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**Review Article**

# *Bhavana* as Liquid-Assisted Mechanochemistry: Its Role in Phase Transformation, Particle Engineering and Pharmaceutical Performance

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**ABSTRACT:**

**Background:** *Bhavana*, the repeated processing of powdered materials with a prescribed liquid, combines mechanical work with exposure to a chemically active medium. Its relationship with liquid-assisted mechanochemistry offers a useful basis for studying Ayurvedic pharmaceutical processing, provided that physical size reduction, compositional enrichment and genuine solid-state transformation are distinguished.

**Objective:** To examine the evidence linking *Bhavana* with phase transformation, particle engineering and pharmaceutical performance, and to identify the experiments needed to establish these relationships.

**Approach:** A narrative review of classical material, primary studies of Ayurvedic preparations, controlled mechanochemistry experiments and official analytical guidance was undertaken. Findings from defined chemical systems were treated as methodological analogues rather than direct proof of mechanisms in complex formulations.

**Discussion:** Direct studies report changes in particle size, surface characteristics, extractive values and selected biological or dosage-form properties after *Bhavana*. These findings establish that processing can alter the preparation, but frequently do not isolate the effects of mechanical energy from those of added constituents, soaking or drying. Controlled liquid-assisted grinding studies demonstrate that liquid identity, quantity and activity can influence solid-form selection. Applying this framework to *Bhavana* requires measurements of the changing liquid content, mechanical input and material composition. Phase claims need complementary structural evidence; particle-size claims require clearly stated measurement methods. Improved dissolution,

systemic exposure and clinical benefit represent separate outcomes.

**Conclusion:** *Bhavana* can be investigated as a heterogeneous family of wet mechanical processes with possible mechanochemical effects. Its pharmaceutical value should be established for each preparation through controlled comparisons, reproducible characterization and relevant performance testing. Current evidence does not support universal claims of nanoparticle formation, improved bioavailability or detoxification.

**Keywords:** *Bhavana*; Ayurveda; liquid-assisted grinding; mechanochemistry; phase transformation; particle engineering; dissolution; pharmaceutical quality.

## Introduction

The pharmaceutical significance of *Bhavana* lies in what happens when mechanical work, a solid material and a prescribed liquid act together. Grinding can expose fresh surfaces. The liquid can dissolve constituents, redistribute them or introduce additional substances. Subsequent drying can consolidate the mixture or change its solid form. These events may occur within the same preparation, but they require different explanations and different evidence.

Ayurvedic descriptions place this process within the broader concept of *Samskara*, pharmaceutical processing that changes the attributes of a material. *Charaka Samhita*, *Vimana Sthana* 1/22(2), describes modification through factors including water, heat, mechanical treatment, time, vessel and *Bhavana*.[1] This provides a historical rationale for studying processing-dependent properties. It does not identify those properties with a particular crystal structure, particle diameter or pharmacokinetic outcome.

Modern mechanochemistry supplies experimentally testable questions. Shan and colleagues demonstrated that small amounts of suitable solvent could accelerate cocrystal formation during grinding.[2] Trask and colleagues subsequently showed that solvent-drop grinding could influence polymorphic outcomes in cocrystallization.[3] These findings establish that a liquid can affect the course of mechanical processing beyond simply making a powder easier to grind.

Direct Ayurvedic research also documents differences between processed preparations. In a study of *Gandhaka Rasayana*, Mitra and colleagues compared methods and media and observed differences in particle-size distribution and surface analysis.[4] The central challenge is attribution: which differences arise from mechanical treatment, which reflect the liquid's composition, and which emerge during drying? This review examines *Bhavana* through those questions and considers what evidence is needed to connect material changes with pharmaceutical performance.

## Review approach

This narrative review used targeted web-assisted searches of PubMed-indexed research, publisher and institutional repositories, an accessible classical text and official scientific guidance, consulted. Search concepts included *Bhavana*, liquid-assisted grinding, mechanochemistry, phase transformation, particle size, dissolution and pharmaceutical characterization. Primary experimental studies were prioritized; retracted material was excluded from the evidentiary synthesis. Findings from defined pharmaceutical or model compounds were distinguished from direct evidence on Ayurvedic preparations. The search was selective, and no systematic-review completeness or pooled effect estimate is claimed.

