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Review Article

Pharmaceutical Adulteration and Toxic Contaminants in Herbal Products: Global Bibliometric Trends and Forensic-Toxicological Implications

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ABSTRACT

Background: Herbal products may contain undeclared pharmaceuticals, toxic elements, pesticides, mycotoxins, or substituted botanicals. This study maps these hazards globally and links bibliometric patterns with forensic-toxicological priorities.

Methods: English-language Scopus articles (2005-2025) were screened using predefined criteria. After metadata, title/abstract, and keyword cleaning, 745 of 1,357 records were analyzed with Bibliometrix/Biblioshiny and VOSviewer 1.6.20.

Results: The 745 articles appeared in 378 sources. Output rose from 11 articles in 2006 to 90 in 2025 (11.7% annual growth); international co-authorship was 17.32%. Major themes were pharmaceutical adulteration, toxic elements, pesticides, mycotoxins, botanical authentication, and advanced analytical methods.

Conclusion: Research has expanded, but detection remains weakly linked to exposure and defensible forensic attribution. Priorities are standardized market sampling, confirmatory workflows, exposure-based assessment, product-to-patient linkage, and international surveillance.

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Introduction

Herbal medicines are widely used, yet product identity and contaminant burden vary. Toxic elements, pesticides, mycotoxins, microorganisms, residual solvents, and under-reported adverse events remain safety concerns [1, 2].

Adulteration includes undeclared pharmaceuticals or botanical substitution, whereas contamination can arise during cultivation, processing, storage, or manufacture. Sibutramine, canrenone, and sildenafil illustrate clinically relevant adulteration [3-4], while toxic elements, pesticides, mycotoxins, and species substitution pose additional risks [5-12].

Detection now combines LC-HRMS, UHPLC-QTOF-MS, ambient-ionization MS, DNA barcoding, and orthogonal authentication [10-16]. Previous bibliometric work has largely examined narrower systems, including Chinese herbal medicine toxicity, rather than the global intersection of adulteration, contamination, authentication, and forensic interpretation [17].

This study is novel because it integrates pharmaceutical adulterants, toxic elements, pesticides, mycotoxins, and species substitution into a single global map, then converts the mapped gaps into an actionable agenda for forensic toxicology, exposure assessment, and market surveillance.

We therefore mapped global research from 2006-2025, focusing on publication and collaboration patterns, citation and keyword structure, temporal evolution, and the gap between analytical detection and clinical-forensic exposure attribution.

Materials and Methods

Study Design

A descriptive bibliometric and science-mapping design assessed publication performance, collaboration, citation structure, and thematic evolution [18, 19]. Bibliometrix/Biblioshiny supported performance analysis, and VOSviewer supported network mapping. Prior applications by the author group illustrate these tools in natural-product bibliometrics [20, 21].

Database, Search Strategy, and Data Source

Scopus was selected for broad peer-reviewed coverage and bibliometric compatibility. The search

