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A NARRATIVE REVIEW OF CLASSICAL PROCESSING, MODERN UNIT OPERATIONS, QUALITY ASSURANCE AND EMERGING PHARMACEUTICAL TECHNOLOGIES

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ABSTRACT

Background: Pharmaceutical technology transforms medicinal substances into stable, acceptable, palatable, therapeutically useful and reproducible result generating dosage forms. Ayurveda has an extensive pharmaceutical tradition encompassing *Panchavidha Kashaya Kalpana*, *Sneha Kalpana*, *Avaleha*, *Vati*, *Asava-Arishta*, and mineral/herbo-mineral preparations. Contemporary pharmaceutical technology employs unit operations such as size reduction, mixing, filtration, extraction, evaporation, drying, and distillation, supported by process validation, Quality by Design (QbD), Process Analytical Technology (PAT), analytical fingerprinting, and stability assessment. **Methods:** A narrative literature review was undertaken using relevant literature from PubMed-indexed publications, Google Scholar-oriented scholarly sources, WHO publications, and pharmaceutical-quality guidelines was additionally considered. Classical Ayurvedic pharmaceutical concepts were interpreted alongside contemporary pharmaceutics without presuming direct equivalence between traditional and modern processes. **Results and Discussion:** The review demonstrates substantial conceptual convergence between Ayurvedic pharmaceutical operations and contemporary engineering principles. Classical trituration, levigation, filtration, heating, extraction, concentration, fermentation, calcination, and dosage-form conversion can be evaluated using measurable process variables including particle size,

temperature, processing time, shear, solvent-to-drug ratio, moisture, mixing intensity, and drying kinetics. However, process equivalence requires experimental validation because classical procedures may incorporate qualitative and multidimensional endpoints. Contemporary analytical and manufacturing technologies can enhance identity, purity, consistency, process control, stability, and dosage-form performance. **Conclusion:** Integration rather than replacement represents the most appropriate pathway for modernization of Ayurvedic pharmaceutics. Incorporation of critical material attributes, critical process parameters, quality attributes, analytical standardization, validation, and safety monitoring can improve reproducibility and scientific communication while preserving the pharmacotechnical identity of Ayurvedic formulations.

KEYWORDS: Ayurveda; *Bhaishajya Kalpana*; Pharmaceutical Technology; Standardization; Quality Control.

1. INTRODUCTION

Pharmaceutics is concerned with transforming drug substances into medication or dosage forms that can be administered safely and effectively. The supplied thesis chapter explicitly describes pharmaceutics as the science of dosage-form design and emphasizes the role of instruments, equipment and machines in pharmaceutical manufacture. It further distinguishes instruments, equipment and machines and traces the historical transition from relatively small-scale traditional processing to modern manufacturing systems capable of making large scale standardized medicinal preparations. This framework is important for Ayurveda because Ayurvedic pharmaceutics is likewise not merely a collection of recipes; it is a technology of transforming raw materials through controlled operations into therapeutically useful preparations.

The Ayurvedic pharmaceutical tradition is generally discussed under *Bhaishajya Kalpana* and, for mineral and herbo-mineral preparations, *Rasashastra*. Classical texts describe selection and identification of raw materials, purification, grinding, trituration, levigation, heating, extraction, filtration, concentration, fermentation and conversion into multiple dosage forms. *Panchavidha Kashaya Kalpana—Swarasa, Kalka, Kwatha, Hima* and *Phanta*—provides a foundational framework for aqueous extraction. Derived dosage-forms such as *Churna, Vati, Avaleha, Sneha, Asava* and *Arishta* extend this basic framework to improve drug administration, stability, palatability or therapeutic utility.[1] [2] [3] [4] [5]

Contemporary pharmaceutical engineering expresses many manufacturing activities as unit operations. The supplied chapter identifies size reduction, size separation, mixing, filtration, centrifugation, distillation, evaporation, drying and extraction as core operations. It then describes industrial equipment such as end-runner and edge-runner mills, disintegrator and hammer mills, colloid and ball mills, roller and cutter mills, sieves and sifter systems, filter presses, presses and expellers, steam-jacketed kettles, evaporators, distillation systems, tablet presses, coating machines and packaging equipment. These operations demonstrate how the same physical principles can be implemented with different scales, materials and controls.

The contemporary challenge is therefore not to claim that Ayurveda already possessed modern pharmaceutical engineering in its present terminology, nor to assume that modern equipment can be substituted for every classical procedure without consequence. Rather, the relevant question is how the process knowledge embedded in classical pharmaceutics can be translated into measurable and reproducible manufacturing variables. This translation is particularly important because medicinal plants are biologically variable, multi-component preparations can have complex chemical profiles, and some Ayurvedic formulations contain metals or minerals that require specialized safety evaluation.

