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HEAVY METAL AND MICROBIAL CONTAMINATION IN MARKETED HERBAL POWDERS

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1. INTRODUCTION

Herbal powders occupy an awkward position between food and medicine. They are sold in markets, health shops and online as digestive aids, tonics and traditional remedies, and they are often taken for weeks or months by people who regard anything plant-based as safe. A powder, unlike a whole root or leaf, hides its origin. Colour and smell can be adjusted, adulterants can be mixed in, and fine grinding exposes every particle to whatever contamination the plant, the soil, the mill or the storage room provides. The result is a

Abstract

This review summarises published evidence on heavy metal and microbial contamination of herbal powders sold over the counter, and it presents no new analytical data. It outlines how contaminants enter the supply chain, which metals and organisms are reported most often, how they are measured, and how pharmacopoeial and regulatory limits are applied. Surveys from several regions find that a minority of products exceed recommended limits for lead, cadmium, arsenic or mercury, and that moulds and enteric bacteria are frequent in powders handled and stored without control. Sampling plans, methods and limits differ between studies, which makes comparison difficult, and exposure-based risk assessments remain uncommon.

product category whose quality is very uneven, as many surveys have shown [1, 2, 3].

Two kinds of contamination dominate the literature. The first is chemical, led by lead, cadmium, arsenic and mercury, which come from soil, water, fertiliser, processing equipment and, in some traditional systems, from metals added deliberately. Poisoning reports and market surveys of Ayurvedic and other traditional Asian products, for example, show detectable lead, mercury or arsenic in a notable minority of the products tested [4, 5]. The second is biological, involving bacteria, yeasts and moulds, and the toxins that some moulds produce. Each type of contaminant has its own health consequences, test methods and legal limits, yet both are governed by the same quality system [1, 6, 7].

Regulation is uneven. In many countries herbal powders are classed as traditional medicines or dietary supplements, which means they escape the full controls applied to conventional drugs. Pharmacopoeias set limits for microbial counts and, increasingly, for toxic elements, and expert groups have reviewed the metal content of herbal drugs, but compliance depends on enforcement and on manufacturers' testing [1, 8, 9]. Patients rarely have any means of judging the quality of what they buy, so pharmacists, who are often asked about these products, need an accurate picture of the evidence. That picture should include both the genuine hazards and the fact that most products in most surveys are acceptable, so that advice is neither dismissive nor alarmist.

This article is a narrative review. The title describes a market survey, but no samples were collected or analysed for it, and no new contamination figures are given. The discussion draws on published surveys, toxicology reviews, regulatory documents and analytical method papers, and quotes numbers only as the original authors reported them. Sections that follow cover sources of contamination, metal toxicity and occurrence, microbial and mycotoxin hazards, analytical approaches, limits and risk assessment, and gaps. The main studies are collected in table 1, with their grouping shown in fig. 1.

It is worth separating contamination from adulteration, since the two are sometimes confused. Contamination refers to unintended presence of unwanted material such as metals,

microbes, pesticides or foreign matter. Adulteration refers to substitution or addition, for instance the use of a cheaper plant, the addition of synthetic drugs, or the deliberate inclusion of mineral ingredients. A single product can show both problems at once, and reviewers of the safety literature treat them together because the consumer experiences them in the same way, as an unexpected harm from a supposedly natural product [3, 10, 11].

2. SOURCES OF CONTAMINATION

Adulteration with soil, sand and other fillers can raise both metal and microbial loads in powders. Ground roots and barks are bulky, cheap and easy to bulk out, and pharmacopoeial quality control relies on simple tests of total ash and acid-insoluble ash to detect mineral matter, in addition to microscopy for foreign organic matter [6]. A high acid-insoluble ash value suggests that soil or sand has been picked up in harvesting or deliberately added, and such material carries both metals and spore-forming organisms. Because the tests are inexpensive, they could be applied far more widely at the point of purchase than they are, and they often give the first warning of poor handling [1, 6].

