, Zhou R, Liu Q. Micro-morphological Identification of Lysimachia christinae and Its Adulterants (Chinese). Strait Pharmacy. 2018; 30(7): 39–41.
6. Li F, Liu Q, Zhao Y. Comparative Study on Micro-morphological Characteristics between Lysimachia christinae and Lysimachia christinae aggregate (Chinese). Inner Mongolia Traditional Chinese Medicine. 2018; 37(11): 97–98. doi: 10.16040/j.cnki.cn15-1101.2018.11.068
7. Hu X, Yuan W, Wang J, et al. Micro-morphological Identification of Different Origins of Amomum villosum Lour and Its Adulterants (Chinese). China Pharmacy. 2021; 32(5): 590–594.
8. Hou F, Guo L, Song J, et al. Study on the Morphological and Micro-morphological Identification of Amomum villosum Lour and Its Adulterants in Hebei Anguo Market (Chinese). Journal of Nanjing University of Chinese Medicine. 2019; 35(2): 214–217.

9. Ju K, Xia D, Wang F, et al. Micro-morphological Identification of Gynostemma pentaphyllum and Cissus trifoliata (Chinese). Journal of Jiangxi University of Traditional Chinese Medicine. 2023; 35(6): 89–91+97.
10. Zou L, Yi D, Pan Y, et al. Micro-morphological and Microscopic Identification Research on Nine Types of Epimedium Leaf (Chinese). Chinese Journal of Pharmacy. 2024; 59(9): 776–788.
11. Hou F, Lin X, Fan W, et al. Micro-morphological Identification Research on the Bones and Scales of Zongrong White Flower Snake and Its Adulterants (Chinese). Journal of Liaoning University of Traditional Chinese Medicine. 2024; 1–9.
12. Liang Q, Ouyang M, Chen B, et al. Comparative Study on the Micro-morphological and Microscopic Identification Differences between Lonicerae Japonicae Flos and Lonicerae Flos (Chinese). Strait Pharmacy. 2023; 35(7): 29–32.
13. Liu A, Zhang S, Wang S, et al. Micro-morphological Identification of Ten Types of Small Fruit Seed Medicinal Materials (Chinese). Chinese Patent Medicine. 2022; 44(6): 1869–1874.
14. Yuan Shijun, Ma Qing, Chen Keli, et al. Micro-morphological Identification of Common Mineral Chinese Medicinal Powders (Chinese). Chinese Traditional and Herbal Drugs. 2021; 52(5): 1454–1461.
15. Buccino F, Bagherifard S, D’Amico L, et al. Assessing the intimate mechanobiological link between human bone micro-scale trabecular architecture and micro-damages. Engineering Fracture Mechanics. 2022; 270: 108582.
16. Liu H, Han D, Hu J, et al. Biomechanical functions analysis of the Mallard webbed foot: A study of macroscopic and microscopic material assembly and tendon morphology. Micron. 2024; 183: 103648.
17. Tu Z, Xu J, Dong Z, et al. Load-bearing optimization for customized exoskeleton design based on kinematic gait reconstruction. Medical & Biological Engineering & Computing. 2024.
18. Ren Z, Huang J, Bai H, et al. Potential application of entangled porous titanium alloy metal rubber in artificial lumbar disc prostheses. Journal of Bionic Engineering. 2021; 18: 584–599.