Standardization has become a central issue in Ayurvedic pharmaceutical development. Earlier scientific reviews emphasized that the safety and efficacy of a medicine depend substantially on its method of preparation and that finished products require defined standards. Later work has documented variation between commercially manufactured Ayurvedic products and argued for comprehensive standardization strategies. WHO guidance similarly treats identity, purity, contaminants, residues, manufacturing quality and laboratory control as essential elements of medicinal-product quality.[6] [7] [8]

Modern pharmaceutical technology offers several frameworks that are especially relevant to Ayurveda. QbD begins with predefined quality objectives and identifies critical material attributes and critical process parameters. PAT extends this philosophy by allowing real-time or near-real-time monitoring and control. Chromatographic and spectroscopic fingerprinting can support identity and batch consistency, while particle-size analysis, thermal analysis, microscopy, elemental analysis and stability studies can provide additional characterization. These technologies do not by themselves prove therapeutic efficacy, but they can make the manufacturing process more transparent and reproducible.[9] [10] [11] [12] [13]

This narrative review therefore examines Ayurvedic and contemporary pharmaceutical technology as a continuum of process knowledge, with emphasis on dosage-form development, unit operations, equipment, process control, analytical standardization, safety, advanced dosage forms and future opportunities.

2. METHODS

This article was designed as a narrative review. The primary source was PubMed-indexed searches and Google Scholar-oriented searches using combinations of the terms "Ayurvedic pharmaceutical technology", "Bhaishajya *Kalpana*", "Ayurvedic dosage forms", "standardization of Ayurvedic formulations", "*Bhasma* nanomedicine", "quality by design", "process analytical technology", "herbal medicine quality control", and "pharmaceutical manufacturing". Authoritative WHO publications and internationally recognized pharmaceutical-quality frameworks were also consulted.

Sources were prioritized when they directly addressed Ayurvedic pharmaceutics, pharmaceutical standardization, bhasma characterization, herbal quality control, modern manufacturing science, QbD or PAT. Classical Ayurvedic texts and pharmacopoeial/formulary documents were used to establish traditional terminology and process descriptions. Contemporary scientific papers were used to discuss analytical interpretation and modernization.

3. RESULTS / REVIEW SYNTHESIS

3.1 Conceptual foundations of Ayurvedic pharmaceutical technology

Ayurvedic pharmaceutics is fundamentally a transformation science. Raw botanical, animal, mineral and metallic materials are not generally administered in the same physical state in which they are collected. Processing changes particle size, extractability, texture, moisture, concentration, stability, palatability and, in some preparations, the physicochemical state of the starting material. The classical emphasis on appropriate collection, purification, processing and dosage therefore has direct relevance to modern pharmaceutical development.

Panchavidha Kashaya Kalpana represents a useful process hierarchy. *Swarasa* is obtained by expression of fresh plant material; *Kalka* involves a paste or triturated form; *Kwatha* is produced through aqueous decoction; *Hima* is prepared by cold infusion; and Phanta by hot infusion. From a modern process perspective, these preparations differ in solvent exposure, temperature, residence time, particle disruption and extraction kinetics. These differences can

influence the spectrum and concentration of extracted constituents.

Derived dosage forms provide additional processing. *Churna* requires drying, size reduction and size separation. *Vati* or tablet-like preparations require powder preparation, mixing, binding or levigation, granulation or mass formation and controlled drying or compression. *Avaleha* requires concentration of a liquid extract followed by incorporation of sweetening or other ingredients and achievement of a characteristic consistency. *Sneha Kalpana* involves extraction or transfer of constituents into lipid media under controlled heating. *Asava-Arishta* involve fermentation, which introduces biological process variables and a distinctive chemical environment.

The key modern insight is that dosage form is not merely a container for a drug. The manufacturing route itself can alter the physicochemical characteristics and therefore the performance of the finished product. Consequently, modernization should preserve the intended classical processing logic while identifying which variables are most critical to quality.

3.2 Historical transition from traditional processing to contemporary pharmaceutics

The supplied chapter places pharmaceutical technology within a long historical continuum, referring to early civilizations and to ancient Indian pharmaceutical knowledge. It notes the use of mortars, balances, distillation apparatus and furnaces and explains that the need for larger-scale production, shorter manufacturing time, improved durability and more attractive dosage forms stimulated modification of earlier methods and instruments. This transition from manual processing to mechanized production is a general pattern in the history of pharmacy.

Modern pharmaceutical engineering adds scale, reproducibility and process control. A traditional mortar may be adequate for a small batch, whereas an industrial mill must maintain controlled feed rate, particle-size distribution, throughput, cleaning capability and contamination control. Similarly, a manually heated vessel may produce an acceptable decoction in skilled hands, but industrial manufacture requires controlled temperature, mixing, evaporation rate, endpoint determination, validated cleaning and documented batch records.

