

**RECENT ADVANCES IN HERBAL DRUGS USED FOR TREATING CHRONIC
OBSTRUCTIVE PULMONARY DISEASE (COPD)**

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ABSTRACT

Chronic Obstructive Pulmonary Disease (COPD) is a progressive and irreversible respiratory disorder characterized by persistent airflow limitation, chronic inflammation, and oxidative stress. It remains a major cause of morbidity and mortality worldwide, largely associated with cigarette smoking, air pollution, and occupational exposure to harmful particles. Conventional pharmacological management—comprising bronchodilators, corticosteroids, and phosphodiesterase inhibitors—offers only symptomatic relief and is often accompanied by severe adverse effects and drug resistance. These limitations have encouraged a growing interest in exploring herbal-based therapeutics that can provide safer, multi-targeted approaches for disease modulation. Recent studies have highlighted several promising herbal agents with potent anti-inflammatory, antioxidant, and immunomodulatory properties capable of addressing the underlying pathophysiology of COPD. *Curcuma longa* (curcumin) suppresses NF- κ B activation and reduces oxidative stress, while *Glycyrrhiza glabra* (glycyrrhizin) exhibits corticosteroid-like anti-inflammatory activity with fewer side effects. *Boswellia serrata* (boswellic acids) inhibits 5-lipoxygenase pathways, reducing leukotriene-mediated inflammation. In addition, *Adhatoda vasica* (vasicine), *Tylophora indica*, and *Camellia sinensis* have demonstrated bronchodilatory, mucolytic, and antioxidant effects in both preclinical and clinical investigations. Collectively, these findings suggest that phytotherapeutic interventions could serve as effective adjuncts or alternatives to conventional COPD therapies. However, further well-designed clinical trials, standardization of active constituents, and pharmacokinetic studies are essential to validate their safety and efficacy for large-scale therapeutic use.

KEYWORDS: COPD, Herbal Medicine, Phytotherapy, Inflammation, Antioxidant, Curcumin, Glycyrrhizin, Boswellic Acids.

INTRODUCTION

Chronic Obstructive Pulmonary Disease (COPD) is a common, preventable, and treatable respiratory disorder characterized by persistent airflow limitation that is usually progressive and associated with an enhanced chronic inflammatory response in the airways and lungs to noxious particles or gases. It ranks among the top three leading causes of death globally, affecting approximately 400 million people and responsible for nearly 3 million deaths annually worldwide.^[1,2] The major risk factors for COPD include cigarette smoking, exposure to air pollution, occupational dust and fumes,

biomass fuel combustion, and genetic predisposition such as α 1-antitrypsin deficiency.^[3,4]

The pathophysiology of COPD is complex, involving chronic inflammation, oxidative stress, mucus hypersecretion, protease–antiprotease imbalance, and structural remodeling of the airways. Persistent exposure to irritants such as cigarette smoke induces infiltration of neutrophils, macrophages, and CD8⁺ T lymphocytes into the airway epithelium, leading to excessive production of pro-inflammatory cytokines like tumor necrosis factor- α (TNF- α), interleukin-6 (IL-6), and activation of

transcription factors such as nuclear factor-kappa B (NF- κ B).^[5,6] This inflammatory cascade results in tissue destruction, mucus overproduction, and narrowing of small airways, ultimately impairing gas exchange and reducing lung function.^[7]

Conventional therapeutic approaches for COPD primarily include bronchodilators (β 2-adrenergic agonists, anticholinergics), inhaled corticosteroids, mucolytics, and phosphodiesterase inhibitors.^[8] While these agents alleviate symptoms and improve airflow, they fail to halt disease progression or reverse the underlying inflammation and oxidative damage. Moreover, long-term corticosteroid therapy is associated with significant side effects, including osteoporosis, hypertension, immunosuppression, and metabolic disturbances.^[9] These limitations highlight the urgent need for novel, safe, and effective therapeutic

alternatives capable of targeting multiple pathological mechanisms simultaneously.

