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Curcuma Longa and Boswellia Serrata Nanoparticle Formulations for Anti-Inflammatory Therapy: A Review of Phytochemistry, Delivery Strategies and Preclinical Evaluation

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Abstract: *Inflammation is a protective tissue response that can progress to damaging pathology when mediator release, oxidative stress and leukocyte infiltration remain uncontrolled. Curcuma longa and Boswellia serrata are two botanical sources widely discussed in anti-inflammatory research because their marker constituents, curcuminoids and boswellic acids, interact with mediator networks relevant to acute and chronic inflammatory processes. However, poor aqueous solubility, lipophilicity, limited bioavailability and extract variability restrict direct translation of many herbal preparations. Nanotechnology, particularly chitosan-sodium tripolyphosphate nanoparticle systems, offers a promising formulation strategy for improving dispersion, protection, controlled release and reproducibility. This review summarizes the biological basis of inflammation, the pharmacological relevance of Curcuma longa and Boswellia serrata, the rationale for chitosan nanoparticles, Quality by Design concepts, characterization requirements and preclinical evaluation using carrageenan-induced paw edema. The review emphasizes cautious interpretation, standardized marker analysis and combined use of paw-volume, biochemical and histopathological endpoints. Keywords: inflammation; Curcuma longa; Boswellia serrata; curcumin; boswellic acids; chitosan; nanoparticles; QbD; carrageenan paw edema.*

Keywords: curcuma longa and boswellia serrata nanoparticle formulations for anti-inflammatory therapy: a review of phytochemistry, delivery strategies and preclinical evaluation

I. INTRODUCTION

Inflammation is a coordinated response intended to eliminate harmful stimuli and initiate repair. It involves vascular leakage, cellular recruitment and mediator generation. When this response is excessive or prolonged, tissue injury, pain, edema and chronic disease progression may occur [1,2].

Plant-based anti-inflammatory research has gained attention because botanical materials contain chemically diverse constituents capable of influencing multiple mediator pathways. However, herbal extracts also create scientific challenges because phytochemical content, extraction conditions and formulation properties can strongly affect reproducibility [4,5].

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II. CURCUMA LONGA IN ANTI-INFLAMMATORY RESEARCH

Curcuma longa contains curcuminoids, especially curcumin, which are frequently discussed in relation to NF-kB-linked mediator regulation, oxidative stress modulation and inhibition of inflammatory enzyme expression. Despite broad pharmacological interest, curcumin has poor aqueous solubility and limited oral availability, which justify formulation improvement [6,7,12,13].

Nanoparticle-based curcumin systems have been reported to improve dispersion and anti-inflammatory performance in experimental models. Such findings support the rationale for including curcumin-rich extract in a chitosan-based delivery system rather than relying only on plain extract administration [6,7].

III. BOSWELLIA SERRATA AND BOSWELLIC ACIDS

Boswellia serrata oleo-gum-resin contains pentacyclic triterpenoid acids. Boswellic acids, including AKBA, are linked with leukotriene-related inflammatory pathways and other mediator networks. The plant is therefore relevant when the goal is complementary anti-inflammatory modulation [8-11].

Like curcumin, boswellic acids are lipophilic and may show limited bioavailability. A nanoparticle formulation can be justified when it is designed to improve dispersion, marker loading and release behaviour while maintaining quality control [10,11].

IV. NEED FOR NANOPARTICLE-BASED HERBAL DELIVERY

Conventional herbal preparations may show inconsistent performance because extract composition and solubility differ between batches. Nanoparticles can improve distribution of poorly soluble constituents, protect labile markers, modify release and increase interaction with biological surfaces [14-18].

Chitosan is especially suitable for ionic gelation because its cationic amino groups interact with anionic TPP. The resulting system can be optimized by controlling polymer concentration, TPP concentration, pH, addition rate, extract load and mixing conditions [14-18].

V. QUALITY BY DESIGN IN HERBAL NANOPARTICLES

Quality by Design connects the target product profile with critical quality attributes, critical material attributes, critical process parameters and control strategy. For herbal nanoparticles, QbD is important because botanical extract composition and process variables can simultaneously affect particle formation and drug release [4,5].

Critical quality attributes for the Curcuma longa-Boswellia serrata system include particle size, PDI, zeta potential, entrapment efficiency, marker content, morphology, in vitro release and stability. These attributes should be evaluated before animal testing so that pharmacological results can be interpreted with confidence.

VI. CARRAGEENAN-INDUCED PAW EDEMA AS A PRECLINICAL MODEL

Carrageenan-induced paw edema is a standard acute inflammation model that produces measurable edema through early vascular mediators and late prostaglandin-, cytokine- and neutrophil-related mechanisms. It is useful for comparing test formulations with plain extract and standard anti-inflammatory drugs [23,24,44-48].

Paw volume alone is not sufficient for mechanistic interpretation. Cytokines, prostaglandin-related markers, myeloperoxidase, oxidative stress markers and histopathology improve the reliability of the conclusion.

VII. SAFETY AND LIMITATIONS

Although plant-based formulations are often perceived as safe, nanosystems and concentrated extracts require careful dose selection, acute observation and toxicity assessment. Chitosan-based systems should be evaluated for physical stability and biological tolerability before extended use.

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The carrageenan model reflects acute inflammation and cannot independently prove clinical efficacy in chronic inflammatory disorders. Further work should include chronic models, pharmacokinetic evaluation, long-term toxicity and regulatory-quality stability studies.

Table 1. Integrated review summary

Review domain	Key point	Relevance to formulation development
Inflammation biology	Vascular leakage, cytokines, prostaglandins and oxidative stress are interconnected	Multiple endpoints are required
Curcuma longa	Curcuminoids are relevant but poorly soluble	Nanoparticle delivery is justified
Boswellia serrata	Boswellic acids complement curcumin-related pathways	Combination may broaden anti-inflammatory coverage
Chitosan-TPP system	Ionic gelation enables mild nanoparticle preparation	Process variables require optimization
QbD approach	CQAs and CPPs improve reproducibility	Supports meaningful animal study interpretation
Carrageenan model	Provides measurable acute edema response	Appropriate for early anti-inflammatory screening

VIII. CONCLUSION

Curcuma longa and Boswellia serrata represent a rational anti-inflammatory herbal combination because their marker constituents may influence complementary mediator pathways. Chitosan-TPP nanoparticles provide a scientifically justified platform to improve formulation quality and preclinical evaluation. Future work should prioritize marker standardization, validated characterization, controlled animal studies and transparent reporting of both positive and negative findings.

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