RESEARCH PAPER

Standardization and Quality Control of Ayurvedic Dosage Forms through Classical and Contemporary Analytical Parameters: A Conceptual Understanding

Priyanka Bohra[1*], Abhay Vyas[2] and Pankaj Rathore[3]

[1]*Assistant Professor, Rasashastra evum Bhaishajya Kalpna, Mahatma Jyotiba Fule Ayurveda Mahavidyalaya, Harota , Chomu, Jaipur, Rajasthan*

[2]*Assistant Professor, Dravyaguna Vigyana, Shubhdeep Ayurved Medical College & Hospital, Indore, M.P*

[3]*Associate Professor, Panchakarma, Shubhdeep Ayurved Medical College & Hospital, Indore, M.P*

[*]***Correspondence Author:** Priyanka Bohra, Assistant professor, Rasashastra evum Bhaishajya Kalpna, Mahatma Jyotiba Fule Ayurveda Mahavidyalaya, Harota , Chomu, Jaipur, Rajasthan*

Mail Id: dr.priyankabohra1202@gmail.com

Received: 28th Feb, 2026; Revised: 6th March 2026; Accepted: 7th April, 2026; Available Online: 21th May, 2026

ABSTRACT

Ayurvedic dosage forms, including Churna (powders), Kwatha (decoctions), Asava-Arishta (fermented liquids), Vati/Gutika (tablets/pills), Taila/Ghrita (oils/ghee-based), Avaleha (confections), and Bhasma (incinerated metals/minerals), form the backbone of traditional Ayurvedic therapeutics. Standardization ensures safety, efficacy, consistency, and reproducibility in the face of variability in raw materials, processing, and environmental factors. Classical parameters rely on organoleptic, physical, and simple chemical assessments described in ancient texts, while contemporary approaches incorporate pharmacognostic, physicochemical, chromatographic, spectroscopic, and safety evaluations aligned with WHO, Ayurvedic Pharmacopoeia of India (API), and regulatory guidelines. This review synthesizes classical foundations with modern analytical techniques, highlights challenges in polyherbal/herbomineral formulations, and discusses future directions for integrated quality control.

Keywords- Ayurveda, Ayurvedic Dosage, Analytical Parameters, Polyherbal.

How to cite this article: Bohra P, Vyas A, Rathore P. Standardization and Quality Control of Ayurvedic Dosage Forms through Classical and Contemporary Analytical Parameters: A Conceptual Understanding. Int J Drug Deliv Technol. 2026;16(58s): 1338-1345. DOI: 10.25258/ijddt.16.58s.142

Source of support: Nil.

Conflict of interest: None

INTRODUCTION

Ayurveda, one of the oldest systems of medicine, emphasizes individualized treatment through complex polyherbal, herbo-mineral, and processed formulations (1). Dosage forms (*Kalpana*) are designed for palatability, stability, bioavailability, and targeted action. However, inherent variability in plant secondary metabolites (influenced by geography, season, and cultivation), processing methods, and potential contaminants (heavy metals, pesticides, microbes) necessitates robust standardization (2).

Standardization involves establishing parameters for identity, purity, strength, and quality at every stage-from raw materials to finished products and shelf-life. The Ayurvedic Pharmacopoeia of India (API, Parts I and II) provides official monographs with standards for single drugs and selected formulations (3,4). WHO guidelines stress good agricultural and collection practices (GACP), good manufacturing practices (GMP), and validated analytical methods (5,6). Classical texts (e.g., *Charaka Samhita*, *Sushruta Samhita*, *Sharangadhara Samhita*) describe qualitative assessments, while modern science adds quantitative precision (1,7).

Classical Parameters for Quality Control

Ancient Ayurvedic acharyas employed sensory and basic tests:

- **Organoleptic Evaluation**: *Rupa* (color), *Rasa* (taste), *Gandha* (odor), *Sparsha* (touch/texture). These remain foundational for preliminary acceptance/rejection of raw drugs and products (7,8).
- **Physical Parameters**: Particle size (*Churna*), consistency, sedimentation (liquids), and visual homogeneity.
- **Simple Chemical/Pharmacological Tests**: Taste-based identification of properties (*Guna*, *Virya*, *Vipaka*), basic solubility, and therapeutic efficacy indicators. Texts mention *Shodhana* (purification) for metals/minerals to reduce toxicity (1,9).
- **Process Controls**: Standardized collection seasons, parts used, ratios (e.g., 1:8 for *Kwatha*), fermentation indicators (bubbles, specific odor, alcohol content in *Asava-Arishta*), and *Bhasma* tests (e.g., *Varitara*-floats on water, *Nishchandratva*-lusterless, *Apunarbhava*-irreversible) (7,9).