In recent years, herbal-based therapeutics have gained growing attention as potential adjuncts or alternatives to conventional COPD management. Medicinal plants possess a wide range of bioactive phytoconstituents—such as flavonoids, alkaloids, terpenoids, and polyphenols—that exhibit anti-inflammatory, antioxidant, immunomodulatory, and bronchodilatory properties.^[10,11] Such multi-targeted effects make herbal interventions promising candidates for addressing the multifactorial pathogenesis of COPD. Exploring phytomedicines not only offers the advantage of reduced side effects but also aligns with the global movement toward integrating traditional medicinal knowledge with modern pharmacotherapy.

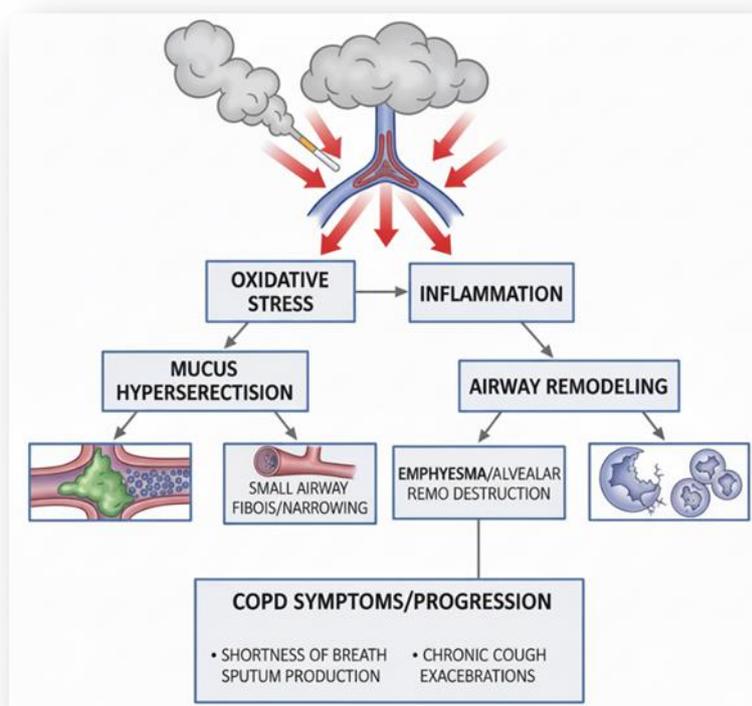


Fig. 1.

Pathophysiology and Molecular Mechanisms of COPD

The pathophysiology of Chronic Obstructive Pulmonary Disease (COPD) is multifactorial, involving complex interactions between environmental exposures, inflammatory mediators, oxidative stress, and structural changes within the lung parenchyma. The disease is primarily triggered by chronic exposure to harmful stimuli such as cigarette smoke, air pollution, and occupational irritants, which collectively induce oxidative injury and persistent inflammation in the respiratory tract.^[1] These pathological processes

ultimately lead to irreversible airflow obstruction, emphysematous destruction, and airway remodeling.^[2]

Oxidative Stress and Protease–Antiprotease Imbalance

One of the central mechanisms underlying COPD is **oxidative stress**, resulting from an overproduction of reactive oxygen species (ROS) and reactive nitrogen species (RNS) that overwhelm endogenous antioxidant defenses such as glutathione, superoxide dismutase, and catalase.^[3] Cigarette smoke alone contains more than 10^{15} oxidant molecules per puff, directly injuring epithelial cells and macrophages.^[4] The excess ROS

activates redox-sensitive transcription factors, including nuclear factor-kappa B (NF- κ B) and activator protein-1 (AP-1), which upregulate inflammatory gene expression.^[5]

In addition to oxidative stress, the **protease-antiprotease imbalance** plays a crucial role in COPD progression. Activated neutrophils and macrophages release proteolytic enzymes such as neutrophil elastase, cathepsins, and matrix metalloproteinases (MMPs), which degrade elastin and other extracellular matrix components in alveolar walls.^[6] Under normal conditions, antiproteases like α 1-antitrypsin and tissue inhibitors of metalloproteinases (TIMPs) neutralize these enzymes. However, chronic oxidative stress and genetic deficiency of α 1-antitrypsin impair this protective balance, leading to alveolar destruction and emphysema.^[7]