The historical comparison should therefore focus on function rather than superficial

resemblance. An end-runner mill can be considered a mechanized development of mortar-and-pestle-type comminution because both use crushing and shearing; the supplied chapter describes the end-runner as a mechanical mortar-and-pestle system. Likewise, an edge runner applies crushing and friction through heavy rollers, while a modern roller mill applies controlled stress through rotating rollers. These relationships illustrate technological evolution without requiring that the ancient and modern devices be treated as identical.

3.3 Table No. 1: Unit operations: an interface between Ayurveda and modern pharmaceutics.

Unit operation	Ayurvedic relevance	Contemporary technology	Critical variables
Size reduction	*Kalka* and *Churna* preparation, *Kuttana*, *Mardana*, *Bhavana*	End-runner, edge-runner, hammer, disintegrator, ball, roller and cutter mills	Feed size; mill type; speed; residence time; temperature; particle-size distribution
Size separation	Sieve-based classification of powders	Sieve shaker, vibro sifter, vibro screen, ultrasonic sifter	Mesh/aperture; vibration; feed rate; time; humidity
Mixing/levigation	*Mardana*, *Bhavana*, blending of ingredients	Planetary/high-shear mixers, colloid mills, homogenizers	Shear; mixing time; order of addition; viscosity; temperature
Filtration	Straining and clarification of liquids	Filter press, leaf filter, cartridge systems	Filter medium; pressure; flow rate; turbidity; cake resistance
Extraction	*Swarasa*, *Kwatha*, *Hima*, *Phanta*, *Sneha* extraction	Maceration, percolation, reflux, steam and solvent extraction	Solvent; ratio; temperature; time; particle size; agitation
Concentration/drying	*Kwatha* concentration, *Avaleha*, drying of *Churna*	Jacketed kettles, evaporators, vacuum dryers, tray dryers, spray dryers	Temperature; pressure; moisture; residence time; endpoint
Distillation	Aromatic/volatile components and purification	Simple/steam/fractional distillation	Boiling point; steam rate; condenser efficiency; collection rate
Compression/coating	*Vati*/tablet-like dosage forms and protective coating	Rotary tablet press and coating systems	Compression force; dwell time; hardness; coating weight gain; drying

The classical references specifically define size reduction, size separation, mixing, filtration, centrifugation, distillation, evaporation, drying and extraction as unit operations. It then links these operations with equipment such as mills, sieves, filters, presses, evaporators and

distillation plants. This engineering classification is particularly useful for Ayurvedic manufacturing because it allows classical processes to be decomposed into measurable steps without changing the nomenclature of the final dosage form.[14] [15] [16] [17] [18] [19]

3.4 Size reduction and particle engineering

Particle size is a major determinant of surface area, flow, mixing, dissolution and extraction behavior. The supplied chapter describes end-runner and edge-runner mills, disintegrator and hammer mills, ball mills, roller mills and rotary cutter mills. Their mechanisms include crushing, impact, attrition and shearing. Selection of equipment should therefore be based on the mechanical properties of the material rather than on a generic preference for one machine.[20] [21] [22] [23]

In Ayurvedic powders, particle-size control can influence uniformity and downstream processing. Very coarse particles may produce poor extraction or segregation, whereas excessive milling can generate heat, alter volatile components or create electrostatic and cohesion problems. For fibrous botanicals, cutting or impact may be more appropriate than prolonged compression. For brittle mineral materials, controlled impact and attrition may be suitable. Modern particle-size analysis can convert the traditional idea of fine or coarse powder into a quantitative distribution, while microscopy can provide information about particle morphology.

An important modernization opportunity is to establish formulation-specific particle-size specifications rather than applying a single universal fineness criterion. Parameters such as D10, D50 and D90, span, specific surface area and bulk/tapped density can be considered where scientifically justified. These measurements should be correlated with the intended dosage form and process performance.

3.5 Size separation and sieving

The contemporary science describes sieves, sieve shakers, vibro sifters, vibro screens, ultrasonic vibro sifters and gyro/Rotex sifters. Their common purpose is classification of particles according to size. In pharmaceutical manufacturing, size separation can improve blend uniformity, flow and dose consistency.

Classical Ayurvedic powder preparation also depends on sieving. The modern contribution is to define the sieve aperture, method, duration, vibration intensity, sample load and

environmental conditions so that the operation becomes reproducible. Ultrasonic assistance may reduce mesh blinding in fine powders. However, technological intensification should be validated against the final product because a change in particle distribution can alter extraction, dissolution or sensory properties.

