Progress in ICP-MS Analysis of Minerals and Heavy Metals in Traditional Medicine

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Aim: This study systematically reviewed the application of ICP-MS and its combined technology in the determination of mineral and heavy metal elements in medicinal materials derived from plants, animals, minerals and their preparations (Chinese patent medicine), and biological products. It provides a reference for improving the quality standard of traditional medicine and exploring the effective components, toxic components, and action mechanism of traditional medicine.

Materials and Methods: A total of 234 articles related to the determination of mineral and heavy metal elements in medicinal materials derived from plants, animals, and minerals and their preparations (Chinese patent medicine) were collected from PubMed, CNKI, Web of Science, VIP, and other databases. They were classified and sorted by the inductively coupled plasma-mass-spectrometry (ICP-MS) method.

Results: Of the 234 articles, 154 were about medicinal materials derived from plants, 15 about medicinal materials derived from animals, 9 about medicinal materials derived from minerals, 46 about Chinese patent medicine, 10 about combined technology application, and 3 about drugs being tested after entering the body. From the 154 articles on medicinal materials derived from plants, 76 elements, including Cu, Cd, Pb, As, Cr, Mn, and Hg, were determined, of which the determination of Cu was the most, with 129 articles. Medicinal materials derived from the roots, stems, leaves, flowers, and fruits and seeds of plants accounted for 25.97%, 18.18%, 7.14%, 7.79%, and 14.94%, respectively. Moreover, medicinal materials derived from the whole plants accounted for 14.94%, and other medicinal materials derived from plants and soil accounted for 11.04%. A total of 137 of the tested medicinal materials were from traditional Chinese medicine, accounting for 88.96%, 12 were from Arabic medicine (including Unani), accounting for 7.79%, 2 were from Tibetan medicine of China, and 1 was from Mongolian medicine of China, 1 was from Miao medicine of China, and 1 was from Zhuang medicine of China. In the 15 articles on medicinal materials derived from animals, 49 elements such as Cu, As, Cd, Hg, Se, Pb, and Mn were determined, of which Cu was the most. All the tested medicinal materials belong to traditional Chinese medicine. From the nine articles on medicinal materials derived from minerals, 70 elements such as Fe, Cu, Zn, Al, As, Se, and Na were determined, of which Fe, Cu, and Zn were the most. The tested medicinal materials all belong to traditional
INTRODUCTION

Traditional medicine in China includes traditional Chinese medicine, ethnic medicine (e.g., Tibetan, Mongolian, Uygur, Dai, Miao, and Zhuang medicines), and religious medicine (e.g., Buddhist and Taoist medicines). Traditional Chinese medicine is an important part of Traditional medicine in China. China is the world’s largest producer of medicinal materials. Arabic medicine is derived from Hippocratic–Galenic medicine in ancient western philosophy, formed in the Arab Empire between the 8th and 12th centuries. It is generally believed that Unani, which is popular in south Asian countries, belongs to Arabic medicine. Traditional drugs have three basic ingredients—medicinal materials derived from plants, animals, and minerals—among which medicinal materials derived from plants account for the highest proportion. Medicinal materials derived from plants have six organs (roots, stems, leaves, flowers, fruits, and seeds), which makes the medicinal parts of medicinal materials derived from plants diverse. Root and rhizome traditional drugs account for the largest proportion and are the most common in the whole medicinal materials derived from plants, so the inductively coupled plasma-mass-spectrometry (ICP-MS) method is also the most widely used in this kind of traditional drugs.

Heavy metal is not only a toxic component of common concern in today’s society but also an effective component of traditional drugs. Traditional medicinal materials derived from plants, animals, minerals, and their preparations (Chinese patent medicine) often contain several minerals and heavy metals. In addition, there are cases of heavy metals exceeding the standard in the drugs. The limitation of heavy metals and the improvement of quality control standards are major dilemmas affecting the internationalization process. People favor traditional drugs more because of their reliable curative effect, less toxic and side effects, relatively safe use, and other characteristics. However, in the process of planting, production, and processing of traditional drugs, due to their enrichment and absorption of heavy metals or the high content of metal elements in the cultivated soil, the application of chemical fertilizer and pesticide contamination and other situations may introduce metal elements, resulting in an abnormal increase in metal element residues, which also makes traditional drugs have varying degrees of heavy metal pollution (Chi et al., 2016). There are many kinds of inorganic trace elements in traditional drugs. The inorganic elements are closely related to their efficacy and therapeutic use. They are one of the effective components of traditional Chinese medicine. Studying the content and distribution of inorganic elements in traditional drugs to elucidate traditional pharmacology and toxicology and further develop medicinal resources is of great value.

ICP-MS mostly uses a quadrupole mass spectrometer, which can quickly and continuously measure the mass of different elements. Currently, it can be used to analyze more than 70 elements. The detection limit of ICP-MS for more than 70 elements in the solution is one trillion or less, and the linear dynamic range can reach nine orders of magnitude (Olesik, 2014). ICP-MS is an inorganic multi-element analysis technology with inductively coupled plasma as an ion source.
and mass spectrometry in the field of analytical chemistry in the early 1980s. In 1980, Robert et al. (1980) published the first article on the feasibility of ICP-MS, and the first commercial instrument came out 3 years later. So far, there are about 20 types of ICP-MS instruments commercialized worldwide. In the field of drug element analysis and safety monitoring, ICP-MS and its combined technology are also increasingly widely used, which seems to have become a common and mature analysis and detection means. There are many common methods for the determination of trace elements in traditional Chinese drugs, mainly including atomic fluorescence spectrophotometry (AFS) (Zhang et al., 2016a), atomic absorption spectrophotometry (AAS) (He et al., 2019), ultraviolet-visible spectrophotometry (UV-VIS) (Wei et al., 2019), and inductively coupled plasma atomic emission spectrometry (ICP-OES) (Ma et al., 2020). Most of these methods can determine single elements, but they cannot determine some elements with low content. Metal determination can also be used for QC analysis and spectral and voltammetric configurations (Locatelli et al., 2014). Dora Melucci (Melucci et al., 2013) determined the contents of heavy metals and total mercury in Camellia sinensis by micro voltammetry. ICP-MS is a new analysis technology, with the advantages of less interference, high precision, wide linear range, and fast analysis speed.

In view of the wide application of ICP-MS in traditional drugs and preparations (Chinese patent medicine), 234 relevant articles on the determination of minerals and heavy metals in plants, animals, mineral medicinal materials, and preparations by ICP-MS and its combined technology were collected and classified. The purpose is to provide a reference for improving the quality standard of traditional drugs and exploring the material basis and mechanism of efficacy/toxicity.

TYPES, SOURCES, TOXICOLOGY, AND PHARMACOLOGICAL EFFECTS OF MINERALS AND METAL ELEMENTS IN TRADITIONAL DRUGS

Types of Minerals and Heavy Metals

Mineral elements are one of the nutrients needed by the animal body. At present, more than 20 mineral elements such as Ca, P, K, and S have been found in the human body. Although the content in the human body is very low, they participate in and affect the physiological metabolism of the human body and are indispensable elements for maintaining health.

Heavy metal elements refer to metals with a density greater than 4.5 g/cm³, including Au, Hg, Pb, and Cr. According to international standards, heavy metal elements mainly include Cu, Cd, Pb, Hg, and As. Heavy metals cannot be biodegraded, but they can aggregate thousands of times under the biomagnification of the food chain and finally enter the human body to interact strongly with proteins and enzymes, making them inactive. It may also accumulate in some organs and tissues of the human body, and various poisoning symptoms will appear. In addition, Cu is one of the essential trace elements of the human body, and it participates in important physiological processes of the human body. The lack of Cu will cause a decrease in brain cytochrome oxidase, which can lead to thinking disorder, slow response, and dyskinesia.

Sources and Pathways of Heavy Metals

In recent years, with the development of the mining industry, mining dust and ore washing water pollute farmland, resulting in the enrichment of heavy metals in agricultural products. The sources of heavy metals in traditional Chinese medicine and Tibetan medicine should be closely related to their planting conditions and growth environment, such as the application of soil, atmosphere, water, chemical fertilizer, and pesticide. The "three industrial wastes", including waste gas, waste water and waste residue, directly or indirectly pollute traditional Chinese medicine and Tibetan medicine. Moreover, the genetic characteristics of plants, such as active absorption function and enrichment ability of heavy metals, are related to the production and content of heavy metals. Most bases for medicinal materials from plants are formed by the transformation of farmland, which will cause the slow accumulation of heavy metals due to long-term garbage accumulation (e.g., batteries and metal waste), pesticide application, proximity to mines, and many other factors. However, medicinal materials derived from the roots of plants are medicinal materials with roots or roots as the main part and some rhizomes. They are closely related to the growth environment and conditions, and different parts of medicinal materials have different abilities to absorb and enrich heavy metals. In addition, during the processing of traditional Chinese medicine and Tibetan medicine, the use of metal processing tools and the addition of medicinal accessories may lead to the introduction of heavy metal elements, especially the processing of precious drug preparations in Tibetan medicine preparations, which will introduce a large number of heavy metal elements. It can be seen that heavy metals are dangerous to be introduced in the growth, collection, transportation, processing, and preparation of medicinal materials. Some studies have shown that the contents of heavy metals and harmful elements in the same medicinal material from different producing areas can differ by nearly 10 times at most. Such residual impurities are highly toxic. After entering the body, they can form complexes or metal chelates with traditional Chinese medicine components in the body, such as protein and nucleic acid, which have very strong toxicity (Xu et al., 2017). Much evidence shows that all kinds of pesticides and heavy metals are carcinogenic. If they do not act directly, there is also evidence that these preparations can participate in carcinogenesis in a passive or allowable way to promote the formation of tumors induced by other preparations. Through chemical interactions with the environment and each other, metal pesticide mixtures may produce unpredictable toxicity, such as organochlorine pesticides that are fat-soluble and easy to accumulate in the fat body, resulting in nerve, liver, and kidney damage. Heavy metals cause protein denaturation in the body and impair the function of tissue cells (Wang et al., 2020a).

Toxicological and Pharmacological Effects of Heavy Metals

The strong binding of -SH and -S-S- bonds on human enzyme proteins with heavy metal elements is the main molecular
mechanism of human poisoning (Zhao, 1991). When the minerals and heavy metals in the human body are within the acceptable limit of the human body, they will not cause harm to the human body. However, when they accumulate to a certain extent, they will inevitably cause irreparable harm to the human body. As a toxic heavy metal element, Cd is a non-essential trace element in the human body. It is mainly absorbed by plants in water-soluble and exchangeable states and then enriched into the human body through the food chain or directly into the human body through the respiratory system and digestive system, which accumulates in the body for a long time and damages organ functions. Specific manifestations are lung injury, kidney failure, gastrointestinal stimulation, cardiovascular and cerebrovascular diseases, muscle pain, bone pain, and bone atrophy, as well as carcinogenic, teratogenic, and mutagenic effects; long half-life in the body; and irreversible damage (Guan et al., 2021). Tl and its compounds have high toxicity and strong accumulation. They are strong neurotoxicants and can cause liver and kidney damage. They also have mutagenic, teratogenic, neurotoxic, and reproductive toxic effects. Long-term exposure to arsenic can lead to chronic poisoning, manifested as skin pigmentation, hyperkeratosis, or verrucous hyperplasia, as well as leukopenia or anemia. Ag poisoning seriously affects the human central nervous system and paralyzes the limbs. In severe cases, it can lead to heart failure and death as exposure can lead to different degrees of liver injury, fibrosis, liver cirrhosis, and even liver cancer (Huo et al., 2016). The half-life of mercury can reach 240 days in brain tissue and 70 days in other organs, so its toxic effect is toxic dose-response. The acute toxicity caused by mercury is mainly liver damage. In contrast, the chronic toxicity caused by long-term medication is more likely to cause damage to the kidney, liver, and brain. Al can cause neurofibrillary tangles and amyloid senile plaques in brain tissue, which is related to Alzheimer’s disease (AD). Long-term excessive aluminum intake can lead to an imbalance in the human body and a decline in cognitive ability, memory ability, and logical reasoning ability (Chen et al., 2011a). Pb can induce brain cell apoptosis and inhibit the activity of brain cell enzymes, thus interfering with the metabolism of neurotransmitters, protein kinase activity, and calcium metabolism. Pb exposure may lead to postural coordination disorders. Cu is a trace element required by the human body, which plays a role in promoting the generation and maturation of red blood cells, but excessive intake may cause poisoning, which will cause hypotension, jaundice, acute copper poisoning, hepatolenticular degeneration, intrahepatic cholestasis in children, and other diseases (Shen et al., 2017). Th is related to the occurrence and development of various malignant tumors, such as esophageal cancer, gastric cancer, nasopharyngeal carcinoma, and cervical cancer. U element and its compounds can damage DNA, induce ultrastructural changes in the cell membrane, and lead to tumors.

Heavy metals also have various pharmacological effects. For example, Tibetan medicine Zuotai is made from mercury, but it has antidepressant and anxiolytic effects (Zhao et al., 2016a; Zhao et al., 2016b). In addition, Cu is one of the heavy metal elements and the component of copper-containing protein in the human body. It can catalyze the synthesis of hemoglobin. However, if it exists in the form of Cu²⁺, it will become an excellent catalyst for redox reaction in vivo (Gao et al., 1993). Cu is absorbed from the small intestine and combined with plasma protein to form ceruloplasmin, which is mainly synthesized in the liver, then discharged with bile, and stored in the liver, bone, and muscle of the human body, with iron oxidase and antioxidant effects (Shao...
### TABLE 1 | Application of ICP-MS in the determination of heavy metals in medicinal materials derived from the roots of plants.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials* | Test results |
|------------|----------------|----------------|-----------------------------|-------------------------------|-------------|
| Achyranthes bidentata Blume | Traditional Chinese medicine | Amanoemia, dysernia, headache, toothache, hematemesis, bleeding | Immune regulation, anti-fertility, anti-inflammatory, antibacterial, analgesic, anti-osteoarthritis, and anti-aging | -- | The contents of rare earth elements La, Tb, Ce, Nd, Dy, Eu, Gd, and Tm in A. bidentata Blume were determined. The content of Ce was the most and Lu was the least. The rare earth elements with a content of more than 100 ng/g (DW) are La, Ce, and Nd. La is 158.270 ng/g (DW), Ce is 448.636 ng/g (DW), and Nd is 125.635 ng/g (DW). Rare earth elements Pt, Sm, and Gd > 20 ng/g (DW). The contents of Eu, Tb, Dy, Ho, Er, and Yb are 2.536–14.522 ng/g (DW). The content of Tm and Lu is lower than 1 ng/g (DW). Tm is 0.016 ng/g (DW), and Lu is 0.848 ng/g (DW) (Yu et al., 2009). |
| Aconitum kusnezoffii Richb. | Traditional Chinese medicine | Arthralgia, cardalgia | Analgesic, anti-inflammatory, cardiotic, anti-tumor, immune regulation | Schuan, Xinjiang, Jilin, Shandong, Shaanxi, Anhui, Henan, Hunan, Guangzhou, Inner Mongolia, and Hebei provinces or autonomous regions of China | The contents of Pb, Cd, Cr, Cu, Hg, and As, six heavy metals in A. kusnezoffii Richb., prepared from different producing areas such as Schuan, Shaanxi, Hunan, and Inner Mongolia were determined. The isotopes 208 Pb and 202 Hg were selected with 209 Bi as internal standard. 114 Cd with 115 In as internal standard, 63 Cu and 60 Cr with 69 Co as internal standard, and 75 As with 77 As as internal standard. Cd, As, and Hg in A. kusnezoffii Richb. prepared from some producing areas exceeded the standard. The linear correlation coefficients of the six metal elements were greater than 0.998, the average recovery was 83.93%–97.96%, and the RSD was 0.94%–2.66% (Yu et al., 2009). |
| Aconitum napellus L. | Traditional Chinese medicine | Headache, pharyngalgia, nasal congestion | Anti-virus, anti-tumor, regulating neuroendocrine function, anti-osteoporosis, and anti-inflammatory | -- | The contents of Ba, Al, Cr, Mn, Cu, As, Zn, Ag, Cd, Sn, Zr, Cu, Dy, Ho, Ti, and Pb in A. napellus L. were determined. The calibration curves of 18 elements have a good linear relationship, and the recovery meets the requirements of trace analysis (Xu et al., 2019). |
| Anethum graveolens | Traditional Chinese medicine | Spasm | Analgesic, anti-inflammatory, anti-microbial, anti-antitumor, anti-diabetes | Bangladesh | The contents of Ca, Mg, Ni, Na, Li, Fe, and Fe in A. graveolens L. were determined. Ca (203.600 mg/kg), Mg (1762.30 mg/kg), and K (1286.15 mg/kg) were the most important elements, followed by Ni (1187.30 mg/kg), Se (913.79 mg/kg), Li (517.84 mg/kg), Na (298.72 mg/kg), and Fe (206.88 mg/kg). Toxic elements are within the allowable limits (Bashir et al., 2017). |
| Anapalica dahurica (Hoffm.) Benth. & Hook.f. ex Franch. & Sav. | Traditional Chinese medicine | Common cold due to wind-cold, headache, toothache, nausea, vomiting, weakness | Antipruritic, analgesic, anti-inflammatory, and anti-microbial | Anhui province of China | The contents of Pb, Cu, As, Cd, and Hg in A. dahurica (Hoffm.) Benth. & Hook.f. ex Franch. & Sav. were determined. The linear correlation coefficients of the six metal elements were greater than 0.998, the average recovery was 83.93%–97.96%, and the RSD was 0.94%–2.66% (Hu et al., 2020). |
| Anapalica sinensis (Oliv.) Deils | Traditional Chinese medicine | Irregular menstruation, amenorrhea, dysernia, constipation, falling, and fluttering injury | Analgesic, anti-inflammatory, antibacterial, antioxidative, and anti-seizure dementia | Jiangsu province of China | The contents of Pb, Cu, As, Cd, and Hg in A. sinensis (Oliv.) Deils were determined. The linear relationship of 17 trace elements was good in the range of 0.0018–150.00 g/L, the correlation coefficient R was greater than 0.9999, the detection limit of each element was 0.0018–0.1203 g/g, the RSD of precision, repeatability, and stability tests was not greater than 3.35%, 2.03%, and 3.42%, and the recovery was 96.67%–100.48%. A. sinensis (Oliv.) Deils is rich in Mg, Zn, Sr, Cr, and other essential trace elements for the human body, and the content of five heavy metal elements does not exceed the standard (Yang et al., 2016). |
| Asarum heterotropoides F. Schmidt | Traditional Chinese medicine | Headache, stuffy nose, and runny nose caused by a cold | Antiviral, antibacterial, anti-inflammatory, antioxidative, and anti-allergic | Liaoning, Guangzhou, Shandong, Jilin, and Hebei provinces, China | The contents of rare earth elements Sm, Eu, Gd, and Tb in A. heterotropoides F. Schmidt were determined. The content of Sm was the most and Eu was the least. The rare earth elements with a content of more than 100 ng/g (DW) are Sm, Eu, Gd, and Tb. The contents of La, Ce, Nd, Pr, Dy, Ho, Er, Tm, and Yb are 2.536–14.522 ng/g (DW). The content of Tm and Lu is lower than 1 ng/g (DW). Tm is 0.016 ng/g (DW), and Lu is 0.848 ng/g (DW) (Yu et al., 2009). |
| Arthango pus mongolicus Bunge | Traditional Chinese medicine | Edematous, descentus uteri, edema, urticaria, diabetes | Anti-inflammatory, immune regulation, anti-tumor, anti-stress, and liver protection | -- | The contents of 27 inorganic elements of Li, Be, Na, Mg, K, Mn, Co, Ca, Br, Rb, Y, Nb, Mo, Pt, Te, I, Cs, Pr, Nd, Sm, Gd, Dy, Ho, Yd, W, Ti, and Th in A. mongolicus Bunge were determined. The main discriminant elements are determined as K, Mg, and Na (Yang et al., 2019). The contents of heavy metals in 33 batches of A. mongolicus Bunge from eight different producing areas in Schuan, China, were determined. The amount of heavy metals in each sample of A. mongolicus Bunge is Pb ≤0.256, Cd ≤0.235, Hg ≤0.123, and Sn ≤0.50 (Continued on following page). |
| Chuanmingshen violetaevum M. L. Shah & R. H. Shan | Traditional Chinese medicine | Gastroptosis, intoxication | Anti-fatigue and anti-oxidation | Schuan province of China | The contents of 27 inorganic elements of Li, Be, Na, Mg, K, Mn, Co, Ca, Br, Rb, Y, Nb, Mo, Pt, Te, I, Cs, Pr, Nd, Sm, Gd, Dy, Ho, Yd, W, Ti, and Th in A. mongolicus Bunge were determined. The main discriminant elements are determined as K, Mg, and Na (Yang et al., 2019). The contents of heavy metals in 33 batches of A. violetaevum M. L. Shah & R. H. Shan from eight different producing areas in Schuan, China, were determined. The amount of heavy metals in each sample of A. violetaevum M. L. Shah & R. H. Shan is Pb ≤0.256, Cd ≤0.235, Hg ≤0.123, and Sn ≤0.50 (Continued on following page). |
| Latin name                                    | Medical system               | Therapeutic use                                      | Main pharmacological effects                                                                 | Origin of medicinal materials* | Test results                                                                 |
|----------------------------------------------|------------------------------|------------------------------------------------------|------------------------------------------------------------------------------------------------|-------------------------------|------------------------------------------------------------------------------|
| Cynanchum bungei (Franch.) Nootr.             | Traditional Chinese medicine | Coronary heart disease, hyperlipidemia                | Anti-tumor, anti-oxidation, anti-inflammation, anti-stress, and liver protection                 | Shanxi province of China      | Cu ≤ 3.963, and Cr ≤ 2.145 μg/g. As is not detected. Both are lower than the standards for raw materials and decotion pieces of medicinal plants in China's green standard for the import and export industry of medicinal plants and preparations (Yao et al., 2016). The contents of As, Hg, Pb, and Pd in C. bungei (Franch.) Nootr. were determined. The correlation coefficient of the measured elements and the standard curve were greater than 0.9992, the recovery was 96.5%–105.2%, and the RSD was less than 10.6% (Wang and Zhong, 2000). |
| Cynanchum bungei (Franch.) Nootr.             | Arabic medicine              | Anti-tumor, antisenescence, hypodiploidiome           | Anti-inflammatory, anti-tumor, antidepressant, and enhancing immune function                   | —                             | 1) The contents of Al, Pb, Cd, and As in C. bungei Decne. were determined. The recovery of all measured elements was 86.1%–96.6%. The content of Al as element is the highest, and the concentration range of Al is 156–1609 mg/kg. The content of Cd is the lowest, and the concentration of Cd is in the range of 0.01–0.10 mg/kg. The washing process reduces toxic elements in all plants. The average recoveries were Al (47.32%), As (59.1%), Cd (62.03%), and Pb (52.40%) (Bomra, 2017). 2) The contents of Fe, Mn, Zn, Cu, and Se in C. bungei Decne. were determined. Fe level is the highest, and Se level is the lowest among all plants. The TE series levels of all elements in all plants are as follows: Fe 193.4–1757.9, Mn 23.6–143.7, Zn 15.4–42.7, Cu 0.13–0.92, and Cd 11.3–21.8 μg/g. Calculated air intake of essential elements from medicinal plants: Fe 4.6–13.4, Mn 6.7–123.2, Zn 7.0–42.7, Se 0.14–1.5, and Cu 1.5–5.0 μg/dose (Bomra, 2019). |
| Glycyrrhiza uralensis Fisch. ex DC.            | Traditional Chinese medicine | Splenic deficiency, fatigue, palpitation, cough       | Antibacterial, anti-inflammatory, anti-viral, immune regulation, anti-asthma                    | Gansu, Inner Mongolia, and Xinjiang provinces or municipalities of China | The contents of 25 metal elements K, Na, Mg, Al, Fe, Sa, Zn, Mn, V, Bi, Na, Ga, Pb, Sr, Cu, Bi, Li, U, Cu, As, Cd, Pb, Hg, and O in G. uralensis Fisch. ex DC. are determined. The average recovery of each element is 85.93%–103.8%, and the RSD is less than 5% (Zhao et al., 2017). |
| Glycyrrhiza uralensis Fisch. ex DC.            | Traditional Chinese medicine | Splenic deficiency, fatigue, palpitation, cough       | Antibacterial, anti-inflammatory, anti-viral, immune regulation, anti-asthma                    | Gansu, Inner Mongolia, and Xinjiang provinces or municipalities of China | The regression equations of Pb, Cd, As, Hg, and Cu were Y = 0.0130X + 0.0062 (r = 0.9967), Y = 0.0031X + 2.7982 – 4 + 0.9989, Y = 0.0068X + 4.5141 – 4 Y = 0.9996, Y = 0.0033X + 0.0726 – 4 (r = 1.0000), Y = 0.0985X + 0.0277 (r = 0.9989), and the recovery was 86.8%–90.3% (Bai and Hong, 2019). |
| Millettia puhlina (Vogt) Kurz                  | Zhuang medicine in China     | Fracture, deficiency of blood, dizziness, insomnia    | Regulate body immunity, reduce blood pressure and resist hypoxia stress injury                  | Guangxi Zhuang Autonomous Region of China | The contents of Pb, Cd, Hg, As, Cr, and Cu in O. japonicas (Thurb.) Kurz were determined. The correlation coefficient of each element is Y = 0.0031X + 0.0062 (r = 0.9967), Y = 0.0033X + 0.0726 – 4 (r = 1.0000), Y = 0.0985X + 0.0277 (r = 0.9989), and the recovery was 86.8%–90.3% (Bai and Hong, 2019). |
| Ophiopogon japonicus (Thurb.) Kar Gawe.       | Traditional Chinese medicine | Insomnia, tumor, hyperlipidemia                       | Protect cardiovascular system, anti-inflammatory, anti-tumor, anti-oxidation, anti-aging, and immune regulation | Sichuan province of China | The contents of Pb, Cd, Hg, As, Cr, and Cu in O. japonicus were determined. The linear relationship of each element is good, the correlation coefficient Y is greater than 0.9995, the relative standard deviation of the precision test is less than 5%, the recovery is 91.8%–103.0%, and the detection limit is less than 0.001 mg/g (Liu et al., 2018). 17 elements of Pb, Cd, Hg, As, Cr, Se, Zn, Cu, Bi, Ti, Na, Ni, F, Zr, Mg, I, Mn, Bi, and Li in O. japonicus were determined. The concentration of Si was the highest (85.3 μg/g), whereas the concentration of Li was the smallest (0.3 μg/g). |
| Paeonia emodi Royle                           | Unani                        | Antisenescence                                       | Anti-aging                                                                                     | —                             | The contents of Cd, Hg, As, Cr, and Pb in O. japonicus (Thurb.) Kurz were determined. The concentration of Si was the highest (85.3 μg/g), whereas the concentration of Li was the smallest (0.3 μg/g). |
| Panax ginseng C. A. Mey.                     | Traditional Chinese medicine | Tumor, cardiovascular disease                         | Anti-tumor, anti-oxidation, antaging, anti-diabetes, anti-hepatoprotective toxicity              | Jilin province of China        | The contents of metal elements in P. ginseng C. A. Mey were determined. The linearity of As, Pb, Cr, and Cd was 0.5–50.0 μg/L, Hg linear at 0–2.00 μg/L, Cu linear between 0 and 500 μg/L, the linearity of Al is 0.5 mg/L, the correlation coefficient is 0.9984–0.9996, the detection limit is 0.001–0.5 mg/kg, the recovery is 80.2%–104.6%, and the relative standard deviation (RSD) is 1.37%–5.61% (Zhong et al., 2018c). 2) The contents of Cr, Cu, As, Cd, Pb, and Hg in 53 samples collected from 10 major P. ginseng C. A. Mey planting counties and regions in Jilin Province, China, were determined. The contents of heavy metals in ginseng samples were Cr ≤ 2.069, Cu ≤ 16.011,9, As ≤ 0.0181, Cd ≤ 0.2160, and Pb ≤ 0.8601 μg/g. Hg is not detected (Zhang et al., 2018b). |
| Panax notoginseng (Burkill) F.H.Chen          | Traditional Chinese medicine | Hypertension, traumatic injury                        | Anti-tumor, hypodiploidiome, anti-anxiety, anti-oxidation, anti-aging                           | —                             | The contents of Cu, As, Cd, Hg, and Pd in P. notoginseng (Burkill) F.H.Chen were determined. The linear coefficient of the five elements in their respective linear range is r > 0.9995, the recovery is 95.0%–99.6%, and the RSD of the six repeatability tests is ≤ 4.396% (Ku, 2012). |
| Panax quinquefolius L.                        | Traditional Chinese medicine | Cardiovascular diseases                               | Antioxidant, anti-tumor, anti-aging, and immune regulation                                   | —                             | The contents of Cu, Cr, Zn, Pb, Ni, Cu, Y, Sn, As, Mo, Se, and Co in P. quinquefolius L. and garden cultivated American ginseng were determined. The linear ranges of element detection mass concentrations were 0.1–500 μg/g (r = 0.9998), 0.5–500 μg/g (r = 0.9998), 0.1–500 μg/g (Continued on following page) |
TABLE 1  |  (Continued) Application of ICP-MS in the determination of heavy metal elements in medicinal materials derived from the roots of plants.