Role of Inflammatory Mediators

COPD is characterized by the persistent activation of the innate and adaptive immune responses. Chronic exposure to irritants induces infiltration of neutrophils, macrophages, and CD8⁺ cytotoxic T lymphocytes into the airway mucosa.^[8] These immune cells secrete pro-inflammatory mediators such as **tumor necrosis factor-alpha (TNF- α)**, **interleukin-6 (IL-6)**, **interleukin-8 (IL-8)**, and **transforming growth factor-beta (TGF- β)**, which contribute to mucus hypersecretion, fibroblast proliferation, and airway fibrosis.^[9]

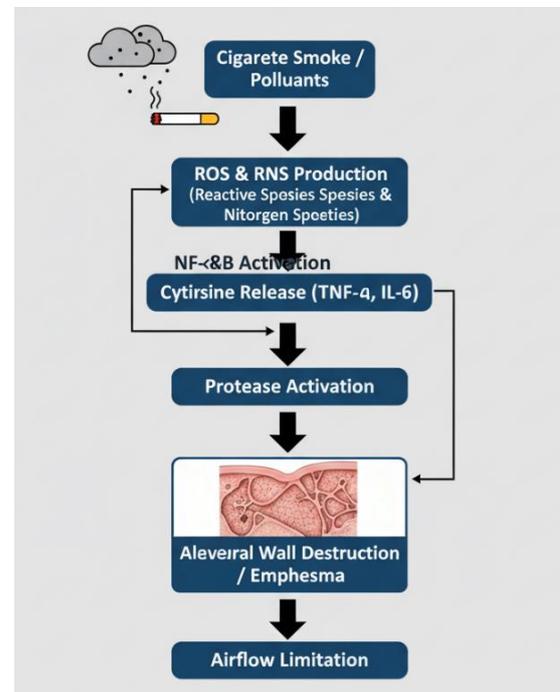
Among these mediators, **NF- κ B** acts as a master regulator of inflammatory gene transcription. Activation of NF- κ B in airway epithelial cells and alveolar macrophages leads to the upregulation of cytokines, chemokines, and adhesion molecules that perpetuate inflammation even after cessation of exposure.^[10] Simultaneously, IL-6 promotes systemic inflammation and muscle wasting, while TNF- α exacerbates tissue injury and enhances apoptosis of epithelial cells.^[11] This chronic inflammatory environment sustains oxidative stress, creating a self-perpetuating cycle of lung damage.

Impact on Lung Tissue and Alveolar Structure

The combined effect of oxidative stress, protease activity, and inflammatory signaling results in progressive **airway remodeling** and **alveolar destruction**. Histopathological features of COPD include goblet cell hyperplasia, mucus gland hypertrophy, loss of alveolar attachments, and thickening of airway walls due to collagen deposition.^[12] These structural alterations reduce elastic recoil and cause air trapping, leading to hyperinflation and decreased gas exchange capacity.^[13] In advanced stages, emphysematous lesions coalesce, resulting in permanent loss of functional alveolar surface area and irreversible decline in pulmonary function.

Furthermore, oxidative injury to pulmonary endothelial cells impairs angiogenesis and promotes pulmonary

hypertension, compounding respiratory insufficiency.^[14] Collectively, these mechanisms highlight the multifaceted and self-amplifying nature of COPD pathogenesis, emphasizing the need for therapeutic agents that can simultaneously target inflammation, oxidative stress, and tissue remodeling.



Role of Herbal Medicines in COPD Management Mechanistic Overview

Herbal medicines have emerged as promising therapeutic agents in the management of Chronic Obstructive Pulmonary Disease (COPD), owing to their multi-targeted pharmacological properties and relatively low toxicity compared to synthetic drugs. Phytoconstituents derived from medicinal plants possess diverse biological activities—including **anti-inflammatory**, **antioxidant**, **mucolytic**, and **bronchodilatory effects**—that collectively contribute to the amelioration of airway inflammation and improvement of lung function.^[1,2]

Anti-inflammatory Actions

Chronic inflammation is the hallmark of COPD pathogenesis, driven by excessive production of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF- α), interleukin-6 (IL-6), interleukin-8 (IL-8), and activation of nuclear factor-kappa B (NF- κ B).^[3] Several herbal compounds effectively downregulate these inflammatory mediators.