Table 1: Selected published evidence on contamination of herbal materials and how it is assessed

Study or source focus	Reported finding	Ref.
Ayurvedic medications five US states, 2000–2003	Lead poisoning in users traced to Ayurvedic medicines that contained lead.	[4]
Asian herbal preparations Netherlands	Mercury, arsenic and lead found; some products would give intakes of concern if taken as directed.	[5]
Raw Chinese herbs	Most herbs low in metals, a few with notable cadmium, lead or arsenic.	[12]
Herbs and spices Austria	Wide variation in metal content by species and site.	[13]
Powdered herbal drugs Japan	Heavy fungal contamination, mainly <i>Aspergillus</i> and <i>Penicillium</i> ; aflatoxin in some samples.	[14]

Study or source focus	Reported finding	Ref.
Herbal drugs Brazil	Toxigenic fungi isolated from marketed herbal drugs.	[15]
Herbal products Nigeria	Pathogenic bacteria isolated from products sold in a city market.	[16]
Medicinal plants review	High loads of spore-forming bacteria and Enterobacteriaceae reported.	[17]
Metal analysis ICP-MS	Preferred for multi-element trace analysis after microwave digestion.	[18, 19]
Elemental impurities ICH Q3D	Permitted daily exposure by route sets exposure-based limits.	[20]
Herbal microbial limits	Pharmacopoeial categories depend on use of boiling water; Salmonella absent.	[8, 9]

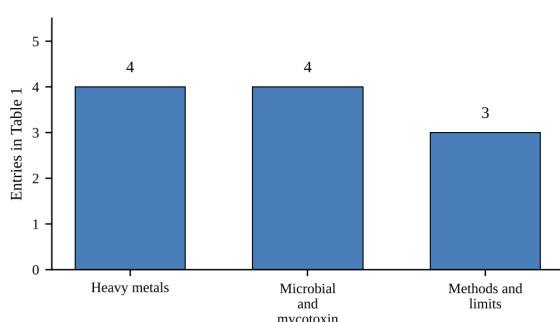


Fig. 1: Number of entries in table 1 by contaminant or topic

Plants take up metals from the soil and, for some species, from the atmosphere. The extent depends on soil chemistry, pH, organic matter and the plant's own physiology, and some medicinal species accumulate cadmium or lead far more readily than others. Reviews of metal accumulation in medicinal plants describe higher concentrations near mines, smelters, busy roads and fields treated with sewage sludge or certain phosphate fertilisers [21, 22]. Irrigation with polluted water adds to the load. Monitoring studies of herbs and spices grown in a single temperate country found considerable variation between species and sites, illustrating that origin matters as much as botanical identity [13].

Post-harvest handling is the next source. Roots are washed, dried and ground, often in small mills used for several products, and metal parts of grinders can release trace elements into the powder. Drying on bare

ground, in open air or on contaminated sheets exposes material to dust, animal droppings and insects. Where moisture remains high or humidity is poor, moulds grow quickly. European guidance on good agricultural and collection practices (GACP) and on good manufacturing practice (GMP) for herbal medicinal products addresses these steps, including water quality, drying conditions, hygiene and storage, but small producers frequently work outside any such system [7, 23, 24].

Traditional preparation practices can introduce metals intentionally. Some Ayurvedic, Chinese and other systems use processed minerals and metals, such as preparations of mercury, lead and arsenic compounds, on the belief that processing renders them safe and therapeutically useful. A systematic review of traditional Chinese medicines and a survey of Asian patent medicines in California documented such ingredients as well as undeclared pharmaceuticals [10, 11]. This is a different problem from environmental uptake, because the metal is part of the formula rather than an impurity. It also means that routine herbal testing, designed around trace-level contamination, may need extended ranges for these products [4, 5, 25].

Microorganisms enter from soil, water, handling and storage. Medicinal plants carry a natural microbial load, particularly of spore-forming bacteria and moulds, and counts often rise during drying, grinding and transport [17]. Powders have a larger surface area than whole herbs, which provides more attachment sites, and they trap moisture if packed warm. Storage in humid climates favours fungal growth, and the addition of other ingredients such as honey or sugar to formulations adds nutrients. Cross-contamination in markets, where powders are scooped from open sacks by hand and re-bagged, adds yet another source [2, 16, 26].

Decontamination steps are used by some manufacturers but are not without issue. Steam sterilisation reduces microbial counts but may change volatile constituents. Ethylene oxide fumigation was widely used in the past and has been restricted in several

jurisdictions because of residues. Irradiation is permitted for dried herbs in a number of countries and can reduce microbial load substantially, yet its acceptance by consumers and regulators varies. None of these methods removes metals or already-formed mycotoxins, so they are not a substitute for controlling raw material quality at source [1, 17, 27].