## Where the mechanochemical comparison is useful

Liquid-assisted grinding usually refers to grinding solids with a limited quantity of added liquid. Mechanochemistry concerns transformations induced or sustained by mechanical action. *Bhavana* encompasses a wider range of conditions, including repeated wet trituration, paste formation and drying. Depending on the formulation and stage, it may involve mechanical comminution, mixing, extraction, solution-mediated reactions or mechanochemical transformation. The term therefore identifies a process family rather than a single reaction mechanism.

One useful descriptor is the liquid-to-solid ratio, conventionally expressed as η: liquid volume in microlitres divided by solid mass in milligrams. Friščić and colleagues used this parameter to compare

cocrystallization outcomes across liquids and concentrations.[5] For *Bhavana*, an initial ratio alone would be insufficient. Evaporation, liquid replenishment and the accumulation of nonvolatile constituents alter the material during processing. Reports should distinguish the liquid present at a particular stage from the cumulative liquid added over all cycles and state how the dry-solid denominator was defined.

The liquid also needs chemical characterization. A plant juice or decoction contains dissolved and suspended substances whose concentrations can vary between batches. Its pH, solids content, viscosity and selected chemical markers may matter independently of the water it supplies. Two liquids added in equal volumes need not provide comparable reaction conditions. Conversely, similar chromatographic fingerprints do not establish identical wetting or flow behaviour.

Recent work by Theodosiou and colleagues illustrates a further consideration. Their controlled solvent-activity liquid-assisted grinding experiments mapped hydrate and solvate stability boundaries in defined pharmaceutical compounds.[6] The implication for *Bhavana* is a research hypothesis: changes in the thermodynamic activity of water or other liquid components may affect solid forms even when nominal liquid volume is unchanged. The study does not demonstrate those equilibria in herbal decoctions, where interacting constituents make their measurement more difficult.

Mechanical input requires equal attention. Hand trituration, an edge-runner mill and a ball mill apply different combinations of shear, compression and impact. Processing time or cycle number cannot by itself establish equivalent mechanical exposure. Equipment geometry, loading, speed where applicable, interruptions and temperature should be recorded. Where direct energy measurement is impractical, these variables provide a reproducible description while acknowledging that the energy transferred to the material remains uncertain.

## Phase transformation requires structural evidence

A phase transformation is a change in the physical form of a material, such as a transition between crystalline arrangements or between crystalline and amorphous states. Formation of a salt, coordination compound or cocrystal introduces additional questions about composition and bonding. These outcomes should be distinguished from a mixture in which unchanged particles carry deposited plant constituents.

The controlled cocrystallization studies provide a clear experimental precedent for liquid-dependent solid-form selection.[2,3] Their relevance to *Bhavana* is methodological. They used defined starting components and identifiable products. A complex Ayurvedic mixture cannot be described as a cocrystal simply because its infrared bands shift or its dissolution changes. Such observations may also reflect overlapping components, altered hydration or adsorption.

Powder X-ray diffraction can identify crystalline phases and detect changes in their relative occurrence when a suitable quantitative method is used. Peak broadening alone is ambiguous because crystallite dimensions, strain and instrumental effects can all contribute. A weaker diffraction pattern may also result from dilution by added amorphous plant material. Differential scanning calorimetry, thermogravimetry, vibrational spectroscopy and, where appropriate, solid-state nuclear magnetic resonance can provide complementary evidence. The analytical combination should answer a defined structural question rather than produce an unconnected collection of instrument outputs.

Time and sequence are essential to interpretation. A new phase found after drying may have formed through evaporation and recrystallization rather than during trituration. Similarly, a phase detected after subsequent *Puta* heating cannot be attributed to *Bhavana* without examining intermediate material and appropriate controls. Wet-stage sampling, standardized drying and samples collected before and after any thermal treatment are therefore central to mechanistic studies.