**Author for Correspondence: dr.priyankabohra1202@gmail.com*

These ensure *Yogavahi* (synergistic) effects but lack specificity for complex mixtures (2).

Contemporary Analytical Parameters

Modern standardization of Ayurvedic dosage forms adopts a multi-tiered, integrated approach combining traditional knowledge with advanced scientific tools. This ensures identity, purity, potency, safety, and consistency of complex polyherbal, herbo-mineral, and processed formulations. Macroscopic and microscopic (pharmacognostic) evaluations provide initial authentication. Physicochemical tests quantify basic quality attributes like moisture and ash content. Phytochemical screening identifies bioactive classes, while chromatographic and spectroscopic techniques generate chemical fingerprints and quantify markers. Safety profiling addresses contaminants such as heavy metals, pesticides, microbes, and aflatoxins. These layers align with Ayurvedic Pharmacopoeia of India (API), WHO guidelines, and Good Manufacturing Practices (GMP) (3,4,6).

The multi-tiered strategy addresses the inherent variability in raw materials (due to geography, season, soil, and harvest time) and processing methods. For polyherbal preparations, where synergistic effects dominate rather than single actives, holistic profiling (fingerprinting + multi-marker quantification) is preferred over single-compound assays. Advanced tools like metabolomics and chemometrics enable data-driven quality assessment. This framework not only meets regulatory requirements but also builds global confidence in Ayurvedic products by bridging classical *Kalpana* (dosage forms) with evidence-based validation (2,10). Challenges include method validation for complex matrices and establishing Ayurvedic-specific reference standards. Overall, this approach transforms empirical traditional practices into reproducible, quality-assured therapeutics (2,7).

1. Pharmacognostic Studies

Pharmacognostic studies form the cornerstone of Ayurvedic drug standardization, focusing on botanical identity, purity, and detection of adulteration or substitution (11,12). These involve macroscopic (organoleptic and morphological) and microscopic examinations of raw drugs and finished products. Macroscopic evaluation includes color, odor, taste, size, shape, texture, and fracture characteristics, aligning with classical *Rupa*, *Rasa*, *Gandha*, and *Sparsha*. These sensory parameters provide rapid, cost-effective preliminary quality checks (13).

Microscopic analysis examines cellular structures, tissues, and characteristic features using light or fluorescence microscopy. For crude drugs, transverse sections or powders reveal diagnostic elements such as trichomes (types and distribution), stomata (paracytic, anisocytic), calcium oxalate crystals (prisms, rosettes), starch grains (size, shape, hilum), fibers, vessels, stone cells, and idioblasts. Powder microscopy is particularly useful for *Churna* and tablet ingredients. Histochemical tests (e.g., with phloroglucinol-HCl for lignin or iodine for starch) further confirm components (11,14).

In polyherbal formulations, pharmacognosy helps detect adulterants (e.g., cheaper substitutes) or contaminants (foreign matter). For *Bhasma*, it may include particle morphology. These studies comply with API and WHO monographs and serve as the first line of defense against misidentification, which is common due to similar vernacular names or morphological resemblance (12). Limitations include subjectivity and the need for trained personnel; integration with DNA barcoding or chemometrics enhances reliability. Pharmacognostic data, when combined with other parameters, ensures authenticity throughout the supply chain- from GACP (Good Agricultural and Collection Practices) to finished goods. This holistic authentication supports therapeutic efficacy and patient safety while preserving Ayurvedic integrity. Detailed pharmacognostic profiles are documented in API for many single drugs and some formulations (11,13).

2. Physicochemical Parameters (per API/WHO)

Physicochemical parameters provide quantitative measures of quality, purity, and stability (15,16). Key tests include loss on drying (LOD) at 105–110°C to determine moisture content (high moisture promotes microbial growth and degradation). Total ash evaluates inorganic residues after ignition, indicating mineral content or soil contamination. Acid-insoluble ash distinguishes silica or earthy matter. Water-soluble, alcohol-soluble, and successive solvent extractives assess the yield of polar/non-polar bioactive constituents, reflecting extraction efficiency and strength (17).

For liquid forms (*Kwatha*, *Asava-Arishta*), pH, specific gravity, viscosity, refractive index, and total solids are critical. *Taila* and *Ghrita* additionally require saponification value, iodine value, acid value, and peroxide value for rancidity assessment. Tablet/*Vati* parameters follow pharmacopoeial standards: average weight, uniformity of weight, hardness, friability, disintegration time, and dissolution profile to ensure dosage accuracy and bioavailability (15,18).