For instance, **curcumin** from *Curcuma longa* inhibits NF- κ B signaling by preventing phosphorylation of I κ B α , thereby reducing cytokine release and leukocyte infiltration.^[4] **Glycyrrhizin** from *Glycyrrhiza glabra* suppresses the production of TNF- α and prostaglandin E2 through modulation of the cyclooxygenase-2 (COX-2) pathway.^[5] Similarly, **boswellic acids** from *Boswellia serrata* inhibit 5-lipoxygenase (5-LOX), preventing

leukotriene synthesis and reducing bronchial inflammation.^[6] These effects help in attenuating airway edema, mucus hypersecretion, and remodeling associated with chronic inflammation.

Antioxidant and Cytokine Modulation

Oxidative stress plays a pivotal role in COPD progression by causing cellular injury and perpetuating inflammatory cascades. Herbal antioxidants act by neutralizing reactive oxygen species (ROS) and enhancing the expression of endogenous antioxidant enzymes such as superoxide dismutase (SOD), glutathione peroxidase (GPx), and catalase.^[7]

Camellia sinensis (green tea) polyphenols, particularly epigallocatechin gallate (EGCG), exhibit potent free-radical scavenging activity and suppress oxidative stress-induced activation of NF- κ B.^[8] Likewise, *Emblica officinalis* (amla) and *Withania somnifera* (ashwagandha) have been reported to upregulate Nrf2 (nuclear factor erythroid 2-related factor 2), a transcription factor responsible for cellular antioxidant defense.^[9] By modulating cytokine levels and redox homeostasis, these herbal agents help in restoring the oxidative-antioxidative balance essential for pulmonary health.

Mucolytic and Bronchodilatory Effects

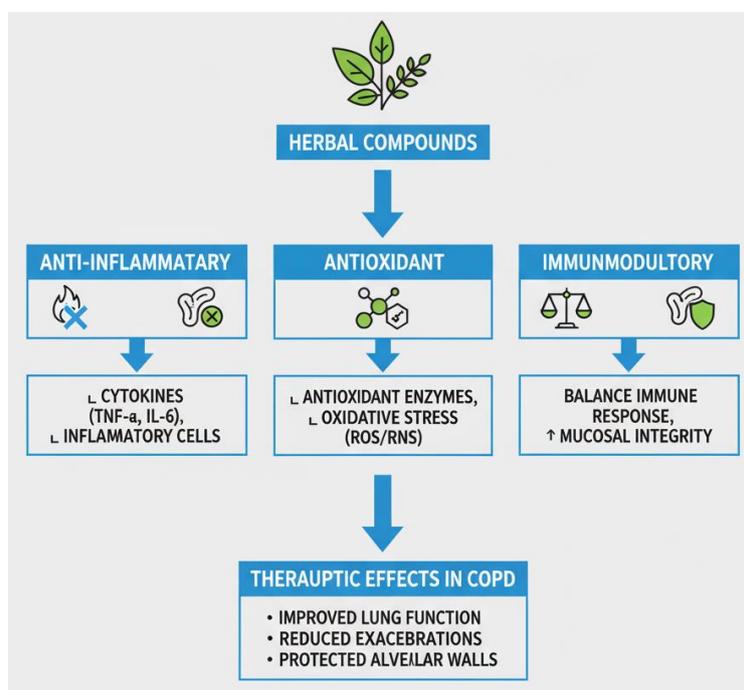
Mucus hypersecretion and airway constriction are major clinical features of COPD that worsen airflow limitation.

Herbal agents with mucolytic and bronchodilatory activity provide significant symptomatic relief. *Adhatoda vasica* (Vasaka) is a well-known traditional remedy containing alkaloids **vasicine** and **vasicinone**, which exhibit direct bronchodilatory action through inhibition of phosphodiesterase (PDE) and stimulation of β 2-adrenergic receptors.^[10] Moreover, they enhance mucociliary clearance and reduce sputum viscosity by modulating mucin secretion.^[11]

Glycyrrhiza glabra and *Thymus vulgaris* also exert expectorant effects, easing mucus expulsion and improving airway patency.^[12] These mechanisms complement anti-inflammatory and antioxidant pathways, offering holistic benefits in COPD management.