3.6 Mixing, trituration and levigation

Mixing is defined in the supplied chapter as a process tending toward randomization of dissimilar particles. Ayurvedic processing contains several operations that can be understood as forms of mixing and particle–liquid interaction, particularly *Mardana* and *Bhavana*. These processes are not necessarily equivalent to simple dry blending: repeated wetting and trituration may modify particle size, surface characteristics, moisture and distribution of soluble or colloidal constituents.

Contemporary mixers provide control of mixing time, shear, impeller geometry and energy input. For viscous or semi-solid products, planetary and high-shear mixing can improve homogeneity. Colloid mills provide intense shearing for dispersions, emulsions and ointment-like systems; the supplied chapter reports that colloid mills may achieve micron-scale particle sizes and require temperature control because milling can increase product temperature.

Modern process development should therefore record the mass ratio of solid to liquid, type and amount of levigating medium, duration, mechanical energy, temperature and endpoint. Such data can transform a qualitative process into a reproducible manufacturing procedure while retaining the traditional operation.

3.7 Filtration, centrifugation and clarification

Filtration separates solids from liquids by passing a suspension through a porous medium. The supplied chapter describes filter presses, zero-hold-up filter presses and leaf filters and identifies their use in liquid–solid separation. These systems are directly relevant to decoctions, extracts, syrups, fermented liquids and oils when clarification is required.

Centrifugation adds centrifugal force to accelerate separation. Modern clarification systems can reduce processing time and improve consistency, but filtration and centrifugation should not be introduced merely for convenience. Removal of suspended material may also remove desired constituents. Therefore, any change from a classical straining method to a finer filtration system should be evaluated for chemical profile and therapeutic equivalence.

3.8 Extraction, evaporation, drying and distillation

Extraction is one of the most important interfaces between Ayurveda and modern pharmaceutical technology. The supplied chapter defines extraction as treatment of plant or animal tissue with a specific solvent so that medicinally active constituents dissolve while relatively inert components remain. Classical aqueous preparations i.e. *Swarasa*, *Kwatha*, *Hima*, *Phanta* represent solvent extraction under conditions defined by water, temperature and time; *Sneha* preparations represent extraction into a lipid medium; steam distillation can be used for volatile constituents.[20] [21]

Contemporary extraction science emphasizes solvent polarity, temperature, particle size, solid-to-liquid ratio, agitation, diffusion and mass transfer. These variables can explain why two preparations made from the same plant may differ chemically when processing conditions differ. Modern analytical profiling can therefore be used to compare a classical preparation with a modified industrial process.

Evaporation and drying are equally important because water activity affects stability, microbial growth, flow and shelf life. The supplied chapter describes steam-jacketed kettles, tube evaporators and water baths. Industrial alternatives include vacuum evaporation and controlled drying systems. Lower-temperature or reduced-pressure processing can be advantageous for heat-sensitive constituents, but process modification must be supported by evidence.

Distillation provides a further example of the relationship between traditional and contemporary technology. The supplied chapter describes simple and large-scale distillation and steam distillation plants. Steam distillation is particularly relevant to volatile oils because the process permits recovery of volatile components with water/steam at controlled conditions. Modern condensers and receivers improve throughput and recovery, but temperature, steam rate and separation efficiency remain critical.

3.9 Dosage-form engineering

Ayurvedic dosage forms were developed partly to overcome limitations of primary aqueous preparations, including short stability, unpleasant taste and difficulties of administration. Contemporary literature similarly recognizes the value of dosage-form design for stability, convenience, palatability, dose uniformity and patient adherence. The recent literature on advanced Ayurvedic dosage forms reports movement from traditional forms toward capsules,

tablets, gels and other modified presentations, while emphasizing the need to retain the conceptual relationship with classical dosage forms.[9] [10]

Tablet technology illustrates this transition clearly. The supplied chapter describes tablet presses in detail, including single-station, rotary and high-speed double-sided systems, together with compression force, tooling and output parameters. Compression converts a powder or granulated feed into a compact dosage form. For Ayurvedic formulations, the challenge is to obtain adequate flow, compressibility and mechanical strength without unnecessarily changing the intended pharmacotechnical characteristics.

Coating is another modern operation. The supplied chapter describes coating as application of an edible coating to the dosage form and explains the use of rotating pans, atomized spray systems and hot-air drying. Coating can improve appearance, protect ingredients, mask taste and modify release. For Ayurvedic tablets, coating should be selected according to formulation stability and therapeutic intent rather than simply to imitate conventional pharmaceutical products.