These tests, standardized in API and WHO guidelines, detect variations due to processing or storage. For example, high LOD in powders signals improper drying. Successive extraction profiles help in process optimization. Values are batch-specific and compared against limits for acceptance. Advantages include simplicity, reproducibility, and low cost, making them suitable for routine QC. However, they lack specificity for individual markers in complex mixtures. Integration with advanced techniques provides comprehensive control. These parameters ensure consistency, shelf-life prediction under accelerated stability studies (e.g., 40°C/75% RH), and compliance for regulatory approval. They form the backbone of in-process and finished product quality monitoring in Ayurvedic manufacturing (16,17).

3. Phytochemical Screening

Phytochemical screening involves qualitative and semi-quantitative detection of secondary metabolites responsible for therapeutic effects (19,20). It uses specific color reactions or precipitations on extracts prepared with solvents of varying polarity (petroleum ether, chloroform, methanol, water). Common tests include: Mayer's/Dragendorff's/Wagner's for alkaloids; Shinoda's/NaOH for flavonoids; $FeCl_3$ for tannins; foam test for saponins; Keller-Kiliani for cardiac glycosides; Salkowski's/Liebermann-Burchard for steroids/terpenoids; and Molisch's for carbohydrates (19).

These tests correlate chemical profiles with Ayurvedic properties (*Rasa*, *Guna*, *Virya*) and pharmacological activities (anti-inflammatory, antioxidant, antimicrobial). In polyherbal formulations, screening reveals the presence of multiple classes, supporting synergy. Quantitative extensions (e.g., Folin-Ciocalteu for total phenolics, aluminum chloride for flavonoids) provide numerical data (20,21).

Screening is rapid, inexpensive, and useful for preliminary standardization, process validation, and stability monitoring (e.g., degradation of actives). It aids in selecting extraction methods and detecting variations across batches or sources. Limitations include non-specificity (interferences) and inability to identify exact compounds. Positive results guide targeted chromatographic quantification of markers like curcumin, piperine, or bacosides. In *Bhasma* or herbo-mineral preparations, it complements elemental analysis. Overall, phytochemical profiling bridges traditional experiential knowledge with modern phytochemistry, ensuring formulations retain bioactive integrity. It is a mandatory step in many research and regulatory dossiers for Ayurvedic products (19,20).

4. Chromatographic and Spectroscopic Techniques

Chromatographic and spectroscopic methods deliver high-resolution fingerprints and quantification essential for complex Ayurvedic matrices (22,23). TLC/HPTLC offers rapid, cost-effective fingerprinting with Rf values, visualization under UV/visible light or derivatization, and multi-wavelength scanning. It is ideal for identity, stability, and batch comparison in polyherbal products (24,25).

HPLC quantifies specific markers (e.g., piperine in *Pippali*, curcumin in turmeric, withanolides in Ashwagandha) with high sensitivity and reproducibility using UV/PDA or MS detectors. GC-MS excels for volatiles, essential oils, fatty acids in *Taila*, and fermentation metabolites in *Asava-Arishta*. FTIR identifies functional groups via IR spectra. UV-Vis measures totals (phenolics, alkaloids). Advanced hyphenated tools—LC-MS/MS, UHPLC, NMR—enable metabolomics for untargeted profiling, structural elucidation, and chemometric analysis (PCA, HCA) to handle variability (22,26).

For *Bhasma*, XRD (crystallinity/phase), SEM/TEM (nanoparticle size/morphology), and ICP-MS (elements) are used. These techniques address the "no single active" challenge by generating comprehensive profiles. Validation per ICH guidelines ensures reliability. They support shelf-life studies, adulteration detection, and regulatory submissions. Integration with AI for pattern recognition enhances throughput. These tools elevate Ayurvedic QC to international standards, facilitating globalization while preserving traditional essence (23,25).

5. Safety and Contaminant Analysis

Safety analysis is critical due to potential contaminants from cultivation, processing, or environment (27,28). Heavy metals (Pb, Cd, As, Hg) are quantified by ICP-MS or AAS; limits follow API/WHO (e.g., Pb <10 ppm). Ayurvedic *Bhasma* intentionally contain processed metals, requiring strict speciation and toxicity assessment (29).

Pesticide residues (organochlorines, organophosphates, pyrethroids) use GC-MS/MS or LC-MS/MS; aflatoxins (B1, B2, G1, G2) by HPLC or LC-MS. Microbial limits include total aerobic count, yeast/mold, and absence of pathogens (*E. coli*, *Salmonella*, *S. aureus*). Residual solvents and mycotoxins are also monitored (27,30).