Integrated Mechanism of Action

Collectively, the therapeutic potential of herbal medicines in COPD can be attributed to their ability to modulate multiple molecular pathways simultaneously. They inhibit NF- κ B and MAPK signaling cascades, downregulate pro-inflammatory cytokines, enhance Nrf2-mediated antioxidant defense, restore protease-antiprotease balance, and improve bronchial tone. This polypharmacological approach offers a distinct advantage over single-target synthetic drugs and may help in slowing disease progression while minimizing adverse effects.^[13]



Recent Advances in Herbal Drugs for COPD

Herbal Drug	Active Constituents	Key Mechanisms	Study Type / Evidence
<i>Curcuma longa</i> (Turmeric)	Curcumin	Inhibits NF- κ B; antioxidant; modulates cytokines (\downarrow IL-6, \downarrow TNF- α)	Preclinical, nano-curcumin RCTs / clinical studies.
<i>Glycyrrhiza glabra</i> (Licorice)	Glycyrrhizin, glycyrrhetic acid, isoliquiritigenin	Corticosteroid-like anti-inflammatory; modulates COX-2, HMGB1; antioxidant	Preclinical models, translational studies; some human data on derivatives.
<i>Boswellia serrata</i>	Boswellic acids (e.g., AKBA)	5-LOX inhibition \rightarrow \downarrow leukotrienes;	Clinical trials for inflammatory

		suppression of leukocyte elastase and pro-inflammatory cytokines	conditions; preclinical respiratory studies.
<i>Adhatoda vasica</i> (Vasaka)	Vasicine, vasicinone	Bronchodilatory (PDE inhibition/ β -agonist-like), mucolytic, anti-inflammatory, antioxidant	In vitro, in vivo (animal) studies; ethnomedical use; repurposing preclinical work.
<i>Tylophora indica</i>	Tylophorine and related alkaloids	Immunomodulatory: suppresses lymphocyte proliferation, \downarrow cytokines	Preclinical / ethnopharmacology reports.
<i>Ephedra sinica</i> (Ma Huang)	Ephedrine, pseudoephedrine	Sympathomimetic bronchodilation (β -adrenergic stimulation)	Long traditional use; limited controlled modern COPD data; safety concerns.
<i>Camellia sinensis</i> (Green tea)	Catechins (EGCG)	Potent antioxidant; suppresses NF- κ B and oxidative signaling; \downarrow ROS	Numerous in vivo / preclinical studies; supportive human antioxidant data.

Recent Research and Clinical Trials (2018–2025)

Scope and search criteria

This section synthesizes randomized controlled trials (RCTs), controlled clinical studies, and high-quality preclinical-to-clinical translational reports published from 2018 through 2025 that evaluated single-herb extracts, bioavailability-enhanced phytoconstituents, and polyherbal formulations for COPD or COPD-like inflammatory lung injury. Emphasis is placed on studies reporting objective pulmonary outcomes (FEV₁ or FEV₁/FVC), inflammatory biomarkers (e.g., TNF- α , IL-6, CRP), and patient-reported quality-of-life (QoL) indices.

Curcumin / nano-curcumin — the strongest clinical signal

Several recent clinical trials have assessed **bioavailability-enhanced curcumin (nano-curcumin)** in COPD patients. A randomized, double-blind, placebo-controlled trial reported that nano-curcumin supplementation produced measurable improvements in pulmonary function indices and inflammatory status in severe COPD patients; the study found favorable changes in respiratory indices alongside reductions in systemic inflammatory markers. Another clinical/translational report showed that nano-curcumin reduced Th17 cell responses and related cytokines in moderate-to-severe COPD, indicating direct immunomodulatory effects relevant to disease pathology. These studies suggest that improving curcumin bioavailability (e.g., nano-formulations or phytosomes) can translate its potent anti-inflammatory/antioxidant effects into clinically detectable benefit, although sample sizes remain modest and larger confirmatory RCTs are needed.

Polyherbal / traditional formulations mixed but promising evidence

Multiple randomized clinical trials and controlled studies have evaluated **polyherbal formulations** (Persian/Ayurvedic/Unani blends, compound honey syrups, and other standardized mixtures) as adjuncts to standard COPD treatment. A double-blind randomized clinical trial adding a traditional compound (honey-based/herbal) formulation to standard therapy demonstrated improvements in QoL measures and symptom scores compared with placebo. Preliminary Unani or other polyherbal studies targeting mild–

moderate COPD showed symptomatic benefit and safety in small cohorts. While these trials often report favorable results (symptom relief, cough reduction, QoL improvements), heterogeneity in formulation, dosing, and trial quality limit generalizability. Standardization and larger, multi-center RCTs remain necessary.