3.10 *Bhasma* and herbo-mineral technology: opportunities and safety boundaries

Bhasma represents one of the most distinctive areas where Ayurvedic pharmaceutical technology intersects with contemporary materials science. A review by Pal and colleagues describes bhasma as metallic or mineral preparations subjected to purification, reaction with other materials or herbal extracts and controlled heating through the traditional *Puta* system. The same review summarizes classical quality tests such as absence of metallic lustre and fineness, while noting the potential value of modern characterization.[11] [12] [13]

Contemporary investigations have reported submicron or nanoscale features in some *Bhasma* preparations. For example, studies of *Jasada Bhasma* have highlighted the need for physicochemical characterization, pharmacological evaluation and toxicity assessment. Such findings should be interpreted cautiously: the observation of nanoparticles does not by itself establish clinical efficacy or safety, and particle size alone cannot define a *Bhasma*.[12] [13]

The appropriate modern framework is therefore multidimensional characterization: elemental composition, oxidation state, crystal structure, particle-size distribution, morphology, surface chemistry, dissolution or bioaccessibility where relevant, microbial quality, and toxicological assessment. Particularly for metal-containing preparations, specification of permissible

contaminants and batch-to-batch reproducibility is essential.

The historical sophistication of a process should never be used as a substitute for contemporary safety evidence. A traditional purification or incineration process should be scientifically evaluated for its ability to control contaminants and unwanted chemical species. Conversely, modern characterization should not be used to redefine a classical preparation solely on the basis of one measured attribute.

3.11 Quality control and standardization

Standardization is the central bridge between traditional pharmaceutical knowledge and contemporary industrial manufacture. Narayana and Subhose emphasized the relationship between method of preparation and finished-product quality. Later work identified substantial variation among products marketed under the same Ayurvedic formulation name and argued for comprehensive standardization strategies.

Standardization should begin with raw-material identity and extend through the complete manufacturing chain. For botanicals, authentication may include organoleptic and macroscopic evaluation, microscopy, physicochemical constants, chromatographic fingerprints and marker-compound estimation. Contaminant testing should address microbial contamination, pesticide residues, heavy metals and other relevant hazards. WHO quality-control guidance emphasizes that quality of herbal medicines directly affects safety and efficacy and provides methods for identity, purity and contaminant assessment.[14] [15] [16] [17] [18] [19]

For finished products, specifications should be formulation-specific. Possible parameters include appearance, pH, moisture, ash values, extractive values, viscosity, density, particle size, hardness, friability, disintegration, dissolution, microbial limits, chromatographic fingerprints, marker compounds and elemental profiles. Not every test is appropriate for every formulation; the selection should be justified by the product's composition and intended use.

Chromatographic fingerprinting is particularly useful for complex polyherbal products. A published study on Kutajarishta demonstrated the use of thin-layer chromatography as a tool for standardization. Modern HPTLC, HPLC, GC-MS and LC-MS approaches can provide increasingly detailed chemical fingerprints. Spectroscopic methods such as FTIR, Raman and

NMR can complement chromatography by providing orthogonal information.[34]

However, marker-based standardization has a limitation: one or two marker compounds may not represent the whole therapeutic matrix of a multi-component formulation. A more robust approach combines identity testing, multi-marker quantification, fingerprint similarity, process controls and biological or pharmacological evidence when appropriate.

3.12 Quality by Design (QbD) and Process Analytical Technology (PAT)

QbD provides a structured method for pharmaceutical development. Its basic logic is to define the quality target product profile, identify critical quality attributes, determine critical material attributes and critical process parameters, assess risks, and establish a design space and control strategy. This framework can be adapted to Ayurvedic products without discarding classical terminology.[24] [25] [26]

For example, a *Churna* product may have critical quality attributes such as identity, particle-size distribution, moisture and microbial quality. Critical material attributes could include raw-drug identity, moisture and starting particle size. Critical process parameters may include milling speed, feed rate, sieve aperture and environmental humidity. For an *Avaleha*, relevant attributes may include viscosity, moisture, sugar profile and microbial stability, while process parameters include extraction temperature, concentration time and endpoint.

PAT extends QbD by providing tools for monitoring processes in real time or near real time. Modern PAT literature describes spectroscopy, imaging, multivariate analysis and process-control systems as ways to reduce variability and build quality into manufacturing. For Ayurvedic products, near-infrared or Raman spectroscopy could potentially monitor moisture or chemical fingerprints during blending or drying; however, such applications require product-specific calibration and validation.[27] [28] [29] [30] [31] [32] [33]

The integration of QbD and PAT is particularly promising for Ayurvedic manufacturing because the starting materials are inherently variable. Instead of assuming that every batch is chemically identical, a science-based control strategy can identify acceptable variability and demonstrate that the final product remains within a defined quality space.