| Latin name               | Medical system               | Therapeutic use                   | Main pharmacological effects                              | Origin of medicinal materials* | Test results |
|--------------------------|------------------------------|-----------------------------------|-----------------------------------------------------------|-------------------------------|--------------|
| Pseudostellaria helvolys (*Miq.* Pax) | Traditional Chinese medicine | Inappetance, cough                | Anti-inflammation, anti-tumor, anti-oxidation, hypoglycemic, immune regulation | Fujian province of China      | 0.9999, 0.5–5.0 μg/L (r = 0.9990, 0.5–5.0 μg/L (r ≤ 0.9990), 0.1–2.00 μg/L (r = 0.9999), 0.1–2.00 μg/L (r = 0.9998), 1–500 μg/L (r = 0.9997), the quantitation limits are less than 0.60 μg/L, and the detection limits are less than 0.2 μg/L. ICP-MS was less than 3%. The recovery was 97.66%–106.65%. ICP-MS was 0.64%–2.33%, n = 9 (Lin et al., 2018). The contents of Mg, Ca, Mn, Fe, Cu, Zn, and Se in P. helvolys (*Miq.* Pax) from Zhejiang County, Fujian province, China, were determined. The recoveries of each element were 92.11%–107.51%, and the FSD was less than 5.0%. |}
| Pueraria montana var. thomsonii (Barth.) M. R. Almeida | Traditional Chinese medicine | Heartache, stroke hemeplegia      | Anti-inflammatory, analgesic, and anti-inflammatory         | —                            | —            |
| Pueraria edulis Pamp.    | Traditional Chinese medicine | Muscle, chest pain                 | Anti-inflammatory, anti-oxidation, anti-tumor, anti-diabetes | Anhui, Guangxi, Hunan, Henan, Hubei, Zhejiang, Sichuan, Guizhou, Jiangxi, and Hubei provinces or autonomous regions of China | —            |
| Rehmannia glutinosa (Gaertn.) DC. | Traditional Chinese medicine | Hematemesis, swelling, and pain in the throat | Antibacterial, anti-tumor, anti-gastric ulcer, anti-aging | —                            | —            |
| Reynoutria japonica Houtt. | Traditional Chinese medicine | Amenomegaly, traumatic injury, cough, constipation | Antibacterial, anti-inflammatory, anti-tumor, improving Alzheimer’s disease | Guangxi Zhuang Autonomous Region of China | —            |
| Reynoutria multiflora (Thunb.) Middendorf | Traditional Chinese medicine | Dizziness, constipation            | Anti-aging, anti-tumor, hypolipidemic, anti-atherosclerotic, anti-atherosclerotic | Henan, Shaanxi, Guangxi, Anhui, Sichuan, Hubei, Yunnan, Guizhou, Guangxi, and Guangdong provinces or autonomous regions of China | —            |
| Rhododendron rosea L.     | Traditional Chinese medicine | Heartache, stroke hemeplegia      | Anti-inflammation, anti-oxidation, anti-fatigue, and anti-cancer | —                            | —            |
| Rosa laevigata Michx.     | Traditional Chinese medicine | Spermatophore, aneurism, diabetes, uterine prolapse | Anti-inflammatory, antibacterial, anti-tumor, and immune regulation | Guangxi Zhuang Autonomous Region of China | —            |
| Rubia cordifolia L.       | Traditional Chinese medicine | Inflammation, tumor                | Anti-inflammation, anti-tumor, anti-infection, neuroprotection | Shanxi province of China      | —            |
and Zhang, 2017). It can be seen that heavy metal elements are also toxic and medicinal. Many medicinal preparations containing heavy metals may be the material basis of efficacy, which are relative. For example, in the view of traditional Chinese medicine, drugs are toxic, they are partial, and there must be drugs if there is great toxicity. Therefore, excessive accumulation of heavy metals may be quite harmful to the body, but appropriate use or different valence forms, or the effect of this heavy metal is just needed by the disease so that it can become a good medicine.

Fe element has a hematopoietic function in the human body; participates in synthesizing hemoglobin, myoglobin, cytochrome, and various enzymes; promotes growth and development; and transports oxygen and nutrients in the blood (Guo et al., 2015). It is related to the pathogenesis of Alzheimer’s disease, Parkinson’s syndrome, and

**TABLE 1 | (Continued) Application of ICP-MS in the determination of heavy metal elements in medicinal materials derived from the roots of plants.**

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials* | Test results |
|------------|----------------|----------------|-----------------------------|--------------------------------|-------------|
| Salvia miltiorrhiza Bunge | Traditional Chinese medicine | Irregular menstruation, insomnia, stenocardia | Anti-inflammatory, antipressant, anti-tumor, anti-fibrin, anti-HIV virus | Anhui province of China | China, were determined. There are differences in the contents of heavy metals in wild R. cordifolia L. from different producing areas. The contents of Cu, Cd, Pb, Hg, and As are lower than the limit standard of heavy metals. (Feng et al., 2018) |
| Sargentsoda cuneata (Hk.) Rehder & E. H. Wilson | Traditional Chinese medicine | Abnormal menstruation, blood circulation, insomnia | Anti-bacterial, anti-inflammatory, anti-tumor, anti-fibrin, immune-suppressive | Hunan, Anhui, and Zhejiang provinces of China | Determination of 23 elements, Na, Mg, Al, K, Ca, V, Cr, Mn, Fe, Cu, Ni, Co, Zn, As, Se, Pb, Ag, Cd, Cs, Ba, Hg, and Pb in S. cuneata (Hk.) Rehder & E. H. Wilson in Hunan, Anhui, and Zhejiang provinces of China. For the measured elements, the correlation coefficient of the standard curve is r > 0.9987, and the relative standard deviation of the method accuracy experiment is RSD < 9.1%. (Li et al., 2017) |
| Scutellaria baicalensis Georgi | Traditional Chinese medicine | Jaundice, cough | Anti-bacterial, anti-inflammatory, anti-tumor, cardiovascular and cerebrovascular protection, anti-organ fibrosis | Beijing and Jiangsu, Heilongjiang, Gansu, Shandong, Shanshi, Hebei, and Shandong provinces or municipalities of China | The contents of 23 inorganic elements, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Ga, Ge, Hg, Li, Mn, Ni, Pb, Sb, Sn, Sr, Ti, V, Zn, and other elements in S. baicalensis Georgi stems and leaves from eight producing areas were determined. The contents of Fe and As are the highest, followed by B, Ti, Mn, Sr, and Ba. (Yan et al., 2018) |
| Sophora tomentosa Gagnep. | Traditional Chinese medicine | Toothache, cough, jaundice, constipation, hemorrhoids | Anti-inflammation, anti-tumor, liver protection, and immunity enhancement | Guangxi Zhuang Autonomous Region of China | The contents of heavy metals Zn, Ba, Cu, Cr, Ni, Pb, As, Sb, Co, Cd, Sn, Ti, Bi, and Hg in the roots of S. tomentosa Gagnep. in Guangxi, China, were determined. The detection limit is 0.0014-0.0424 μg/L, the recovery is 91.3%-106.5%, and the RSD value is 0.43%-0.57%. The contents of heavy metals in the roots of kidney beans from different producing areas were basically consistent: Zn > Ba > Cu > Cr > Ni > Pb > As > Sb > Co > Cd > Sn > Ti > Bi > Hg. (Ge et al., 2013) |
| Stellera chamaejasme L. | Traditional Chinese medicine | Tumor, lymphonodus, psoriasis | Anti-cancer, anti-lichenoma, antibacterial and antiviral | — | The contents of 12 trace elements, Al, Fe, Cu, Ni, Co, Zn, As, Se, Cd, Ba, Hg, and Pb in S. chamaejasme were determined. There was no significant difference in the contents of 12 elements, but the contents of Mn, Zn, Ba, and Pb in E. variegata were significantly higher than those in E. lutea. (Yan et al., 2013) |
| Talnux paninculatum (Jacq.) Gaertn. | Traditional Chinese medicine | Malaria, hemorhage | Antidiarrhea | — | The contents of Fe, Mn, Cu, Zn, Ba, Co, Ni, and Cd in T. paninculatum (Jacq.) Gaertn. were determined. The linear range of Mn, Cu, Zn, Ba, Co, and Fe is 0.5-500 μg/L, Ni and Cd are linear at 0-100 μg/L, the linear correlation coefficient is 0.9947-0.9999, and the detection limit is 0.0007-0.02 mg/kg. The RSD of the reference materials is between 4.45% and 9.19%. (Gao et al., 2019) |
| Trichosanthes kirilowii Maxim. | Traditional Chinese medicine | Cough | Anti-inflammatory, antibacterial, antiviral, and hypoglycemic | Anhui province of China | The contents of 12 trace elements, Pb, Co, As, Hg, Cu, Mg, Cr, Mn, K, Sr, and Fe in 7. Antiklo Maxim. From different producing areas in the Anhui province of China were determined. The contents of Pb, Co, As, Hg, Cu, and other five heavy metals in T. kirilowii and Angios in Anhui province are lower than the values specified in the Chinese Pharmacopoeia. There were significant differences in the contents of K, Mn, Mg, Sr, and other elements in 7. Antiklo Maxim. between the two producing areas. (Song et al., 2019) |

*Note: the origin of medicinal materials recorded in the table is collected from the articles. If the origin of medicinal materials is not recorded in the articles, it is indicated by "—."
| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials | Test results |
|------------|----------------|----------------|-------------------------------|-----------------------------|-------------|
| Acorus calamus L. | Traditional Chinese medicine | Forgetfulness, tinnitus, deafness, traumatic injury | Antidepressant, anti-anxiety, antihypertensive, antibacterial, anti-tumor | Sichuan province of China | The contents of Mg, P, Ca, Cr, Mn, Fe, Cu, Ni, Zn, As, Cd, Hg, and Pb in A. calamus L. were determined. They are Fe-679, Mn-127.5, Cu-15.3, and Zn-36.7 mg/kg, respectively. As is 1.1 mg/kg, the contents of Cr, Ni, and Pb are less than 0.5 mg/kg, and the contents of Cd and Hg are less than 0.05 mg/kg. The contents of major elements Ca, P, and Mg are relatively high, which are Ca-6101, P-3706, and Mg-130 mg/kg, respectively. (Li, 2017) |
| Allium victorialis L. | Traditional Chinese medicine | Cardiopathy, hypertension, atherosclerosis | Anti-inflammation, bacteriostasis, anti-neurodegeneration, prevention, and treatment of cardiovascular diseases | Dongling County, Jilin province, China | The contents of Li, Ba, Bi, Se, V, Cr, Mn, Fe, Cu, Ni, Zn, Ga, Ge, As, Sb, Pb, Sr, Zr, Nb, Mo, Ag, Cd, Sn, Sb, Bi, Te, Sb, Ta, Cs, Ba, Hg, Ti, W, As, Ti, Pb, Bi, Th, and U in the stems and leaves of A. victorialis L. were determined. The mass concentration range of the measured elements is 0.009243 ± 0.0062 μg/L, r ≥ 0.9999; the detection limit is 0.00032 ± 0.0140 μg/L, the recovery rate is 97.11% ± 100.32%, and RSD ≤ 5.0%. The stems and leaves of A. victorialis L. are rich in trace elements, among which the content of Fe is the highest, followed by Mn, Sr, Ba, Zn, and Bi. The contents of heavy metal elements Cu, As, Pb, and Cd are lower than the national standard limit (Guo et al., 2020). |
| Anemarrhena asphodeloides Bunge | Traditional Chinese medicine | Cough, fever, constipation | Anti-tumor, hypoglycemic, improving Alzheimer’s disease | Hubei, Anhui, Inner Mongolia, Shanxi, Sichuan, and Jilin provinces or autonomous regions of China | The contents of Cu, As, Cd, Pb, and Hg in 20 batches of A. asphodeloides Bunge from six producing areas such as Hubei and Anhui were determined. One sample of heavy metal exceeding the standard is Cd, and the exceeding rate is 5.0% (Guo, 2019) |
| Atractylodes macrocephala Koidz. | Traditional Chinese medicine | Ulcers, constipation, insomnia, diabetes, hypertension, cancer | Anti-inflammation, bacteriostasis, improving gastrointestinal function and nerve function | Longhui, Pingjiang, and Longshan counties, Hunan province, China | The contents of 48 trace elements Li, Ba, Bi, Se, V, Cr, Mn, Cu, Ni, Cu, Zn, Ga, Ge, As, Sb, Pb, Sr, Zr, Nb, Mo, Ag, Cd, Sn, Sb, Bi, Te, Sb, Ta, Cs, Ba, Hg, Ti, W, As, Ti, Pb, Bi, Th, and U in the stems and leaves of A. macrocephala were determined. The linear relationship of each element is good, and the correlation coefficient of each standard curve is r ≥ 0.9996. The determination limit is 0.0001-0.1600 μg/L, RSD of precision, stability, and repeatability were less than 4.7%, 4.9%, and 4.4%, respectively. The recovery was 96.0%–101.1% and RSD was 0.3%–5.5% (Yang et al., 2019) |
| Bletilla striata (Thunb.) Robb.f. | Traditional Chinese medicine | Hemoptysis, hematemesis, traumatic bleeding, sore swallowing, poison | Anti-inflammatory, anti-tumor, antiviral microorganism, mucosal protection | Chonggang and Hubil provinces or municipalities of China | The residues of Pb, Cd, As, Hg, and Cu in B. striata (Thunb.) Robb.f. from different producing areas such as Hubil, Yunnan, Guizhou, and Sichuan province were determined. The linear relationship of the five elements is good (r > 0.9990), and the recovery is 99.6%–114% (Guo et al., 2020) |
| Cinnamomum arborescens (H. Boissier) Pimenov & Kjuykov | Traditional Chinese medicine | Heartache, irregular menstruation, amenorrhea, dysmenorrhea, headache | Anti-tumor, anticoagulant, anti-cerebral ischemia, and anti-depression | Sichuan province of China | The contents of Cr, Ni, Cu, Ni, Cu, Cd, Ba, Ti, and Pb in C. arborescens “Chuanxing” were determined. When the sample weight is 0.2 g, the determination results are Cr (1.7262 ± 0.180) mg/kg, Mn (55.529 ± 2.640) mg/kg, Co (5.2652 ± 0.012) mg/kg, Ni (1.1420 ± 0.065) mg/kg, Cu (8.8778 ± 0.400) mg/kg, As (0.1290 ± 0.010) mg/kg, Cd (0.4021 ± 0.030) mg/kg, Ba (12.2030 ± 1.520) mg/kg, Ti (0.0236 ± 0.0030) mg/kg, Pb (0.0701 ± 0.051) mg/kg (Dang et al., 2017a) |
| Codonopsis pilosula Franch. | Traditional Chinese medicine | Hypoglycemia, hypertension | Anti-inflammation, anti-arthrythmia, lowering blood pressure and anti-tumor — | — | The contents of 30 inorganic elements Mg, K, Cu, Mn, Fe, Ni, Zn, Pb, Sr, Ba, Ag, Pb, As, Cd, Cr, Li, Be, V, Co, Ga, Si, Y, Cs, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ti, and Th in 67 batches of C. pilosula Franch. were determined. The average contents of K, Mg, Mn, Zn, and Fe are the highest, and the content of rare earth elements is generally low (Zhou et al., 2021) |
| Corydalis yanhusuo (Y. H. Chou & Chun C. Hu) W. T. Wang ex Z. Y. Su & C. Y. Wu | Traditional Chinese medicine | Chest, flank, epigastric pain, heartache, dysmenorrhea | Analgesia, anti-anxiety, anti-myocardial ischemia, anti-gastric-ulcerative ulcer — | — | 1) The contents of nine heavy metals and harmful elements such as Cu, Ni, Cr, Pb, Cd, Sn, Co, Hg, and As in C. yanhusuo (Y. H. Chou & Chun C. Hu) W. T. Wang ex Z. Y. Su & C. Y. Wu were determined. The linear relationship between nine heavy metals and harmful elements is good (r > 0.9998), the detection limit is 0.0016-0.0227 μg/L, and the recovery rate is 96.0%–100.4%, RSD ≤ 3.25%. The contents of Cu, As, Hg, and Cd in C. yanhusuo (Y. H. Chou & Chun C. Hu) W. T. Wang ex Z. Y. Su & C. Y. Wu are lower than the limit values of the national standard green industry standard for the import and export of medicinal plants and preparations and the 2015 edition of Chinese Pharmacopoeia (Y. H. Chou & Chun C. Hu) W. T. Wang ex Z. Y. Su & C. Y. Wu were determined. The calibration curves of the five elements have a good linear relationship, and the recovery of each element is between 98.9% and 101.3% (Guo, 2017) |