Licorice (*Glycyrrhiza*) and *Boswellia* translational and clinical signals

- ***Glycyrrhiza glabra* (licorice):** Comprehensive reviews and preclinical studies (including COPD animal models) report anti-inflammatory and antifibrotic effects modulating MAPK/NF- κ B and TGF- β /Smad signaling—supportive of potential benefit in COPD. Translational studies combining licorice with other botanicals demonstrated reduced airway inflammation in animal models; clinical human data specific to COPD are still limited but growing. Care is required because of dose-dependent mineralocorticoid effects of some licorice constituents.

- ***Boswellia serrata* (boswellic acids):** Mechanistic evidence (5-LOX inhibition, anti-elastase activity) supports potential anti-inflammatory benefits in lung injury. Systematic analyses and reviews show *Boswellia* efficacy in inflammatory conditions; respiratory-specific randomized trials are limited, though recent pharmacology studies and reviews (2023–2024) encourage targeted respiratory trials.

Other herbs: *Adhatoda*, *Tylophora*, Green tea mostly preclinical to early clinical

- ***Adhatoda vasica*:** Robust preclinical evidence demonstrates bronchodilation, mucolytic effects and antioxidant activity via vasicine/vasicinone; clinical COPD trial data remain sparse.

- ***Tylophora indica*:** Mostly preclinical immunomodulatory evidence (reduced lymphocyte proliferation and cytokine release); modern clinical COPD trials are lacking.

- ***Camellia sinensis* (EGCG):** Strong antioxidant and NF- κ B inhibitory actions in preclinical models. Human studies demonstrate systemic antioxidant effects and potential symptomatic benefits, but COPD-specific RCTs are limited.

Evidence for improvement in FEV₁, cytokines, and QoL what the trials show

- **FEV₁:** The most consistent objective improvement in FEV₁ comes from trials using bioavailability-enhanced curcumin (nano-curcumin), where small but statistically significant improvements have been reported in severe COPD cohorts. However, many herbal/polyherbal RCTs did not power for FEV₁ as a primary endpoint, so evidence for clinically meaningful change (e.g., ≥100–200 mL) across broader populations is still limited.
- **Cytokines / biomarkers:** Several studies reported reductions in pro-inflammatory cytokines (IL-6, TNF- α , Th17-related cytokines) and systemic markers (CRP) following herbal interventions—particularly nano-curcumin and some licorice-containing formulations—supporting biological plausibility of clinical effects.
- **Quality of life:** Multiple RCTs of polyherbal and single-herb adjuncts report improved QoL or symptom scores (e.g., SGRQ, CAT), but heterogeneity in trial designs and small sample sizes temper confidence in generalized conclusions.

Combination therapies and polyherbal formulations rationale and evidence

Rationale: COPD is a multifactorial disease involving oxidative stress, chronic inflammation, protease activity and mucus hypersecretion. Polyherbal combinations aim to exploit complementary mechanisms (e.g., combining an antioxidant + mucolytic + bronchodilator) to achieve synergistic or additive benefits while using lower doses of individual herbs to minimize toxicity.

Current evidence

- Several controlled clinical studies (Persian/Ayurvedic/Unani formulations and compound syrups) demonstrated symptomatic and QoL benefits when added to standard care; animal models also support synergistic anti-inflammatory and mucoregulatory