3. HEAVY METALS: TOXICITY AND OCCURRENCE

The toxicity of the four metals of main concern has been reviewed extensively. Lead is a cumulative toxicant whose effects include neurodevelopmental impairment in children, anaemia, raised blood pressure and kidney damage, and no safe threshold has been identified for some of its effects [28, 29]. Cadmium accumulates in the kidney over decades and is associated with renal tubular injury and bone effects [30]. Inorganic arsenic is a human carcinogen and causes skin lesions and cardiovascular disease [31]. Mercury has different forms, with organic methylmercury a neurotoxicant and inorganic mercury mainly harming the kidney and gut [32, 33, 34].

Plant species and the part used influence metal content. Roots and rhizomes, which are in direct contact with soil, often contain more cadmium and lead than leaves or flowers, whereas leafy material may show higher levels of atmospheric deposition near roads. Within a species, concentrations vary with soil pH and with age at harvest [13, 21]. Reviews from India point out that some widely used species behave as accumulators, which means that a powder made from them can exceed limits even when the soil appears only mildly contaminated [21, 22]. Botanical identity and origin should therefore both be recorded when results are interpreted.

The health risk from a herbal powder depends on dose and duration. A trace of lead in a product used once is not a concern, whereas the same product taken daily for years may contribute meaningfully to total exposure, especially in a child or pregnant woman. Risk assessments therefore compare estimated daily intake with health-based guidance values. The Joint FAO/WHO Expert

Committee on Food Additives (JECFA) withdrew its provisional tolerable weekly intake for lead because it could no longer be considered health protective, and the European Food Safety Authority (EFSA) reached a similar view on the absence of a threshold [35, 36]. For mercury, the focus has been on methylmercury in food [37].

Surveys of marketed products show a mixed picture. Lead poisoning traced to Ayurvedic medicines in several US states, and monitoring of Asian herbal preparations on the Dutch market, both point the same way, with some products that would deliver more lead, mercury or arsenic than accepted limits allow if taken as directed [4, 5]. Studies of traditional Chinese medicines, Asian products and herbal medicines in Nigeria reported similar problems in a minority of samples, with some products far above guideline values [10, 11, 38]. A study of single herbs used in Chinese medicine found that most raw herbs had low levels but that some contained notable cadmium, lead or arsenic [12].

Regional evidence from Africa illustrates how regulatory weakness and market structure interact. Analyses of herbal remedies sold in Nigeria found some products with lead, cadmium or other metals above guideline values, and a review of the South African medicinal plant trade described the difficulty of controlling quality when thousands of species are sold informally by traders with no testing capacity [24, 38]. Such markets supply large populations, and the products are often taken without medical advice. Where whole sacks of powder are sold by weight and decanted into small bags, labelling and traceability are essentially absent, so a contaminated lot may reach many buyers [2, 24].

Findings for plain herbal powders and teas are generally less alarming, with most samples within limits and a small proportion above them. Austrian herbs and spices showed wide variation but were largely acceptable [13]. Botanical supplements purchased in the United States showed measurable metals in several products, though few exceeded limits, and microbial counts were sometimes high [39]. Reports from India on medicinal herbs identified lead, cadmium and other metals in

some commonly used species at levels that would be of concern if consumed in quantity [21, 22]. Thus the risk is real but concentrated in particular products and origins.

Interpreting such figures requires care because the same concentration can mean different things in different contexts. A value in milligrams per kilogram of powder must be converted to a daily intake using the recommended dose, and the result compared with limits that assume lifelong exposure. Many surveys report concentrations only and apply raw-material limits to finished powders, which can overstate or understate risk. A useful report also indicates the form of the metal, especially for arsenic and mercury, since inorganic and organic species differ greatly in toxicity [20, 31, 34].

4. MICROBIAL AND MYCOTOXIN CONTAMINATION

Microbial quality studies of herbal drugs began in earnest in the 1970s. Work on powdered herbal drugs in Japan found heavy fungal contamination, mostly *Aspergillus* and *Penicillium* species, and detected aflatoxin in some samples [14]. A review of medicinal plants emphasised the high counts of aerobic spore-forming bacteria and Enterobacteriaceae that can occur and recommended that hygiene control start with cultivation rather than with finished-product testing [17]. These early observations remain valid, and later surveys on all continents have repeatedly confirmed the pattern, which suggests that the underlying causes are structural rather than local, and that they have not been removed by decades of guidance.