Surface changes deserve their own category. Mitra and colleagues' *Gandhaka Rasayana* study supports the possibility of altered particle distributions and surface composition after different processing schedules.[4] It does not establish a universal reaction pathway or a structurally defined new crystalline phase. Surface-sensitive chemical measurements can help examine deposition or interaction, but a signal from plant-derived constituents is not automatically proof of covalent bonding or a uniform protective coating.

## Particle engineering involves more than making a finer powder

Mechanical processing can reduce particle dimensions by fracture and can separate existing agglomerates. At the same time, wet particles can associate through liquid bridges or binding constituents. Drying may preserve a fine dispersion, create persistent aggregates or generate larger composite particles. The final distribution therefore reflects competing processes; additional cycles need not produce progressively smaller particles.

Jagtap and colleagues' study of *Badarashma Pishti* provides a useful direct example. Their preparation underwent preliminary processing followed by wet levigation with rose water, and the resulting material showed smaller particles than the starting powder. The reported particles remained in the micrometre range, with calcite, quartz and aragonite identified in the preparation.[7] These findings support particle engineering under a documented route. They do not establish universal nanosizing or show that all observed changes were caused exclusively by mechanical action during *Bhavana*.

Particle size must also be tied to its measurement method. Electron microscopy describes dimensions and morphology in imaged fields. Dynamic light scattering estimates hydrodynamic size in a dispersion and is sensitive to sample preparation and the dispersion environment. NIST's batch-mode dynamic-light-scattering protocol emphasizes controlled preparation and measurement conditions.[8] A hydrodynamic diameter should not be treated as interchangeable with an image-based particle dimension or an X-ray-derived crystallite size. Representative sampling and distribution breadth are more informative than a single small particle selected from a micrograph.

Claims of surface engineering require comparable care. Adsorbed or deposited constituents could modify wettability, surface charge or redispersion, but these are proposed effects until measured. Zeta potential depends on the medium, including pH and ionic conditions; one value cannot establish long-term stability. Washing and redispersion experiments, chemical analysis of the wash liquid and complementary surface methods can help distinguish loosely deposited solids from more persistent interactions.

The liquid's contribution to final mass also changes the interpretation of a dose. Repeated treatment with a decoction can add nonvolatile matter even when the original powder mass remains the same. Comparisons should report final dry yield and, where relevant, the amounts of selected constituents per gram and per administered dose. Otherwise, an apparent increase in activity may represent a larger amount of active material rather than an improvement in delivery.

**Table 1. Selected evidence and the limits of its application to *Bhavana***

| Evidence | Observation supported | Relevance | Inference not established |
|---|---|---|---|
| Controlled cocrystal grinding studies[2,3] | Liquid addition can change reaction rate and solid-form outcome | Demonstrates a testable mechanochemical principle | Identical mechanisms in complex Ayurvedic mixtures |
| *Gandhaka Rasayana* comparison[4] | Processing schedules yielded different particle and surface characteristics | Direct evidence that preparation conditions matter | Universal phase conversion or improved clinical efficacy |
| Controlled solvent-activity grinding[6] | Hydrate and solvate stability boundaries could be mapped | Identifies liquid activity as a possible variable | Equivalent behaviour in plant juices or decoctions |

| | | | |
|---|---|---|---|
| *Badarashma Pishti* study[7] | Wet levigation produced a preparation with micrometre-scale particles | Supports process-dependent particle engineering | Routine nanoparticle formation or a delivery advantage in patients |

Table note: Model-system findings establish possibilities; direct *Bhavana* studies must determine which possibilities occur in each preparation.

## Pharmaceutical performance needs its own measurements

Material characterization becomes pharmaceutically useful when the observed change is connected with a relevant function. For an oral solid, this may include redispersion, disintegration, dissolution, content uniformity or stability. These outcomes can move in different directions. A finer powder may wet more readily yet agglomerate during storage; stronger binding may improve tablet integrity while delaying disintegration. The appropriate target depends on the intended dosage form.