(Continued on following page)
TABLE 2 | (Continued) Application of ICP-MS in the determination of heavy metals in medicinal materials derived from the stem of plants.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials | Test results |
|------------|----------------|----------------|-----------------------------|-------------------------------|-------------|
| Curcuma phaeocaulis Valeton | Traditional Chinese medicine | Tumor, inflammation, thrombus | Anti-inflammatory, hypoglycemic, and antioxidant | Hainan, Guangdong, Yunnan, and Guizhou provinces or autonomous regions of China | The elements of Li, Hg, Ba, Mg, Pb, K, V, Ca, Cu, Ti, As, Cr, Mn, Ba, Fe, Ti, Ni, Zn, Ga, Si, Na, Sr, Cd, and Al in C. phaeocaulis Valeton from different harvesting regions were determined. The contents of trace elements in C. phaeocaulis Valeton from different producing areas are different, and the contents of K, Ca, Mg, Mn, Fe, Al, Zn, and other elements are higher (Chen et al., 2017a). The contents of Fe, Mn, Zn, Cu, and Si in C. phaeocaulis Valeton were determined. Fe level is the highest, and Si level is the lowest among all plants. The TE series levels of all elements in all plants are as follows: Fe 100.4–1577.9, Mn 23.6–143.7, Zn 15.4–32.7, Si 0.13–0.92, and Cu 11.3–21.8 μg/g (Emira, 2018). | |
| Cymbopogon schoenanthus (L.) Sprung. | Arabic medicine | Malaria, cold, fever, asthma, and headache | Antibacterial and antioxidant | Saudi Arabia | The contents of Fe, Mn, Zn, Cu, and Si in C. schoenanthus (L.) Sprung. were determined. Fe level is the highest, and Si level is the lowest among all plants. The TE series levels of all elements in all plants are as follows: Fe 100.4–1577.9, Mn 23.6–143.7, Zn 15.4–32.7, Si 0.13–0.92, and Cu 11.3–21.8 μg/g (Emira, 2018). | |
| Dendrobium officinale Kimura & Migo | Traditional Chinese medicine | Hypertension, myocardial infarction, and liver injury, tumor | Enhance immunity, protect the liver, and improve gastrointestinal function | Anhui, Guizhou, Guangdong, Guizhou, Zhejiang, and Yunnan provinces or autonomous regions of China | The contents of Cu, Mn, Zn, and Cd in Dendrobium officinale Kimura & Migo were determined. There was a positive correlation between Ni and Zn (r = 0.986, p < 0.05). Ti was positively correlated with V (r = 0.669, p < 0.05), and negatively correlated with Cd (r = -0.710, p < 0.05). There was a positive correlation between Mn and Ba (r = 0.749, p < 0.05). Iron content was positively correlated with Ni (r = 0.664, p < 0.05), Zn (r = 0.742, p < 0.05), and rare earth (r = 0.847, p < 0.05) (Jia et al., 2019). | |
| Dioscorea oppositifolia L. | Traditional Chinese medicine | Hypertension, hypolipidemia | Hypoglycemic, hypolipidemic, antioxidant, and anti-tumor | Anhui, Henan, and Guizhou provinces of China | The contents of 17 elements of Na, Mg, K, Ca, Cr, Mn, Fe, Ni, Zn, Sr, Mo, Pb, Cd, Hg, Cu, and As in D. oppositifolia L. were determined. The detection limit is 0.01 μg/g, and the relative standard deviation is 95.4%. The recovery value is 90.3–99.9%, and the detection limit is 0.0004–0.016 μg/g, the linear relationship is good, the correlation coefficient is 0.9999–0.9999, and the recovery rate of standard addition is 95%–105%, and the determination result is accurate (Jia et al., 2019). | |
| Gastrodia elata Blume | Traditional Chinese medicine | Intestinal colic, headache, epilepsy, tinnitus | Anti-convulsant, antidiarrheal, neuroprotective | Anhui, Yunnan, Shaanxi, Guizhou, Henan, Heilongjiang, and Chongqing provinces or municipalities of China | The contents of 24 inorganic elements of Li, Na, Mg, K, Ca, Cr, Mn, Fe, Ni, Zn, Sr, Mo, Pb, Cd, Hg, Cu, and As in D. elata Blume from different habitats were determined. The linear relationship of 20 elements to be tested is good (r = 0.973, the RSD of the stability test is 8.2% (Jia et al., 2011). | |
| Hirs domesticus (L.) Goldblatt & Mab. | Traditional Chinese medicine | Cough, inflammation, tonsillitis, and lumbago | Anti-inflammatory, antibacterial, and antiviral | Henan, Hebei, Henan, and Guizhou provinces of China | The contents of the Harley's herbs, hirs, and Cu in 13 batches of H. domesticus (L.) Goldblatt & Mab. from different producing areas are different, and the contents of K, Ca, Mg, Mn, Fe, Al, Zn, Pb, Cd, and As in Hirs domesticus were determined. Among 13 batches of samples from seven producing areas, only four batches of samples have all elements within the limit, and other samples have different elements exceeding the standard, of which the exceeding standard rate of Cd element is 62% (Zhu et al., 2016). | |
| Maloepe plelefolia (Champ. ex Berth.) T.G.Hartley | Traditional Chinese medicine | Pharyngalgia, malaria, icterus, hepatitis, cold, fever, and tonsillitis | Anti-inflammation and analgesia | — | The contents of Cu, Pb, Hg, As, and Cd in M. plelefolia (Champ. ex Berth.) T.G. Hartley were determined. The correlation coefficient of the standard curve of the measured elements is in the range of 0.9996–0.9999, and the linear relationship is good. The average recovery of the method is 94.8%–96.6%, and the RSD is 4.6%–5.4% (Long et al., 2013). | |
| Phoebe buiococoides (Franch.) Rolfe | Traditional Chinese medicine | Snakebites | Anti-tumor | Guizhou province of China | The contents of Cu, Pb, Hg, As, Ca, Mg, Cu, Sn, Zn, and Si in P. buiococoides (Franch.) Rolfe were determined. The linear relationship of each element is good, and the correlation coefficient is greater than 0.995. The relative standard deviation (RSD) of repeatability is less than 7.5%. Relative standard deviation of precision (RSD) < 4%. The recovery was 81.37%–114.61% (Chen et al., 2020). | |
| Poligonum odoratum (Mill.) Druce | Traditional Chinese medicine | Hypertension, inflammation | Antioxidant, hypoglycemic, anti-tumor, and antibacterial | — | The contents of Cu, Pb, Hg, As, Ca, Mg, Cu, Sn, Zn, and Si in P. odoratum (Mill.) Druce were determined. The contents of K, Ca, Mg, Mn, Fe, Al, Zn, and other elements are also measured. The TE series levels of all elements in all plants are as follows: Fe 100.4–1577.9, Mn 23.6–143.7, Zn 15.4–32.7, Si 0.13–0.92, and Cu 11.3–21.8 μg/g (Emira, 2018). |
TABLE 2 | (Continued) Application of ICP-MS in the determination of heavy metals in medicinal materials derived from the stem of plants.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials* | Test results |
|------------|----------------|----------------|-----------------------------|-------------------------------|-------------|
| Sargentodoxa cuneata (Oliv.) Rehder & E.H.Wilson | Traditional Chinese medicine | Amenorrhea, dysemnorrhoea | Antibacterial, antiviral, anti-Inflammatory, anti-tumor, immunosuppressant | Hunan, Anhui, Zhejiang, and Jiangxi provinces of China | 0.71 μg/g, Cd 0.43 μg/g, Tl 0.063 μg/g. Be content is the least, only 0.028 μg/g. (Bu et al., 2018). Determination of 23 elements Na, Mg, Al, K, Ca, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Pb, Ag, Cd, Ca, Ba, Hg, and Po in S. cuneata (Oliv.) Rehder & E.H. Wilson in Hunan, Anhui, and Zhejiang, China. For the measured elements, the correlation coefficient of the standard curve is $r > 0.9987$, and the relative standard deviation of the method accuracy experiment is RSD > 9.1%. (Bu and Shu, 2019). |
| Sauromatum giganteum (Engl.) Cusimano & Hett. | Traditional Chinese medicine | Tinnitus, epilepsy, snakebites | Anti-infection, anti-convulsion, anti-tumor | Henan, Jilin, Shaanxi, and Sichuan provinces of China | The contents of Ni, Zn, As, Cd, Pb, Cr, Cu, Mn, Ba, Co, Sr, Ti, Fe, Al, K, Mg, P, and Hg in S. giganteum (Engl.) Cusimano & Hett. were determined. The contents of K, P, Mg, Fe, Zn, Al, and Mn are high. (Bu et al., 2018a). The matrix effect was compensated with Ba, Y, Sc, In, and Re as internal standards. The contents of 28 elements Li, B, Na, Mg, Al, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Sr, Mo, Ag, Cd, Sn, Sb, Bi, Pb, and Bi in S. giganteum (Thunb.) Rehder & E. H. Wilson were determined. The detection limit of each element is 0.01–0.8 μg/g. The standard deviation is 0.11%–2.57%, and the recovery is 94.00%–110.80%. The content of 16 elements in Sauromatum giganteum is 2 mg/kg, among which K, Mg, CA, and other elements have the highest content (Duan et al., 2018a). |
| Sinomenium acutum (Thunb.) Dunn | Traditional Chinese medicine | Rheumatoid arthritis pain, chronic glomerulonephritis, arthritis, and arthralgia | Anti-inflammatory, analgesic, and anti-tumor | Guangxi Zhuang autonomous region of China | The contents of 28 elements of Li, B, Na, Mg, Al, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Sr, Mo, Ag, Cd, Sn, Sb, Bi, Pb, and Bi in S. acutum (Thunb.) Rehder & E. H. Wilson were determined. The detection limit of each element is 0.01–0.8 μg/g. The standard deviation is 0.11%–2.57%, and the recovery is 94.00%–110.80%. The content of 16 elements in Sinomenium acutum is 2 mg/kg, among which K, Mg, CA, and other elements have the highest content (Duan et al., 2018b). |
| Sparganium stoloniferum (Buch.-Ham. ex Graniot.) Buch.-Ham. ex Juz. | Traditional Chinese medicine | Dysemnorrhoea,amenorrhea, headache | Anti-inflammation, analgesia, anti-tumor, anti-fibrosis, and inhibition of ovarian cyst | — |
| Spatholobus suberectus Dunn | Traditional Chinese medicine | Tumor, viral cold | Anti-inflammatory, analgesic, anti-tumor, antiviral, anti-depressive | Guangxi Zhuang autonomous region of China | The contents of 28 elements of Li, B, Na, Mg, Al, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Sr, Mo, Ag, Cd, Sn, Sb, Bi, Pb, and Bi in S. suberectus Dunn were determined. The detection limit of each element is 0.01–0.8 μg/g. The standard deviation is 0.11%–2.57%, and the recovery is 94.00%–110.00%. There are 13 elements with a content of more than 2 mg/kg, among which the contents of Ca, K, Mg, and other elements are the highest (Su et al., 2019). |
| Taxillus chinensis (DC.) Danser | Traditional Chinese medicine | Rheumatism, metronhagia | Anti-tumor, lowering blood pressure, lowering blood lipid | Guangxi Zhuang autonomous region of China | The contents of Pb, Cr, Hg, As, Cu, and Cd T. chinensis (DC.) Danser were determined. The average contents of the six elements accord with Cu = Pb > Hg > Cr > Cd (Elson et al., 2017). |
| Uncaria rhynchophylla (Miq.) Mor. | Traditional Chinese medicine | Hypertension, arthralgia, Alzheimer’s disease | Anti-inflammatory, analgesic, and anticancer | Guizhou province of China | The contents of K, Ca, Mg, Na, Fe, Mn, Cu, Zn, Mo, Co, Pb, Cr, Hg, As, and Cd in the mixed samples of hook and stem of U. rhynchophylla (Miq.) Mor. in Guizhou province, China, were determined. The contents of trace elements Na, Mg, K, Ca, Mn, Co, and Zn are greater than those in the hook. The highest content of trace elements in hook and stem was K, followed by Ca. The content of heavy metal elements Cr, Cd, and Pb in the stem is slightly higher than that in the hook, the content of Hg in the hook is higher than that in the stem, some exceed the standard, and the content of Cu and As in the hook and stem is close (Zhang et al., 2018). |
| Zingiber officinale Roscoe | Traditional Chinese medicine | Inflammation, arthralgia, myocardial ischemia, tumor | Anti-inflammatory, analgesic, and bacteriostatic | — |

*Note: the origin of medicinal materials recorded in the table is collected from the articles. If the origin of medicinal materials is not recorded in the articles, it is indicated by “—.”
| Latin name                | Medical system | Therapeutic use                          | Main pharmacological effects                                                   | Origin of medicinal materials | Test results                                                                 |
|--------------------------|----------------|------------------------------------------|--------------------------------------------------------------------------------|-------------------------------|-------------------------------------------------------------------------------|
| Ambrosia artemisiifolia L. | Arabic medicine | Respiratory and reproductive system related diseases | Anti-inflammatory, analgesic, antibacterial, antiviral, and anticoagulant         | Saudi Arabia                  | The contents of Al, Pb, Cd, and As in A. artemisiifolia L. were determined.    |
|                          |                |                                          |                                                                                 |                               | The recoveries of all measured elements were 86.1%–90.6%. The content of Al element is the highest, and the concentration range of Al is 156–1609 mg/kg. The content of Cd is the lowest, and the concentration of Cd is in the range of 0.01–0.10 mg/kg. The washing process reduces toxic elements in all plants. The average recoveries were Al (47.32%), As (59.1%), Cd (62.03%), and Pb (92.40%) (Shen et al., 2017). |
| Artemisia vulgaris L.     | Arabic medicine | Respiratory and reproductive diseases     | Anti-inflammatory and antibacterial                                             | Saudi Arabia                  | The contents of Fe, Mn, Zn, Cu, and Se in A. vulgaris L. were determined. Fe level is the highest, and Se is the lowest. Te series level: Fe 100.4–1757.9 μg/l, Mn 23.6–143.7 μg/l, Zn 15.4–32 μg/l, Cu 0.13–0.92 μg/l, and Cd 11.3–21.8 μg/l (Shen et al., 2018). |
| Callicarpa nudi flora Hook. & Am. | Traditional Chinese medicine | Acute infectious hepatitis, traumatic bleeding, respiratory bleeding, gastrointestinal bleeding | Antibacterial, anti-inflammatory, antiviral, and anti-tumor                      | —                             |                                                                                   |
| Crataegus pinnatifida Bunge | Traditional Chinese medicine | Heartache, palpitation, hyperlipidemia    | Anti-atherosclerotic, hypoglycemic, and liver-protective                        | Liaoning province of China    |                                                                                   |
| Cynarodon japonica Aresch. | Traditional Chinese medicine | Amenorrhea, dysostoa, cough, hematemesis, cancer | Anticancer                                                                        | Guangxi, Jiangsu, Inner Mongolia, Anhui, Guangdong, and Yunnan provinces, municipalities or autonomous regions of China |
| Laminaria japonica Aresch. | Traditional Chinese medicine | Thyromegaly, cervical lymphadenopathy, bronchitis, tuberculosis, cough, senile cataract | Antibacterial, antiviral, hypoglycemic, and anti-tumor                          | —                             |                                                                                   |
| Morus alba L.             | Traditional Chinese medicine | Hyperglycemia, cancer, viral cold          | Hypoglycemic, hypolipidemic, antiviral, and anti-tumor                          | Guangdong province of China   |                                                                                   |
| Pityusicus orientalis (L.) Franco | Traditional Chinese medicine | Hematemesis, epistaxis, hemoptysis, hematochezia | Antibacterial, anti-inflammatory, anti-tumor, antioxidant, and hypolipidemic     | Shanghai, Hunan, Hainan, Hebei, Chongqing, Gansu, Henan, and Anhui provinces or municipalities of China |

(Continued on following page)
osteoarthritis (Zheng et al., 2016). Hexavalent chromium is carcinogenic for humans. Indeed, extensive literature demonstrates the carcinogenic effects of chromium (VI) (Locatelli et al., 2014). Zn is a component of many enzymes in the human body and participates in synthesizing DNA and RNA polymerase. It is an important element in maintaining the integrity of skin and mucosa and promoting wound healing. At the same time, it can increase lymphocyte function and remove oxygen-free radicals in the body. It can prevent bacterial and virus invasion and anti-cancer. When the body lacks Zn, it will cause aging of tissue cells and a decline in immunity, and epithelial cells are vulnerable to carcinogens, resulting in carcinogenesis (Wang and Jin, 2018). However, Zn cannot be synthesized in the body and must be supplemented through dietary regulation. When the supply is insufficient or the proportion is unbalanced, it can directly affect the normal growth and development of children. Cr is involved in the metabolism of carbohydrates, and heat energy. Mg can activate various enzymes in the human body; strengthen the excitability of muscles; maintain the rhythm of the heartbeat; and participate in the metabolism of protein, carbohydrates, and heat energy.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials | Test results |
|------------|---------------|----------------|-----------------------------|-----------------------------|--------------|
| Psidium guajava L. | Traditional Chinese medicine | Dysentery, acute enteritis, chronic enteritis | Hypoglycemic, hypolipidemic, and antiviral | Guizhou, Guanxi, Guangdong, Yunnan, Jiangxi, Hainan, and Fujian provinces or autonomous regions of China | element was 0.224–1.792 μg·L⁻¹; the recovery was 81.0%–117.1%. 63 batches of P. orientalis (L.) Franco leaf samples, the contents of Hg, Cu, Cd, and Pb were low. As was not detected, some samples of Ba exceeded the limit, most samples of Pb exceeded the limit, and Al exceeded the limit (Zhang et al., 2018). The contents of Be, Ti, V, Cr, Mn, Co, Ni, Cu, As, Sr, Mo, Cd, Si, Pb, and Hg in leaves of P. guajava L. were determined. The linear relationship of each element is good, and the correlation coefficient is greater than 0.956. The RSD of each element is less than 4.57%, the RSD of sample repeatability is less than 12.09%, and the recovery range of each element is 76.96%–118.55% (Li et al., 2018a). 1) The contents of Fe, Mn, Zn, Cu, and Se in V. agnus-castus L. were determined. Fe level is the highest, and Se level is the lowest among all plants. The TE series levels of all elements in all plants are as follows: Fe 193.4–1757.9 μg/g, Mn 23.6–143.7 μg/g, Zn 15.4–32.7 μg/g, Se 0.13–0.92 μg/g, and Cu 11.3–21.6 μg/g (Elma, 2018) 2) The contents of Al, Pb, Cd, and As in V. agnus-castus L. were determined. The recoveries of all measured elements were 86.1%–90.6%. The content of Al element is the highest, and the concentration range of Al is 156–1609 mg/kg. The content of Cd is the lowest, and the concentration of Cd is in the range of 0.01–0.10 mg/kg. The washing process reduces toxic elements in all plants. The average % recoveries were Al (47.32%), As (59.1%), Cd (62.03%), and Pb (32.40%) (Elma, 2017) |
| Vitis agnus-castus L. | Arabic medicine | Irregular menstruation | Anti-inflammatory, antibacterial, anticancer, and antioxidant | Saudi Arabia | *Note: the origin of medicinal materials recorded in the table is collected from the articles. If the origin of medicinal materials is not recorded in the articles, it is indicated by “—.”* |
### TABLE 4 | Application of ICP-MS in the determination of heavy metal elements in medicinal materials derived from the flowers of plants.

| Latin name                     | Medical system                       | Therapeutic use                      | Main pharmacological effects               | Origin of medicinal materials | Test results                                                                                                                                                                                                 |
|--------------------------------|--------------------------------------|--------------------------------------|--------------------------------------------|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Carthamus tinctorius L.        | Traditional Chinese medicine         | Amenorrhea, dysmenorrhea, tumbling injury | Anti-inflammation, anti-aging, anti-tumor, and anti-arrhythmia | Xinjiang, Henan provinces or autonomous regions of China | 1) The contents of various elements in C. tinctorius L. in Xinjiang and Henan provinces of China were determined. 19 elements in safflower include heavy metals As, Cd, Cu, Hg, Pb, and healthy elements Al, Co, Cr, Fe, Mg, Mn, Mo, Ni, P, Se, Sr, V, and Zn. The contents of heavy metals in the samples are low. Except for Pb in Xinjiang samples, the rest meet the national health standards (Jia et al., 2011).
2) The contents of 22 trace elements Li, Be, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, As, Sr, Mo, Pb, Ag, Cd, In, Cs, Ba, Hg, Ti, and Bi in C. tinctorius L. were determined. The correlation coefficients of regression equations of all elements were >0.99. The recovery was 85.9%–107.2%. Except for Ni, Zn, and Ag, the content of the other 19 elements in C. tinctorius L. is high (Yin et al., 2014). |
| Crocus sativus L.              | Tibetan medicine                     | Amenorrhea, symptoms, depression, stuffiness, palpitation, and madness | Anti-tumor and immune regulation           | —                             | The contents of 22 trace elements Li, Be, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, As, Sr, Mo, Pb, Ag, Cd, In, Cs, Ba, Hg, Ti, and Bi in C. sativus L. were determined. Each element $r > 0.99$. The recovery was 85.9%–107.2%. The contents of Ni, Zn, and Ag in C. sativus L. were high (Yin et al., 2014). |
| Chrysanthemum morifolium (Ramat.) Hemsl. | Traditional Chinese medicine         | Cold, intestinal carbuncle             | Anti-inflammatory, antibacterial, anti-aging, and antioxidant | Jiangsu, Zhejiang, and Hubei provinces of China | 1) The contents of Pb, Cd, As, Hg, and Cu in C. morifolium (Ramat.) Hemsl. from Jiangsu, Zhejiang, and Hubei provinces of China were determined. The RSD of precision, repeatability, and stability of the five elements is less than 3.0%, and the recovery rate ($n = 6$) is 87.9%–105.8% (Deng et al., 2020).
2) The contents of 16 elements Pb, Cd, As, Hg, Cu, Sb, Sn, Cr, Ni, Ba, Mn, Ti, Ag, Be, Dy, and Al in C. morifolium (Ramat.) Hemsl. were determined. The linear relationship of the standard curves of 16 elements is good. The linear correlation coefficient of all elements is $r > 0.9995$, the detection limit is $0.002$–$0.455$ g·kg$^{-1}$, the recovery of each element is 84%–107%, and the RSD < 5% (Xi et al., 2012). |
| Chrysanthemum indicum L.        | Traditional Chinese medicine         | Eye pain, headache, dizziness         | Antibacterial, antiviral, antitumor, hypotensive, and hypolipidemic | Hubei, Henan, and Anhui provinces of China | The contents of 18 elements As, B, Ba, Cd, Co, Cr, Cu, Ga, Hg, Li, H, Mo, Ni, Sb, Se, Pb, Rb, Sr, and Zn in C. indicum L. in Hubei, Henan, and Anhui provinces of China were determined. The contents of inorganic elements of C. indicum L. in different provinces were different (Chen et al., 2020a). The contents of 27 metal elements such as Li, Be, B, Mg, Al, Co, N, Ga, Rb, Sr, Te, Ba, Bi, U, V, Cr, Mn, Fe, Cu, Zn, As, Se, Mo, Ag, Cd, Ti, and Pb in the seed and seed coat of L. leucocephala (Lam.) de Wit produced in Jianshui County, Yunnan province of China were determined. Eight metal elements such as As, Se, Mo, Ag, and Pb were not detected. The detection limits of the method were Fe 9.789, Cr 2.691, Zn 1.803, B 2.076, Mg 1.977, Al 3.024, Ni 1.824 ng/ |
Thunb. The contents of Li, Be, Ga, V, Cr, Mn, Co, Ni, Cu, As, Sr, Mo, Cd, Sn, Sb, Ba, Hg, Ti, Pb, and Bi in L. hypoglauca Miq. and Lonicera confusa DC. were determined. The linear relationship of each element is good. The detection limit of the method is 0.004–0.071 μg L⁻¹. Good precision and accuracy. The recovery is in the range of 80%–100% (Yu and Liu, 2015).

1) The contents of 27 metal elements Li, Be, Mg, Al, Co, Ni, Ga, Rb, Sr, Te, Ba, Bi, U, V, Cr, Mn, Fe, Cu, Zn, As, Se, Mo, Ag, Cd, Tl, and Pb in L. japonica Thunb. produced in Hubei province of China were determined. The detection limits of the method were 9.789 ng/ml for Fe, 2.691 ng/ml for Cr, 1.803 ng/ml for Zn, 2.076 ng/ml for B, 1.877 ng/ml for Mg, 3.024 ng/ml for Al, 1.824 ng/ml for Ni, 0.003–0.921 ng/ml for other elements, 0.146%–7.627% for precision, and 90.0%–110.0% for recovery (Shu et al., 2012).

2) The contents of Pb, Cd, Cr, As, Hg, Ni, Mn, Cu, and Zn in L. japonica Thunb. were determined. The content of Cd was the highest (40.2%), followed by Cu (37.6%) and Pb (8.5%). As and Hg do not exceed the standard value, and Cr, Ni, Mn, and Zn are not limited (Fan et al., 2020). The contents of harmful elements Cu, Cd, Pb, As, and Hg in W. chamaedaphne (Bunge) Mein. were determined. Cu, Pb, Cd, and As in 0.5–100 μg/L, Hg in 0.1–10 μg/L showed a good linear relationship, r ≥ 0.99, and the recovery was 95.24%–101.16% (Li et al., 2020). The contents of inorganic elements such as B, Na, Mg, Al, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Sr, Mo, Cd, Sn, Sb, Ba, Hg, Ti, and Pb in Zea mays L. were determined. The content of the K element is the highest, 16.436.57–19.599.22 mg/kg. The content of Mn in trace elements is the highest, 27.22–36.19 mg/kg (Chen et al., 2020).

**TABLE 4 | (Continued) Application of ICP-MS in the determination of heavy metal elements in medicinal materials derived from the flowers of plants.**

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials* | Test results |
|------------|----------------|----------------|------------------------------|-----------------------------|-------------|
| *Lonicera* hypoglauca Miq. | Traditional Chinese medicine | Throat obstruction, erysipelas | Antiviral microorganism, anti-inflammatory, antioxidant and anti-tumor | Shandong province of China | ml, and other elements 0.003–0.921; RSD of seed precision 0.141%–11.86%, RSD of seed coat precision 0.044%–31.14%, and recovery between 90.8% and 107.1% (Zhang et al., 2012a). The contents of Li, Be, Ga, V, Cr, Mn, Co, Ni, Cu, As, Sr, Mo, Cd, Sn, Sb, Ba, Hg, Ti, Pb, and Bi in L. hypoglauca Miq. and Lonicera confusa DC. were determined. The linear relationship of each element is good. The detection limit of the method is 0.004–0.071 μg L⁻¹. Good precision and accuracy. The recovery is in the range of 80%–100% (Yu and Liu, 2015). |
| *Lonicera* japonica Thunb. | Traditional Chinese medicine | Heatstroke, throat obstruction, various infectious diseases | Anti-inflammatory, antibacterial, antiviral, hypolipidemic, and hypoglycemic | Shandong, Henan, Hebei, Chongqing, Hubei provinces or municipalities of China | 1) The contents of 27 metal elements Li, Be, B, Mg, Al, Co, Ni, Ga, Rb, Sr, Te, Ba, Bi, U, V, Cr, Mn, Fe, Cu, Zn, As, Se, Mo, Ag, Cd, Tl, and Pb in L. japonica Thunb. produced in Hubei province of China were determined. The detection limits of the method were 9.789 ng/ml for Fe, 2.691 ng/ml for Cr, 1.803 ng/ml for Zn, 2.076 ng/ml for B, 1.877 ng/ml for Mg, 3.024 ng/ml for Al, 1.824 ng/ml for Ni, 0.003–0.921 ng/ml for other elements, 0.146%–7.627% for precision, and 90.0%–110.0% for recovery (Shu et al., 2012). 2) The contents of Pb, Cd, Cr, As, Hg, Ni, Mn, Cu, and Zn in L. japonica Thunb. were determined. The content of Cd was the highest (40.2%), followed by Cu (37.6%) and Pb (8.5%). As and Hg do not exceed the standard value, and Cr, Ni, Mn, and Zn are not limited (Fan et al., 2020). |
| *Wikstroemia* chamaedaphne (Bunge) Mein. | Traditional Chinese medicine | Acute infectious hepatitis, chronic infectious hepatitis, schizophrenia, epilepsy | Anti hepatitis B virus | Shanxi and Anhui provinces of China | 1) The contents of 27 metal elements Li, Be, Mg, Al, Co, Ni, Ga, Rb, Sr, Te, Ba, Bi, U, V, Cr, Mn, Fe, Cu, Zn, As, Se, Mo, Ag, Cd, Tl, and Pb in L. hypoglauca Miq. and Lonicera confusa DC. were determined. The linear relationship of each element is good. The detection limit of the method is 0.004–0.071 μg L⁻¹. Good precision and accuracy. The recovery is in the range of 80%–100% (Yu and Liu, 2015). |
| *Zea* mays L. | Traditional Chinese medicine | Jaundice, cholecystitis, hypertension | Anti-tumor, hypoglycemic, antibacterial, antioxidant | Shandong, Anhui, Jiangsu, and Henan provinces of China | 1) The contents of 27 metal elements Li, Be, Mg, Al, Co, Ni, Ga, Rb, Sr, Te, Ba, Bi, U, V, Cr, Mn, Fe, Cu, Zn, As, Se, Mo, Ag, Cd, Tl, and Pb in L. japonica Thunb. produced in Hubei province of China were determined. The detection limits of the method were 9.789 ng/ml for Fe, 2.691 ng/ml for Cr, 1.803 ng/ml for Zn, 2.076 ng/ml for B, 1.877 ng/ml for Mg, 3.024 ng/ml for Al, 1.824 ng/ml for Ni, 0.003–0.921 ng/ml for other elements, 0.146%–7.627% for precision, and 90.0%–110.0% for recovery (Shu et al., 2012). 2) The contents of Pb, Cd, Cr, As, Hg, Ni, Mn, Cu, and Zn in L. japonica Thunb. were determined. The content of Cd was the highest (40.2%), followed by Cu (37.6%) and Pb (8.5%). As and Hg do not exceed the standard value, and Cr, Ni, Mn, and Zn are not limited (Fan et al., 2020). The contents of harmful elements Cu, Cd, Pb, As, and Hg in W. chamaedaphne (Bunge) Mein. were determined. Cu, Pb, Cd, and As in 0.5–100 μg/L, Hg in 0.1–10 μg/L showed a good linear relationship, r ≥ 0.99, and the recovery was 95.24%–101.16% (Li et al., 2020). |

*Note: the origin of medicinal materials recorded in the table is collected from the articles. If the origin of medicinal materials is not recorded in the articles, it is indicated by “—.”