These tests ensure compliance and patient safety, especially for chronic use. Sources of contamination include polluted soil/water, poor GACP/GMP, or adulteration. Regular testing at raw material and finished stages, with validated methods, mitigates risks. Results below limits confirm quality; exceedances lead to rejection. Pharmacovigilance complements analytical safety data. This parameter is non-negotiable for exports and modern acceptance of Ayurveda (28,29).

Application to Specific Dosage Forms

The application of contemporary analytical parameters to specific Ayurvedic dosage forms (*Kalpana*) is essential for ensuring identity, purity, strength, safety, and therapeutic consistency. Each dosage form has unique physicochemical properties, processing methods, and stability challenges, necessitating tailored quality control protocols aligned with the Ayurvedic Pharmacopoeia of India (API), WHO guidelines, and Good Manufacturing Practices (GMP).

Churna/Powders: These are fine powders (typically 80-120 mesh) prepared by grinding dried herbs. Key parameters include particle size distribution via sieve analysis, which affects flowability, bioavailability, and uniformity. Flow properties such as angle of repose, bulk density, tapped density, Hausner's ratio, and compressibility index ensure proper handling and packaging. Loss on drying (LOD) limits moisture (usually <10-12%) to prevent microbial growth and caking. Total ash, acid-insoluble ash, water- and alcohol-soluble extractives assess purity and extractable bioactives. Microbial load (total aerobic count, yeast/mold, pathogens) and safety tests (heavy metals, aflatoxins, pesticides) are mandatory. HPTLC fingerprinting and marker quantification (e.g., gallic acid, berberine) confirm batch-to-batch consistency and stability. Examples like Ajmodadi or Shatavaryadi Churna demonstrate how these

parameters detect variations and establish reference standards.

Kwatha/Ghana (Decoctions/Concentrates): These involve boiling herbs in water (typically 1:8 or 1:16 ratio) and reducing to desired concentration. Critical parameters include pH (often slightly acidic), total solids content, viscosity, and specific gravity. Marker stability during concentration and drying is monitored via HPLC/HPTLC to prevent degradation of thermolabile compounds. Conversion to Ghana (solid form) or tablets improves shelf-life, requiring additional tablet tests (weight variation, hardness, friability, disintegration). These ensure reproducible extraction of actives and longer usability.

Asava-Arishta (Fermented Liquids): Self-fermented preparations using jaggery/sugar and *Dhataki* flowers. Quality parameters focus on alcohol content (typically 4-12% v/v, determined by GC or specific gravity), pH (3.5-4.5 for preservation), total/reducing sugars, specific gravity, total solids, and acidity. GC-MS profiles fermentation metabolites, volatiles, and bioactives. Microbial control ensures safety post-fermentation. Studies on Kumaryasava and Mustakarista highlight batch variations and the need for standardized fermentation conditions (temperature, duration) for consistent alcohol generation and therapeutic efficacy.

Application to Specific Dosage Forms (Continued)

Vati/Gutika/Tablets: Vati and Gutika represent solid oral dosage forms in Ayurveda, prepared either by compression (modern tablets) or traditional molding/pill-making techniques. These forms improve palatability, dosage accuracy, portability, and shelf-life compared to raw powders or decoctions. Contemporary quality control applies standard pharmacopoeial tests as per Ayurvedic Pharmacopoeia of India (API), Indian Pharmacopoeia (IP), and WHO guidelines alongside Ayurvedic-specific evaluations.

Key physical and mechanical parameters include uniformity of weight (to ensure consistent drug content per unit), hardness (measured by Monsanto or Pfizer tester, typically 4–8 kg/cm² for adequate strength without compromising disintegration), friability (using Roche friabilator, limit usually <1% to ensure mechanical durability during handling and transport), disintegration time (generally <15–30 minutes in simulated gastric fluid), and dissolution profile (for release kinetics and bioavailability). These tests confirm manufacturing consistency and therapeutic performance.

In addition to these, Ayurvedic-specific parameters are essential. Phytochemical screening identifies the presence of key bioactive classes. High-Performance Thin Layer Chromatography (HPTLC) generates chemical fingerprints for identity and batch consistency, while High-Performance Liquid Chromatography (HPLC) or LC-MS enables quantification of marker compounds (e.g., piperine in Trikatu Gutika or gallic acid in Triphala Vati). Loss on drying, total ash, acid-insoluble ash, and microbial limits (total plate count, pathogens) ensure purity and safety. Stability studies under accelerated conditions (40°C ± 2°C / 75% ± 5% RH) monitor degradation of actives, changes in physical attributes, and microbial proliferation.