Madappattu and Rajam compared *Agnikumara Rasa* preparations made with different numbers of *Bhavana* and reported changes in attributes including hardness and disintegration.[9] This supports measuring dosage-form behaviour rather than assuming that more processing is always beneficial. Hardness and disintegration remain performance measurements; neither independently demonstrates increased systemic exposure or therapeutic potency.

A controlled pharmaceutical example shows the next evidentiary step. Chaudhari and colleagues prepared ritonavir–L-tyrosine cocrystals by liquid-assisted grinding, characterized the solid form and evaluated solubility, dissolution and compaction.[10] The study links a defined preparation with measured pharmaceutical properties. It provides an experimental model for the questions to ask of *Bhavana*, while supplying no direct evidence that traditional preparations form comparable cocrystals or share the same benefits.

For complex preparations, dissolution testing should specify the measured constituent or elemental species, medium, pH, sampling procedure and distinction between dissolved material and suspended particles. An increase in water-soluble extractive value measures extractable material under a stated procedure. It does not establish dissolution kinetics for an active constituent. Changes in total extractive mass or chromatographic peak area also need a mass balance because the processing liquid may introduce the same analytes being measured.

Sharma and colleagues compared *Guduchi* powder preparations processed with its own juice, decoction or water. They reported differences in enzyme-inhibition assays, chemical profiling and antihyperglycaemic responses in mice.[11] Including a water-processed preparation helps distinguish the botanical medium from wet treatment alone. However, differences in constituent dose and composition still complicate attribution. These preclinical findings do not demonstrate a new solid phase, improved human bioavailability or clinical efficacy of the process itself.

Bioavailability requires evidence about exposure to an identified substance or an appropriately justified set of constituents. Improved dissolution may be relevant, but absorption, metabolism and elimination can alter the relationship. A clinical comparison addresses an additional question: whether the processed preparation improves outcomes at a specified dose with acceptable safety. Those conclusions cannot be supplied by particle-size measurements, docking predictions or extractive values.

## How to establish a causal role for processing

The decisive experiment compares a defined *Bhavana* process with controls that separate its components. Untreated powder provides a baseline, while dry grinding examines mechanical treatment without the liquid. Soaking with the same liquid tests contact without sustained grinding. A matched mixture containing the liquid's dried solids helps assess the effect of adding ingredients. Water-assisted processing can investigate whether the prescribed botanical medium contributes beyond wet mechanical treatment. No single control resolves every mechanism.

**Table 2. Proposed comparisons for testing mechanisms in *Bhavana***

| Comparison | Question addressed | Essential matching | Remaining limitation |
|---|---|---|---|
| Untreated versus dry-ground powder | What changes follow mechanical processing alone? | Starting batch, sampling and storage | Dry and wet grinding transfer energy differently |
| Soaked versus wet-ground material | Does sustained mechanical work add to liquid contact? | Liquid composition, contact time and drying | Temperature and mixing still need measurement |
| Water-processed versus prescribed-medium material | Does the medium contribute beyond water? | Mechanical schedule and liquid addition record | Viscosity and dissolved solids may differ |
| Dried-medium mixture versus fully processed material | Can added constituents explain the result? | Final composition and constituent dose | Spatial distribution may remain different |
| Wet-stage versus dried product | When does the observed transformation occur? | Sampling time and defined drying conditions | Sampling itself can alter the wet material |

Table note: This is a proposed study-design framework. Experimental replication should use independent manufacturing batches, not only repeated measurements from one batch.

Time-resolved analysis could make these comparisons more informative. Friščić and colleagues used in situ synchrotron X-ray diffraction to follow intermediates and structural changes during mechanochemical milling.[12] Gracin and colleagues demonstrated laboratory Raman monitoring through translucent milling vessels.[13] These studies show that reaction progression can be observed during controlled milling. Applying either approach to *Bhavana* would require validation for its vessel, opaque botanical matrix, fluorescence, changing liquid content and sampling geometry.

Routine development need not begin with advanced monitoring. Paired samples collected at defined stages can be examined for phase composition, particle distribution, marker content and a relevant performance attribute. Mechanical and thermal records should accompany them. A practical endpoint would be attainment of a justified material or performance criterion, with no unacceptable change in other attributes. “Dry to touch” may describe a reproducible operational stage, but it is not by itself proof of chemical completion.