Surveys from Brazil, Argentina, Croatia and Nigeria illustrate the geographical breadth of the problem. In Brazilian herbal drugs, toxigenic *Aspergillus* species were found among the fungal isolates [15]. Argentinian medicinal herbs also carried toxigenic fungi [26], while moulds and mycotoxins were reported in herb teas and medicinal plants in Croatia [40]. Herbal products sold in a Nigerian city were contaminated with pathogenic bacteria such as *Escherichia coli*, *Salmonella* and *Staphylococcus aureus* [16]. Although methods and criteria differ, the studies agree that powders handled without

hygiene control are at risk, and that the organisms isolated are those one would expect from soil, water and human handling rather than from the plants themselves.

Mycotoxins add a chemical dimension to microbial contamination. *Aspergillus flavus* produces aflatoxins, including aflatoxin B₁, a potent liver carcinogen, while *Aspergillus* and *Penicillium* species produce ochratoxin A, which targets the kidney, and *Fusarium* species produce fumonisins and other toxins [27]. These compounds are heat stable and are not destroyed by ordinary drying or cooking, so killing the mould does not remove the toxin. Detection in herbal material has been reported in several surveys, which is why mycotoxin testing is increasingly proposed alongside microbial counts for high-risk species and powders stored in humid conditions [14, 27, 40].

The consequences of bacterial contamination differ from those of mycotoxins. Enteric organisms such as *Salmonella* and pathogenic *Escherichia coli* can cause gastrointestinal infection, and in immunocompromised or elderly patients more serious illness. Because many powders are swallowed without heating, there is no kill step before consumption. Pharmacopoeial standards for herbal medicinal products reflect this by setting stricter criteria for preparations that are not prepared with boiling water, and by requiring absence of *Salmonella* in a stated mass of material [8, 9]. Tests for specified organisms therefore matter more than total counts for patient safety.

Survival in dry powders deserves attention. Many bacteria do not grow at low water activity, yet some enteric pathogens survive for months in dry materials and become active again when the powder is mixed with water, milk or honey, or when it reaches the moist gut. Spores of *Bacillus* and *Clostridium* species persist indefinitely and germinate when conditions allow [8, 17]. A dry powder that meets a total count criterion may still harbour viable pathogens at low numbers, which is the reason pharmacopoeias include tests for specified organisms in addition to enumeration, and why absence in a stated mass of sample is the criterion used for *Salmonella* [8, 9].

Moisture is the controlling variable. Water activity below about 0.6 prevents most microbial growth, but powders absorb moisture from the air, and packaging that is not moisture-proof lets that happen during storage and sale. Studies in humid regions note that fungal counts increase with storage time in open or loosely sealed containers [2, 15, 17]. Drying to a defined moisture content, rapid cooling, appropriate packaging and storage out of damp conditions are therefore effective and inexpensive controls. Guidance on good manufacturing practice for herbal medicinal products includes these points, but implementation in small units remains patchy [7, 23].

Quality of reporting in this group of studies is variable. Some papers report total viable counts only, while others identify species, and a few quantify mycotoxins by chromatographic methods. Different media and incubation conditions give different counts from the same sample, and sampling of powders is rarely described in detail. Readers should treat reported prevalence figures as indicative rather than precise and should check whether the criteria used correspond to current pharmacopoeial categories. Differences of this type can produce apparent contrasts between regions that may be partly artefacts of method [9, 15, 16, 17].

5. ANALYTICAL APPROACHES AND SAMPLING

Sampling comes first and is often the weakest link. Powders are heterogeneous, with contaminants unevenly distributed in particles of different sizes, and a few grams taken from the top of a sack may not represent the lot. Standard pharmacognosy texts describe procedures for taking primary samples from several containers, combining and reducing them to a laboratory sample [6]. Papers on marketed powders usually purchase a single package from each outlet, which is realistic for consumer exposure, but conclusions about a brand or a lot require replicates. Homogenisation by grinding and sieving before analysis helps reduce variability.

Metals are measured after digestion of the powder to bring them into solution.

Microwave-assisted digestion with nitric acid, sometimes with hydrogen peroxide, is the modern standard and is faster and less prone to loss of volatile elements than open-vessel methods; reviews of sample preparation emphasise the risk of contamination and loss at this stage [19]. Inductively coupled plasma mass spectrometry is now preferred for trace elements because of its sensitivity and multi-element capability, and a practical guide describes its principles and interferences [18]. Atomic absorption spectrometry (AAS), including graphite furnace and cold-vapour techniques for mercury, remains widely used in laboratories without ICP-MS [18, 19].