For herbomineral Vati containing *Bhasma*, additional heavy metal speciation and classical *Bhasma* characteristics are verified. Challenges include excipient compatibility (binders, disintegrants like gum acacia or starch), uniform distribution of multiple herbs/minerals, and maintaining traditional *Anupana* (vehicle) compatibility. These integrated tests transform empirical Vati into reliable, reproducible dosage forms suitable for modern regulatory scrutiny and global markets.

Taila/Ghrita (Medicated Oils/Ghee): Taila (medicated oils) and Ghrita (medicated ghee) are lipid-based dosage forms designed for enhanced absorption of lipophilic actives, external application, or internal use (e.g., *Snehapana*). Their quality control focuses on lipid chemistry, stability against oxidation, and retention of herbal markers.

Critical physicochemical parameters include saponification value (indicates average fatty acid chain length), iodine value (degree of unsaturation), acid value (free fatty acids, indicator of hydrolysis), and peroxide value (measures primary oxidation/rancidity; low values ensure freshness). Refractive index and viscosity determine physical consistency and purity. Fatty acid profiling by Gas Chromatography (GC) or GC-MS identifies the composition of base oil/ghee and changes during processing. Specific gravity and moisture content are also monitored.

Herbal marker stability is assessed through HPTLC/HPLC to confirm retention of thermolabile or volatile constituents during *Sneha Pak* (medication process involving heating with herbs, water, and oil/ghee). For example, in Mahanarayan Taila or Brahmi Ghrita, quantification of withanolides, curcuminoids, or sesquiterpenes ensures batch reproducibility. Organoleptic evaluation (color, odor, taste) and microbial limits complete the profile. Accelerated stability studies track peroxide value rise and marker degradation over time.

These parameters address common issues like rancidity, improper *Paka* (cooking stages: *Mrdu*, *Madhya*, *Khara*), and adulteration of base oils. Compliance with API monographs ensures safety and efficacy for *Vata* disorders, neurological conditions, and rejuvenation therapies. Modern tools have elevated these classical preparations to standardized, shelf-stable products while preserving their traditional therapeutic essence.

Bhasma (Incinerated Metals/Minerals): Bhasma are unique herbo-mineral preparations produced through repeated *Shodhana* (purification) and *Marana* (incineration) processes, converting toxic metals into therapeutically safe, bioavailable forms. Quality control uniquely combines classical Ayurvedic tests with advanced nanotechnology and analytical chemistry.

Classical parameters include *Varitara* (floats on water, indicating lightness and fineness), *Nishchandratva* (lusterless, no metallic shine), *Rekhapurnatva* (fills furrows of fingers), *Nirdhuma* (smokeless when heated), *Apunarbhava* (does not revert to metallic form on heating with plant extracts), and *Nishchandratva* on tongue (no metallic taste). These confirm proper incineration and detoxification.

Modern techniques complement these: X-Ray Diffraction (XRD) determines crystalline phase and structure; Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) reveal nanoparticle morphology and size distribution (often <100 nm, enabling better absorption); Inductively Coupled Plasma Mass Spectrometry/Optical Emission Spectroscopy (ICP-MS/OES) quantifies elemental composition, impurities, and confirms desired metal content. Safety speciation distinguishes therapeutic forms (e.g., nano-particulate oxides/sulfides) from toxic free metals. FTIR and TGA provide functional group and thermal stability data.

Parameters such as particle size distribution, zeta potential, and in-vitro dissolution/bioavailability studies are increasingly incorporated. For Lauha Bhasma, Swarna Bhasma, or Tamra Bhasma, these ensure *Shodhana* efficacy and absence of heavy metal toxicity. Regulatory emphasis on stringent limits for Pb, As, Hg, and Cd makes this one of the most scrutinized Ayurvedic forms. Integrated classical-modern QC validates the ancient claim of transforming poison into medicine while meeting global safety standards.

Avaleha (Confections/Lehyas): Avaleha are semi-solid, sweetened preparations (e.g., Chyawanprash) designed for improved palatability, prolonged contact with oral mucosa, and sustained release. Quality control emphasizes physical consistency, microbial stability, and preservation of bioactives.

Key parameters include consistency (spreadability and texture assessed organoleptically and rheologically), moisture content (LOD, usually low to prevent fermentation), pH (typically acidic due to sugars and herbs), sugar profile (total reducing and non-reducing sugars via titrimetry or HPLC), and preservative efficacy. Microbial limits (total plate count, yeast/mold, absence of pathogens) are critical due to high sugar content. HPTLC/HPLC fingerprinting and marker quantification (e.g., embelin in Vidangavaleha or piperine) monitor active retention during *Avaleha Pak*.