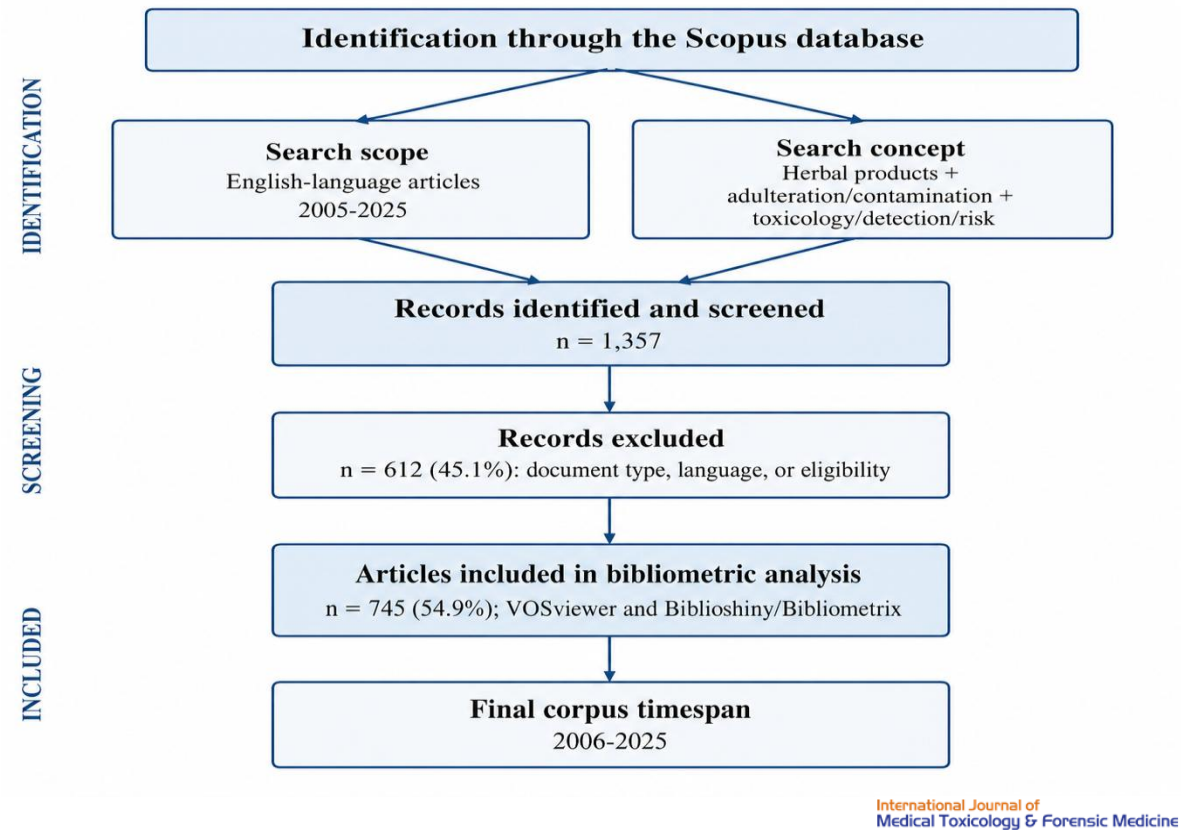

Figure 1. Study selection flow based on the Scopus workflow.

was run on July 18, 2026, for English-language journal articles published between 2005 and 2025; the eligible corpus began in 2006.

Search query: ("Herbal Product*" OR "Herbal Medicine*" OR "Herbal Supplement*" OR Phytomedicine*) AND (Adulterat* OR Contaminant* OR "Undeclared Drug*" OR "Heavy Metal*" OR Pesticide* OR Mycotoxin*) AND (Toxic* OR Forensic* OR Detect* OR "Health Risk*").

Eligibility Criteria

Eligible records were English-language research articles on herbal products addressing adulteration, hazardous contaminants, analytical/forensic detection, botanical authentication, toxicological outcomes, or health-risk assessment. Reviews, non-article documents, non-English records, retractions, incomplete records, and out-of-scope studies were excluded. Sequential metadata and title/abstract screening excluded 612 of 1,357 records, leaving 745 articles (Figure 1).

Data Extraction and Cleaning

Fields included year, source, authors, keywords, citations, references, affiliations, and countries. Records were checked for duplicate identifiers and obvious metadata errors. A controlled thesaurus standardized case, spacing, punctuation, singular/plural forms, spelling variants, and unambiguous abbreviations. Synonyms were merged only when conceptually equivalent; distinct concepts were retained. The same cleaned vocabulary was used for network and overlay analyses. Scopus author and institution names were retained, so homonymy may affect productivity estimates.