Quality assurance in these methods depends on certified reference materials, spiked recovery, procedural blanks and participation in proficiency testing. Studies that omit them cannot distinguish a real low result from a digestion loss. Arsenic poses special difficulties because speciation matters, and methods that couple chromatography with ICP-MS separate inorganic from organic arsenic, though few survey papers do this [18, 31]. For mercury, rapid direct analysers and cold-vapour methods avoid losses during digestion. The ICH guideline on elemental impurities specifies validated methods with defined limits of quantitation relative to the permitted exposure [20].

Method validation turns an instrument reading into evidence. For metals, the usual parameters are linearity, accuracy by recovery of spiked and certified reference materials, precision, and limits of detection and quantitation low enough to measure well below the limit of interest. The elemental impurities guideline expects quantitation limits suitably below the control threshold for each element [20]. Matrix effects in plant digests, such as high dissolved solids, require internal standards and dilution, and polyatomic interferences in ICP-MS can be removed with collision cell technology [18, 19]. A paper that omits these details leaves its numbers unverifiable, and many survey papers do exactly that.

Microbial testing follows pharmacopoeial procedures in which a weighed sample is dispersed in diluent and plated on defined

media for total aerobic and total yeast and mould counts, then enriched and tested for specified organisms such as *Salmonella* and *Escherichia coli* [8, 9]. Herbal powders can inhibit growth through natural antimicrobial constituents, so method suitability tests are needed to show that organisms can be recovered in the presence of the sample. Rapid molecular tests and mycotoxin assays by chromatography or immunoassay supplement culture methods. The choice depends on purpose, since screening tolerates a simpler test than release testing [17, 27].

Cost and capacity limit testing in many settings. ICP-MS instruments and clean-lab conditions are expensive, and small producers rarely have access to them, so testing often depends on commercial or government laboratories. Colorimetric field kits and portable X-ray fluorescence can screen products for heavy metals, although they are less sensitive and less selective than laboratory methods. A tiered approach, in which cheap screening identifies suspect lots for confirmatory testing, is practical, provided that the screening method's limitations are understood and positive results are always verified in an accredited laboratory [1, 18, 19].

6. LIMITS, RISK ASSESSMENT AND REGULATION

Limits come from several sources. Proposed limits for toxic metals in raw plant material differ between authorities, with frequently quoted figures running from about 5 to 10 mg/kg for lead and from 0.3 to 1 mg/kg for cadmium [1, 2]. The European Pharmacopoeia sets its own limits for specified elements in herbal drugs, and national authorities apply a mixture of food and drug limits [8]. Because these values vary and were derived in different ways, a product may pass in one jurisdiction and fail in another. Readers of surveys should check which limit was used and whether it applies to raw material or to a finished product.

The ICH guideline on elemental impurities takes a different approach by defining permitted daily exposure (PDE) for each element by route of administration, based on toxicology. For oral products, the permitted

daily exposures are 5 micrograms for lead and cadmium, 15 for inorganic arsenic and 30 for mercury [20]. Converting a concentration limit from this requires the maximum daily dose of the powder, which leads to lower acceptable concentrations for high-dose products. Applying this exposure-based logic to herbal medicines is attractive, and regulators in several regions have moved in that direction, though many traditional products fall outside pharmaceutical regulation [1, 20, 36].

Microbial limits follow a similar logic. The European Pharmacopoeia divides herbal medicinal products for oral use into categories according to whether boiling water is added before use, with tighter criteria for those that are not, and it requires absence of *Salmonella* and limits on *Escherichia coli* and bile-tolerant Gram-negative bacteria [8]. The United States Pharmacopoeia (USP) provides enumeration and specified-organism tests and criteria for non-sterile products and for dietary supplements [9]. For mycotoxins, limits have been set mainly in food legislation, and application to herbal products is uneven, a gap noted in reviews [27].

Enforcement and registration are the practical gap. Many countries accept herbal powders as traditional medicines on the basis of history of use, with only light requirements for testing, and some allow them to be marketed as foods or supplements with fewer controls still. Guidance on good manufacturing practice sets out what a responsible producer should do, yet inspection capacity is limited in many places and imports are checked less thoroughly than domestic production [1, 3, 7]. Labelling requirements, such as naming the plant, the part used and the batch, are inexpensive to meet and would make recalls and traceback possible when a problem is found.

