Shruti S. Chevale, 2026, 14:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Herbal and Polyherbal Formulations in the Management of Osteoarthritis: A Review of Mechanistic Rationale, Standardization and Evaluation Strategies

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Abstract- Osteoarthritis is a progressive whole-joint disorder characterized by cartilage degradation, subchondral bone remodelling, synovial inflammation, oxidative stress and functional disability. Conventional therapies provide symptomatic benefit but may have limitations during long-term use. Herbal and polyherbal formulations have attracted interest because several botanicals contain phytoconstituents with anti-inflammatory, antioxidant, analgesic and chondroprotective potential. This review summarizes the rationale for selected herbs such as Curcuma longa, Boswellia serrata, Zingiber officinale, Withania somnifera, Piper longum, Acacia nilotica, Sida cordifolia and Triphala-related formulations. It also discusses experimental models, biomarkers, histopathological endpoints and quality-by-design considerations. The review emphasizes that traditional use should be supported by authentication, standardization, marker-based quality control, toxicity assessment and controlled pharmacological or clinical evidence.

Keywords: Osteoarthritis; herbal medicine; polyherbal formulation; curcumin; boswellic acids; gingerol; withanolides; piperine; chondroprotection; Quality by Design.

I. INTRODUCTION

Osteoarthritis is one of the most common chronic joint disorders and a major cause of pain, stiffness and disability among adults and elderly populations. The disease affects the whole joint, including cartilage, synovium, subchondral bone, ligaments and periarticular muscle. Cartilage erosion, osteophyte formation, joint-space narrowing and synovitis are central features of disease progression [1,11,24].

The traditional description of painful and stiff joints in Ayurveda overlaps with features of Sandhigatavata. This historical background provides a lead for plant selection, but scientific validation requires objective evaluation of anti-inflammatory, analgesic, antioxidant and chondroprotective actions. Modern research must therefore connect traditional knowledge with pharmacognosy, phytochemistry, standardization and experimental pharmacology.

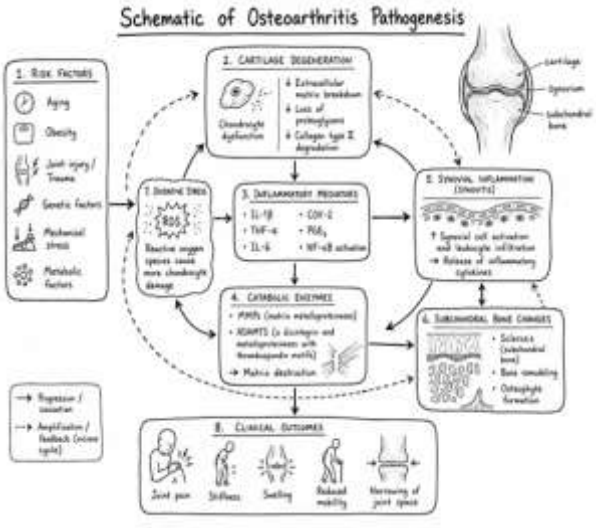

Figure 1. Pathogenesis of osteoarthritis and major targets for herbal intervention.

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II. METHOD OF LITERATURE ORGANIZATION

This review was prepared by organizing the dissertation literature records, reference list and drug-profile chapter into thematic sections. The discussion focuses on disease biology, treatment gaps, selected herbs, formulation strategy, experimental models and evaluation parameters. References are presented in Vancouver style.

III. DISEASE MECHANISMS RELEVANT TO HERBAL RESEARCH

The pathogenesis of osteoarthritis involves mechanical overload, chondrocyte dysfunction, extracellular matrix imbalance, inflammatory mediator release, oxidative injury and subchondral bone changes. Cytokines such as IL-1 beta, TNF-alpha and IL-6 stimulate COX-2, prostaglandins, nitric oxide and matrix metalloproteinases, thereby promoting collagen type II and proteoglycan degradation [15,18,28].

Oxidative stress contributes to chondrocyte damage and can amplify inflammatory signalling. Synovitis also plays a major role because cartilage debris and matrix fragments activate synovial cells, which release additional cytokines and degradative enzymes. A rational herbal strategy should therefore address inflammation, oxidative stress, pain and cartilage preservation rather than only one symptom.