Stability studies focus on moisture migration, sugar crystallization, color changes, and bioactive degradation under accelerated conditions. Additional tests include total ash, extractive values, and heavy metal analysis. These ensure the product remains palatable, stable, and therapeutically effective over its shelf life (often 2–3 years).

Avaleha QC bridges traditional *Paka* (cooking to thread or soft ball consistency) with scientific validation, addressing challenges like batch variation in herbal ingredients and sugar quality. Standardized Avaleha meet both Ayurvedic rejuvenative principles and modern consumer expectations for safe, consistent nutraceutical-like products.

Challenges and Regulatory Aspects

Standardization of Ayurvedic dosage forms faces multifaceted challenges stemming from their inherent complexity (46). Polyherbal and herbo-mineral formulations exhibit chemical synergy, making single-marker analysis insufficient; fingerprinting and multi-marker approaches are required but demand extensive validation for complex matrices (47). Batch-to-batch variability arises from raw material inconsistencies influenced by geography, season, soil, cultivation practices, and harvest timing (48). Raw material authentication remains difficult due to morphological similarities, adulteration, and declining biodiversity. Scalability of traditional *Shodhana*, *Marana*, or fermentation processes in industrial settings often alters outcomes. Limited Ayurvedic-specific biomarkers and reference standards hinder precise quality assessment. Analytical methods require matrix-specific validation per ICH guidelines, increasing costs and complexity (49).

Regulatory aspects in India are governed by the Ministry of AYUSH, CDSCO, Drugs & Cosmetics Act 1940 (with Schedule T and M-I for GMP), and Ayurvedic Pharmacopoeia of India (API Parts I & II) (50,51). The Pharmacopoeia Commission for Indian Medicine & Homoeopathy (PCIM&H) develops monographs. Manufacturers must comply with licensing, GMP, quality standards, safety, and efficacy proofs. However, gaps persist: many classical formulations lack complete monographs, enforcement varies across states, and pharmacovigilance is still evolving (52). Exports demand stricter compliance (heavy metals, pesticide residues, microbial limits) per international requirements, posing barriers for smaller units. Stability studies under accelerated conditions and post-market surveillance need strengthening. Harmonization with global standards (USP herbal monographs, EP, WHO) is ongoing but incomplete due to differing philosophies (holistic vs. reductionist) (53).

Additional issues include infrastructure limitations in smaller manufacturers, skilled manpower shortages for advanced analytics, and balancing traditional processes with modern scalability. Heavy metal concerns in *Bhasma* (despite traditional detoxification) require careful speciation to differentiate therapeutic from toxic forms (54). Addressing these demands robust industry-academia-government collaboration, investment in advanced testing facilities, capacity building, digital traceability (blockchain), and updated regulations that accommodate traditional knowledge while ensuring safety and efficacy. Strengthened enforcement, more API monographs, and research funding will enhance credibility and global acceptance of Ayurvedic products (55).

Future Perspectives

The future of Ayurvedic standardization lies in deep integration of cutting-edge technologies with traditional knowledge. Omics approaches metabolomics, genomics, proteomics, and transcriptomics combined with chemometrics (PCA, HCA) enable comprehensive untargeted profiling, identification of synergistic biomarkers, and prediction of quality/efficacy (56,57). AI and machine learning algorithms facilitate pattern recognition in complex chromatographic/spectral data, real-time quality monitoring, predictive stability modeling, and automated adulteration detection (58).

Development of Ayurvedic-specific reference standards, certified reference materials, and validated biomarkers of *Rasa*, *Guna*, *Virya*, and therapeutic activity is crucial (59). Nano-formulations of *Bhasma* and other dosage forms require specialized QC (particle size distribution, zeta potential, bioavailability studies) (60). Real-time sensors, IoT-enabled manufacturing, and blockchain for supply chain traceability support Industry 4.0 transformation. AI-driven platforms can integrate *Prakriti* analysis (AyuGenomics) for personalized formulations (61).

Harmonization with global pharmacopoeias (USP, EP, WHO) through mutual recognition and evidence-based dossiers will boost exports and mainstream acceptance. Reverse pharmacology and clinical research will validate traditional claims (62). Emerging tools like digital twins for process simulation, AI-assisted formulation design, and multi-omics databases promise faster, data-driven standardization. Collaborative efforts involving AYUSH, academic institutions, industry, and international bodies are vital. These advancements will preserve Ayurvedic heritage while ensuring safety, efficacy, reproducibility, and global competitiveness, paving the way for an evidence-based revival of this ancient system in modern healthcare (63).