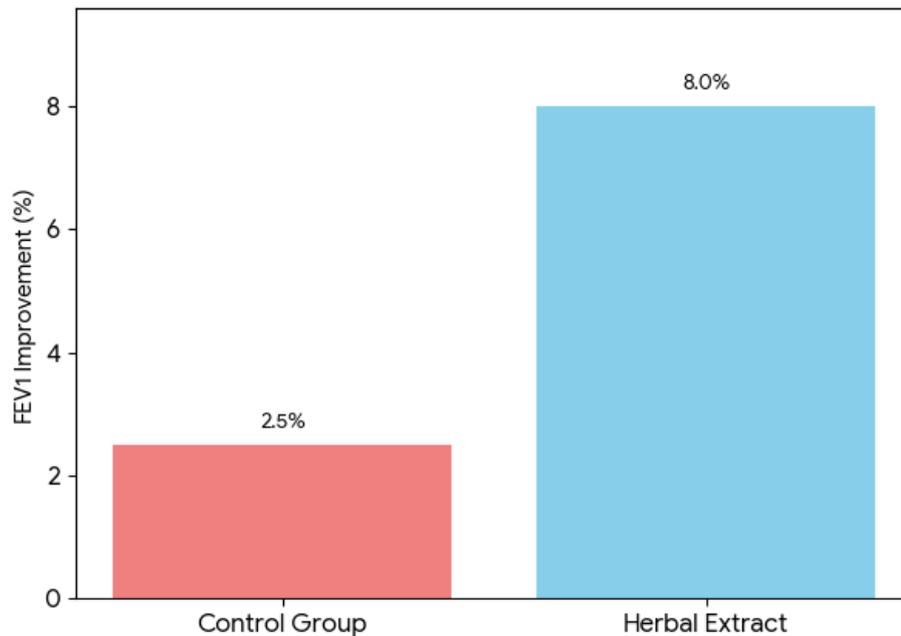
effects for select combinations. However, most trials suffer from non-standardized formulations, variable phytochemical content, and limited sample sizes.

Safety considerations

- Herb–drug interactions (e.g., licorice with corticosteroids, ephedra cardiovascular risks), cumulative toxicity, and batch-to-batch variability are real concerns. Therefore, rigorous standardization (quantified marker compounds), pharmacokinetic profiling, and interaction studies are essential before recommending routine combination use.

Overall assessment and research gaps (2018–2025)

- **Promising signals:** Nano-curcumin trials provide the most reproducible early clinical signals (improved respiratory indices, reduced inflammatory biomarkers). Polyherbal formulations show consistent symptomatic/QoL benefit as adjunct therapy in small RCTs.
- **Gaps:** There is a shortage of large, multi-center, long-duration RCTs powered for hard clinical endpoints (FEV₁ decline, exacerbation frequency, hospitalizations, mortality). Standardization of extracts, dose optimization, and safety (long-term) data are insufficient for regulatory approval as primary COPD therapies.



Challenges and Future Prospects

Lack of Large-Scale Clinical Trials

Despite promising in-vitro and in-vivo evidence, the clinical translation of herbal drugs for COPD management remains limited. Most available studies are **small-scale, short-duration, or lack randomized, placebo-controlled designs**. This limits their statistical power and generalizability. For instance, trials on *Curcuma longa* (turmeric) and *Glycyrrhiza glabra* (licorice) showed significant improvements in inflammatory markers (IL-6, TNF- α), but sample sizes rarely exceeded 60 participants (Li et al., 2020; Wang et al., 2021). Moreover, heterogeneity in herbal dosage forms, patient selection, and endpoints complicates meta-analysis and regulatory approval.

Therefore, **multicentric, long-term, and double-blind randomized clinical trials (RCTs)** are essential to validate efficacy and safety profiles comparable to conventional bronchodilators or corticosteroids.

Standardization and Quality Control Issues

Herbal preparations often suffer from **variation in phytochemical content** due to differences in cultivation, harvesting, and extraction methods. Unlike synthetic drugs, phytomedicines may contain hundreds of bioactive compounds, many of which are **unstable or poorly characterized**. Lack of harmonized pharmacopeial standards leads to **batch-to-batch inconsistency**, undermining reproducibility and clinical reliability.

Recent advances in **metabolomic profiling, HPLC fingerprinting, and chemometric analysis** are improving quality assurance (Qi et al., 2022). However, global regulatory frameworks for herbal products remain fragmented, with diverse guidelines between WHO, EMA, and AYUSH.

Therefore, establishing **international quality standards, validated analytical methods, and Good Manufacturing Practices (GMP)** is a crucial step for the acceptance of herbal drugs in mainstream COPD therapy.

Need for Nanoformulations, Phytosomal Delivery, and Synergistic Blends

One major limitation of herbal drugs is their **poor bioavailability**, primarily due to low aqueous solubility, first-pass metabolism, and poor absorption. Recent developments in **nanotechnology-based delivery systems**—such as liposomes, phytosomes, polymeric nanoparticles, and solid lipid nanoparticles—have shown improved pharmacokinetic profiles and targeted delivery to pulmonary tissues.