Bibliometric Indicators and Science Mapping

Bibliometrix/Biblioshiny generated production, source, authorship, citation, collaboration, and country indicators for all 745 articles. VOSviewer 1.6.20 mapped author citations and author-keyword co-occurrence/overlays using full counting, association-strength normalization, and standard clustering/layout. Minimum thresholds removed low-frequency terms while retaining interpretable networks; the same thesaurus and keyword thresholds were applied to both the network and overlay views. Node size represents weight, links represent relationship strength, cluster colors represent communities, and overlay colors represent the average publication year. Thresholds were interpretive, not inferential.

Data Analysis

All indicators were descriptive; no inferential statistics were used. Bibliometric networks indicate research activity and relationships, not contaminant prevalence, exposure, clinical incidence, or causality. Forensic-toxicological implications were interpretive syntheses supported by the cited literature.

Results

Corpus Selection and Overall Bibliometric Profile

The corpus comprised 745 articles (2006-2025)

Table 1. Main characteristics of the bibliometric corpus.

Domain	Indicator	Value
Coverage	Search period	2005-2025
Coverage	Observed corpus timespan	2006-2025
Corpus	Identified records	1,357
Corpus	Included articles	745 (54.9%)
Corpus	Excluded records	612 (45.1%)
Sources	Journals and other indexed sources	378
Growth	Annual growth rate	11.7%
Impact	Average citations per article	22.95
Impact	Average document age	7.06 years
Knowledge base	Cited references	78,785
Content	Keywords Plus	7,448
Content	Author keywords	2,105
Authorship	Unique author-name entries	3,174
Collaboration	Co-authors per article	5.8
Collaboration	Single-authored articles	20 (2.7%)
Collaboration	Multi-authored articles	725 (97.3%)
Collaboration	International co-authorship	17.32%

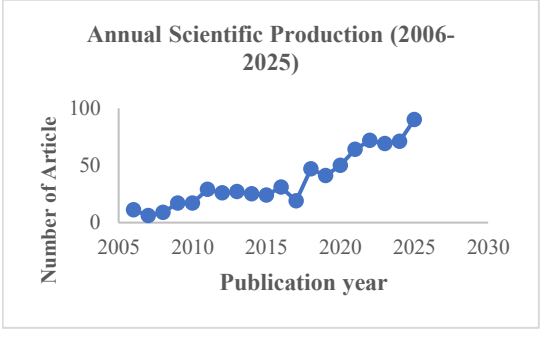

Figure 2. Annual scientific production 2006-2025.

from 378 sources and 3,174 author-name entries. Annual growth was 11.7%; 97.3% were multi-authored, and international co-authorship was 17.32% (Table 1).

Annual Scientific Production

Output rose from 11 articles in 2006 to 90 in 2025; 67.7% were published in 2018-2025 and 49.1% in 2021-2025 (Figure 2).

Productive Authors

The most frequent Scopus author-name entries were WANG Y (22), ZHANG J (18), LI J (16), and LI X (16) (Table 2). Without formal disambiguation, these counts do not verify individual productivity.

Citation Network Analysis

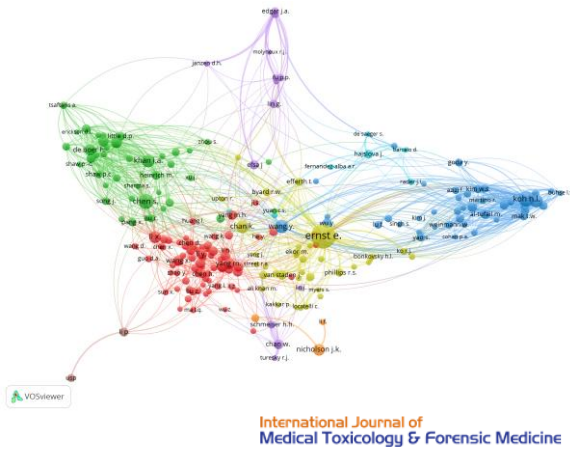

Figure 3. VOSviewer author citation network: node size, citation weight; links, citation relations; colors, clusters.

The author citation map showed interconnected clusters, with highly cited authors occupying larger or more central nodes (Figure 3). This reflects the citation structure within the corpus, not the quality of external researchers.