Table 1. Mechanistic targets in osteoarthritis

Pathological component	Major events	Possible herbal target
Cartilage degradation	Proteoglycan loss and collagen type II disruption	Anti-catabolic and chondroprotective action
Synovial inflammation	Cytokine and prostaglandin release	Anti-inflammatory activity
Oxidative stress	Reactive oxygen species and lipid peroxidation	Antioxidant protection
Pain and stiffness	Peripheral sensitization and inflammation	Analgesic and functional improvement
Subchondral bone change	Sclerosis and osteophyte formation	Long-term structural support

IV. LIMITATIONS OF CONVENTIONAL MANAGEMENT

Conventional treatment includes education, weight management, exercise, physiotherapy, analgesics, NSAIDs, intra-articular therapy and surgery in advanced disease. These measures remain important, but drug-related adverse effects and the inability of many symptomatic medicines to regenerate cartilage support the search for safe adjunctive strategies [12,17,23].

Herbal formulations should not be positioned as replacements for evidence-based clinical care. Their role should be explored as standardized supportive candidates, especially where they demonstrate measurable reductions in inflammatory markers, pain behaviour and cartilage damage in controlled studies.

V. SELECTED HERBS AND PHYTOCHEMICAL RATIONALE

The selected herbs represent complementary phytochemical classes. Curcuma longa provides curcuminoids, Boswellia serrata provides boswellic acids, Zingiber officinale provides gingerols and shogaols, Withania somnifera provides withanolides, and Piper longum or Piper nigrum provides piperine. Additional plants such as Acacia nilotica, Sida cordifolia, Vitex negundo and Ricinus communis may contribute anti-inflammatory, antioxidant or analgesic relevance depending on formulation design.

Table 2. Selected herbs and phytochemical rationale

Herb/formulation	Major marker group	Rationale in osteoarthritis
Curcuma longa	Curcuminoids	Inflammatory mediator modulation and

		antioxidant support
Boswellia serrata	Boswellic acids/AKBA	Leukotriene-linked anti-inflammatory relevance
Zingiber officinale	Gingerols/shogaols	Analgesic, antioxidant and anti-inflammatory relevance
Withania somnifera	Withanolides	Stress-response, antioxidant and tissue-supportive role
Piper longum/Piper nigrum	Piperine	Bioenhancing and supportive anti-inflammatory relevance
Triphala formulation	Phenolics and tannins	Antioxidant and formulation-level supportive relevance

Curcuma longa and curcumin

Curcumin is a diarylheptanoid polyphenol associated with anti-inflammatory and antioxidant mechanisms. It is commonly discussed in relation to NF-kB, COX-2 and cytokine-linked pathways. Its poor aqueous solubility and low oral bioavailability are major formulation challenges, making bioenhancement or suitable delivery strategies important [12,37].

Boswellia serrata and boswellic acids

Boswellia serrata oleo-gum resin contains boswellic acid derivatives, including AKBA. These constituents are relevant because they are associated with inflammatory mediator modulation and may complement curcumin by influencing leukotriene-linked mechanisms [37,38].

Zingiber officinale and gingerols

Ginger contains gingerols and shogaols, which are studied for analgesic, anti-inflammatory and antioxidant effects. In osteoarthritis, these effects are relevant to pain, stiffness and inflammatory mediator burden [16].

Withania somnifera and withanolides

Withania somnifera is traditionally used as a Rasayana and supportive musculoskeletal herb. Withanolides such as withaferin A provide a theoretical link with anti-inflammatory and stress-response pathways, although dose and safety require careful consideration.

Piperine as a bioenhancer

Piperine is included in many polyherbal strategies because it may enhance systemic exposure of poorly absorbed phytoconstituents, especially curcumin. The same bioenhancing property also requires attention to drug-herb interaction risk, particularly in patients using chronic medicines [33,34].

VI. FORMULATION AND QUALITY-BY-DESIGN CONSIDERATIONS

Herbal formulation development should include authentication of plant materials, control of drying and powdering, extraction optimization, dose selection, compatibility assessment and quality testing. Without standardization, biological findings may not be reproducible across batches or laboratories.