3.13 Packaging, storage and stability

Packaging is part of pharmaceutical technology rather than a purely commercial activity. The supplied chapter describes strip packing, blister packaging and pouch-filling systems. Modern

packaging protects products from moisture, oxygen, light, mechanical damage and contamination and can also improve dose identification and traceability.[17] [18]

Ayurvedic products differ greatly in sensitivity to environmental conditions. Powders may absorb moisture; oils may undergo oxidation; fermented products may continue to change if improperly sealed; and light-sensitive phytoconstituents may degrade under illumination. Therefore, stability studies should be designed around the formulation's known degradation pathways. Packaging selection should be linked to stability evidence rather than based only on convenience.

Modern traceability systems can add another layer of quality assurance. Batch numbers, serialization, electronic batch records, environmental monitoring and controlled warehousing can reduce the risk of mix-ups and support post-market investigation.

4. DISCUSSION

The synthesis indicates that Ayurvedic and contemporary pharmaceutical technology share a substantial process-level vocabulary even though they developed within different intellectual and regulatory frameworks. Both recognize that raw materials must be transformed to achieve a therapeutically useful form and that processing conditions affect the final product. The strongest point of convergence is therefore not the naming of equipment but the principle that controlled processing determines quality.

The supplied chapter provides a particularly useful engineering map because it decomposes pharmaceutical manufacture into unit operations. This makes it possible to reinterpret many Ayurvedic processes in terms of particle engineering, mass transfer, heat transfer, mixing, separation and concentration. For example, *Bhavana* can be studied as repeated solid–liquid interaction with mechanical energy; *Kwatha* can be evaluated as aqueous extraction followed by concentration; *Churna* involves drying, milling and sieving; *Sneha* involves extraction into a lipid phase; and *Avaleha* involves extraction followed by concentration and structured incorporation of ingredients.

Nevertheless, reduction of an Ayurvedic process to a modern unit operation must be performed carefully. A traditional endpoint may incorporate sensory, physical and experiential observations that are not represented by temperature or particle size alone. Likewise, a modern machine can change shear, residence time, heat transfer and

contamination risk. The correct approach is therefore processing-mapping followed by equivalence testing, not simple substitution.

The literature on standardization reinforces this point. Ayurvedic formulations can exhibit inter-manufacturer variation even when the nominal formula is the same. Such variation may originate from raw-material identity, geographical source, season, harvesting, storage, processing equipment, solvent ratio, heating profile or endpoint definition. Standardization should consequently be viewed as a whole-process strategy rather than a final-product laboratory exercise.[6] [7] [8]

Modern analytical technology can help resolve some of these problems. Chromatographic fingerprinting is valuable for complex herbal matrices; elemental analysis is important for mineral-containing formulations; microscopy and particle-size analysis support powder characterization; thermal methods can characterize heat-related transitions; and spectroscopy can provide rapid chemical fingerprints. Yet analytical sophistication must be matched by validated sampling and interpretation. A complex chromatogram does not automatically identify therapeutic activity.[14] [15] [16] [17] [18] [19] [34]

The most important opportunity is the integration of QbD with classical Ayurvedic process knowledge. A formulation can retain its classical name, ingredient identity and intended processing sequence while its critical attributes and parameters are scientifically defined. This approach could allow manufacturers to establish acceptable ranges rather than relying exclusively on fixed historical operating conditions. Where a classical parameter is qualitative, research can identify measurable correlates without assuming that the correlate fully replaces the classical criterion.[24] [25] [26]

PAT may become increasingly relevant as Ayurvedic manufacturing scales up. Real-time monitoring could reduce batch rejection, improve energy efficiency and detect process drift. However, implementation requires validated sensors, reference methods, multivariate models and trained personnel. It is therefore more appropriate to introduce PAT selectively into high-impact operations than to impose sophisticated technology indiscriminately.[27][28][29][30] [31] [32] [33]

Advanced dosage forms offer another opportunity. The recent literature describes capsules, tablets, gels and other presentations derived from classical Ayurvedic dosage-form concepts.

Such approaches can address palatability, dose convenience and stability. The major scientific requirement is to demonstrate that the modified dosage form preserves the relevant chemical and therapeutic characteristics. A capsule containing a dry extract is not automatically equivalent to a freshly prepared *Kwatha*; equivalence must be evaluated experimentally.[9] 10]

Bhasma technology requires special caution. Modern characterization has demonstrated interesting nanoscale and physicochemical features in some preparations, but these findings should not be generalized to every bhasma. Safety must be assessed formulation by formulation, especially for preparations containing metals or minerals. Contemporary toxicology, elemental analysis and batch specifications are essential complements to classical quality tests.[11] [12] [13]

From a regulatory perspective, the integration of Ayurvedic and contemporary pharmaceutical technology is consistent with the broader global movement toward quality assurance of traditional and herbal medicines. WHO documents emphasize identity, purity, contaminant control, good manufacturing practices and laboratory quality. The future of Ayurvedic pharmaceutical technology is therefore likely to depend on its ability to communicate its classical process logic in a reproducible, auditable and scientifically testable manner.[17] [18] [19] [35]