Most Productive Publication Sources

Journal of Pharmaceutical and Biomedical Analysis led with 31 articles (4.2%), followed by Molecules (15) and Microchemical Journal (13); the top ten sources contributed 16.9% (Table 3).

Geographic Distribution of Scientific Production

China had the highest country-associated frequency (605), followed by India (283) and the United States (98); Indonesia and Nigeria each contributed 63.

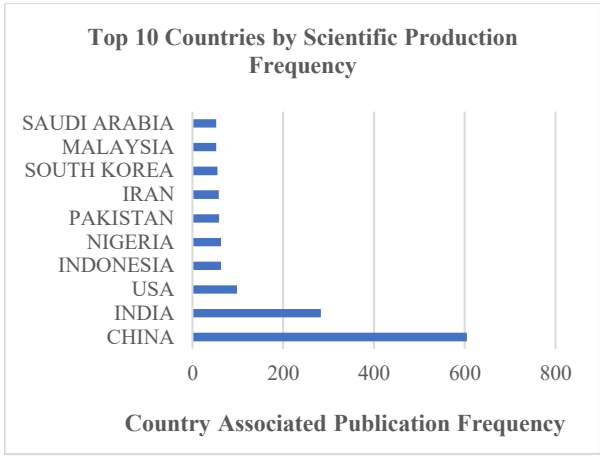

Figure 4. Top ten countries by country-associated publication frequency.

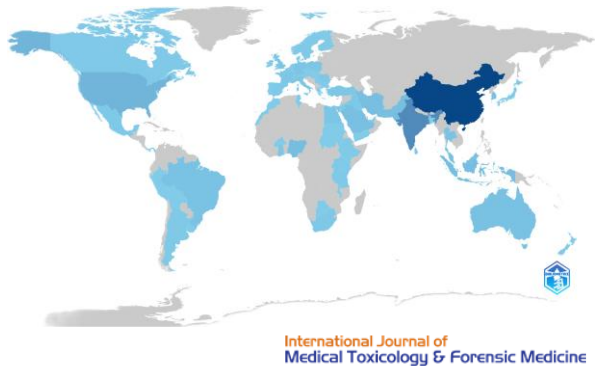

Figure 5. Global distribution of scientific production; darker shading indicates greater output.

Counts are non-exclusive (Figure 4).

Research was global but concentrated in Asia, with contributions from other regions (Figure 5).

Keyword Co-occurrence and Conceptual Structure

Keyword co-occurrence produced six communities:

Table 2. Most frequent author-name entries in the retrieved corpus.

Rank	Author	Documents	Share of corpus
1	WANG Y	22	3.0%
2	ZHANG J	18	2.4%
3	LI J	16	2.1%
4	LI X	16	2.1%
5	ZHANG L	15	2.0%
6	WANG L	14	1.9%
7	WANG H	13	1.7%
8	WANG X	13	1.7%
9	LI Y	12	1.6%
10	ZHANG H	12	1.6%

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adulteration/quality control, toxic elements/exposure, pesticides, mycotoxins/natural toxicants, botanical authentication/substitution, and clinical-forensic translation (Figure 6; Table 4). Recurrent methods included LC-MS/MS, GC-MS, ICP-MS, NMR, chemometrics, and DNA-based authentication. These clusters represent the structure of the literature, not hazard prevalence.

Temporal Overlay of Research Themes

Temporal overlays indicated a shift from targeted

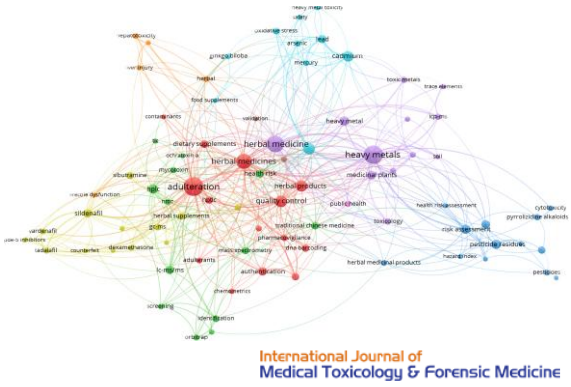

Figure 6. VOSviewer keyword network: node size, occurrence; links, relationship strength; proximity, relatedness; colors, clusters.