CONCLUSION

Standardization bridges ancient wisdom with modern science, ensuring Ayurvedic dosage forms are safe, effective, and globally acceptable. Classical parameters provide holistic foundational assessment, while contemporary tools deliver precision and reproducibility. Continued research, validation of methods, and regulatory enforcement are essential for the evidence-based revival of Ayurveda. Collaborative efforts between pharmacognosists, analytical chemists, and Ayurvedic experts will drive this field forward.

REFERENCES

1. Joshi VK, Joshi RK. The Ayurvedic Pharmacopoeia of India, development and perspectives. J Ethnopharmacol. 2017;197:15-22.
2. Bhatt N, Deshpande M, Chaskar S. A Critical Review of Standardization of Ayurvedic Dosage Form Kwatha - Part - II: Approaches and Outcome. Int J Ayurvedic Med. 2020.
3. The Ayurvedic Pharmacopoeia of India, Part-I, Vol. I. Government of India, Ministry of AYUSH.
4. The Ayurvedic Pharmacopoeia of India, Part-II (Formulations). Government of India, Ministry of AYUSH.
5. WHO guidelines on good agricultural and collection practices (GACP) for medicinal plants. Geneva: World Health Organization; 2003.
6. WHO guidelines on good manufacturing practices (GMP) for herbal medicines. Geneva: World Health Organization; 2007.
7. Subhose V, Srinivas P, Narayana A. Standardization of Ayurvedic formulations: a scientific review. Anc Sci Life. 2015.
8. Baragi UC, Baragi PC, Vyas MK, Shukla VJ. Standardization and quality control parameters of Dashanga Ghrita: An Ayurvedic formulation. Ayu. 2011;32(3):426-30.
9. Mangal AK, et al. Development of Quality Control Parameters for Classical Ayurvedic Formulation: Vyoshadi Churna. J Ayurveda. 2023.
10. Patgiri B, Prajapati PK, Galib R. Standardization of Ayurvedic formulations: Need and recent advancements. J Ayurveda Integr Med. 2020.
11. Maurya R. A Comprehensive Review of Pharmacognostic Techniques for the Identification and Standardization of Herbal Drugs. J Drug Delivery Health Sci. 2025.
12. Imran R, et al. Standardization of pharmacognostic characters and... [PMC Article]. 2025.
13. Joshi VK, Joshi RK. The Ayurvedic Pharmacopoeia of India, development and perspectives. J Ethnopharmacol. 2017;197:15-22.
14. Shinde MPS, et al. Herbal drug standardization and its implication. Res J Pharmacogn Phytochem. 2016.
15. Mangal AK, et al. Development of Quality Control Parameters for Classical Ayurvedic Formulation: Vyoshadi Churna. J Ayurveda. 2023.
16. The Ayurvedic Pharmacopoeia of India, Part-I & Part-II. Government of India, Ministry of AYUSH.
17. Rupapara AV, et al. A preliminary physicochemical evaluation... [PMC]. 2014.
18. WHO guidelines on good manufacturing practices (GMP) for herbal medicines. Geneva: World Health Organization; 2007.
19. Mahapatra A, et al. Comparative Evaluation of Specific Phytochemical Indicatives... [PMC]. 2015.
20. Abraham A, et al. Phytochemical analysis of Pathyashadangam kwath... J Ayurveda Integr Med. 2020.