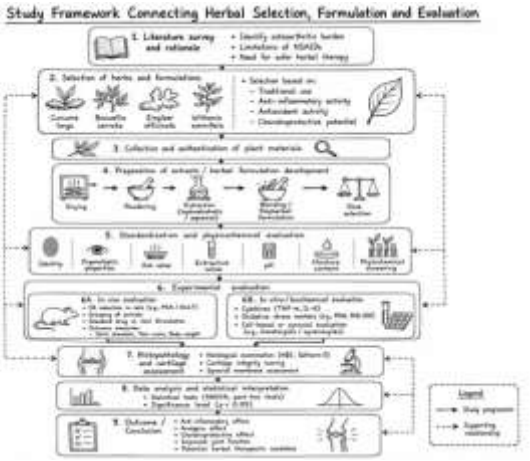

Figure 2. Research framework connecting herbal selection, formulation and evaluation.

Quality by Design principles can improve herbal research by defining the quality target product profile, critical material attributes, critical process parameters and control strategy. Examples include plant identity, part used, particle size, extraction solvent, extraction time, mixing ratio, moisture content, marker content and microbial quality.

Table 3. Quality-by-Design approach for herbal formulations

QbD element	Example in herbal formulation	Importance
Critical material attribute	Plant identity, part used, marker content	Controls raw-material variability
Critical process parameter	Drying temperature, solvent, extraction time	Affects yield and phytochemical profile
Quality attribute	Ash value, extractive value, pH, moisture	Defines formulation consistency
Control strategy	Authentication, batch records, acceptance limits	Maintains reproducibility
Risk assessment	Ranking of high-risk variables	Focuses development on critical steps

VII. EXPERIMENTAL MODELS AND EVALUATION ENDPOINTS

Preclinical models of osteoarthritis include chemical, surgical, spontaneous and genetically modified models. Chemical models are often practical for academic work because they are reproducible and allow assessment of inflammation, pain and cartilage changes within a defined period. However, model limitations should be acknowledged before translating findings to clinical use [4,26].

A balanced evaluation should include physical, biochemical and histological outcomes. Joint diameter and paw withdrawal or pain score reflect symptomatic response. TNF-alpha, IL-6 and CRP reflect inflammatory activity. Oxidative markers such as MDA, SOD, catalase and GSH may support antioxidant interpretation. Histopathology provides evidence of cartilage and synovial changes.

Table 4. Evaluation endpoints for osteoarthritis herbal studies

Endpoint	Purpose	Interpretation
Joint Diameter	Local Swelling Measurement	Reduction Suggests Anti-Inflammatory Effect
Pain Score/Withdrawal Response	Behavioural Pain Assessment	Improvement Suggests Analgesic Potential
Tnf-Alpha And Il-6	Cytokine-Mediated Inflammation	Reduction Supports Mediator Control
Crp	Systemic Inflammatory Marker	Lower Value Supports Reduced Inflammatory Load
Histopathology	Cartilage And Synovial Structure	Improvement Supports Chondroprotective Potential

VIII. SAFETY AND HERB-DRUG INTERACTION CONSIDERATIONS

Natural origin does not guarantee safety. Herbal formulations require acute and repeated-dose toxicity assessment, behavioural observation, body-weight monitoring, organ examination and biochemical safety markers where applicable. Piperine-containing formulations need special caution because bioavailability enhancement may also change exposure to co-administered drugs.

Clinical translation requires careful evaluation in patients who may already be using analgesics, antihypertensives, antidiabetics, anticoagulants or other chronic medicines. Therefore, standardization and pharmacovigilance should accompany future clinical studies.

IX. FUTURE PROSPECTS

Future research should include chromatographic fingerprinting, simultaneous estimation of curcumin, AKBA, 6-gingerol, withaferin A and piperine, stability testing, mechanism-based cell-line evaluation, MMP/TIMP studies, oxidative stress analysis and well-designed clinical trials using validated outcome measures such as WOMAC score, pain scale, mobility and quality of life.

X. CONCLUSION

Herbal and polyherbal formulations offer a scientifically interesting adjunctive area for osteoarthritis research because the disease involves multiple interacting pathways. Curcuma longa, Boswellia serrata, Zingiber officinale, Withania somnifera and piperine-containing formulations are mechanistically relevant candidates. However, meaningful acceptance requires authenticated raw materials, standardized formulation, validated

markers, safety evaluation and objective preclinical or clinical evidence.

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