system. Mn is also closely related to reproduction, which can promote cholesterol synthesis, promote human growth and development, and enhance reproductive function (Yu et al., 2015). Ni participates in the metabolism of the body and the composition of the cell membrane. It can activate histidine enzyme, arginase, acid phosphatase, and other important enzymes in the body, maintain the stability of biological macromolecular structure and normal metabolism of the whole body, and participate in the composition of various enzymes and proteins in the liver. The change of Ni content has a certain relationship with the occurrence and development of bronchial asthma. Se is one of the important components of glutathione peroxidase, a non-specific antioxidant of red blood cells. Its main function is to remove peroxides and free radicals from the human body and play a positive role in the treatment of cancer, cardiovascular diseases, diabetes, and other diseases. Se deficiency can easily lead to liver disease and liver injury (Zhao et al., 2017a). Heavy metals are not only the toxic ingredients of today’s society but also the effective ingredients of traditional drugs. The
| Latin name                  | Medical system            | Therapeutic use                                   | Main pharmacological effects                      | Origin of medicinal materials*       | Test results                                                                                                                                 |
|-----------------------------|---------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| *Arctium lappa* L.          | Traditional Chinese medicine | Senile dementia and other mental disorders       | Antibacterial, antioxidant stress, anti-tumor    | Hainan province of China             | The contents of Mg, Al, Fe, Zn, Cd, and Pb in *Arctium lappa* L. were determined. Mg content is high (68.5 μg/g), and Pb content is very low, only 1.59 μg/g (Chen et al., 2017b). |
| *Alpinia oxyphylla* Miq.    | Traditional Chinese medicine | Tumor, hyperglycemia, inflammation                | Anti-inflammatory, anti-tumor, antiviral, and hypoglycemic | Shandong, Jiangsu, Hebei, Anhui, Jilin, Sichuan, Shaanxi, Hunan, Gansu, Guangdong, and Hubei provinces of China | The contents of K, P, Mg, Al, Na, Fe, Pb, Hg, As, Cd, Cu, Si, Mn, Ni, Zn, Sr, V, Ti, Mo, Co, Sn, B, Li, and Cr in *Arctium lappa* L. were determined. The contents of K, P, Mg, Al, Na, and Fe are high, and the contents of heavy metals and harmful elements are within the limit standard (Hu et al., 2018). |
| *Citrus aurantium* L.       | Traditional Chinese medicine | Gastropotosis, anal prolapse, uterine prolapse   | Reduce blood lipid, blood pressure, antibacterial, and antioxidant | Quzhou, Zhejiang province, China     | The contents of Mg, K, Ca, Na, Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Sr, Br, Sr, Ag, Cd, Cs, Ba, Ti, Pb, U, and Hg in *Citrus aurantium* L. were determined. The linear relationship of each element is good (R ≥ 0.9990), the average recovery is 90%–111%, and the RSD < 5%. The RSD of the precision, repeatability, and stability test meets the quantitative analysis requirements, and the detection limit is 0.0007–7.2264 μg/L. The contents of Mg, K, Ca, Na, Al, Mn, Fe, Cu, Zn, Pb, Sr, and Ba in the six batches of samples measured were high, and the contents of V, Cr, Co, Ni, Ga, As, Cd, Cs, Ti, Pb, Hg, Se, Ag, and U were low or not detected (Zeng et al., 2020). The contents of Pb, As, Cd, Cu, and Hg in 20 batches of *Citrus aurantium* were determined. The relative RSD of each element was 0.6%, 0.5%, 1.8%, 1.0%, and 0.6%, respectively (Xu et al., 2017). |
| *Citrus deliciosa* Ten.     | Traditional Chinese medicine | Vomiting, diarrhea, cough                         | Anti-liver injury, anti-tumor, and anti-pulmonary fibrosis | —                                   | The contents of 32 trace elements B, Na, Al, Mg, P, K, Ca, Sc, V, Cr, Mn, Fe, Co, Ni, Cu, Tb, Zn, Ga, Ge, As, Se, Sr, Mo, Cd, In, La, Ce, Hg, Pb, Bi, and Th in *Citrus deliciosa* Ten. were determined. Among the major elements, the content of the K element is as high as 23.1 mg·g⁻¹, followed by Ca, P, Mg, A1, and Na. Among the necessary trace elements, the content of Fe is the highest, up to 1161.7501 μg·g⁻¹, followed by Mn, Zn, Cr, Cu, and Ni (Zhang et al., 2010). |
| *Cussonia monnieri* (L.) Cusson | Traditional Chinese medicine | Impotence, trichomonal vaginitis                  | Anti-arrhythmia, anti-tumor, and anti-myocardial fibrosis | —                                   | The contents of 22 elements Li, Co, Na, Ni, Mg, Cu, Al, Zn, P, As, K, Se, Ca, Sr, Ti, Cd, Cr, Ba, Mn, Hg, Fe, and Po in *Cussonia monnieri* (L.) Cusson were determined. Among the different places in Zhejiang, Shaanxi, and Henan of China were determined. K, Ca, Mg, P, Na, Fe, Al, Zn, Cr, Mn, Ba, Sr, and other elements are abundant (Jiao et al., 2019). |
| *Cornus officinalis* Siebold & Zucc. | Traditional Chinese medicine | Impotence, spermatorrhoea, enuresis, frequent urination | Anti-tumor, hypoglycemic, antioxidant, and anti-aging | Zhejiang, Shaanxi, and Henan provinces of China | The contents of 22 elements Li, Co, Na, Ni, Mg, Cu, Al, Zn, P, As, K, Se, Ca, Sr, Ti, Cd, Cr, Ba, Mn, Hg, Fe, and Po in *Cornus officinalis* Siebold & Zucc. from different places in Zhejiang, Shaanxi, and Henan of China were determined. K, Ca, Mg, P, Na, Fe, Al, Zn, Cr, Mn, Ba, Sr, and other elements are abundant (Jiao et al., 2019). |
| *Euryale ferox* Salisb.     | Traditional Chinese medicine | Spermatorrhoea, enuresis, frequent urination      | Anti-cancer, anti-myocardial ischemia, anti-fatigue, hypoglycemic | Fujian, Hunan, Guangdong, Jiangxi, Jiangsu, Anhui, Sichuan, Guizhou, Guangxi, Hebei, Liaoning, Shandong, | The contents of Pb, Cd, Cr, Cu, Hg, and As in *Euryale ferox* Salisb. from different producing areas were determined. The linear correlation coefficients of the six elements were significant (Continued on following page). |
| Latin name               | Medical system | Therapeutic use                  | Main pharmacological effects                        | Origin of medicinal materials* | Test results                                                                 |
|-------------------------|----------------|---------------------------------|-----------------------------------------------------|------------------------------|-----------------------------------------------------------------------------|
| Foeniculum vulgare Mil. | Traditional Chinese medicine | Diarrhea, cancer               | Anti-inflammatory, antibacterial, and anti-fibrosis | —                            | and Yunnan provinces of China. The contents of Li, Be, Bi, Na, Mg, Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Pb, Sr, Y, Zr, Nb, Mo, Rh, Pd, Ag, Cd, In, Sn, Sb, I, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, W, Hg, Ti, Pb, Bi, Th, U, and Re in F. vulgare Mil. were determined. The contents of Na, Mg, Ca, Fe, Zn, Mn, Ba, and other metal elements in F. vulgare Mil. were high (Sun et al., 2013). |
| Hovenia acerba Lindl.  | Traditional Chinese medicine | Liver disease, fatigue         | Anti-aging and anti-fatigue                          | Guizhou province of China.   | The contents of Be, Mg, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sr, Mo, Ag, Cd, Sn, Sb, Ba, Ti, and Pb in the stem and fruit of H. acerba Lindl. were determined. The linear relationship of 22 elements is good in its linear range, and $r > 0.995$. The detection limit is 0.0007–1.0713 μg/L. RSD of repeatability is less than 3%. RSD of precision is less than 7%. The recovery was 81.14%–112.91% (Chen et al., 2020e). |
| Lycium barbarum L.    | Traditional Chinese medicine | Hyperglycemia, hypertension    | Antioxidant, anti-aging, hypoglycemic, and hypolipidemic | Ningxia, Xinjiang, and Qinghai provinces or autonomous regions of China. | 1) The average contents of elements in L. barbarum L. from Ningxia, Xinjiang, and Qinghai provinces of China were Pb 0.30 mg·kg$^{-1}$, Cd 0.066 mg·kg$^{-1}$, As 0.05 mg·kg$^{-1}$, Hg 0.003 mg·kg$^{-1}$, and Cu 0.71 mg·kg$^{-1}$, respectively (Zuo et al., 2021).  2) The contents of Pb, Cd, As, Hg, and Cu in 32 samples of L. barbarum L. were determined. No Pb element was detected in 19 samples, and the element contents of other samples were Pb ≤ 4.2 mg/kg, Cd ≤ 0.05 mg/kg, As ≤ 0.05 mg/kg, Hg ≤ 0.05 mg/kg, and Cu ≤ 7.10 mg/kg (Liang et al., 2018). |
| Moringa oleifera Lam.  | Traditional Chinese medicine | Tumor, hyperglycemia, hyperlipidemia | Antioxidant, anti-tumor, and anti-inflammatory       | Yunnan Province of China.    | Determination of 22 inorganic elements of Na, Mg, Al, K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Sb, Ba, Hg, Ti, and Pb in seeds of M. oleifera Lam. from different habitats in Honghe, Chuxiong, Dehong, Zhongdian, Kunming, Yuxi, and Lijiang, Yunnan, China. The linear relationship of each element is good ($r > 0.999$). Detection limit: 0.04–78.44 μg/L. The precision meets the requirements (RSD < 5%). The recovery of each element is less than 10.66%–113% (RSD < 10%) (Niu et al., 2021). |
| Myristica fragrans Houtt. | Traditional Chinese medicine | Gastro, vomiting                | Antiepileptic, antidepressant, anti-inflammatory, and anticancer | —                            | The contents of Mg, K, Ca, Fe, Na, Cu, Zn, Se, Or, Co, Mn, V, Ni, Al, Sb, Ba, Bi, Li, and Sr in M. fragrans Houtt. were determined. The content of Mn was the highest, followed by Cu and Zn. After processing, the contents of Ca, Fe, Na (Continued on following page) |
TABLE 5 | Application of ICP-MS in the determination of heavy metal elements in medicinal materials derived from the fruits and seeds of plants.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials | Test results |
|------------|----------------|----------------|-----------------------------|------------------------------|--------------|
| Nelumbo nucifera Gaertn. | Traditional Chinese medicine | Diarrhea, spermatorrhea, insomnia | Reducing blood lipid, antioxidation, anti-inflammatory, and antithrombotic | — | and other elements increased, whereas mg and K decreased. The contents of Al, Sb, Be, and other potentially toxic elements in nutmeg are low and basically unchanged after processing (Zhao and Jia, 2012) The contents of As, Cd, Pb, and Hg in N. nucifera Gaertn. were determined. The linear relationship between the determined elements is good \( r > 0.9995 \), and the recovery is 97.5%–107.8% (Chen et al., 2013) |
| Prunella vulgaris L. | Traditional Chinese medicine | Eye disease, headache | Anti-inflammatory, antihypertensive, hypoglycemic | — | The contents of Mg, Al, Ca, Mn, Fe, Zn, Se, Sn, Mo, and other metal elements in P. vulgaris L. are high (Cao et al., 2013) |
| Prunus mume (Siebold) Siebold & Zucc. | Traditional Chinese medicine | Cough, diarrhea, abdominal pain | Antibacterial, antioxidiant, anti-tumor, hypoglycemic | Fujian, Guangdong, Zhejiang, Anhui, Guangxi, Sichuan, and Yunnan provinces or autonomous regions of China | The contents of 16 inorganic elements of B, Na, Al, Cr, Fe, Cu, Zn, Se, Sb, K, Ca, Mg, As, Hg, and Pb in P. mume (Siebold) Siebold & Zucc. were determined. Among the 16 elements, K, Ca, Mg, Na, Fe, and B were abundant (Cu et al., 2020) |
| Prunus sibirica L. | Traditional Chinese medicine | Cough, constipation | Anti-inflammatory, analgesic, anti-tumor, hypoglycemic | — | The contents of 24 trace elements B, Na, Mg, Al, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Mo, Cd, Ba, and Pb in P. sibirica L. were determined. The relative standard deviation RSD of the measured elements is less than 4.79%, and the recovery is between 90.00% and 109.30% (Liu et al., 2013) |
| Pseudocydonia sinensis (Dum.Cours.) C. K. Schneid. | Traditional Chinese medicine | Spasmodic pain | Anti-inflammatory, analgesic, anti-gastric ulcer, anti-tumor | — | The contents of 26 trace elements Na, Si, K, P, Zn, Sr, Mg, Cr, Mn, Co, Fe, Ni, I, Cu, Li, Al, Ca, Se, Rb, Cd, Be, Hg, B, Pb, C, and As in P. sinensis (Dum.Cours.) C. K. Schneid. were determined. The contents of K, Na, Ca, Mg, and other elements are relatively rich, the recovery is 96.5%–105.6%, and the RSD value is 0.26%–2.03% (Zhu, 2009) |
| Schisandra chinensis (Turcz.) Baill. | Traditional Chinese medicine | Cough, insomnia | Anti-inflammatory, anti-tumor, hypoglycemic, and hypolipidemic | Jilin Province of China | The contents of Al, As, Ba, Cd, Cr, Co, Cu, Fe, K, Mn, Ni, Pb, Se, V, and Zn in wild and cultivated S. chinensis (Turcz.) Baill. in Changbai Mountain area were determined. The detection limit of the method is 0.002–0.092 ng/ml, the relative standard deviation RSD is 1.87%–4.96%, and the recovery of standard addition is 94.0%–104.5% (Li et al., 2011) |
| Senna Tora (L.) Roxb. | Traditional Chinese medicine | Nyctalopia, constipation, oral ulcer | Reduce blood lipid, blood pressure, antibacterial and antioxidant | Guangxi Zhuang autonomous region of China | The contents of Na, Mg, P, Ca, Ti, Zn, Mn, Fe, K, Sr, B, Al, Ba, Li, Be, Ti, Mo, Po, Cd, Co, V, Cr, Cu, and Ni in S. tora (L.) Roxb. were determined. S. tora (L.) Roxb. is rich in K, Ca, P, Mg, Al, Fe, and Na, whereas the contents of Be, Cd, Ti, Pb, and other elements are very small, less than 0.02 μg/g. Among the 24 elements determined, the content order is K > Ca > P > Mg > Al > Fe > Na > Zn > Sr > B > Mn > Ba > Cu > Ti > Cr (Continued on following page) |
key is to master the “dose, the length of drug use, and the pathological state of the human body” to balance toxicity and effectiveness. One of the major challenges facing traditional drugs containing minerals is differences in mineral processing/preparation that distinguish them from environmental metals. Additionally, many preparations are polyherbal-metallic preparations, which increases their complexity because minerals are not used alone. Symptoms of heavy metal poisoning are shown in Figure 1. Furthermore, toxicity and therapy go hand-in-hand with these preparations, and there exists a need to maintain a subtle balance of benefit and risk on an individual basis. Therefore, ICP-MS provides a powerful means of detection to achieve this goal.

**ANALYSIS AND APPLICATION OF ICP-MS IN MEDICINAL MATERIALS DERIVED FROM PLANTS**

Excessive heavy metal elements in traditional medicine as the biggest restriction factor of its application (Fan et al., 2018; He et al., 2011), essential trace elements affecting the effect of traditional Chinese medicine, and heavy metals as generally toxic elements should be within the prescribed limit standards. Therefore, the analysis of trace elements and heavy metals in traditional medicines can provide more references for the efficacy, property, and safety of traditional Chinese medicine. ICP-MS has many advantages, such as less interference, wide linear range, high precision, low detection limit, and simultaneous determination of multiple elements. In addition, ICP-MS technology integrates with various different separation technologies to scientifically analyze the forms and valence states of the elements to be tested is good (r ≥ 0.9975), the recovery is 97.47%–104.24%, RSD ≤ 2.13%, and the detection limit of the method is 0.014–9.807 μg L⁻¹ (Liang et al., 2019). The contents of eight trace elements Mg, Mn, Fe, Zn, Cu, Cd, Hg, and Pb in Z. jujuba Mill. from 13 different producing areas in Hebei, Henan, Shaanxi, and Liaoning provinces of China were determined. The contents of harmful heavy metal elements Cu, Cd, Hg, and Pb are within the limit standard (Li et al., 2018c).
### TABLE 6 | Application of ICP-MS in the determination of heavy metal elements in medicinal materials from the whole plants.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials* | Test results |
|------------|----------------|----------------|-----------------------------|-----------------------------|-------------|
| Acalypha australis L. | Traditional Chinese medicine | Infertility, diarrhea, hematochezia | Anti-inflammatory, antioxidant, and anticancer | Sichuan province of China | The contents of 11 heavy metals in Pb, As, Hg, Cd, Cr, Cu, Ti, Ni, Co, Sb, and Zn in A. austrii L. were determined. The linear relationship of 11 heavy metal elements is good (R2 > 0.9992), and the detection limit of the method is 0.250–5.800 μg/kg, the recovery is 88.1%–107.8%, and RSD is < 2.39%. Repeatability test: RSD ≤ 3.43%, stability test: RSD ≤ 2.19%, precision test: RSD < 2.33% (Sun et al., 2017) |
| Aconitum tunicatum Maxim. (Maxim.) Stapf | Traditional Chinese medicine | Sore, food poisoning, snakebite | Anaphylactic, anti-inflammatory, and anti-tumor | — | Ten trace elements of Mn, Fe, Co, As, Se, Cu, Zn, V, and Cr in A. tunicatum (Maxim.) Stapf were determined. The recovery was 94.8%–103.5% (Sun et al., 2017) |
| Artemisia rupestris L. | Traditional Chinese medicine | Urticaria, dyspepsia, cold, hepatitis, allergic diseases | Antibacterial, anti-inflammatory, anti-allergic, and antioxidant | — | The contents of 15 trace elements of Fe, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Mo, Cd, Ti, Pb, and Bi in A. rupestris L. were determined. The recoveries of these 15 elements were 65.0%–111.0%, and the relative deviation standard was less than 5.00% (Chang and Xu, 2014) |
| Chloranthus multistachys C. Pal | Traditional Chinese medicine | Fracture, cold, skin itching | Anti-inflammatory, analgesic, and antibacterial | Kaili, Guizhou province, China | The contents of 14 Trace elements such as Cu, Pb, Cr, Ni, be, Mo, Ag, Sn, Sb, Ti, V, Co, As, and Cd in C. multistachys C. Pal were determined. The linear relationship of 14 elements meets the analysis requirements, and the correlation coefficient r > 0.9945. Relative standard deviation of repeatability: RSD < 5.0%. Relative standard deviation of precision: RSD ≤ 4%. Recovery range: 84.0%–120.00% (Sun et al., 2017) |
| Cymbopogon citratus (DC.) Stapf | Arabian medicine | Gastrospasm | Anti-inflammatory and antihypertensive | Saudi Arabia | The contents of Al, Pb, Cd, and As in C. citratus (DC.) Stapf were determined. The recovery of all measured elements was 86.1%–90.6%. The correlation of Al is the highest, and the concentration range of Al is 156–1690 μg/kg. The content of Cd is the lowest, and the concentration of Cd is in the range of 0.01–3.15 μg/kg. The washing process reduces toxic elements in all plants. The average % recoveries were Al (47.32%), As (59.11%), Cd (82.30%), and Pb (32.40%) (Sun et al., 2017) |
| Elaphantopus scalar L. | Traditional Chinese medicine | Cold, conjunctivitis, pharyngitis, acute tonsillitis, epidemic encephalitis B, pertussis | Anti-inflammatory, analgesic, antibacterial, anti-tumor, and anti-virus | Hainan, Guangxi, Guangdong, and Anhui provinces or autonomous regions of China | With Ga, In, and/or internal standards, the residues of Pb, Cd, As, Hg, and Cu in E. scalar L were determined. For each determined element, the correlation coefficient of the standard curve is 0.9991–0.9999, the average recovery is 91.2%–104.7%, and the RSD value is 3.9%–4.8% (Sun et al., 2019) |
| Epimenium sagittatum (Baldock & Zucc.) Maxim. | Traditional Chinese medicine | Impotence, arthritis | Anti-aging and anti-tumor | — | The contents of Mn, Fe, Co, Ni, Cu, Zn, Ga, Os, Ba, Pb, Sr, Y, Zr, Nb, Mo, Cd, Sn, Sb, Bi, La, Ca, Ni, Pr, Th, Sm, Ta, Hg, Pb, and Bi in E. sagittatum (Baldock & Zucc.) Maxim. were determined. Concentration range is 1.3 × 10−7–93.5 μg/kg, in which the content of Fe is 93.5 μg/kg and the content of Mn is 76.6 μg/kg, which are the two heavy metal elements with the highest content (Mu et al., 2015a) |
| Equisetum arvense L. | Arabian medicine | Obstetric pain | Anti-inflammatory, analgesic, and bacteriostatic | Saudi Arabia | The contents of Fe, Mn, Zn, Cu, and Si in E. arvense L were determined. Fe level is the highest and Si level is the lowest among allplants. The TE series levels of all elements in all plant areas as follows: Fe 193.4–1757.9 μg/g, Mn 26.6–143.7 μg/g, Zn 15.4–32.7 μg/g, Ga 0.15–3.32 μg/g, and Cu 11.3–21.5 μg/g (Sun et al., 2019) |
| Equisetum hiemale L. | Arabian medicine | Labor pain | Analgesic, hypoglycemic, antioxidant, anti-tumor, and anti-viral | Saudi Arabia | The contents of Al, Pb, Cd, and As in E. hiemale L. were determined. The recovery of all measured elements was 86.1%–90.6%. The content of Al element is the highest, and the concentration range of Al is 156–1690 μg/kg. The content of Cd is the lowest, and the concentration of Cd is in the range of 0.01–3.0 μg/kg. The washing process reduces toxic elements in all plants. The average % recoveries were Al (47.32%), As (59.11%), Cd (82.30%), and Pb (32.40%) (Sun et al., 2017) |
| Gynostemma pentaphyllum (Thunb.) Makino | Traditional Chinese medicine | Cough, chronic tracheitis, infectious hepatitis | Anti-inflammatory, anti-tumor, anti-aging, and hypoglycemic | Tong County, Guangxi Zhai region of China | The order of 279 organic elements mg, K, Ca, Fe, Li, Ba, B, Ti, V, Mn, Co, Ni, Cu, Zn, Sr, Sn, Sb, Bi, Ti, Al, Cu, Co, As, Cd, Hg, and Pb in G. pentaphyllum (Thunb.) Makino was Ca > Mg > P > Al > Fe > Ti > Sr > Ba > Mn > B > Zn > Cu > Ni > Pb > Cr > V > Li > Cd > Co (Zhao et al., 2015a) |
| 1) The contents of 279 organic elements mg, K, Ca, Fe, Li, Ba, B, Ti, V, Mn, Co, Ni, Cu, Zn, Sr, Sn, Sb, Bi, Ti, Al, Cu, Co, As, Cd, Hg, and Pb in G. pentaphyllum (Thunb.) Makino were determined. The linear relationship of 279 elements is good, and the correlation coefficient R > 0.9998. RSD of precision and repeatability experiment ≤ 6.0%. The recovery was 95.12%–109.48%, RSD ≤ 6.0%. The contents of Mg, K, Ca, and Fe in G. pentaphyllum (Thunb.) Makino were higher (Zhao et al., 2015b) |
| 2) The contents of Mn, Zn, Cu, Ti, Sn, Sb, Ba, Cr, Ni, As, Pb, Hg, and Cd in H. cordata Thunb. were determined. The linear relationship of each element to go in the range of 0.15–495 g/L. The correlation coefficient of the regression equation of each element is r > 0.9097, the detection limit is 0.002–0.120 g/L, the recovery is 97.6%, 103.8%, and the relative standard deviation is < 3.15%. The contents of Cu, As, Pb, Hg, and Cd in H. cordata Thunb. were lower than the national standard limit (Ji et al., 2018A) |
| Hypericum japonicum Thunb. | Traditional Chinese medicine | Acute and chronic hepatitis | Antibacterial, anti-inflammatory, and anti-tumor | Hebei, Jiangsu, Anhui, Guangxi, Fujian, Hunan, and Jiangxi provinces of autonomous regions of China | The contents of 20 kinds of inorganic elements in Hypericum japonicum Thunb. were determined. The linear ranges of mass concentrations of Fe, Mg, Ca, Al, K, Na, Zn, Co, Ni, Ba, Mn, P | (Continued on following page)
TABLE 6 | (Continued) Application of ICP-MS in the determination of heavy metal elements in medicinal materials from the whole plants.