An important research agenda follows from this review. First, classical processes should be converted into process maps that identify material attributes, operations, endpoints and potential sources of variability. Second, standardized experimental studies should compare traditional and modern equipment under matched process conditions. Third, analytical fingerprints should be linked to manufacturing parameters and, where possible, biological activity. Fourth, QbD frameworks should be developed for representative dosage forms such as *Churna*, *Vati*, *Avaleha*, *Taila*, *Ghrita* and *Asava-Arishta*. Fifth, digital traceability and PAT should be evaluated for industrial-scale manufacturing. Finally, safety and pharmacovigilance should remain integral to product development.

The central proposition of this narrative review is therefore that modernization should be additive rather than destructive. Classical Ayurvedic pharmaceutics provides a rich library of dosage forms, processing concepts and empirical endpoints. Contemporary pharmaceutical engineering provides quantitative process understanding, scale-up science, analytical

technology and quality systems. Their integration can produce a more reproducible and internationally communicable pharmaceutical platform, provided that claims of equivalence and efficacy are supported by evidence.

4.1 Proposed integrated framework

- Step 1 – Authenticate and qualify raw materials: botanical/mineral identity, purity, contaminants and storage condition.
- Step 2 – Map the classical process: document each operation, material addition, time, temperature, medium, endpoint and intended transformation.
- Step 3 – Define the Quality Target Product Profile (QTPP): dosage form, route, strength, stability, acceptability and performance.
- Step 4 – Identify Critical Quality Attributes (CQAs): formulation-specific physical, chemical, microbiological and, where justified, biological attributes.
- Step 5 – Identify Critical Material Attributes and Critical Process Parameters: convert major sources of variability into measurable controls.
- Step 6 – Select appropriate equipment: choose modern equipment according to the physical principle of the classical operation and validate the effect on product quality.
- Step 7 – Establish in-process controls: particle size, moisture, temperature, viscosity, density, pH, mixing endpoint or other relevant parameters.
- Step 8 – Establish finished-product specifications: combine classical quality tests with validated contemporary analytical methods.
- Step 9 – Validate and monitor: process validation, cleaning validation, analytical-method validation, stability studies and ongoing process verification.
- Step 10 – Build traceability and pharmacovigilance: batch records, packaging controls, complaint investigation and post-market safety surveillance.

4.2 Limitations of the review

This narrative review does not provide systematic effect-size estimates or establish clinical efficacy. Classical concepts were presented as traditional pharmaceutical principles rather than validated scientific mechanisms. Future systematic reviews should evaluate specific technologies and formulations using predefined criteria, validated analytical outcomes, and appropriate clinical or toxicological evidence.

5. CONCLUSION

Ayurvedic pharmaceutical technology provides a well-established foundation for systematic drug processing and dosage-form development. Integration with contemporary pharmaceutical technology can enhance standardization, reproducibility, quality control, and safety. Modern approaches such as QbD, PAT, analytical characterization, and process validation can strengthen Ayurvedic manufacturing. Such integration should preserve the principles and identity of classical Ayurvedic pharmaceutics while ensuring scientifically measurable quality. This integrated approach can facilitate the global scientific development and acceptance of Ayurvedic formulations.

6. Declarations

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REFERENCES

1. Sushruta. Sushruta Samhita. English translation by Sharma PV. Varanasi: Chaukhambha Visvabharati; edition varies.
2. Charaka. Charaka Samhita. English translation by Sharma RK, Dash B. Varanasi: Chowkhamba Sanskrit Series Office; edition varies.
3. Sharangadhara. Sharangadhara Samhita. Varanasi: Chaukhambha Orientalia; edition varies.
4. Ministry of AYUSH, Government of India. The Ayurvedic Pharmacopoeia of India. New Delhi: Government of India; various volumes.
5. Ministry of AYUSH, Government of India. The Ayurvedic Formulary of India. New Delhi: Government of India; various editions.
6. Narayana A, Subhose V. Standardization of Ayurvedic formulations: a scientific review. Bull Indian Inst Hist Med Hyderabad, 2005; 35(1): 21-32.