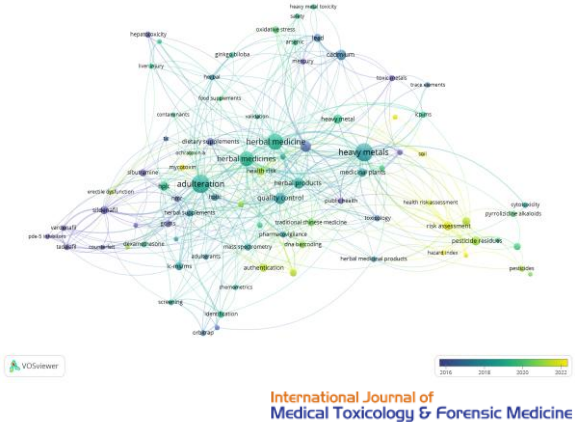

Figure 7. Temporal keyword overlay; color represents average publication year.

adulterant detection toward multi-residue analysis, health-risk assessment, DNA authentication, and non-targeted screening. Heavy metals and adulteration remained persistent themes. Overlay color indicates average publication year, not effect size or risk (Figure 7).

Discussion

Interpretive Boundary Between Bibliometric Findings and Toxicological Inference

Bibliometric outputs quantify research activity, collaboration, citations, and keyword relationships. They do not measure contamination prevalence,

Table 3. Ten most productive publication sources.

Rank	Source	Articles	Share
1	Journal of Pharmaceutical and Biomedical Analysis	31	4.2%
2	Molecules	15	2.0%
3	Microchemical Journal	13	1.7%
4	Biological Trace Element Research	12	1.6%
5	Frontiers in Pharmacology	12	1.6%
6	Phytochemical Analysis	9	1.2%
7	Phytomedicine	9	1.2%
8	Scientific Reports	9	1.2%
9	Forensic Science International	8	1.1%
10	Journal of AOAC International	8	1.1%

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exposure, adverse-event incidence, or causality. Forensic-toxicological statements below are interpretive syntheses supported by analytical, clinical, and toxicological evidence.

Growth and Evolution of the Research Field

The field grew rapidly, with 67.7% of publications in 2018-2025 and 11.7% annual growth, consistent with increasing attention to herbal-medicine toxicity [17]. Publication growth does not mean safety problems are resolved; heterogeneous contamination and inconsistent market sampling remain documented [1].

The literature is multidisciplinary, linking analytical chemistry, pharmacognosy, toxicology, environmental health, pharmacovigilance, and forensic science. International co-authorship was only 17.32%, indicating limited cross-border research integration despite global supply chains [2].

Major Research Themes

Pharmaceutical adulteration

Pharmaceutical adulteration remained prominent. Reports of sibutramine, canrenone, and sildenafil show clinical consequences [3-4]. LC-HRMS, molecular networking, UHPLC-QTOF-MS, and ambient-ionization MS increasingly support broad screening of known and unexpected compounds [13-16].

Toxic contaminants

Heavy metals, pesticides, and mycotoxins formed another major theme. Interpretation should extend beyond detection to intake, hazard quotients,

Table 4. Empirical description of the principal keyword clusters.