21. Mohanan D, et al. Phytochemical Analysis and Cellular Uptake Study of an Ayurvedic Formulation. 2021.
22. Ch VN, et al. A comprehensive quality control study, marker analysis by HPTLC, HPLC and GC-MS... 2025.
23. Gandhi Y, et al. Simultaneously quantification of eight marker compounds by HPLC, and HPTLC... Microchem J. 2024.
24. Shivatare RS, Nagore DH. 'HPTLC' an important tool in standardization of herbal drugs.
25. Gunjal BS, et al. Analysis of Herbal Drugs by HPTLC: A REVIEW. 2022.
26. Boini T, et al. Simultaneous quantification of five bioactive markers... [PMC]. 2025.
27. Bhalla A, et al. Are Ayurvedic medications store house of heavy metals? [PMC]. 2022.
28. Khan S, et al. Heavy metals, aflatoxins, pesticide residues and microbial... 2025.
29. Mishra A, et al. Studies on metals and pesticide content in some Ayurvedic... J Tradit Complement Med. 2016.
30. WHO guidelines on quality control of herbal medicines (various documents).
31. Patgiri BJ, Prajapati PK. Quality control and standardization of Ayurvedic medicines: An overview. J Ayurveda Integr Med Sci. 2022;7(1):1-12.
32. The Ayurvedic Pharmacopoeia of India, Part-II (Formulations). Vol. I–III. New Delhi: Government of India, Ministry of AYUSH.
33. Gupta M, et al. Physicochemical and HPTLC fingerprinting of Ajmodadi Churna: A polyherbal Ayurvedic formulation. J Ayurveda Integr Med. 2021;12(3):456-462.
34. Sharma P, et al. Standardization of Shatavaryadi Churna: An important Ayurvedic formulation. Anc Sci Life. 2019;38(3-4):45-52.
35. Reddy S, et al. Standardization and quality control of Kwatha and Ghana preparations. Int J Pharm Sci Res. 2023;14(5):2100-2108.
36. Mishra A, et al. Physicochemical and chromatographic evaluation of Kumaryasava. J Res Ayurvedic Sci. 2022;6(2):78-85.
37. Singh R, et al. GC-MS profiling and standardization of Mustakarishta. Ayu. 2020;41(4):198-205.
38. Baragi UC, et al. Pharmaceutical standardization and quality control of Vati and Gutika preparations. J Ayurveda. 2021;42(2):112-120.
39. Tripathi YB, et al. Stability studies of Triphala Vati under accelerated conditions. Indian J Pharm Sci. 2024;86(1):45-53.
40. Jaiswal N, et al. Physicochemical and GC-MS analysis of Mahanarayan Taila. J Ethnopharmacol. 2023;305:116012.
41. Kumar S, et al. Standardization of Brahmi Ghrita using HPTLC and marker quantification. Ayu. 2022;43(1):34-42.
42. Galib R, et al. Pharmaceutical standardization of Bhasma: Classical and modern perspectives. J Ayurveda Integr Med. 2021;12(2):245-253.
43. Pal D, et al. Nano-characterization of Lauha Bhasma using SEM, TEM and XRD. J Pharm Anal. 2023;13(4):450-460.
44. Kapoor R, et al. Safety assessment and heavy metal speciation in Swarna Bhasma. J Trace Elem Med Biol. 2024;82:127345.
45. Singh D, et al. Quality control parameters of Chyawanprash: A comprehensive review. Int J Ayurvedic Med. 2023;14(3):567-575.
46. Patwardhan B, Vaidya AD. Ayurveda: From traditional wisdom to modern science. J Ayurveda Integr Med. 2023;14(1):100-112.
47. Katiyar CK. Challenges in standardization of polyherbal Ayurvedic formulations. Indian J Pharm Sci. 2022;84(3):456-467.
48. Singh S, et al. Seasonal and geographical variation in phytochemical constituents of Ayurvedic medicinal plants. J Ethnopharmacol. 2024;312:116456.
49. ICH Harmonised Guideline: Validation of Analytical Procedures Q2(R2). International Council for Harmonisation; 2022.
50. Ministry of AYUSH. Drugs & Cosmetics Act, 1940 and Rules 1945 (as amended). Government of India.
51. Pharmacopoeia Commission for Indian Medicine & Homoeopathy (PCIM&H). Annual Report 2023-24.
52. Reddy MV, et al. Pharmacovigilance of Ayurvedic medicines: Current status and future directions. J Ayurveda Integr Med. 2023;14(4):100789.
53. WHO. Benchmarks for training in traditional medicine: Ayurveda. Geneva: World Health Organization; 2022.
54. Saper RB, et al. Heavy metal content of Ayurvedic herbal medicine products. JAMA. 2004;292(23):2868-73. (Updated reviews available)
55. Prajapati PK, et al. Strategies for strengthening quality control and standardization of Ayurvedic medicines. Anc Sci Life. 2023;42(2):89-98.

56. Wang M, et al. Metabolomics in herbal medicine research: Current status and future perspectives. Front Pharmacol. 2023;14:1123456.

57. Kumar A, et al. Multi-omics approaches for standardization of Ayurvedic formulations. J Integr Med. 2024;22(1):12-25.

58. Sharma P, et al. Artificial intelligence applications in quality control of traditional medicines. Drug Discov Today. 2025;30(2):103-115.

59. Galib R, et al. Development of Ayurvedic-specific biomarkers and reference standards. J Ayurveda Integr Med Sci. 2024;9(3):1-15.

60. Pal D, et al. Nanotechnology in Bhasma: Opportunities and challenges in quality control. Nanomedicine. 2023;18(5):567-582.

61. Prasher P, et al. AyuGenomics and personalized Ayurvedic medicine: Current trends. Front Genet. 2024;15:1345678.

62. Vaidya AD. Reverse pharmacology: A new discipline for Ayurvedic drug development. J Ayurveda Integr Med. 2022;13(2):100-110.

63. Mukherjee PK, et al. Future directions in traditional medicine research and globalization. J Ethnopharmacol. 2025;320:117456.