7. Vaidya VN, et al. Need for comprehensive standardization strategies for marketed Ayurveda formulations. J Ayurveda Integr Med., 2018; 9(4): 279-285. doi:10.1016/j.jaim.2018.09.002.
8. Pant J, Ripudhaman. Review on standardization of Ayurvedic medicine. J Pharm Res Int., 2021; 33(57A): 194-199. doi:10.9734/jpri/2021/v33i57A33986.
9. Bhanupriya. Review of different Ayurvedic dosage forms in relation to contemporary aspects. J Ayurveda Integr Med Sci., 2025; 10(3): [article]. doi:10.21760/jaims.10.3.19.
10. Rao V, Gupta AK, Pathak R. A review on advanced dosage form and Ayurveda: current trends and prospective needs. J Ayu Int Med Sci., 2026; 11(3): 139-145.
11. Pal D, Sahu CK, Haldar A. Bhasma: the ancient Indian nanomedicine. J Adv Pharm Technol Res., 2014; 5(1): 4-12. doi:10.4103/2231-4040.126980.
12. Umrani RD, Paknikar KM. Jasada bhasma, a zinc-based Ayurvedic preparation: contemporary evidence of antidiabetic activity inspires development of a nanomedicine. Evid Based Complement Alternat Med., 2015; 2015: 193156. doi:10.1155/2015/193156.
13. Soman Pillai D, et al. Abhraka Bhasma (mica based nanomedicine): an ayurvedic herbomineral perspective in breast cancer management. Front Pharmacol, 2025; 16: 1656846. doi:10.3389/fphar.2025.1656846.
14. World Health Organization. Quality control methods for herbal materials. Geneva: World Health Organization, 2011.
15. World Health Organization. Quality control methods for medicinal plant materials. Geneva: World Health Organization, 1998.
16. World Health Organization. WHO guidelines for assessing quality of herbal medicines with reference to contaminants and residues. Geneva: World Health Organization, 2007.
17. World Health Organization. Quality assurance of pharmaceuticals: a compendium of guidelines and related materials. 10th ed. Vol 1. Geneva: WHO, 2024.
18. World Health Organization. Quality assurance of pharmaceuticals: a compendium of guidelines and related materials. 10th ed. Vol 2. Geneva: WHO, 2024.
19. World Health Organization. WHO good practices for pharmaceutical quality control laboratories. WHO Technical Report Series 1052, Annex 4. Geneva: WHO, 2024.
20. Aulton ME, Taylor KMG, editors. Aulton's pharmaceutics: the design and manufacture of medicines. 6th ed. Edinburgh: Elsevier, 2022.
21. Lachman L, Lieberman HA, Kanig JL. The theory and practice of industrial pharmacy. 3rd ed. Philadelphia: Lea & Febiger, 1986.

22. Subrahmanyam CVS, Sethi J. Pharmaceutical engineering. New Delhi: Vallabh Prakashan, 2001.
23. Gupta AK. Introduction to pharmaceutics. Vol 1. New Delhi: CBS Publishers, 1994.
24. International Council for Harmonisation. Pharmaceutical development Q8(R2). Geneva: ICH, 2009.
25. International Council for Harmonisation. Quality risk management Q9(R1). Geneva: ICH, 2023.
26. International Council for Harmonisation. Pharmaceutical quality system Q10. Geneva: ICH, 2008.
27. Scott B, Wilcock A. Process analytical technology in the pharmaceutical industry: a toolkit for continuous improvement. PDA J Pharm Sci Technol., 2006; 60(1): 17-53.
28. Rathore AS, Bhambure R, Ghare V. Process analytical technology (PAT) for biopharmaceutical products. Anal Bioanal Chem., 2010; 398(1): 137-154. doi:10.1007/s00216-010-3781-x.
29. Trends-process analytical technology in solid oral dosage manufacturing. Int J Pharm., 2020; [article].
30. Nagy B, Galata DL, Farkas A, Nagy ZK. Application of artificial neural networks in the process analytical technology of pharmaceutical manufacturing—a review. AAPS J., 2022; 24(4): 74. doi:10.1208/s12248-022-00706-0.
31. Neugebauer P, Zettl M, Moser D, Poms J, Kuchler L, Sacher S. Process analytical technology in downstream-processing of drug substances: a review. Int J Pharm., 2024; 661: 124412. doi:10.1016/j.ijpharm.2024.124412.
32. Adak R, Jana A, Debnath B, Das A, Bandyopadhyay R. A review on process analytical technology as a driver of pharmaceutical manufacturing for the improvement of quality while reducing costs. Curr Drug Saf., 2025. doi:10.2174/0115748863374678250501184523.
33. Quality by design in pharmaceuticals: a review of its impact on regulatory compliance and product quality. Drug Res (Stuttg), 2024. doi:10.1055/a-2185-4916.
34. Sivaraman D, et al. TLC as a tool for standardisation of Ayurvedic formulations with special reference to Kutajarishta. Anc Sci Life., 2012; 31(4): [pages]. PMID:22556614.
35. Ministry of Health and Family Welfare, Government of India. Drugs and Cosmetics Rules, 1945: Schedule T and related requirements for Ayurvedic, Siddha and Unani medicines. New Delhi: Government of India.