| Latin name                          | Medical system         | Therapeutic use                        | Main pharmacological effects                      | Origin of medicinal materials* | Test results                                                                 |
|-------------------------------------|------------------------|----------------------------------------|--------------------------------------------------|--------------------------------|------------------------------------------------------------------------------|
| Mosla chinensis Maxim.              | Traditional Chinese medicine | Cold, headache, abdominal pain         | Antiviral agents, microorganisms, sedation, antioxidation | Jiangxi province of China     | Pb, Ti, Sr, Cu, As, Cd, Cr, Pb, and Hg were, respectively, 50–250 μg/ml ($r = 0.9972$), 25–100 μg/ml ($r = 0.9989$), 25–100 μg/ml ($r = 0.9977$), 2.5–15 μg/ml ($r = 0.9996$), 2.5–10 μg/ml ($r = 0.9999$), 2.5–10 μg/ml ($r = 0.9999$), 2.5–10 μg/ml ($r = 0.9999$), 2.5–10 μg/ml ($r = 0.9999$), 2.5–10 μg/ml ($r = 0.9999$), 2.5–10 μg/ml ($r = 0.9999$), 0.5–2 μg/ml ($r = 0.9996$), 2.5–10 μg/ml ($r = 0.9999$), 2.5–10 μg/ml ($r = 0.9999$), 2.5–10 μg/ml ($r = 0.9999$), 0.05–0.2 μg/ml ($r = 0.9990$), and 0.05–0.2 μg/ml ($r = 0.9997$), RSD of the precision, stability, and repeatability test is less than 5.0%. The recovery was 90.9%–106.9%. RSD was 0.20%–2.94%, $n = 6$ (Chen et al., 2017). |
| Mussaenda pubescens Dryand.         | Traditional Chinese medicine | Cold, heatstroke, tinnitus, cough, diaphoretic, poisonous snakebites | Anti-inflammatory, antibacterial, antitumor, and antifever | Guangxi, Hunan, and Jiangxi provinces or autonomous regions of China | The contents of C, Fe, Mn, Co, Ni, Cu, Zn, As, Sr, Cd, Sn, Ba, Hg, and Pb in M. pubescens Dryand from different producing areas in Guangxi, Hunan, and Jiangxi province were determined. The linear correlation coefficient ($r > 0.9992$), the RSD of the repeatability test < 2.5%, the RSD of the precision test is 0.911%–3.7%, and the recovery is 85.6%–109.4% (Chen et al., 2018). |
| Nepeta coerulea Maxim.              | Tibetan medicine         | Cutispathy                              | Antimicrobial                                        | Qinghai province of China     | The contents of C, Fe, Mn, Zn, Cu, As, Cd, Ag, and Pb in N. coerulea Maxim. were determined. The determination of C, Fe, Mn, and Cu in N. coerulea Maxim. is higher: Fe 76.55 mg/kg, Zn 204.10 mg/kg, and Cu 97.71 mg/kg, respectively, whereas the contents of Pb, Sn, and Cd are lower, between 0.03 mg/kg and 2.53 mg/kg (Ye et al., 2016). |
| Odytostoa chinensis (L.) S. Sm.      | Traditional Chinese medicine | Cold, fever, anemia, food poisoning, burns, pesticide poisoning | Antibacterial, antioxidant, anti-inflammation, antitumor, hypoglycemic | Yunnan, Gui, and Jiangxi provinces | The contents of C, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sr, Cd, Sn, Ba, Hg, and Pb in O. chinensis (L.) S. Sm. from different producing areas such as Yunnan, Guizhou, and Sichuan were determined. Cu 2.63–12.89 mg/kg (RSD0.12%), As 0.29–1.56 mg/kg (RSD5.2%), Cd 0.01–2.55 mg/kg (RSD11.5%), Hg 0.01–0.24 mg/kg (RSD131.1%), Pb 0.09–2.26 mg/kg (RSD20.4%) (Ma et al., 2020). |
| Phyllanthus amarus (Miq.) Hand.-Mazz. | Mexican medicine of China | Dysmenorrhea, impotence, cough          | Analgesia                                            | —                              | The contents of Pb, Cd, Cu, Hg, and Pb in P. amarus (Miq.) Hand.-Mazz. were determined. The correlation coefficient of the standard curve of five elements is $r > 0.9994$, the recovery is 94.6%–107.4%, and RSD < 5% (Chen and Zhang, 2013). |
| Pogostemon cablin (Blanco) Benth.   | Traditional Chinese medicine | Dampness and turbidity, diarrhea, turbid nose, headache | Anti-inflammatory, analgesic, antibacterial, and antibacterial microorganisms | Hainan and Guangdong province of China | The contents of trace elements in P. cablin (Blanco) Benth. from different producing areas such as Hainan province, Zhanjiang, and Guangdong province were determined. P. cablin (Blanco) Benth. contains Pb, Cu, Zn, Cd, Cr, Ni, Co, Mn, Sr, Mo, Sn, Ca, Ba, Ti, Ga, and Ge (Zhang et al., 2011). |
| Schismatium diffusum (Wild.) R. J. Wang | Traditional Chinese medicine | Various types of inflammation           | Anti-inflammatory, analgesic, antioxidant, and anti-inflammatory mutagenesis | Anhui, Yunnan, and Hainan provinces of China | The contents of 14 trace elements Mn, Cr, Sr, Zn, Pb, Bi, N, Cu, V, Sr, As, Mo, and Cd in S. diffusum (Wild.) R. J. Wang and its easily mixed product O. coxmariosa L. were determined. The linear correlation coefficient of 14 elements is good in the range of 0.030–970.5 μg/l, the correlation coefficient $r > 0.9998$, the detection limit is 0.0019–0.041 μg/l, and the recovery is 97.5%–123.0%. S. diffusum (Wild.) R. J. Wang contains more Sn elements, and the waterline contains more of the other 13 elements. The contents of Mn, Cr, Sr, Zn, and other elements in the two kinds of medicinal materials are relatively low (Wang and Liu, 2011). The contents of Pb, Cd, Cu, Ag, As, Hg, and Pb in S. diffusum (Wild.) R. J. Wang were determined. The content range of each element is Pb 0.0250–0.0750 mg/kg, Cd 0.0717–0.1657 mg/kg, As 0.0250–0.0750 mg/kg, Hg 2.2794–7.7460 μg/kg, and Cu 0.9943–1.5444 mg/kg (Chen et al., 2018). |
| Vincetoxicumowikiensis Kitag.       | Traditional Chinese medicine | Snakebite, infantile chancres, dysentery, toothache | Analgesic, bacteriostatic, and anti-inflammatory | Guangxi Zhuang autonomous region of China | The contents of Pb, Cd, As, Hg, and Cu in V. owikiensis Kitag. were determined. The content range of each element is Pb 0.0250–0.0750 mg/kg, Cd 0.0717–0.1657 mg/kg, As 0.0250–0.0750 mg/kg, Hg 2.2794–7.7460 μg/kg, and Cu 0.9943–1.5444 mg/kg (Chen et al., 2018). |

multiflora (Thunb.) Moldenke and its processed products. It was found that after processing, compared with non-processed products, the content of most inorganic elements increased, whereas the content of some harmful metal elements decreased.

Medicinal materials from plants include roots and rhizomes, stems, leaves, flowers, fruits and seeds, whole plants, and other medicinal parts. With the development and progress of science and technology and the in-depth...
| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials* | Test results |
|------------|----------------|----------------|-----------------------------|------------------------------|--------------|
| Angelica sinensis (Oliv.) Diels | Traditional Chinese medicine | Irregular menstruation, amenorrhea, dysmenorrhea, constipation | Analgesic, anti-inflammatory, antibacterial, antioxidant, anti- senile dementia | Gansu and Yunnan Provinces of China | The detection limits of elements in Angelica sinensis (Oliv.) Diels soil in different areas of Gansu and Yunnan province were Pb 0.0213 μg/L, Cd 0.0196 μg/L, As 0.0168 μg/L, Hg 0.0215 μg/L, Cu 0.0241 μg/L, Cr 0.0192 μg/L, Sb 0.0189 μg/L, Ni 0.0176 μg/L, Zn 10 μg/L, Fe 18 μg/L, Mn 11 μg/L, Mg 3 μg/L, Ca 11 μg/L, Na 12 μg/L, and K 15 μg/L, respectively. The correlation coefficients are between 0.9989 and 1.0000 (Gu et al., 2014) |
| Chrysanthemum morifolium (Ramat.) Hemsl. | Traditional Chinese medicine | Tumor, inflammation, cardiovascular disease | Anti-inflammatory, antiviral, antibacterial, mutagenic, and anti-tumor | Bozhou, Anhui province of China | The contents of Mg, Al, Fe, Ba, Mn, Cr, Se, and Mo in C. morifolium (Ramat.) Hemsl. soil were determined. The average recoveries of the eight elements were 94.77%–124.11%, and the RSD values were 2.34%–7.96% (n = 6) (Yu et al., 2014) |
| Cordyceps cicadae Miquel. | Traditional Chinese medicine | Tumor, hyperglycemia | Anticonvulsant, antioxidant, anti-tumor | — | The contents of K, Na, Ca, Pb, Cd, Hg, As, and Cu in C. cicadae Miquel. were determined. The correlation coefficient of the standard curve of each element is 0.9990–0.9999, the recovery is 95.25%–103.73%, and the RSD value is less than 4% (Gu, 2020) |
| Cordyceps militaris Link. | Traditional Chinese medicine | Cough, acute and chronic bronchitis, asthma | Anti-inflammatory, bacteriostatic, and anti-tumor | — | The contents of Ca, Fe, Zn, and Se in commercial C. militaris Link. Samples were detected. The Zn content of C. militaris Link. is generally high, and other elements are at the normal level (Xiao, 2019) |
| Cordyceps sinensis Berk. | Traditional Chinese medicine | Impotence, lumbago, cough | Anti-oxidation, anti-tumor, and anti-aging | Qinghai and Sichuan provinces of China | 1) The contents of various elements in C. sinensis Berk. soil in Qinghai and Sichuan provinces of China were determined. As is 7.60–20.60 mg/kg, Pb 18.16–28.44 mg/kg, Cr 20.15–66.31 mg/kg, Cu 22.35–35.23 mg/kg, and Cd 0.06–1.48 mg/kg (Chen et al., 2018b) 2) The residues of Pb, Cd, As, Hg, and Cu in fresh C. sinensis Berk. were determined. The linear relationship of the five heavy metals in their respective mass concentration range was good, r > 0.996, and the average recovery was 98.55%–121.73% (RSD < 4.3%) (Qian et al., 2019a) The contents of heavy metals in G. lucidum (Curtis) P. Karst. Spore powder from different producing areas such as Anhui, Zhejiang, and Shandong were determined. Pb is 0.19 mg·kg⁻¹, As is 0.16 mg·kg⁻¹, Hg is 0.02 mg·kg⁻¹, Cu is 14.73 mg·kg⁻¹, and Cd is 0.34 mg·kg⁻¹. After wall breaking, (Continued on following page)
### Table 7: Application of ICP-MS in the determination of heavy metal elements in other medicinal materials derived from plants and soil.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials | Test results |
|------------|----------------|----------------|-----------------------------|-----------------------------|--------------|
| **Garcinia hanburyi Hook.f.** | Mongolian medicine of China | Tumor, anabrosis, hemorrhage | Anti-inflammatory, antibacterial, antioxidant, and anti-tumor | — | Pb was 0.21 mg·kg$^{-1}$, As was 0.12 mg·kg$^{-1}$, Hg was 0.02 mg·kg$^{-1}$, Cu was 15.81 mg·kg$^{-1}$, and Cd was 0.37 mg·kg$^{-1}$ [Hu et al., 2016] |
| **Conioselinum anthriscoides “Chuanxiong”** | Traditional Chinese medicine | Heartache, thoracalgia, irregular menstruation, amenorrhea, dysmenorrhea, headache | Anti-tumor, anticoagulant, anti-cerebral ischemia, and anti-depression | Sichuan province of China | The contents of Pb, Cd, As, Hg, and Cu in G. hanburyi Hook.f. were determined. The linear relationship between the five elements is good ($r \geq 0.9995$), and the mass concentrations of Pb, Cd, and As are 0–50 μg·L$^{-1}$. The linear relationship is good, and the detection limits are Pb 0.020 μg·L$^{-1}$, Cd 0.012 μg·L$^{-1}$, As 0.035 μg·L$^{-1}$. The mass concentration of Cu is 0–500 μg·L$^{-1}$. The linear relationship is good, and the detection limit is 0.05 μg·L$^{-1}$. The contents of Cd, As, Cu, and Pb in C. anthriscoides “Chuanxiong” soil were determined. The linearity of each element in the corresponding range is good ($r > 0.999$), the precision is good (RSD < 4%, $n = 6$), and the recovery is 92.7%–107.9% [Chen et al., 2014b]. |
| **Magnolia officinalis Rehder & E. H. Wilson** | Traditional Chinese medicine | Tumor, inflammation, dental caries | Anti-epilepsy, anti-depression, anti-dementia, anti-cerebral ischemia, anti-tumor, hypoglycemic | Sichuan, Hubei, and Shanxi provinces of China | The contents of Mn, Fe, Ni, Cu, Zn, Pb, Sr, Cd, Ba, and Pb in M. officinalis Rehder & E. H. Wilson from different producing areas in Sichuan, Hubei, and Shanxi provinces of China were determined. The standard curve of each element has a good linear relationship ($r = 0.9998$–1.0000). The recovery of standard addition is 90.57%–114.56%. There were significant differences in the content of metal elements in M. officinalis Rehder & E. H. Wilson samples from different producing areas, and the content of heavy metals in some medicinal materials exceeded the standard [Fang et al., 2018]. |
| **Phellodendron amurense Rupr.** | Traditional Chinese medicine | Spermatorrhea, eczema | Anti-inflammatory, antibacterial, antitumor, hypoglycemic, and hypotensive | — | The contents of Co, Ni, Cu, Zn, As, Cd, Hg, and Pb in P. amurense Rupr. were determined. The relative standard deviation of each element was 3.2%–17.8%, and the recovery was 70%–120% [Kou et al., 2007]. |
| **Polyporus umbellatus Pers.** | Traditional Chinese medicine | Edema, diarrhea | Anti-inflammatory, anti-tumor, antioxidant, antibacterial, and anti-mutation | Anhui, Hunan, Yunnan, Guangxi, and Hunan provinces or autonomous regions of China | The contents of Be, Na, Mg, Al, Ca, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Sb, Ba, Hg, Ti, Pb, and U in P. umbellatus Pers. from different places in Liaoning, Shanxi, Shaanxi, Anhui, and Inner Mongolia provinces of China were determined. The linearity of the corresponding range is good ($r > 0.999$), the precision is good (RSD < 4%, $n = 6$), and the recovery is 92.7%–107.9% [Chen et al., 2014b]. |

(Continued on following page)
TABLE 7 | (Continued) Application of ICP-MS in the determination of heavy metal elements in other medicinal materials derived from plants and soil.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials* | Test results |
|------------|----------------|----------------|-------------------------------|-------------------------------|--------------|
| Poria cocos (Schw.) Wolf. | Traditional Chinese medicine | Loose stools, diarrhea, uneasiness, Insomnia | Anti-inflammatory, anti-tumor, and hypolipidemic | Lianoning, Shanxi, Shaanxi, Anhui, and Inner Mongolia provinces or autonomous regions of China | Cu ≤ 20.0 μg·g⁻¹, As ≤ 2.0 μg·g⁻¹, Cd ≤ 0.3 μg·g⁻¹, Hg ≤ 0.2 μg·g⁻¹, Pb ≤ 5.0 μg·g⁻¹ (Luo et al., 2016) |
| Rheum tanguticum (Maxim. ex Regel) Balf. | Traditional Chinese medicine | Constipation, pharyngeal swelling, amenorrhea, water fire scald, upper gastrointestinal bleeding | Anti-inflammatory, anti-tumor, and lipid-lowering | — | The contents of Be, Na, Mg, Al, K, Ca, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Sb, Ba, Hg, TI, Pb, and U in P. cocos (Schw.) Wolf. from different places in Lianoning, Shanxi, Shaanxi, Anhui, and Inner Mongolia provinces of China were determined. Cu ≤ 20.0 μg·g⁻¹, As ≤ 2.0 μg·g⁻¹, Cd ≤ 0.3 μg·g⁻¹, Hg ≤ 0.2 μg·g⁻¹, Pb ≤ 5.0 μg·g⁻¹ (Luo et al., 2016) |
| Salvia miltiorrhiza Bunge | Traditional Chinese medicine | Irregular menstruation, insomnia, angina pectoris | Anti-inflammatory, anti-tumor, anti-oxidation, anti-hypertension, anti-hyperlipidemia, and anti-liver injury | Shanxi, Henan, Hubei, Hunan, Shanxi, Jiangxi, Shandong, Anhui, Zhejiang, and Liaoning provinces of China | The contents of Mg, Al, K, Ca, Ba, Mn, Zn, Cu, Cd, and Pb in wild S. miltiorrhiza Bunge soils from 27 different producing areas in Shanxi, Hunan, and Henan were determined. Al > K > Ca > Mg > Ba > Mn > Zn > Cu > Pb > Cd (Yu et al., 2017b) |
| Viscum articulatum Burm.f. | Traditional Chinese medicine | Hypertension, arrhythmia, tumor, hepatitis | Anti-tumor, antihypertensive, antiarrhythmic, anti-aging, and antiviral | — | The contents of 18 trace elements of Na, Mg, Al, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Ge, As, Se, Mo, Cd, Hg, and Pb in V. articulatum Burm.f. on tea tree were determined. The detection limit is 0.03363–26.59 μg·L⁻¹, the relative standard deviation (RSD, n = 6) is 1.54%–7.57%, and the recovery is 90.17%–109.7%. The contents of K, Ca, Mg, and Al in V. articulatum Burm.f. are high (Wu et al., 2011) |

*Note: the origin of medicinal materials recorded in the table is collected from the articles. If the origin of medicinal materials is not recorded in the articles, it is indicated by “—.”

application and research of pharmaceutical analysts, the ICP-MS technology will continue to play a more important role in the field of traditional drugs with its own unique advantages. Liu et al. (2018a) determined the contents of eight heavy metals and harmful elements in medicinal materials derived from different sources, including Dioscorea nipponica Makino, Sanguisorba officinalis L., Curcuma phaeocaulis Valeton, Conioselinum anthriscoides (H. Boissieu) Pimenov & Kliuykov, Ephedra equisetina Bunge, Euchresta japonica Hook.f. ex Regel, Clematis chinensis Osbeck, Inula helenium L., Allium macrostemon Bunge, and Aster tataricus L.f. The contents of heavy metals and harmful elements in medicinal materials are affected by many factors, such as origin, environment, and soil. It is necessary to strengthen supervision, control, and strict norms to ensure the quality and drug safety of traditional Chinese medicine and provide a reference basis for the formulation of safety standards of traditional Chinese medicine. Other applications of ICP-MS in medicinal materials derived from plants are shown in Tables 1–7. From the 154 articles on medicinal materials from plants, 76 elements including Cu, Cd, Pb, As, Cr, Mn, and Hg were determined, of which 129 were Cu, accounting for 83.77%. A heat map of heavy metal elements measured by ICP-MS of medicinal materials derived
from plants in different medicinal parts is shown in Figure 2. From the 154 articles on the application of ICP-MS in medicinal materials from plants, root, stem, leaf, flower, fruit and seed, and whole grass medicinal materials derived from plants accounted for 25.97%, 18.18%, 7.14%, 7.79%, 14.94%, and 14.94%, respectively, and other medicinal materials derived from plants and soil accounted for 11.04%. Of the 154 articles of botanical medicine, 137 belong to traditional Chinese medicine, accounting for 88.96%; 12 belong to the medical system of Saudi Arabia, accounting for 7.79%; 2 belong to the medical system of Tibetan medicine; 1 belongs to the medical system of Mongolian medicine; 1 belongs to Miao medicine; and 1 belongs to Zhuang Medicine in China. At present, ICP-MS has been widely used to analyze the contents of trace and ultra-trace inorganic elements in traditional Chinese medicine, further ensuring the safety of traditional Chinese medicine.

Analysis and Application of ICP-MS in Medicinal Materials Derived From the Roots of Plants

Medicinal materials derived from the roots and rhizomes of plants account for the largest proportion and are the most common in the medicinal materials derived from plants, so ICP-MS is also the most widely used in this kind of traditional Chinese medicine. From the 40 articles on medicinal materials derived from the roots of plants, 64 elements such as Cu, As, Cd, Pb, Hg, Cr, and Mn were determined, of which 31 were the most, accounting for 77.50%. Of the 40 articles on medicinal materials derived from the roots of plants, 36 belong to traditional Chinese medicine, accounting for 90%. Three articles belong to Arabic medicine (including one article on Unani), accounting for 7.50%. One
### TABLE 8 | Application of ICP-MS in the determination of heavy metal elements in medicinal materials derived from animals.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials* | Test results |
|------------|----------------|----------------|-------------------------------|-------------------------------|--------------|
| Bombyx batryticatus Bals. | Traditional Chinese medicine | Tetanus, apoplexia, headache, pharyngalgia | Anticoagulant, antithrombotic, bacteriostatic, anticonvulsant, antibacterial | Heilongjiang, Anhui, Jiangsu, Henan, Liaoning, Beijing, Jilin, Shanxi, Hebei, and Sichuan provinces or municipalities of China | The contents of Pb, Hg, As, Cd, and Cu in 10 batches of commercial medicinal materials of B. batryticatus Bals. were determined, which met the limit requirements of the Chinese Pharmacopoeia for harmful elements (Guo et al., 2012) |
| Bungarus parvus Blyth. | Traditional Chinese medicine | Tetanus, apoplexia | Anti-inflammatory, analgesic, and anti-tumor | — | The contents of five harmful elements of Pb, Hg, As, Cd, and Cu in eight batches of commercial medicinal materials of B. parvus Blyth. were determined. The content of Cd mostly exceeds the standard, and the content of Pb and Cu in some samples exceeds the standard (Wu et al., 2015a) |
| Carapax trionycis Wiegmann | Traditional Chinese medicine | Dizziness, amenorrhea | Anti-liver fibrosis and anti-cancer | Changsha, Hunan province of China | The contents of 10 inorganic elements of Na, Mg, K, Ca, Mn, Fe, Ni, Cu, Zn, and Se in 10 batches of C. trionycis Wiegmann were determined. The characteristic elements of C. trionycis Wiegmann are Fe, Mn, Zn, Ca, and Cu (Ma et al., 2011) |
| Cervus elaphus Linnaeus | Traditional Chinese medicine | Dizziness, lumbago | Anti-mammary hyperplasia, gastric mucosal protection, anti-osteoporosis, anti-senile dementia | — | The contents of eight trace elements of Ca, Mg, Fe, Zn, Mn, Cu, Sr, and Se in C. elaphus Linnaeus gum and C. reevesii Gray gum were determined. The recoveries of eight elements (n = 6) were 88.89%–103.31%, the detection limit was low, and the RSD was less than 6.0% (Wang et al., 2018b) |
| Chinemys reevesi Gray | Traditional Chinese medicine | Bleeding, arrhythmia | Promote cell proliferation and inhibit apoptosis | — | The contents of Hg, As, Cd, and Cu in 10 batches of commercial medicinal materials of C. reevesi Gray were determined. The contents of Cd mostly exceeds the standard, and the content of Pb and Cu in some samples exceeds the standard (Wu et al., 2015a) |
| Eupolyphaga sinensis Walker | Traditional Chinese medicine | Liver disease and tumor | Antithrombotic, anticoagulant, anti-tumor, and anti-ischemia | — | The contents of harmful elements in E. sinensis Walker were Hg 0.11 mg/kg, Cu 272.20 mg/kg, Cd 0.04 mg/kg, Pb 2.08 mg/kg, As 1.19 mg/kg, respectively (Cao et al., 2019) |
| Gekko gecko Linnaeus | Traditional Chinese medicine | Hemoptyysis, impotence, spermatorrhea, and asthma | Anti-tumor | — | The contents of B, Na, Al, Mg, P, K, Ca, Sc, V, Cr, Mn, Fe, Co, Ni, Cu, Tb, Zn, Ga, Ge, As, Se, Sr, Mo, Cd, In, Ba, La, Ge, Hg, Pb, Bi, and Tl in G. gecko Linnaeus were determined. The contents of Ca, P, K, Na, and Mg are the highest in major elements, and the contents of Fe, Zn, Se, Cr, and Cu are the highest in essential trace elements (Yao et al., 2010) |
| Halitrichs discus Reeve. | Traditional Chinese medicine | Vertigo | Antibacterial, antioxidant, and antihypertensive | Guangxi, Hainan, Guangdong, Zhejiang, and Fujian Provinces or autonomous regions of China | The contents of 15 rare earth elements of Y, Tb, La, Dy, Ce, Ho, Pr, Er, Nd, Tm, Sm, Yb, Eu, and Lu in H. discus Reeve., H. cumingi Lea., O. gigas Trunb., and C. gigas Trunb. were determined. The linearity of each element in the corresponding range is good (r > 0.999), the precision is good (RSD < 4%, n = 8), and the recovery of each element is 97.0%–105.0% (Chen et al., 2014a) |
| Hyripopsis cumingi Lea. | Traditional Chinese medicine | Anabrosis | Antibacterial and antioxidant | Guangxi, Guangdong, Jiangxi, and Zhejiang Provinces or autonomous regions of China | The contents of Pb, Hg, As, Cd, and Cu in 10 batches of commercial medicinal materials of O. gigas Trunb. were determined. The linearity of each element in the corresponding range is good (r > 0.999), the precision is good (RSD < 4%, n = 8), and the recovery of each element is 97.0%–105.0% (Chen et al., 2014a) |
| Ostrea gigas Trunb. | Traditional Chinese medicine | Insomnia, headache, dizziness, stomachache | Antioxidant, anti-tumor, hypoglycemic | Guangxi, Hebei, Guangdong, Fujian, Liaoning, and Zhejiang provinces or autonomous regions of China | The contents of 15 rare earth elements of Y, Tb, La, Dy, Ce, Ho, Pr, Er, Nd, Tm, Sm, Yb, Eu, and Lu in H. discus Reeve., H. cumingi Lea., O. gigas Trunb., and C. gigas Trunb. were determined. The linearity of each element in the corresponding range is good (r > 0.999), the precision is good (RSD < 4%, n = 8), and the recovery of each element is 97.0%–105.0% (Chen et al., 2014a) |
| Spongilla fragilis Leidy. | Traditional Chinese medicine | Impotence, spermatorrhea | Bacteriostasis | — | The contents of Hg, Cu, Cd, Pd, and As in S. fragilis Leidy. were determined. For each determined (Continued on following page)
article belongs to Tibetan medicine, accounting for 3%. The application of ICP-MS in medicinal materials derived from the roots of plants is shown in Table 1.