Analytical procedures should have a stated purpose and demonstrated fitness for that purpose. ICH Q14 provides a framework for analytical development, while Q2(R2) addresses validation.[14,15] For a proposed phase endpoint, specificity against relevant mixtures and partially processed samples matters. For a marker assay, recovery and extraction consistency matter. Calibration and any predictive model should be challenged with independent batches. International guidance supplies methodological principles here; it does not replace applicable Ayurvedic compendial requirements or establish automatic regulatory acceptance.

## Stability and safety constrain optimization

A freshly prepared sample cannot establish performance throughout storage. Processing may alter moisture retention, aggregation, solid form or chemical stability, and the container can affect those changes. Stability assessment should follow the attributes implicated by the proposed mechanism. ICH Q1A(R2) provides a general pharmaceutical framework for examining time-dependent quality under defined storage conditions.[16] A claim of improved dissolution should therefore be checked after storage, alongside chemical and microbiological quality as applicable.

Safety needs independent attention when the process increases dissolution or exposure. Greater release of an undesirable constituent would be an adverse outcome. Equipment wear, changes in botanical constituents and contamination during repeated wet processing are also variables to assess. Where nanoscale material is actually demonstrated, FDA guidance on nanomaterial-containing drug products provides a methodological reminder that size-related changes may require additional product-specific examination.[17] Neither small particle size nor the

traditional name of the process establishes detoxification.

Optimization should consequently seek a reproducible and justified product profile. Maximizing cycle number, surface area or extractive yield without considering composition and performance can favour the wrong endpoint. Claims of environmental advantage similarly require measurements of energy, liquid use, drying and waste across the complete process; use of an aqueous botanical medium alone is insufficient evidence of a lower environmental burden.

## Discussion

The strongest argument for interpreting *Bhavana* through mechanochemistry is that it makes traditional processing experimentally examinable. It directs attention to liquid composition, mechanical conditions and the material present at each stage. Controlled liquid-assisted grinding research shows that these variables can influence transformation pathways and solid forms. Direct Ayurvedic studies show that preparations can differ after processing. The connection between those two bodies of evidence remains a product-specific research task.

The present literature does not establish one dominant mechanism across *Bhavana*. Studies of different preparations may legitimately find different outcomes because the starting solids, media and subsequent operations differ. Physical comminution and deposition may explain one preparation, while dissolution and reprecipitation or a chemical reaction may contribute to another. Requiring every preparation to fit a nanoparticle or cocrystal explanation would obscure these differences.

The review has limitations. Its search was targeted, the direct studies used heterogeneous formulations and measurements, and several comparisons did not isolate all contributors to processing. Results from defined cocrystal systems offer experimental precedents rather than direct validation of Ayurvedic mechanisms. Pharmaceutical measurements were more readily available than evidence connecting processing to human exposure or clinical outcomes. These limits constrain the conclusions without reducing the value of well-designed material studies.

The most useful next step is a preparation-specific sequence of evidence: establish what changes, determine when and why it changes, and test whether that change improves a relevant pharmaceutical function. Independent batches and matched constituent doses are essential. This approach would allow *Bhavana* to be assessed on its actual products and performance while retaining the identity and sequence of the traditional procedure being investigated.

## Conclusion

*Bhavana* is a useful subject for liquid-assisted mechanochemical investigation because it brings mechanical work into sustained contact with a prescribed liquid and a solid preparation. Its effects can include particle modification and compositional redistribution; phase transformation must be demonstrated rather than presumed.

The pharmaceutical relevance of these changes depends on evidence linking them with reproducible performance. Structural characterization, representative particle measurements, controlled processing comparisons and dose-normalized functional testing provide the necessary foundation. Improved dissolution, systemic exposure, clinical benefit and safety require separate assessment. Treating *Bhavana* as a preparation-dependent process offers a sounder basis for research and standardization than assigning it universal claims of nanosizing, bioavailability enhancement or detoxification.

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