Cluster	Theme	Representative concepts	Methods	Risk terms
1	Adulteration/QC	adulteration; QC; supplements	LC-MS/MS; HRMS; GC-MS; NMR	toxicity; interactions
2	Elements/exposure	Pb; Hg; As; Cd; health risk	ICP-MS; ICP-OES; AAS	neuro/nephrotoxicity; developmental risk
3	Pesticide residues	residues; organophosphates; hazard index	LC-MS/MS; GC-MS/MS; QuEChERS	repeated/mixture exposure
4	Mycotoxins	aflatoxins; pyrrolizidine alkaloids	LC-MS/MS; immunoassay; HRMS	hepato/genotoxicity; carcinogenicity
5	Authentication	DNA barcoding; species ID; substitution	DNA; microscopy; spectroscopy; chemometrics	toxic species; allergens
6	Clinical/forensic	poisoning; liver injury; adverse effects	chain of custody; confirmatory toxicology; causality	adverse effects; causality

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Table 5. Research gaps and an actionable forensic-toxicology agenda.

Observed gap	Priority action	Expected contribution
Poor cross-country comparability	Probability-based market sampling; report batch, dosage form, origin, and denominator	Comparable prevalence estimates
Target lists miss new analogues	Non-targeted HRMS/NMR plus confirmatory assays and shared spectral libraries	Earlier detection; fewer false negatives
Concentration lacks exposure context	Report serving size, daily intake, duration, uncertainty, and vulnerable groups	Clinically meaningful risk interpretation
Clinical cases lack product linkage	Preserve products and biological samples; document chain of custody; perform paired analysis	Stronger product-to-patient causality
Botanical and chemical authenticity are separated	Use orthogonal DNA, microscopy, spectroscopy, chromatography, and elemental methods	Integrated detection of substitution and contamination
Low international collaboration	Multicountry surveillance, proficiency testing, reference materials, and shared alerts	Cross-border comparability and response
Limited bibliometric reproducibility	Archive search strings, metadata, screening logs, thesaurus/settings, and code	Reproducible updates

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carcinogenic risk, cumulative exposure, and mixture assessment [5-9].

Authentication and quality assurance

DNA barcoding can identify substitution or misidentification, while chromatographic, spectroscopic, and chemometric methods assess chemical authenticity [10-12].

Standardization and forensic integration

Reliable forensic interpretation requires standardized, validated workflows and orthogonal confirmation when findings may affect clinical or regulatory decisions [14-16].

Forensic and Public Health Implications

Forensic translation requires linking product identity, analytical confirmation, plausible dose/exposure, clinical findings, and regulatory action. Product-to-patient linkage helps distinguish an adulterant or contaminant from the herbal matrix, co-medications, or unrelated causes [3, 4].

The literature is stronger on hazard detection than on exposure attribution and defensible causality. Detection alone does not establish dose, biological exposure, or causal contribution. Better integration with pharmacovigilance, clinical toxicology, exposure reporting, preserved products, biological specimens, orthogonal confirmation, and surveillance is needed [2,10-16].

Strengths and Limitations

A strength is the integrated global mapping of performance, collaboration, citations, keywords, and temporal evolution across multiple adulteration and

contaminant domains.

Limitations include Scopus-only coverage, search-vocabulary omissions, author homonymy, affiliation changes, non-exclusive country counts, citation bias, and sensitivity of networks to thresholds and thesaurus decisions. Bibliometric indicators describe activity and intellectual structure, not analytical validity, exposure burden, or clinical importance.

Research Gaps and Future Priorities

Table 5 translates recurring bibliometric gaps and supporting toxicology evidence into an action-oriented agenda. It is an interpretive framework, not a direct software output. Priorities include representative market sampling, integrated authentication, exposure-based reporting, product-to-patient linkage, multicountry surveillance, and reproducible workflows.

Conclusion

Global research expanded from 2006-2025 and shifted toward integrated authentication, advanced detection, multi-residue screening, and exposure assessment. The central challenge is linking product findings with dose, biological exposure, clinical evidence, and defensible forensic attribution. Table 5 therefore prioritizes standardized sampling, orthogonal confirmation, exposure-based risk assessment, product-to-patient linkage, and international surveillance.

Ethical Approval

None.

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Conflicts of Interest

The authors report there are no competing interests to declare.

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