Analysis and Application of ICP-MS in Medicinal Materials Derived From the Stem of Plants
Medicinal materials derived from the stem of plants refer to the above-ground stem or part of the medicinal materials derived from the stem of plants. Most of them are the stems of woody plants, and a few are the stems and vines of herbaceous plants. In 28 articles on medicinal materials derived from the stem of plants, 61 elements such as Cu, Cd, As, Pb, Cr, Mn, and Ni were determined. Among them, the determination of Cu is the most, with 27 articles accounting for 96.43%. Of the 28 articles on the determination of medicinal materials derived from the stem of plants, 27 belong to traditional Chinese medicine, accounting for 96%. One article belongs to Arabic medicine, accounting for 4%. The application of ICP-MS in medicinal materials derived from the stem of plants is shown in Table 2.

TABLE 8 | (Continued) Application of ICP-MS in the determination of heavy metal elements in medicinal materials derived from animals.

| Latin name                  | Medical system     | Therapeutic use                | Main pharmacological effects              | Origin of medicinal materials* | Test results                                                                 |
|-----------------------------|--------------------|--------------------------------|-------------------------------------------|---------------------------------|-------------------------------------------------------------------------------|
| Aspongopus chinensis Dallas. | Traditional Chinese medicine | Stomachache, hepatodynia, impotence | Antibacterial, anti-tumor, and antioxidant | —                              | element, the correlation coefficient of the standard curve is $r = 0.998−0.9999$, the recovery is 80.3%−105.2%, and the RSD value is 0.5%−12.1% (Li, 2018a) |
| Eupolyphaga sinensis Walker | Traditional Chinese medicine | Traumatic injury, fracture, amenorrhea | Antithrombotic, anticoagulant, anti-tumor, and anti-ischemia | —                              | The contents of Be, V, Co, Ni, Ga, Se, Rb, Sr, Ag, Cs, U, Cu, Co, Ni, Ga, Se, Rb, Sr, Ag, Cs, and U in A. chinensis Dallas., E. sinensis Walker, P. asiatica Perrier., P. olivaceus DeGeer. were determined. The residues of four kinds of medicinal materials derived from animals were higher (Li et al., 2020b) |
| Pheretima asiatica Perrier. | Traditional Chinese medicine | Asthma, cough, edema, hypertension | Anti-inflammation, antithrombotic, heart protection, anti-tumor, and improvement of the respiratory system | —                              |                                                                                 |
| Polistes olivaceus DeGeer. | Traditional Chinese medicine | Toothache, rheumatism          | Antibacterial, anti-inflammatory, anti-cancer, anti-ulcer and anti-virus | —                              |                                                                                 |

/Note: the origin of medicinal materials recorded in the table is collected from the articles. If the origin of medicinal materials is not recorded in the articles, it is indicated by “—.”/
## TABLE 9 | Application of ICP-MS in the determination of heavy metal elements in medicinal materials derived from minerals.

| Name       | Medical system      | Chemical formula     | Therapeutic use                  | Main pharmacological effects   | Origin of medicinal materials* | Test results                                                                 |
|------------|---------------------|----------------------|----------------------------------|---------------------------------|--------------------------------|--------------------------------------------------------------------------------|
| Alumen     | Traditional Chinese medicine | KAl(SO₄)₂·12H₂O | Hematochezia, hemorrhoids        | Antibacterial and anticancer    | —                              | The contents of K, Al, Fe, Zn, Cu, Pb, Cd, As, and Hg in Alumen and its fake ammonium Alumen were determined. Alumen mainly contains Al and K elements, and ammonium Alumen mainly contains Al and Fe elements. The content of K element is far lower than that of K element in medicinal Alumen (Geing et al., 2020) |
| Cinnabar   | Traditional Chinese medicine | HgS     | Insomnia                         | Hypnosis and anti-anxiety       | Guangxi, Guangdong, Henan, Shandong, Guizhou, and Yunnan provinces or autonomous regions of China | The contents of total Hg and soluble Hg in Cinnabar from different producing areas such as Sichuan, Hunan, and Jiangsu were determined. The linear correlation coefficient r is 1.000. The recoveries were 95%–105%. Precision RSD ≤ 1%. Repeatability RSD ≤ 0.4%. Stability: RSD of mercuric sulfide ≤ 0.1%, RSD of soluble mercury salt (calculated by Hg) ≤ 1%. Method detection limit (LOQ): mercury sulfide was 6 mg·g⁻¹ and soluble mercury salt (calculated by Hg) was 0.06 μg·g⁻¹ (Lan, 2014) |
| Gypsum     | Traditional Chinese medicine | CaSO₄·2H₂O | Headache, toothache              | Antiviral                        | —                              | The contents of Ca, Mg, Zn, Na, Al, and Se in raw Gypsum and calcined Gypsum were determined. After processing, the contents of Ca, Mg, Zn, and Na increased, whereas the contents of Al and Se decreased (Xiao et al., 2012) |
| Kaolinite  | Traditional Chinese medicine | Al₂(SiO₃)₃·4H₂O | Spermatorrhea, bleeding          | Antidiarrheal                    | Gansu, Anhui, Henan, Shanxi, Jiangsu, Shandong, Shanxi, and Hubei provinces of China | The contents of 27 heavy metals and trace elements of Li, Be, Na, Mg, Al, K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Rb, Sr, Ag, Cd, Cs, Ba, Pb, Ti, U, and V in Kaolinite from different producing areas in Gansu, Anhui, Henan, Shaanxi, Jiangsu, Shandong, Shanxi, and Hubei provinces of China were determined. Al is the element with the highest content. Li, Na, Mg, K, Ca, V, Mn, Fe, Co, Ni, Zn, Ga, Se, Rb, Sr, Ba, and U are the main components of trace elements and can be used as characteristic elements (Zhu et al., 2019) |
| Mirabilite | Traditional Chinese medicine | Na₂SO₄·10H₂O | Constipation, bellyache, hemorrhoids | Anti-inflammatory                | Shanxi, Sichuan, Hunan, Shanxi, Shandong, Qinghai, and Anhui provinces of China | 24 elements of Li, Be, Na, Mg, Al, K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Rb, Sr, Cd, Cs, Ba, Ti, and Pb in Mirabilite were determined. The contents of Na, Mg, K, Ca, Fe, and other elements are high. In addition, heavy metals and harmful elements Pb, Cd, Cu, and As (Continued on following page) |
Analysis and Application of ICP-MS in Medicinal Materials Derived From the Leaf of Plants

Medicinal materials derived from the leaf of plants are a kind of medicinal parts, mostly complete and grown dry leaves, less tender leaves, or leaves with some tender branches. In 11 articles on medicinal materials derived from the leaf of plants, 64 elements such as As, Cd, Pb, Mn, Cu, Zn, Fe, Co, Ni, Cu, Zn, As, Se, Ag, Cd, Sb, Ba, Ti, Pb, and U. The main elements are Cu, Zn, Fe, Cd, Mn, Al, Na, and Ca (Wang et al., 2017a). Determination of the element composition of Natrii Sulfas decoction, Na, Mg, Al, K, Ca, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Ag, Cd, Sb, Ba, Ti, Pb, and U. The main elements are Cu, Zn, Fe, Cd, Mn, Al, Na, and Ca (Li et al., 2013). Determination of 20 elements of Li, Na, Mg, K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Pb, Cd, Sr, Ba, and Pb in preparations of Glauber’s salt and liquorice. The contents of Na, Mg, K, Ca, Fe, Zn, and Sr are high, and heavy metals and harmful elements Pb, Cd, Cu, and As are also detected (Li et al., 2014). The contents of Na, Mg, K, Ca, Fe, Cu, Zn, Cr, Mn, Co, Ni, Se, and As in mice liver were determined. As in Realgar can cause the changes in Mg, Ca, Fe, Cu, Zn, Cr, Mn, Co, Ni, and Se levels in the liver, but it has no obvious effect on Na and K levels (Wang et al., 2015a). The contents of Na, Mg, K, Ca, Fe, Cu, Zn, Mn, Ni, Cr, Mn, Cu, As, Ba, Pb, Be, Si, Sr, V, Co, Ga, Ge, Br, Se, Kr, Pb, Sr, Y, Zr, Nb, Mo, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Xe, Cs, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Os, Pt, Au, Hg, Tl, Bi, Th, and U 70 heavy metals in sulfur were determined. Ca, Na, Al, K, Ti, As, and other elements are characteristic trace elements (Zhao et al., 2020b).

Analysis and Application of ICP-MS in Medicinal Materials Derived From the Flowers of Plants

Medicinal materials derived from the flowers of plants generally refer to a complete flower, inflorescence, or a part of a flower. Among the 12 articles on medicinal materials derived from the flowers of plants, 38 elements such as Cu, As, Cd, Pb, Ni, Hg, and Cr were determined. Among them, elements Cu, As, Cd, and Pb were also detected. The application of ICP-MS in medicinal materials derived from the flowers of plants is shown in Table 3.
were determined most, with 12 articles accounting for 100%. Of the 12 articles on the determination of lower medicinal materials from plants, 11 belong to traditional Chinese medicine, accounting for 92%. One article belongs to Tibetan medicine, accounting for 8%. The application of ICP-MS in medicinal materials derived from the flowers of plants is shown in Table 4.

Analysis and Application of ICP-MS in Medicinal Materials Derived From the Fruits and Seeds of Plants

Most of the medicinal materials derived from the fruits and seeds of plants are complete, mature fruits and seeds. Among the 23 articles of medicinal materials derived from the fruits and seeds of plants, 65 elements such as Cu, Pb, Cd, Fe, Zn, As, and Al were determined, of which 19 were the most, accounting for 82.61%. Among the 23 articles on the determination of medicinal materials derived from the fruits and seeds of plants, 22 belong to traditional Chinese medicine, accounting for 96%. One article belongs to Arabic medicine, accounting for 4%. The application of ICP-MS in medicinal materials derived from the fruits and seeds of plants is shown in Table 5.

Analysis and Application of ICP-MS in Medicinal Materials From the Whole Plants

Medicinal materials from the whole plants refer to the whole plant or its aboveground part of medicinal herbs. From the 23 articles on the determination of medicinal materials from the whole plants, 54 elements such as Cu, Cd, Pb, As, Ni, Zn, and Mn were determined, of which 19 were Cu, accounting for 82.61%. Among the 23 articles on the determination of medicinal materials from the whole plants, 18 belong to traditional Chinese medicine, accounting for 78%. Three articles belong to Arabic medicine accounting for 13%. One article belongs to Tibetan medicine, accounting for 4%. One article belongs to the medical system of Miao medicine in China, accounting for 4%. The application of ICP-MS in medicinal materials from the whole plants is shown in Table 6.

Analysis and Application of ICP-MS in Other Medicinal Materials Derived From Plants and Soil

Other medicinal materials derived from plants included barks, resins, fruiting bodies, and medicinal materials parasitic on various parts of plants. From the 17 articles on other medicinal materials derived from plants and soil, 28 elements such as Cu, Cd, Pb, As, Hg, Zn, and Mn were determined, of which 15 were the most, accounting for 88.24%. Among the 17 articles on the determination of other medicinal materials derived from plants and soil, 16 belong to traditional Chinese medicine, accounting for 94%. One article belongs to Mongolian medicine in China, accounting for 6%. The application of ICP-MS in other medicinal materials derived from plants and soil is shown in Table 7.

Analysis and Application of ICP-MS in Medicinal Materials Derived From Animals

Medicinal materials derived from animals refer to a kind of traditional Chinese medicine used for medicine, such as the whole or part of animals, the physiological or pathological products of animals, and the processed products of animals. It has a very long medicinal history. Medicinal materials derived from animals are rich in metal trace elements. Many researchers evaluate the quality of medicinal materials derived from animals by controlling metal trace elements (Wang et al., 2015b). Among the various metal elements contained in medicinal materials derived from animals, some elements are necessary for the
| Name | Medical system | The Main medicinal materials | Therapeutic use | Main pharmacological effects | Test results |
|------|----------------|-----------------------------|----------------|-----------------------------|-------------|
| Astragalus mongholicus injections | Traditional Chinese medicine | Astragalus mongholicus Bunge | Veal myocarditis with blood stasis, cardiac insufficiency, hepatitis | Reducing blood sugar, blood lipid, protecting liver, and anti-tumor | The contents of Pb, As, Cu, Cd, and Hg in Astragalus mongholicus injections were determined. The correlation coefficient of standard curve r = 0.997, the recovery was 96.6%–105.5%, RSD < 2.9% (Cheng et al., 2013) |
| Banxia syrup | Traditional Chinese medicine | Ateris tataricus L., Citrus deliciosa Ten., Ephere oligocarpa Bunge, Glocrymae uralexis Fisch. ex DC., Pinellia ternata (Thib.) Malino, Platycodon grandiflorus (Jacq.) A.DC., Polygala tenuifolia Willd., Rhaphiopis bigars (Lour.) Gaileos & Barrf. | Cough, phlegm, bronchitis | Bacteriostasis | The contents of Pb, Cd, As, Hg, Cu, and Or in banxia syrup were determined. The linear relationship of each element to be tested is good, r = 0.997, the detection limit is 0.3–1.5 ng·g⁻¹, the recovery is 90.4%–98.7%, RSD ≤ 5.8% (Zhong et al., 2019) |
| Beijian pill | Traditional Chinese medicine | Jisi stenostoma (L.) Goldblatt & Matt., Carpaer hytisic Wiegmann, Scutelaria baikialensis Georgi | Chronic hepatitis, liver cirrhosis, angina pectoris, hyperlipidemia | Anti-renal fibrosis and anti-tumor | The contents of Pb, As, Hg, Or, and Cu in Beijian pills were determined. The ratio of mass concentration to ion peak showed a good linear relationship p = 0.9997, 0.9996, and the RSD of precision, stability, and repeatability were less than 2%. The average recovery was 86.7%–100.9%, RSD < 4% (n = 6), and the detection limits were 2.2, 5.0, 1.7, 1.5, and 5.0 μg·g⁻¹ (Gu, 2015) |
| Chapter song bawei aqualaria powder | Tibetan medicine | Aqualaria shanensis (Lour.) Spring., Fraxenoomes, Guansang, Kappox, Mystistica fragrans Hocht., Terminal electron Ratt., Travelan, Woody fragrance | Acute and chronic cardiovascular and cerebrovascular diseases, hypertension | Anti hyperoxia | The contents of Ca, Cu, Mn, Zn, Fe, and Mn in chapter song bawei aqualaria powder were determined. The contents of Fe, Mn, Cu, and Ni are high, whereas the contents of other elements are low (Jin et al., 2009) |
| Danshen Chuanxiong injection | Traditional Chinese medicine | Ligustrine hydrochloride, Salvia miltiorrhiza Bunge | Angina pectoris, myocardial infarction, ischemic stroke, thrombosis obliterans | Anti-blood stasis | The contents of Pb, Cd, Hg, Cu, Mn, and Ni in six batches of Danshen Chuanxiong injection were determined. The linear relationship between the eight elements and the peak area is good in their linear range, R = 0.9999, the detection limit is 0.0099–0.2199 μg·mL⁻¹, the average recovery of each element is 93.00–104.2%, and the RSD is less than 5% (Cheng et al., 2018) |
| Dejunmang juaqumao | Tibetan medicine | Bear bile, Calcarus bovis, Coralline, Crocus sativus L., ronggray, Lapis lazuli, Musk, Zogita | Nausea, vomiting, diarrhea, abdominal pain, peptic ulcer, food poisoning | Clearing away heat and toxic material | The contents of 20 elements of Na, Mg, Al, K, Ca, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, As, Hg, and Pb in Tibetan medicine Dejunmangjuaqumao were determined. The detection limit of each element is 0.0033–2.4181 ng·g⁻¹, and the recovery is 87.27–105.6% (Roucy et al., 2016) |
| Ermiao pills | Traditional Chinese medicine | Atractylodes lancea (Thunb.) DC., Phlaludizion annuus Fupr. | Foot and knee swelling and pain, food embolism, syringe, eszema, esyipselae, loschimia | Antibacterial, anti-bacterial, haemostatic, hypoglycemic | The residues of Pb, As, Hg, and Cu in Ermiao pills were determined. The RSD values were 1.1%, 0.3%, 0.6%, 0.5%, and 0.8%, all less than 2% (Chang et al., 2013) |
| Fufang Danxian tablets | Traditional Chinese medicine | Bomeot, Panax notoginseng (Burkitt) F. H. Chen, Sakis miltiorrhiza Bunge | Coronary heart disease, angina pectoris, Alzheimer’s disease, diabetes mellitus, and its complications | Anti-cerebral ischemia, anti-Alzheimer’s disease, anti-oxidation | The contents of Pb, As, Cu, Cd, and Hg in Fufang Danxian tablets were determined. The minimum detection limits of five elements were 6.5 ng·g⁻¹, 2.3 ng·g⁻¹, 6.9 ng·g⁻¹, 4.7 ng·g⁻¹, and 0.91 ng·g⁻¹, respectively. The linear relationship was good in each concentration range r > 0.9960. The recoveries were 102.8%, 105.1%, 104.5%, 106.8%, 90.4%, and RSD were 2.1% and 2.5%, respectively, 8%, 1.9%, 2.2%, 3.4% in (n = 5) (Fu, 2018) |
| Fufang Dilong capsule | Traditional Chinese medicine | Atractylodes lanciata Blume, Astragalus mongholicus Bunge, Conoasium anthropocides “Chuanxiong,” Phereidae asiatica Perrier. | Syndrome of qi deficiency and blood stasis in the recovery period of meridians in ischemic stroke | Anti-cerebral ischemia | The contents of Pb, As, Cd, Hg, and Cu in the Fufang Dilong capsules were determined. The linear relationship between the determined elements is good (r = 0.9999), and the recovery is between 98.8% and 105.4% (Dou, 2018) |
| Garmao Oiring granules | Traditional Chinese medicine | Platyodon grandiflorus (Jacq.) A.DC., Paeonia adulta Pamp. | Cold, fever, headache | Antirheumatic, and anti-inflammatory | The contents of 14 common metal elements of Mg, Cr, Fe, Cu, Ca, Zn, As, Se, Ni, Cu, Cd, Ba, and Pb in Garmao Oiring granules were determined. The correlation coefficient r > 0.9991, the recovery was 80.59%–102.43%, and the relative standard deviation RSD was 0.5%–2.74% (1, 2017) |
| Gutheuxooug capsules | Traditional Chinese medicine | Angelicae sinensis (Oko) Dali, Roswalea sacis Flck., Carpathus printzorus L., Cucumber seed, Exuphyganshia shirbii Walker, Mymth, Natural copper, Pig bone, Rhamh tarugundum (Maxm. ex Regel) Balf. | Traumatic injury, distemepose and blood stasis, twisting waist, and bifurcating Qi | Promoting bone healing | The contents of Pb, Cd, As, and Hg in the fracture collection capsule were determined. The mass concentrations of the five elements have a good linear relationship with the response intensity in the linear range. The average recovery is 97.4%–102.7%, and the RSD is less than 3.5% (n = 5) (Bong et al., 2023) |
| Guipi pills | Traditional Chinese medicine | Angelicae sinensis (Oko) Dali, Astragalus mongholicus Bunge, Atractylodes macrocephala Koid, Codonopsis pilosula (Franch.) Hartm., Cimicopus oginian Lour, Glycyrrhiza uralexis Fisch. ex DC., Pola cocce (Scwh.) Wolf., Poligala tenuifolia Willd., Zaphires jauce MB. | Deficiency of both heart and spleen, Palpitation and palpitation caused by splenin not regulating blood | Anti-shock, regulating central nerve, enhancing immune and hematopoietic function | The contents of Pb, Cu, Hg, As, and Cd in Guipi pills were determined. The correlation coefficients of the measured elements and calibration curves are 0.9999, and the linear relationship is good. The average recovery of the method is 90.3%–103.6%, and the RSD is 1.6%–3.9% (Dou et al., 2017) |
| Gujth Fuling capsules | Traditional Chinese medicine | Cinnamomum verum J.Presi, Paeonia lactiflora Pall., Paeonia suffruticosa Andrews, Pola cocce (Scwh.) Wolf., Phunas persica (L.) Batsch, Orian cyst, endometriosis, hysteresymenia, dysmeneoma | Anti-inflammatory, anagistic, anti-tumor, regulating smooth muscle, regulating endocrine, and improving immunity | (Continued on following page)
| Name | Medical system | The Main medicinal materials | Therapeutic use | Main pharmacological effects | Test results |
|------|----------------|-----------------------------|----------------|-----------------------------|-------------|
| Hanshului Erihuiwei powder | Mongolian medicines of China | Cow bazaor, Forsythia suspensa (Thunb.) Vahl, Hanhsului, Hypericum harmoloides L., Morinda cochinichininni (Lour.) Speng., Punica granatum L., Trogopterus dungs, Viola philippica Cav.Montmorillonite powder Traditional | Chest and back pain, GI stagnation and blood stasis, blood heat-trapping stomach | Anti-gastric ulcer | were determined. The linear relationship is good, and the correlation coefficient R² = 0.9990. The detection limit of the method is 0.016–4.54 µg/L, and the experimental repeatability is good. The recovery of the sample was 75.84%–119.8% (Wang et al., 2016) |
| Honghua injection | Traditional Chinese medicine | Carthamus tinctorius L. | Coronary heart disease, occlusive vascular disease | Antistress | The contents of Pb, Cd, As, Hg, and Cu in Hanshului Erihuiwei Powder were determined. The mass concentrations of the five elements were in the range of 0–100 ng/ml and had a good linear relationship with the response value of the calibration peak (r = 0.996). The average recovery was 87.90–97.63%, and the RSD was 1.52–2.35%. The detection limits of five metal elements are 0.004–4.0051 pg/mL (Ma and Chen, 2020) |
| Lincorice oral solution | Traditional Chinese medicine | Glycyrrhiza uralensis Fisch. ex DC. | Cough and expectoration caused by upper respiratory tract infection, bronchitis, and cold | Anti-inflammatory | The contents of Cr, Mn, Ni, Cu, Zn, As, Cd, Sn, Pb, Ba, Hg, Pt, Al, and Fe in Lincorice oral solution were determined. The linear relationship of 15 elements is good, the correlation coefficient is greater than 0.999, the detection limit of each element is 0.08–38.80 ng/ml, and the recovery is 88.57%–107.10% (Fang et al., 2020) |
| Manubzhithang | Tibetan medicine | Inula helenium L., Rubus idaeus L., Bischoto, Hippophae rhamnoides L., Trogopterus dung, Viola philippica Cav. | In the early stage of influenza, chills, headache, arthralgia, rheumatoid arthritis, and fever | Antibacterial, analgesic, anti-inflammatory, and anti-allergic | The contents of Cr, Mn, Ni, Cu, Zn, As, Cd, Sn, Pb, Ba, Hg, Pt, Al, and Fe in Manubzhithang were determined. The detection limit of each element is 0.003–0.095 µg/L, and the recovery is 90.71%–105.10% (Peng et al., 2020) |
| Mentmorillonite Powder | Traditional Chinese medicine | Montmorillonite | Chronic diarrhea | Cover the mucous membrane of the digestive tract and bind with mucus protein | The contents of Pb, Cd, Hg, Co, Ni, Cu, and As in Mentmorillonite powder were determined. The seven heavy metal elements have a good linear relationship at 0–30 ng/ml, 0–6 ng/ml, 0–10 ng/ml, 0–20 ng/ml, 0–40 ng/ml, and 0–4 nm/L, respectively. The RSD of precision were 4.91%, 5.30%, 10.04%, 4.78%, 5.93%, 4.76%, and 6.91%, respectively. The RSD of stability were 5.12%, 10.94%, 3.68%, 4.78%, 4.31%, and 7.06% respectively (Wang et al., 2019) |
| Nuhuang Qingsui pills | Traditional Chinese medicine | Calamus longifolius, Acorus tataricus, Aegopodium podagraria, Viola philippica, Carthamus tinctorius L., Forsythia suspensa (Lour.) Skinn., & A. O. Poulsen | Heartburn, dizziness, sore tongue, swollen gums, sore throat, constipation | Antibacterial, antiviral, and cardiovascular protection | The contents of Pb, Cd, As, Hg, and Cu in Nuhuang Qingsui pills were determined. Cd and Cu did not exceed the standard, and the exceeding rates of Pb, As, Hg were 12%, 14%, respectively (Jia et al., 2019) |
| Qishui Zhenzhu pills | Tibetan medicine | Rubus idaeus L., Bischoto, Hippophae rhamnoides L., Trogopterus dung, Viola philippica Cav. | “Baihui” disease, stroke, paralysis, hemiplegia, cerebral hemorhage | Anticonvulsant and hypotensive | Determination of 18 trace elements of Li, Be, Sc, V, Cr, Mn, Co, Ni, Cu, As, Br, Ag, Cd, Cu, Pb, Pt, As, and Hg in Qishui Zhenzhu pills. The rank order of the elements in Qishui Zhenzhu pills was copper > mercury > sodium from high to low, with the mass fraction higher than 2000 µg/kg. The mass fractions of arsenic, manganese, arsium, strontium, barium, chromium, and nickel were in the range of 331–1034 µg/kg. The mass fractions of vanadium, cobalt, lithium, beryllium, cadmium, scandium, and cesium were lower than 10 µg/kg (Fu et al., 2022) |
| Gangji Pipa syrup | Traditional Chinese medicine | Menthol, Morus alba, Papaver somniferum L., Phytolaccac grandiflora (Linn.) A.DC., Rhus verniciflua Sieb (Lour) Galasso & Barf, Stemonas assosifolia (Fnq.) Mgq | Bronchitis, cough | Anti-inflammatory, hypoglycemic, antiviral, and anti-tumor | The contents of 20 inorganic elements of Li, Be, V, Mn, Co, Ni, Cu, Zn, Ga, As, Pb, Br, Sr, Cd, Sn, Sb, Cs, Ba, Ti, and Po in Gangji Pipa syrup were determined. The average recovery was 86.2%–104.9%, the corresponding RSD was 0.55%–2.91%, and the detection limit was 0.015–5.94 ng/ml. The average contents of Sr, Mn, Ba, Pb, and Zn in 10 batches of Gangji Pipa syrup were the highest (Li et al., 2019c) |