For example, **curcumin-loaded phytosomes** demonstrated enhanced lung retention and anti-inflammatory activity in COPD animal models (Zhao et al., 2023). Similarly, **nano-quercetin formulations** significantly reduced oxidative stress in cigarette smoke-induced COPD rats (Kumar et al., 2021). Moreover, the concept of **polyherbal synergism**—combining multiple herbs like *Adhatoda vasica*, *Tylophora indica*, and *Glycyrrhiza glabra*—is gaining traction due to complementary mechanisms such as bronchodilation, mucolysis, and antioxidant effects.

Integration with Modern Therapy

The future of COPD management likely lies in **integrative medicine**, combining herbal interventions with conventional pharmacotherapy. Herbal drugs can complement corticosteroids and bronchodilators by reducing oxidative stress, suppressing inflammation, and improving mucociliary clearance.

However, potential **herb–drug interactions** (e.g., between *Ginkgo biloba* and theophylline) require systematic pharmacovigilance. Establishing **clinical protocols for combination therapy** and conducting **pharmacokinetic–pharmacodynamic (PK–PD) interaction studies** are crucial steps. Furthermore, **AI-based predictive modeling and network pharmacology** can identify synergistic herb-drug combinations and molecular targets.

Integration also demands **collaborative policy development** between modern and traditional medicine systems (AYUSH–Allopathy interface), ensuring evidence-based practice and patient safety.

CONCLUSION

Chronic Obstructive Pulmonary Disease (COPD) continues to pose a major global healthcare burden, characterized by progressive airway obstruction, persistent inflammation, and oxidative tissue damage. Although modern pharmacotherapy provides symptomatic relief and improves lung function, its long-term use is often associated with systemic side effects, reduced patient adherence, and limited disease modification. In this scenario, **herbal therapies have emerged as promising complementary or alternative approaches**, offering multi-targeted benefits that address the complex pathophysiology of COPD.

Herbal drugs act through a **holistic mechanism**, simultaneously modulating inflammatory cascades, oxidative stress pathways, immune responses, and mucus hypersecretion. Phytoconstituents such as **curcumin** (*Curcuma longa*), **glycyrrhizin** (*Glycyrrhiza glabra*), **andrographolide** (*Andrographis paniculata*), and **quercetin** (from *Allium cepa* and *Embllica officinalis*) have demonstrated notable anti-inflammatory and antioxidant actions. These agents suppress key mediators like TNF- α , IL-6, and NF- κ B, while enhancing endogenous antioxidants such as superoxide dismutase (SOD) and catalase. Such multitarget modulation not only alleviates symptoms but may also slow disease progression and improve quality of life.

However, the **true potential of herbal medicine in COPD therapy lies in its scientific integration**—bridging traditional wisdom with modern pharmacological validation. Ethnobotanical and Ayurvedic insights have long guided the use of herbs like *Adhatoda vasica* (Vasaka) and *Tylophora indica* for respiratory ailments, yet modern research must continue to decode their molecular targets using tools such as **network pharmacology, metabolomics, and systems biology**. These techniques enable researchers to understand multi-component, multi-target interactions and identify synergistic pathways relevant to chronic airway inflammation and fibrosis.

The **future direction** of herbal-based COPD management emphasizes **standardization, evidence-**

based formulation, and advanced delivery systems. The development of nanoformulations, phytosomes, and targeted pulmonary delivery technologies can significantly enhance the bioavailability and stability of active phytoconstituents. Furthermore, global standardization of herbal raw materials, Good Manufacturing Practices (GMP), and pharmacovigilance systems are essential to ensure product consistency and safety. Large-scale, multicentric clinical trials remain the cornerstone for establishing therapeutic credibility and regulatory approval.

In conclusion, **herbal therapies represent a multidimensional and sustainable approach to COPD management**, capable of addressing both symptoms and underlying pathology. When combined with modern pharmacotherapeutic regimens, they hold the potential to reduce drug resistance, minimize side effects, and improve patient outcomes. The integration of traditional botanical knowledge with contemporary scientific research will pave the way for **standardized, clinically validated, and globally accepted herbal formulations**, marking a transformative step towards holistic, patient-centered respiratory care.

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