Exposure assessment is the step most often missing in survey papers. A complete assessment combines concentration, daily intake, duration and body weight, and compares the result with a health-based reference value. Where this has been done, as in some analyses of Asian and Indian remedies, risk has been concentrated in specific products rather than the category as a

whole [4, 5, 12]. The approach also allows regulators to rank hazards, focusing resources on high-risk combinations such as mineral-containing preparations, products for children, or herbs grown in contaminated areas, in preference to testing everything equally [1, 3, 36]. Risk-based prioritisation of this kind is cheaper and more defensible than blanket testing.

Good practice at the pharmacy level is simple to describe. Buy from licensed suppliers who can supply a certificate of analysis, check that batch numbers are present, be cautious with products that make strong therapeutic claims or contain minerals, and report adverse events through available systems. Advice to patients can stress that natural does not mean tested, and that people who are pregnant, are giving products to children, or take medicines with narrow safety margins should consult a healthcare professional. These steps do not remove risk, yet they reduce it where regulation is thin [1, 3, 7].

7. LIMITATIONS AND FUTURE DIRECTIONS

The literature on herbal powder contamination has several weaknesses. Most surveys use convenience samples from a few markets, with small numbers per product, so prevalence cannot be generalised. Methods, limits and reporting differ widely, and many papers describe only concentrations without exposure estimates. Few studies report quality control data, and microbial work often relies on total counts. Geographic coverage is uneven, with much information from a handful of countries. Publication bias is probable, since reports of high contamination are more likely to be written up than reports of clean products [2, 38].

Priorities for future work are clear. Surveys should use random or stratified sampling, validated methods with reference materials, speciation for arsenic and mercury, and microbial testing aligned with pharmacopoeial categories. They should translate results into daily exposure and compare them with health-based limits [18, 20]. Studies that follow products from field to shelf would show where contamination arises and which controls matter most. Harmonised

limits for herbal materials would end the confusion produced by competing standards, and cheaper screening tools would help small producers. Pharmacists can contribute through adverse event reporting and by documenting the products patients actually use [7, 23, 36].

Environmental change adds a further dimension that has received little attention. Flooding, drought and shifting rainfall can alter soil metal availability and fungal growth, and expanding wild harvesting for popular herbs may push collection into polluted or poorly controlled areas. Climate-related increases in mycotoxin risk have been discussed for cereals, and similar effects are plausible for herbs grown in warm, humid regions. Data are lacking, but producers and regulators would be wise to include such factors in future risk assessments of botanical raw materials, alongside the more familiar issues of soil, water and handling [21, 23, 27].

8. CONCLUSION

Published surveys indicate that contamination of marketed herbal powders is real but unevenly distributed, and that the answer to whether herbal powders are safe depends heavily on the product, the origin and the supply chain. Most plain herbal powders comply with common limits for toxic metals, whereas a minority of products, particularly some mineral-containing traditional preparations and materials from polluted areas, contain lead, cadmium, arsenic or mercury at levels of clinical concern [4, 5, 10, 12, 13]. Moulds, mycotoxins and enteric bacteria are repeatedly found where powders are handled, dried and stored without hygiene control [14, 15, 16, 17].

Better control rests on good agricultural and manufacturing practice, validated analytical methods and exposure-based limits that recognise the dose and the consumer [7, 18, 20, 23]. The evidence is limited by small convenience samples, inconsistent limits and sparse speciation data. Pharmacists can help by advising patients to choose products with batch information and analysis certificates, by reporting suspected harm, and by supporting wider adoption of harmonised testing, with clear limits that apply equally to local and

imported products [1, 3, 8]. Until such measures are routine, selecting a herbal powder should be treated as a decision with a risk to weigh, and not as a neutral choice.

9. ABBREVIATIONS

AAS-Atomic absorption spectrometry, EFSA-European Food Safety Authority, ICH-International Council for Harmonisation, ICP-MS-Inductively coupled plasma mass spectrometry, JECFA-Joint FAO/WHO Expert Committee on Food Additives, GACP-Good agricultural and collection practices, GMP-Good manufacturing practice, USP-United States Pharmacopeia, WHO-World Health Organization, PDE-Permitted daily exposure

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All the authors have contributed equally.

12. CONFLICT OF INTERESTS

Declared none

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