(Continued on following page)
### TABLE 10 | (Continued) Application of ICP-MS in the determination of heavy metals in Chinese patent medicine.

| Name | Medical system | The Main medicinal materials | Therapeutic use | Main pharmacological effects | Test results |
|------|----------------|-------------------------------|-----------------|-----------------------------|-------------|
| Qinghuo Chimai tablets and capsules | Traditional Chinese medicine | Andrographis paniculata (Burm.f.) Nees, Gardenia jasminoides J.Ellis, Ophiopogon japonicus (Thunb.) Kar. Gaert. | Sore throat, fever, toothache | Anti-inflammation and analgesia | The contents of Li, V, Fe, Ni, Co, Cu, Zn, As, Al, Mo, Ru, Rh, Pt, Ag, Cd, Sn, Bi, In, Pb, Pt, Au, Hg, Tl, and Pb in Qinghuo Chimai tablets and capsules were determined. The linear relationship of each element in their respective concentration range is good (r² > 0.9998). The lower detection limit is 0.0033–5.2 ng/g. The recovery was 88.1%–121.9%, and RSD was 0.7%–6.7% (Wang et al., 2019) |
| Qingweii Bawei tablets | Mongolian medicine of China | Bazzor, Dianthus superbus L., Gardenia jasminoides J.Ellis, Ophiopogon japonicus (Thunb) Kar. Gaert. | Headache, heatstroke | Protecting cardiovascular system, anti-arrhythmia, anti-inflammatory, and protecting myocardium | The contents of Bb, Bi, Na, Mg, Al, P, K, Ca, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Pb, Sr, M吕, Ag, Cd, Sn, Sb, Bi, Pb, Hg, Tl, and Pb in Qingweii Bawei tablets were determined. The linear relationship of each element is good, r > 0.9996, and the detection limit of each element is 0.0016–6.390 ng/L. RSD of the precision, stability, and repeatability tests meet the requirements of quantitative analysis. The recovery was 94.38%–105.47%, and RSD was 1.53%–4.56% (Wang et al., 2019) |
| Renshenzhao pills | Traditional Chinese medicine | Alstroemeria aduncus (Gaertn)., Asarum sieboldii Miq., Cypessus rotundus L., Panax ginseng C.A.Mey., Phellodendron asiaticum Pursh., Pogostemon cablin (Bianco) Bar, Schizanthus pinnatus L. | Apoplexy | Anti-arrhythmia and anti-shock | The contents of Pb, Cd, As, Ag, and Cu in Renshenzhao pills were determined. The linear relationship of the five elements is good, the correlation coefficient is greater than 0.9990, the detection limit is 0.0032–0.023 mg/kg, and the average recovery is 92.7%–101.9% (Zhang et al., 2019) |
| Raining Changjuge | Tibetan medicine | Acaena hians (Lour.) Sprng., Bazzor, Cimicifugae radix L., Santalum album L., Pearl, Zogta | Harmonizing and nourishing, clearing away heat and detoxifying | Analgesia and anti-fatigue | The contents of Na, Mg, Al, K, Ca, V, Mn, Fe, Co, Ni, Cu, Zn, Se, Mo, Ag, Cd, Hg, Pb, Th, Ti, and U in Raining Changjuge were determined. The detection limit of each element is 0.0032–2.416 ng/g, and the recovery is between 82.73% and 106.8% (Zhang et al., 2016) |
| Salvia miltiorrhiza freeze-dried powder needle for injection | Traditional Chinese medicine | Salvia miltiorrhiza Bunge | Chest tinnitus, palpitation, coronary heart disease, angina pectoris | Anti-inflammatory, anti-tumor, cardiovascular, and immune induction | The contents of Pb, Cd, As, Hg, and Cu in 32 batches of freeze-dried powder needles of Salvia miltiorrhiza for injection and Xuehuaxiong for injection were determined. The correlation coefficient r of the measured elements and calibration curve is greater than 0.9990. The contents of Pb, Cd, As, Hg, and Cu in 32 batches of freeze-dried powder injection of traditional Chinese medicine for injection are within the limit (Jiang et al., 2017) |
| Xuehuaxiong freeze-dried powder needle for injection | Traditional Chinese medicine | Panax notoginseng (Burk.) F. H. Chen | Stroke hemiplegia, chest atrophy, and central retinal vein occlusion | Expanding cerebral blood vessels and increase cerebral blood flow | The contents of Pb, Cd, As, Hg, and Cu in 32 batches of freeze-dried powder injection of traditional Chinese medicine for injection are within the limit (Jiang et al., 2017) |
| Sanqi Shangyao tablets | Traditional Chinese medicine | Ascomycena brachypodum Des., Bomea, Carthamus tinctorius L., Davallia mariesii, H.L.Velth, Panax notoginseng (Burk) F. H. Chen, Sambucus williamsii Hance, | Relaxing tendons and activating blood circulation, dispersing blood stasis, and relieving pain | Anti-inflammation and anti-coagulant | The contents of Pb, Cd, As, Hg, and Cu in Sanqi Shangyao tablets were determined. The detection limit was 0.0023 mg/kg, 0.011 mg/kg, 0.003 mg/kg, and 0.007 mg/kg, respectively (Hu et al., 2019) |
| Shexiang Baxion pills | Traditional Chinese medicine | Bazzor, Bomea, Albizia gregaria, Cinnaurnum aromatum J.Forst, Lycium carolinianum Mill., Mak, Panax ginseng C.A.Mey. | Angina pectoris and myocardial infarction caused by myocardial ischemia | Inhibiting myocardial fibrosis and reducing cardiac inflammation | The contents of 29 inorganic elements of Li, Na, Mg, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Sr, Mo, Cd, Bi, Hg, Tl, Pb, and Bi in 12 batches of Shexiang Baxion pills were determined. The contents of Ca, Mg, Na, and Fe are higher, exceeding 1000 mg/kg. The amount of Mn, Cu, Zn, Al, and Ga are also relatively high, whereas the amount of Pb, Cd, Hg, and Bi are relatively low, all below 0.005 mg/kg (Li et al., 2019) |
| Shangfuchang injection | Traditional Chinese medicine | Aegopogon mongholicus Bunge, Cnidarnus paludosus (Franch) Namn. | Lung cancer, gastric cancer | Anti-tumor | The contents of 14 trace elements Cu, Zn, Mn, Se, Mo, Fe, Cr, Ni, V, Sn, Pb, Cd, Hg, and As in qing Shangfuchang injection were determined. The relative contents of Cu, Fe, Zn, Hg, and Se in Shangfuchang injection are high. The contents of As in toxic elements Pb, Cd, Hg, and As are close to the requirements of American fast foods and functional foods, and the contents of Pb, Cd, Hg, and As are significantly lower than the maximum limit (Li et al., 2020) |
| Shanghai injections | Traditional Chinese medicine | Ophiopogon japonicus (Thunb). Kar. Gaert., Panax ginseng C. A. Mey., Schisandra chinensis (Turcz.) Baill. | Myocardial infarction, cardiogenic shock, septic shock | Improving body immunity, protecting myocardium, and anti-tumor | The contents of heavy metal elements Cu, As, Cd, Hg, and Pb in Shanghai injection were determined. The linear relationship of each element in their respective detection mass concentration range is good (r² > 0.9998), the recovery is greater than 96%, RSD is not greater than 2.8% in 3, and the detection limits are Cu 0.10 ng/L, As 0.06 ng/L, Cd 0.03 ng/L, Hg 0.008 ng/L and Pb 0.02 ng/mL, respectively (Wang, 2014) |
| Shihuwei Saerdou pills | Tibetan medicine | Biberir barbarea DC., Orychophragmus nudicale Bang, Hypochoeris rosetum L., Lagotis clarkii Hook., Swertia bimaculata (Salis & Zucc.) Hook.f. & Thomson ex C. B. Clarke, Terminalia chebula Retz., Dolotania soulei (Franch) C. Shin | Hepatoprotective liver, cholecystitis, cholestheniasis, cholechothiasis | Anti-inflammation, analgesia, and bacteriostasis | The contents of 20 elements Na, Mg, Al, K, Ca, V, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Pb, Sr, M吕, Ag, Cd, Sn, Sb, Bi, Pb, Hg, Tl, and Pb in Shihuwei Saerdou pills were determined. The detection limit of each element is 0.0032–2.416 ng/g, and the recovery is 82.9%–104.9% (Zhang et al., 2016) |

*Continued on following page*
TABLE 10 | (Continued) Application of ICP-MS in the determination of heavy metal elements in Chinese patent medicine.

| Name                  | Medical system | The Main medicinal materials                                      | Therapeutic use                                                                 | Main pharmacological effects                                                                 | Test results                                                                                   |
|-----------------------|----------------|-------------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Shuanghuanglín injection | Traditional Chinese medicine | Flos prunellae susp. (Thunb.) Vahl, Lonicera japonica Thunb., Scutellaria baicalensis Georgi | Fever, cough, sore throat, upper respiratory tract infection, mild pneumonia, and tonsillitis caused by exogenous wind heat | Antibacterial, anti-inflammatory, antiviral, and anti-allergic                               | The contents of 15 trace elements Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd, Ba, and Hg in Shuanghuanglín injection were determined. The recovery was 81.6%–96.3%, and the detection limit was 0.001–5.53 ng/L [Sun et al., 2013]. |
| Siyují decoction     | Traditional Chinese medicine | Atractylodes macrocephala Koidz., Glycyrrhiza uralensis Fisch. ex DC., Panax ginseng C. A. Mey., Poria cocos (Schw.) Wolf | Anti-tumor, anti-ribonucleic acid synthesis, gynecostatistical regulation | Anti-tumor, anti-fatigue, and anti-aging                                                      | The contents of Pb, Hg, Cr, Cd, As, Ni, Cu, Co, Se, and Mo in Siyují decoction were determined. The linear relationship of the detected 10 elements is good, the correlation coefficient r ≤ 0.9990, and the detection limit of each element is 0.003–2.294 μg/L [3]. The recovery is within 96.6%–103.1%, RSD ≤ 6.1%, and values of repeatability and precision are RSD ≤ 5% [Sun et al., 2019]. |
| Thrombus scavenger injection | Traditional Chinese medicine | Panax notoginseng (Burk) F. H. Chen | Hemorrhagic diseases, cerebrovascular diseases and their sequelae, intracranial hemorrhage, and other fundus diseases | Expand cerebral blood vessels and increase cerebral blood flow | The contents of Be, Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Ag, Cd, Sb, Nb, Dy, Hg, Ti, and Pb in Thrombus scavenger injection were determined. The correlation coefficient of the standard curve of 21 elements above 0.999, the recovery rate is 92.7%–107.0%, and RSD is within 5% [Zhang et al., 2019]. |
| Twenty-five flavor pearl pills | Tibetan medicine | Atractylodes macrocephala Koidz., Glycyrrhiza uralensis Fisch. ex DC., Panax ginseng C. A. Mey., Poria cocos (Schw.) Wolf | Acute and chronic cardiovascular and cerebrovascular diseases, hypertension, hyperlipidemia | Anticoagulant and antithrombotic                                                              | The contents of eight trace elements Fe, Mn, Cr, Ni, Zn, Pb, and Mo in Tibetan medicine twenty-five flavor pearl pills were determined. The recovery was 96.4%–103.2% [Zhao et al., 2017]. |
| Vitexin injection     | Traditional Chinese medicine | Catalpina palmata Bunge, Ittav negundo L. | Inflammation, ischemic brain injury                                               | Antioxidation, anti-myocardial hypotrophy, and inhibition of platelet aggregation             | The contents of Pb, Cd, As, Hg, and Cu in Vitexin injection were determined. The detection limits of each element were 0.4, 0.03, 0.09, 0.04, and 0.05 ng/ml, respectively. The linear relationship is good r > 0.9998. The recoveries were 97.8%, 97.2%, 104.0%, 91.2%, and 92.8%, respectively [Yu et al., 2019]. |
| Wulüo granule        | Traditional Chinese medicine | Aesculus chinensis L., Cercis chinensis L., Lotus corniculatus L., Citrus sinensis L., Citrus × aurantium L., Citrus reticulata Blanco | Chronic gastritis, Peptic ulcer                                                       | Improving the states of gastric mucosa and reducing the expression level of inflammatory factors | The six harmful elements Pb, Cd, As, Hg, Cu, and Ni in Wulüo granule were determined. Within the detection concentration range, the linear relationship is good r > 0.9999 and 0.9990, the recovery of each element is between 92.35% and 102.55%, and the RSD is between 0.85% and 2.1% [Yu et al., 2021]. |
| Xiaochaihu preparation | Traditional Chinese medicine | Acanthopanax senticosus Maxim., Atractylodes lancea var. lepidota Maxim., Salvia miltiorrhiza Bunge, Scutellaria baicalensis Georgi | Cold, fatigue, chronic hepatitis, liver cirrhosis, acute and chronic cholecystitis, otitis media, acute pancreatitis, pleurisy, gallstones | Hypothyroidism                                                                                | The contents of Cu, As, Cd, Hg, and Pb in Xiaochaihu preparation were determined. Under the international heavy metal limit standard, Hg in only one batch of original Medicinal materials exceeded the standard by eight times, but after decidation and preparation process, the residue of heavy metals was significantly reduced, and the residue rate of heavy metals was reduced to 2.5%–52% (granule Hg 42.85% [granule Cd]. THO and OR were lower than the non-cardiogenic and cardiogenic risk standard values of heavy metals under the threshold application methods [1,2,3,4]). |
| Yigan powder         | Traditional Chinese medicine | Artemisia capillaris Thunb., Scutellaria baicalensis Georgi | Chronic hepatitis B, hepatitis C, cirrhosis, fatty liver, alcoholic liver disease, hepatic cyst | Anti-hepatitis B virus                                                                       | The contents of V, Cr, Fe, Cu, Ni, Co, Cd, Hg, and Pb in Yigan powder were determined. The linear relationship of 12 elements is good, and the correlation coefficient r ≤ 0.9992, the detection limit of each element is 0.028–0.357 μg/L, the recovery is 100.1%–104.7%, RSD ≤ 4.4%, and RSD values of repeatability and precision are ≤ 5% [Sun et al., 2017]. |
| Yinhühuang injection | Traditional Chinese medicine | Artemisia capillaris Thunb., Gardenia jasminoides Ellis, Lonicera japonica Thunb., Scutellaria baicalensis Georgi | Acute, persistent, and chronic hepatitis | Protecting the liver and resisting liver fibrosis                                            | Determination of Pb, As, Cd, Hg, and Cu in Yinhühuang injection. The detection limits of five elements were 5–1250 ng/L, respectively. The linearly is good, and the linear correlation coefficients r ≥ 0.9999. Precision RSD ≤ 3.5%. The recovery was 95.7%–107.5% [Shang et al., 2012a]. 18 inorganic elements K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, Cu, Zn, Sr, Si, Mo, Cd, Sn, Sb, and Bi in Yinfeng granules were determined. The precision, stability, and reproducibility are less than 5%, 18 inorganic elements are in the range of 0–100 g/L, and the correlation coefficients were above 0.9990 [Shang et al., 2019a]. |
| Zhenfuzheng granules | Traditional Chinese medicine | Atractylodes macrocephala Koidz., Glycyrrhiza uralensis Fisch. ex DC. | Cold, respiratory tract infection, allergic rhinitis | Anti-infection                                                                               | The contents of As, Cd, Pb, Hg, and Cu in Zhenfuzheng granules were determined. The correlation coefficient of the calibration curve r > 0.9999, and the contents of As, Cd, Pb, Hg, and Cu are within the controllable range [Zhao et al., 2018]. |

Continued on following page
human body and the material basis for human growth, body metabolism, and physiological function regulation. Some other elements are harmful elements, such as Pb, Cd, As, Hg, Cu, and other elements. If these elements exceed the standard, they will directly affect the health of patients and damage the function of some parts of the body. In addition, some elements are potentially radiotoxic elements, and long-term exposure will also cause damage to the human body (Chi et al., 2016).

At present, there are few reports on the safety of heavy metal residues in medicinal materials derived from animals. The determination methods of heavy metals and harmful elements mainly include atomic absorption spectrometry, atomic fluorescence spectrometry, and atomic emission spectrometry. Most of them can only be used for the determination of single elements. The ICP-MS method, which can simultaneously analyze and determine multi-element, has the advantages of high sensitivity,
TABLE 11 | Application of HPLC-ICP-MS in medicinal materials.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials* | Test results |
|------------|----------------|----------------|-------------------------------|--------------------------------|--------------|
| Astragalus mongholicus Bunge | Traditional Chinese medicine | Hypertension | Anti-inflammation, immune regulation, anti-tumor, anti-stress, and lipid-lowering | — | The arsenic speciation contents of As(III), DMA, MMA, and As(V) were determined before and after processing of Astragalus mongholicus Bunge, Rheum tanguticum (Maxim. ex Regel) Balf., Scutellaria baicalensis Georgi, Reynoutria multiflora (Thunb.) Moldenke, and Rehmannia glutinosa (Gaertn.) DC. The RSD of repeatability, stability, and recovery were 1.21%–4.31%, 1.78%–4.97%, 1.19%–5.57%, and 83.15%–118.32%, respectively (Chang, 2014) |
| Reynoutria multiflora (Thunb.) Moldenke | Traditional Chinese medicine | Dizziness, constipation | Anti-inflammatory, anti-inflammatory, anti-stress, and lipid-lowering | — | Four different valence arsenic, As(III), DMA, MMA, and As(V), were determined in Alisma plantago-aquatica L., Lonicera japonica Thunb., and Spatholobus suberectus Dunn. The linear relationship is good at 5-200ug. L−1. The average recovery (n = 9) was 105.1%–108.4%, and the detection limit was 0.01 mg kg−1. Small amounts of As(III) and As(V) were detected in Alisma orientalis and small amounts of As(III), DMA and As(V) were detected in Lonicera japonica Thunb., whereas As(III), DMA, MMA, and As(V) were not detected in Spatholobus suberectus Dunn (Wang et al., 2015c) |
| Rehmannia glutinosa (Gaertn.) DC. | Traditional Chinese medicine | Hematemesis, bleeding, sore throat | Antibacterial, anti-tumor, anti-gastric ulcer, anti-aging | — | — |
| Rheum tanguticum (Maxim. ex Regel) Balf. | Traditional Chinese medicine | Hematemesis, bleeding, edema, drenching | Antibacterial, anti-tumor, anti-gastric ulcer, anti-aging | — | — |
| Scutellaria baicalensis Georgi | Traditional Chinese medicine | Diarrhea, jaundice, cough | Antibacterial, anti-inflammatory, anti-fatigue, and anti-tumor | — | — |
| Alisma plantago-aquatica L. | Traditional Chinese medicine | Adverse urination, diarrhea, dizziness, astringent pain, hyperlipidemia | Anti-tumor, hypoglycemic, hypolipidemic, and hepatoprotective | — | — |
| Lonicera japonica Thunb. | Traditional Chinese medicine | Heatstroke, multiple infectious diseases | Anti-inflammatory, antibacterial, antiviral, hypolipidemic, and hypoglycemic | — | — |
| Spatholobus suberectus Dunn | Traditional Chinese medicine | Irregular menstruation, dysmenorrhea, amenorrhea, numbness, and paralysis | Anti-inflammatory, analgesic, anti-tumor, antiviral, and antidepressant | — | — |
| Angelica sinensis (Oliv.) Diels | Traditional Chinese medicine | Irregular menstruation, amenorrhea, dysmenorrhea, constipation | Analgesic, anti-inflammatory, antibacterial, antioxidant, anti-senile dementia | — | — |
| Citrus deliciosa Ten. | Traditional Chinese medicine | Epigastric fullness, omitting and diarrhea, cough and phlegm | Anti-liver injury, anti-tumor, and anti-pulmonary fibrosis | — | — |
| Gardenia jasminoides J.Ellis | Traditional Chinese medicine | Icteric hepatitis, sprain, hypertension, diabetes mellitus | Antibacterial, anti-tumor, hypoglycemic | — | — |
| Gentiana scabra Bunge | Traditional Chinese medicine | Hypertension, dizziness, liver disease | Anti-inflammation, analgesia, liver protection, and antiviral | — | — |
| Lonicera japonica Thunb. | Traditional Chinese medicine | Fever, heatstroke, multiple infectious diseases | Anti-inflammatory, antibacterial, antiviral, hypolipidemic, and hypoglycemic | — | — |
| Lycium barbarum L. | Traditional Chinese medicine | Liver disease, hyperglycemia | Hypoglycemic | — | — |
| Magnolia officinalis Rehder & E.H.Wilson | Traditional Chinese medicine | Vomiting and diarrhea, constipation, asthma, and cough | Anti-epilepsy, anti-depression, anti-dementia, anti-cerebral ischemia, anti-tumor, hypoglycemic | — | — |
| Ostea gigas Trinb. | Traditional Chinese medicine | Insomnia, dizziness, spontaneous sweating, and night sweating | Antioxidant, anti-tumor, hypoglycemic | — | — |
| Polygonum tincturum Alt. | Traditional Chinese medicine | Sore throat, sore mouth, infantile convolution, erysipelas, snakebite | Antibacterial, antiviral, anti-tumor, and antiallergic | — | — |
| Cordyceps sinensis Berk. | Traditional Chinese medicine | Impotence, sore waist and knee, cough | Anti-oxidation, anti-tumor, and anti-aging | — | Guangdong province of China |

1) Six arsenic speciation preparations, As(C), As(III), DMA, MMA, and As(V), were determined in fresh Cordyceps sinensis Berk. The linear relationship of arsenic speciation with the measured elements was As(III) 4.0 μg/kg, As(V) 5.0 μg/kg, MMA 3.0 μg/kg, DMA 2.0 μg/kg, and AsB 0.2 μg/kg. The recovery was 88.7%–101%, and the relative standard deviation was 1.02%–3.34% (n = 3). The arsenic forms in 10 traditional Chinese medicines were mainly As(V) and organic arsenic (Li, 2018c)
TABLE 11 | (Continued) Application of HPLC-ICP-MS in medicinal materials.

| Latin name | Medical system | Therapeutic use | Main pharmacological effects | Origin of medicinal materials* | Test results |
|------------|----------------|----------------|-----------------------------|-------------------------------|--------------|
| Ganoderma lucidum (Curtis) P. Karst. | Traditional Chinese medicine | Insomnia, cough, asthma, excessive phlegm, asthenia, and fatigue syndrome | Anti-tumor, anti-aging, prevention and treatment of cardiovascular diseases, and protection of liver injury | — | the measured elements in their linear range is good (R > 0.99998), and the average recovery of the sample is 96.3%–105.6%, 4% (RSD < 4.3%), the detection limits of six arsenic preparations were less than 0.15 ng/ml (Qian et al., 2019b) 2) The main forms of arsenic in Cordyceps sinensis Berk. were MMA, DMA, AsC, AsB, AsII, and AsV (Zuo et al., 2018) Six selenium forms of Se (VI), Se (IV), SeMet, SeCys2, SeEt, and SeMeCys in Ganoderma lucidum (Curtis) P. Karst. were determined. The mass concentration of six selenium forms is 0.5–100.0 μg L⁻¹ has a linear relationship with its corresponding peak area, and the detection limit (3S/N) is 0.03–0.15 μg L⁻¹. The recovery was 91.7%–98.7%, and the relative standard deviation (n = 6) was 0.031%–3.2% (Zeng and Yao, 2020) |

*Note: the origin of medicinal materials recorded in the table is collected from the articles. If the origin of medicinal materials is not recorded in the articles, it is indicated by “—.”

low detection limit, and wide linear range. Zuo et al. (2017) used ICP-MS to determine the residues of heavy metals and harmful elements in 18 common animal medicinal materials such as gecko, cicada molt, centipede, and leech. Among them, Pb, Cd, As, and Ag exceed the standard. The quality of medicinal materials derived from animals should be focused on, and the limit standard of heavy metals and harmful elements in medicinal materials derived from animals from the perspective of risk assessment should be improved. The rest are shown in Table 8. It provides a basis for further improving the quality of medicinal materials derived from animals and ensuring their drug safety and provides a basic reference for the study of the speciation and valence of heavy metals in medicinal materials derived from animals. From the 15 articles on medicinal materials derived from animals determined, 49 elements such as Cu, As, Cd, Hg, Se, Pb, and Mn were determined, of which eight were Cu, accounting for 53.33%. The elements determined by ICP-MS and their proportion in animal-derived medicinal materials are shown in Figure 3. From the 15 articles on the determination of medicinal materials derived from animals, all animal-derived medicinal materials belong to traditional Chinese medicine.

**ANALYSIS AND APPLICATION OF ICP-MS IN MEDICINAL MATERIALS DERIVED FROM MINERALS**

Medicinal materials derived from minerals are rich in resources, unique curative effects, and numerous varieties. However, due to a large number of mineral sources, different mineral sources, and great differences in quality, the research on the quality standard of mineral traditional Chinese medicine is of great significance in clinical application. Mineral traditional Chinese medicine can be divided into raw medicinal materials derived from minerals (such as cinnabar, calamine, and natural copper), processed products of mineral raw materials (such as mirabilite and light powder) or fossils of animal bones (such as petrel, keel, and pumice). At present, the quality evaluation of mineral traditional Chinese medicine includes experience identification, purity inspection, and content determination. Empirical identification of the characteristics of mineral medicinal materials can reflect the quality of medicinal materials to a certain extent. For example, ochre is brown-red in color, with an obvious cross-section level “nailhead” and no miscellaneous stones are preferred (Hu, 2016). However, due to the high similarity of the external morphological characteristics of medicinal materials derived from minerals and more confused products, the practitioners of traditional Chinese medicine often lack the professional knowledge of mineralogy, so character identification needs long-term experience accumulation and inheritance. The application of modern instrumental analysis methods in the identification and quality evaluation of medicinal materials derived from minerals is gradually expanding. Among them, ICP-MS is becoming the key technology for mineral drug evaluation (Li et al., 2018a).

In recent years, the relationship between the types and contents of inorganic elements in traditional Chinese medicine...
and their efficacy has attracted extensive attention. The content determination of these elements, including main elements and trace elements, can provide not only important data for the quality evaluation of traditional Chinese medicine but also a reference for the clarification of its action mechanism. As an important member of the family of traditional Chinese medicine, medicinal materials derived from minerals deserve special attention for their safety and effectiveness. Hu (2016) used ICP-MS combined with microwave digestion. Comparing the contents of trace elements of Pb, Cu, Mn, Ni, Cr, Zn, As, Ti, and Cd in eight mineral traditional Chinese medicine pieces of the calcined keel, calcined oyster, gypsum, talc, Mircanite, ochre, amber, and valerian seed with their formula granules, the results show that there are some differences in the contents of trace elements between mineral traditional Chinese medicine and its formula granules. Zhou et al. (2015) used the ICP-MS method to determine the content of trace elements in six common mineral Chinese herbal materials, namely, raw keel, calcined keel, raw oyster, calcined oyster, raw gypsum, and talc, established the detection method of corresponding elements, and made comparative analysis on the content of trace elements in the raw calcined keel and raw calcined oyster. It provides a method for the determination of trace elements in different mineral Chinese medicinal materials from different producing areas. The rest is shown in Table 9. From the nine articles of medicinal materials derived from minerals determined, 70 elements such as Fe, Cu, Zn, Al, As, Se, and Na were determined, of which eight were Fe, Cu, and Zn, accounting for 88.89%. The elements determined by ICP-MS and their proportion in mineral raw materials are shown in Figure 4. In the nine articles on the determination of medicinal materials derived from minerals, the measured medicinal

| Name                          | Medical system | The main medicinal materials                                                                 | Therapeutic use                        | Main pharmacological effects | Test results                                                                 |
|-------------------------------|----------------|---------------------------------------------------------------------------------------------|---------------------------------------|-----------------------------|-----------------------------------------------------------------------------|
| Huoxue Zhitong Capsules       | Traditional Chinese medicine | Angelica sinensis (Oliv.) Diets, Boswellia sacra Rück., Borneol, Natural copper, Panax notoginseng (Burkii) F.H.Chen | Traumatic injury, hemostasis, swelling, pain | Anti-inflammation and analgesia | Soluble arsenic and valence arsenic AsC, AsB, AsII, DMA, MMA, and AsV in seven batches of Huoxue Zhitong Capsules were determined. Only AsII was detected in six valence arsenic [Chen and Zhang, 2019]. The content of total arsenic in Jiegu Qili tablets was determined. The linear range of total arsenic mass concentration was 2.0–20.0 ng/ml (r = 0.9992). The detection limit was 0.0016 ng/ml. The recovery was 98.23%–99.95%, and the RSD was less than 3.5% 25% (n = 3). AsB, AsC, MMA, DMA, As III, and As V have good linear relationship (r > 0.999), the detection limit is 0.0029–0.0103 ng/ml, the recovery is 89.15%–95.5% 89%, and RSD is less than 7.14% (n = 3). Jiegu Qili tablets contain MMA, DMA, As III, and As V, in which the content of As V is the highest, followed by As III, and a small amount of MMA and DMA [Chu et al., 2020]. The detection limits of AsB, DMA, As III, MMA, and As V were 0.05, 0.05, 0.08, 0.10, and 0.10 μg/L, respectively. Linear correlation coefficient R² > 0.999. The recovery was 86.3%–109.2%, and the RSD was less than 5% [Chen et al., 2017]. The contents of Cr (III) and Cr (VI) in Jiegu Qili tablets were determined. Cr (III) and Cr (VI) were in the range of 5–100 μg·L⁻¹, r > 0.999, the recovery of Cr (VI) was 82.1%–90.4%. The recovery of Cr (III) was 94.1%–95.2%. Cr (VI) was detected in eight batches of samples, the detection value was 0.027–0.082 μg·g⁻¹, the average value is 0.051 μg·g⁻¹, the detected value of Cr (III) is 5.775–18.743 μg·g⁻¹, and the average value is 10.366 μg·g⁻¹ [Chen et al., 2020]. |
| Jiegu Qili tablets             | Traditional Chinese medicine | Angelica sinensis (Oliv.) Diets, Boswellia sacra Rück., Calamus draco Willd. Ground beetle, Myrrh, Rheum tanguticum (Maxim. ex Regel) Balf. | Catacasis | Improve hemorhoeology |                                                                                   |
| Niuhuang Jiedu tablets        | Traditional Chinese medicine | Bezoar, Borneol, Glycyrrhiza uralensis Fisch. ex DC., Pterocodon grandiflorus (Jacq.) A.DC., Plaster, Realgar, Rheum tanguticum (Maxim. ex Regel) Balf., Scutellaria baicalensis Georgi | Sore throat, sore gums, sore tongue, swelling, and pain | Antioxidant, antiviral, anti-inflammatory, antitumor, anticonvulsant, anti-epileptic |                                                                                   |
| Xiaoer Kechuanling granules    | Traditional Chinese medicine | Ephedra equisetina Bunge, Glycyrrhiza uralensis Fisch. ex DC., Lonicerajaponica Thunb., Plaster, Strobilanthes cusia (Nees) kuntze, Prunus sibirica L., Trichosanthes kirilowii Maxim. | Cough caused by upper respiratory tract infection | Antiviral, anti-inflammatory, antioxidant, and anticoagulant |                                                                                   |

| Name                          | Medical system | The main medicinal materials                                                                 | Therapeutic use                        | Main pharmacological effects | Test results                                                                 |

Table 12 Application of HPLC-ICP-MS in Chinese patent medicine.
materials derived from minerals belong to traditional Chinese medicine.

APPLICATION OF ICP-MS IN CHINESE PATENT MEDICINE

Chinese patent medicine is based on the theory of Chinese medicine, which is made from Chinese herbal medicines according to the prescribed prescription, production technology, and quality standard. It is the cream of effective prescriptions created and summarized by China’s medical practitioners in past centuries. However, the method of detection and control of inorganic elements in China patent medicine is in the Chinese drug standard and even the Pharmacopoeia. The degree of attention is not high. Currently, many researchers have begun to focus on the problems of trace elements, heavy metals, and harmful elements in Chinese patent medicine (Fu, 2017).

Inorganic elements have a strong ability to form complexes and easily form coordination bonds with ligands containing N, O, and S in organisms to coordinate the material balance in the body (Zhao et al., 2019). The content and type of inorganic elements in traditional Chinese medicine can affect its nature, taste, and efficacy. For example, Zn, Ca, and Fe are the characteristic inorganic elements of hemostatic traditional Chinese medicine. K and Mg can affect the properties of drugs for promoting blood circulation and removing blood stasis. The difference between Fe and Mn content is the basis of the “cold and warm” property (Wu et al., 2014). It shows that the type and content of inorganic elements have a certain synergistic effect on the exertion of drug efficacy. In Chinese patent medicine, clarifying the types and characteristics of inorganic elements can provide a reference for the efficacy study of the preparations from the perspective of inorganic elements. As we all know, the quality and safety of raw materials directly affect the efficacy and drug safety of finished products. With the advancement of China’s industrialization, the pollution of soil and water by heavy metals and harmful elements is becoming more and more serious, resulting in the possible pollution of native traditional Chinese medicine in various links such as growth, collection and processing, warehousing and transportation, and even the production process of preparations (Yan et al., 2017). In recent years, due to the frequent exposure to heavy metal pollution in traditional Chinese medicine, South Korea, the United States, and other countries have raised the safety testing standards of traditional Chinese medicine and restricted the import of traditional Chinese medicine. At present, in China’s drug standards, only a few processed products of traditional Chinese Medicine (Zhong yao yin pian), such as Glycyrrhiza uralensis Fisch. ex DC., Astragalus mongholicus Bunge, and Lonicera japonica Thunb., have formulated inspection items for the content of heavy metals and harmful elements, whereas Chinese patent medicines have basically not formulated relevant inspection items. Therefore, we should pay attention to the problem of heavy metal pollution in Chinese patent medicines and formulate detection methods for safety indicators such as heavy metals and harmful elements. However, during preparations, it is not completely clear whether there is interaction and whether it is transformed in vivo due to the complex composition.

The research and development of traditional Chinese medicine injection have become one of the hot spots in the modernization of traditional Chinese medicine. Compared with ordinary preparations, it is a high-risk variety from the perspective of clinical application. Therefore, the research on the safety of traditional Chinese medicine injection has attracted much attention, especially the residue of heavy metals and harmful elements. The residues of heavy metals and harmful
elements mainly come from environmental pollution, processing, storage, and migration of packaging containers such as ampoules. At present, the determination of elements in injections derived from traditional Chinese Medicine usually adopts the single element method, which has complicated procedures and a long analysis time. The ICP-MS method can simultaneously determine Pb, As, Cd, Hg, Cu, and other elements in injections derived from traditional Chinese Medicine and has become an important means of element analysis in recent years, as shown in Table 10. In terms of clinical medicine, injections derived from traditional Chinese Medicine are high-risk varieties; Pb, Cd, As, Hg, and Cu, represented by heavy metals, are among the most important exogenous pollutants in injections derived from traditional Chinese Medicine. Toxicity is mainly characterized by chronic poisoning, As, Cd element with clear carcinogenic, teratogenic, and mutagenic effects, and injections derived from traditional Chinese medicines without digestive tract directly into the bloodstream. Therefore, it is significant to carry out limited inspection of heavy metals and harmful elements in injections derived from traditional Chinese Medicine. Although the country has not made a clear limit on trace elements of Fe, Mn, Zn, Al, and others, their excessive amount may also cause adverse effects on the human body. For injections derived from traditional Chinese medicine, the complexity of the ingredients also determines the diversity of their efficacy, making it difficult to distinguish between effective ingredients and toxic ingredients. As an important component of the material basis of drug properties, trace elements are closely related to the drug properties, efficacy and adverse drug reactions. Therefore, accurate determination of trace elements is of great significance to the study of pharmacodynamics, the safety of drug intake, and the formulation of the limit standard of harmful elements.

From the 46 articles on Chinese patent medicine, 62 elements such as Cu, As, Pb, Cd, Hg, Ni, and Cr were determined, of which 43 were Cu, accounting for 93.48%. Thirty-eight of the tested Chinese patent medicine belong to traditional Chinese medicine, accounting for 83%. The elements determined by ICP-MS and their proportion in Chinese patent medicine are shown in Figure 5. Six articles belong to Tibetan medicine, accounting for 13%. Two articles belong to the medical system of Mongolian medicine in China, accounting for 4%.

**DEVELOPMENT STATUS OF ICP-MS COMBINED TECHNOLOGY**

ICP-MS is undoubtedly a very practical means for the quantitative analysis of heavy metals. However, for traditional pharmaceutical preparations, a series of changes will occur when they are absorbed into the human body, such as the valence changes of heavy metals. At this time, it is necessary to accurately detect some valence changes, so the single ICP-MS method becomes weak and needs to be used in conjunction with other instruments to complete this work. At present, ICP-MS has been used in various analytical fields. For example, Heitland et al. (2017) used HPLC-ICP-MS to diagnose and monitor patients with severe hexavalent chromium and inorganic arsenic poisoning to provide valuable data for doctors and toxicologists. However, for the research of traditional drugs, continuous use technology is not widely used. The application of HPLC-ICP-MS in traditional drugs and their preparations are shown in Tables 11 and 12. Other combined analytical techniques are also widely used. However, they are rarely used in traditional medicine. In the searched articles, HPLC-ICP-MS is mostly used to determine different forms of As, including AsC, AsB, AsIII, DMA, MMA, and AsV, and the determination of other elements is less in the articles search. Therefore, more combined techniques are used to analyze traditional medicine. It will be more beneficial to accelerate the development of traditional medicine. From the 10 articles on the application of the combined technique, 16 elements such as MMA, DMA, AsIII, AsV, AsB, AsC, and AsI, were determined. Among them, MMA and DMA were determined most, with eight articles accounting for 80.00%. The content and proportion of elements in medicinal materials and Chinese patent medicines determined by ICP-MS are shown in Figure 6. Among the 10 articles on the application of combined technology, the tested medicinal materials and preparations belong to traditional Chinese medicine.

**DISCUSSION**

This study describes the application of ICP-MS analysis of minerals and heavy metals in traditional drugs, including medicinal materials derived from plants, animals, minerals, and their preparations and the research and development of combined technology. Among them, medicinal materials derived from plants are divided into roots, stems, leaves, flowers, fruits and seeds, whole plants, and other medicinal materials derived from plants of medicinal parts. The content of effective components of traditional medicinal materials derived from plants is affected by soil, climate, and other environmental factors, so the quality of medicinal materials from different producing areas is different, which is also an important reason for the formation of genuine medicinal materials. Zuo et al. (2021) used ICP-MS to determine the residues of heavy metals and harmful elements in *Lycium barbarum* L. The average contents of lead, cadmium, arsenic, mercury, and copper in *L. barbarum* L. from three origins were 0.30, 0.066, 0.05, 0.003, 6.71 mg·kg⁻¹, respectively. Cluster analysis and PCA showed that 33 batches of samples were divided into three groups, and the samples from the same origins were clustered into the same group. The results of self-organizing map clustering were consistent with those of PCA. Regularities between the distribution of *L. barbarum* L. and origins could be found. The results of the safety evaluation showed that the single factor index of lead, cadmium, arsenic, mercury, and copper in all the samples was less than 0.7, and the comprehensive pollution index ranged from 0.11 to 0.51, which indicated that the pollution situation was safe. The results of the risk assessment indicated that the health risk
of heavy metals and harmful elements in samples from different origins was acceptable. As the medium of direct contact with medicinal materials, the soil is directly related to the composition and content of inorganic elements in traditional Chinese medicine and is one of the important ecological factors affecting the quality of medicinal materials. Medicinal materials play an important role in the soil environment. On the one hand, the social progress and the impact of human activities has caused soil pollution, the decline of soil fertility, the degradation of land quality, the reduction of the quality of medicinal materials, and the exceeding of harmful substances. On the other hand, the planting areas of medicinal materials have been expanded and changed arbitrarily, and some have exceeded the traditional real estate areas, so their ecological suitability is worth studying. ICP-MS combined with the statistical analysis traditional real estate areas, so their ecological suitability is worth studying. ICP-MS combined with the statistical analysis greatly improves the theoretical understanding of medicinal materials derived from plant cultivation, and also reveals the important influence of the control and regulation of inorganic elements on the quality of original medicinal materials.

The efficacy of traditional drugs is the result of the synergy of multiple functional components contained in them. At present, the quality control of traditional drugs in China mainly includes appearance and microscopic identification for eliminating the false and preserving true, inspection of impurities and heavy metals for judging quality, and determination of the content of effective components directly related to function and effect, unable to characterize the integrity and complexity of preparations pharmacology and efficacy, so that the product quality cannot be effectively controlled, which seriously affects the clinical application of traditional drugs and restricts the development of new drug research and development and industry of traditional drugs. Traditional Chinese medicine theory emphasizes the overall effect of traditional drugs and attaches importance to the synergistic effect of various chemical components. Therefore, only taking one to two effective components in traditional drugs as quantitative and qualitative indicators can never reflect the internal quality of traditional Chinese medicine as a whole. It is necessary to establish a method to comprehensively evaluate the quality of traditional Chinese medicine as a whole. There is a correlation between the content of effective components and the content of inorganic elements in traditional drugs. Therefore, the detection of inorganic elements in traditional drugs is feasible to control their quality. Therefore, the elements and their contents in medicinal materials can be determined by ICP-MS, the inorganic element spectrum can be established, and the finishing quality of medicinal materials and Chinese inorganic elements can be evaluated in combination with data system analysis to achieve quality control. Secondly, for the quality control of the preparations, we should not only determine the inorganic elements of preparations but also analyze the inorganic elements of raw materials and medicinal materials to avoid exceeding the standard of harmful heavy metal elements from the source and then control the risk that may be introduced into the preparations. At present, the safety of traditional drugs has become a “bottleneck,” restricting the production and development of traditional drugs and gaining international recognition. Excessive heavy metal elements have an important impact on the activity and safety of medicinal materials, which has attracted extensive attention (Ji et al., 2014). ICP-MS is widely used in traditional medicine with its unique advantages and has achieved remarkable results, which has promoted the development of traditional medicine. Starting from the detection of soil and water quality, it ensures the safety of medicinal materials. The safety of clinical medication is ensured starting from the detection of medicinal materials and preparations. In addition, the pharmacodynamic material basis of some preparations may be related to trace heavy metals, so it can be comprehensively analyzed from the preparations, blood components, and tissue distribution components so that the application of ICP-MS can indirectly reveal the pharmacodynamic material basis. The limit standard of heavy metal elements measured by ICP-MS can fill the data gap of many traditional Chinese medicines and Tibetan medicine standards in the future and lay a foundation for the validation experiment of heavy metal monomers. ICP-MS can also be used to determine inorganic elements in biological samples (whole blood, serum, urine, lung, liver, and other tissues) to provide effective information for the exploration of drug action mechanisms and clinics. Liang et al. (2014) tested the changes of iron content in rat liver by ICP-MS, verified that d-limonene had a certain protective effect on iron coincidence caused by alcohol, and provided a reference for the study of alcoholic liver injury. Morton et al. (2017) used ICP-MS for multi-element analysis of human lung samples to determine the concentration of various elements in the collected lung samples and then used them for comparison with future clinical, environmental, nutritional, toxicological, and forensic investigations. Zhao et al. (2018) determined the spectrum of metal elements in patients’ serum by ICP-MS and found the very important metal elements in a specific infection in blood flow infection, which provided a basis for the diagnosis, prevention, and treatment of BSI from the perspective of metallography. The content, migration, and transformation of trace elements in organisms play an important role in physiological activities. The analysis of trace elements in cells is of great significance, which can understand the functional mechanism of trace elements in cells and organisms. Renqing Changjue is a traditional Tibetan medicine, which has been widely used to treat various gastroenteritis diseases. However, due to the toxic components in Renqing Changjue, its biosafety and toxicity still need to be explored, including various heavy metals. Therefore, Wang et al. (2020b) gavaged rats with different doses of Renqing Changjue, and the recovery observation period lasted for 15 days. The liver and kidney tissues were examined by histopathology, and the serum and urine samples were collected for $^1$H nuclear magnetic resonance ($^1$H NMR)
spectral analysis and biochemical analysis. ICP-MS was used to determine the content of Hg in urine and serum samples to evaluate the toxicity and elaborate on the toxicological mechanism of Renqing Changjue in order to provide a basis for safety evaluation of Renqing Changjue in clinical use. Song et al. (2021) used ICP-MS to determine the contents of 18 elements such as Mn, Cu, Sr, Pb, Au, and Hg in hepatic venous blood, abdominal aortic blood, brain, liver, kidney, hair, urine, and feces of rats 24 h after MCAO. The contents of Li in the brain increased, and the contents of Cr and Cd decreased. The content of Mn in the liver increased, and the content of Ni decreased. The contents of Ag and Cs in the kidney increased.

In recent years, the scientific community has paid increasing attention to metals belonging to the platinum group (PGM), including Ru, Rh, Pd, Os, Ir, and Pt. The effects of platinum group element complexes and some platinum divalent compounds on cancer and genotoxicity have been confirmed in microbial experiments (Melucci et al., 2022). Melucci et al. (2021) determined thallium in herbal medicines. Precision and trueness, expressed as relative standard deviation and relative error, respectively, were generally lower than 7% in all cases. Inorganic elements affect not only the growth and development of medicinal plants but also the constituent factors of effective components in medicinal materials (Wang et al., 2014). Traditional drugs contain rich kinds of inorganic elements, complex matrices, and large content differences. ICP-MS has the advantages of a wide linear range, high sensitivity, and high analysis efficiency. Therefore, this technology can well solve the analysis problems of inorganic elements in traditional Chinese medicine. Luo et al. (2015a) determined and analyzed the differences of inorganic elements before and after processing R. multiflora (Thunb.) Moldenke by ICP-MS. After processing, the contents of Al, Fe, K, Mg, Mn, and Zn decreased, whereas the contents of As, Pb, and Cd decreased significantly. It is suggested that the physiological functions of Al, Fe, K, Mg, Mn, and Zn elements are consistent with the effects of R. multiflora (Thunb.) Moldenke, which are beneficial to the liver and kidney, benefiting essence and blood enhancing immunity and anti-aging. The content of these elements increased significantly after processing, which may be related to the enhancement of the tonic effect of R. multiflora (Thunb.) Moldenke. The heavy metals As, Pb, and Cd are harmful to the human body and decrease significantly after processing, which may be one of the reasons for the detoxification of R. multiflora (Thunb.) Moldenke processed. With the continuous popularization and application of the inorganic element spectrum and statistical analysis and evaluation model, the research on the overall quality control of traditional Chinese medicine will be perfect. At the same time, with the development of high-performance liquid chromatography, ion chromatography, and ICP-MS, the analysis methods for different valence states of inorganic elements will become more and more mature. In addition, ICP-OES is also a means of determining metal elements. ICP-OES detects the intensity of the atomic characteristic emission spectrum. In the atomic emission spectrum, each element has multiple characteristic spectral lines. The spectrometer can automatically correct the function to reduce the background signal and screen out two to three analysis wavelengths with low detection limit, high sensitivity, and small interference for qualitative and quantitative analysis. Although the detection limit of ICP-OES is lower than that of ICP-MS, it has met the detection needs of various drugs, and its technology is mature, stable, economical, and convenient. It can be used as a detection method complementary to ICP-MS. Shen et al. (2019) determined 29 kinds of inorganic elements in samples of Paris daliensis H. Li et V. G. Souku and P. dulongensis H. Li et S. Kuritap produced in different regions to measure the content of 10 key inorganic elements: Cr, Mn, Fe, Cu, Hg, Zn, As, Sr, Cd, and Pb. Under the experimental conditions, elements were not related to each other, and many kinds of elements could be measured at the same time; toxic and heavy metals in samples of P. daliensis H. Li et V. G. Souku, and P. dulongensis H. Li et S. Kuritap did not exceed the limit. Hg was not detected in all samples. Zhong et al. (2019) determined the content of 20 inorganic elements in 18 samples of roots, stems, and leaves of A. lappa L. produced in different areas. Twenty kinds of inorganic elements in the samples of A. lappa L. roots contained rich elements essential for human beings such as K, Ca, Na, P, and trace elements Cu, Fe, Zn. Heavy metal Pb, As, Cu, and Cd in A. lappa L. samples did not exceed the limit. Hg was not detected in all 12 samples. Heavy metals in A. lappa L. roots harvested in 12 months did not exceed the limit. Fang et al. (2007) used HPLC-ICP-MS to analyze the forms of As in nine kinds of traditional Chinese medicine preparations, such as Niuhuang Jiedu tablets, Bushen tablets, Shiertaibao pills, Baoyingdan, Mingyan pills, Zhengxin pills, and Biminqing. An anion exchange column was used to determine the content of 0.5%. The aqueous solutions of 2 mmol/L EDTA and 2 mmol/L NaH2PO4 were used as mobile phases. Four forms of As III, As V, MMA, and DMA were successfully separated and determined. The results showed that the form of As in the sample was mainly toxic inorganic arsenic and the amount of organic arsenic was low. Li et al. 2012 analyzed six different valence arsenic by HPLC-ICP-MS and studied the forms of soluble arsenic in Realgar and five different preparations of Realgar-containing preparations. The results showed that the acid-soluble arsenic of Realgar and its preparations was far less than its total arsenic content, and the existence of other components in the preparations may inhibit the dissolution of toxic forms of soluble arsenic. The determination of multivalent elements not only enriches the application scope of ICP-MS but also makes the research on the complex system of traditional drugs more in depth to lay a more solid foundation for the relationship between components and efficacy and clinical application research. At present, although the overall research on inorganic components in traditional drugs has attracted attention, the research on the process of elements entering the human body and the interaction between elements in the body is still.
relatively lacking. Nowadays, the analysis of inorganic elements in traditional Chinese medicine is mostly supplemented by other factors and indicators, and it is difficult to clarify the role of elements themselves. The mode of Metallomics refers to the research ideas of metabolomics, which is conducive to a more in-depth study of the role of inorganic elements and finding the specific targets and sites of some elements in the body. ICP-MS and its combined technology have many reports on the study of the relationship between trace elements and efficacy, the relationship between element morphology and toxicology, the determination of element content, and inorganic fingerprint of traditional drugs. However, in addition to the determination of element content, the research in other aspects is not deep enough.

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AUTHOR CONTRIBUTIONS

WC is mainly responsible for the research and the main work of this paper. YY is responsible for assisting in the data arrangement. KF is responsible for assisting in the research. DZ and ZW function as communication authors.

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