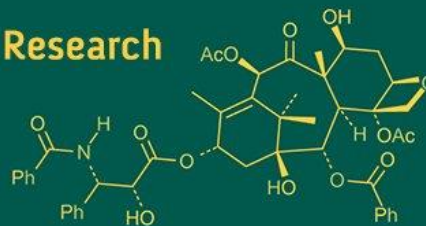


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Role of Indian medicinal plants in the management of bovine respiratory disease

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Abstract

The aim of this study is to determine the chemo-profile of aqueous extract of *Nauclea latifolia* using GC-MS. The GC-MS analysis of the plant extract was performed by using GC-MS QP-2010 (Shimadzu) and the mass spectra of the compounds found in the extract were matched with the data in the library of the National Institute of Standards and Technology (NIST). The result revealed the presence of eighteen compounds. The most prevailing compounds were 9-Octadecenoic acid (Z) - methyl ester, Oleic acid, and Benzamide 2-bromo-N-[2-(3-fluorophenyl)-5-benzoxazolyl] having a percentage area of 16.93%, 14.01%, and 9.18% respectively. The least abundant compound was 5-Methyl-2-phenylindolizine (0.66%). Some of these phytochemicals' bioactivities include anti-inflammatory, antibacterial, and antimalarial activities. As a result, the leaf extract has the potential to be a source of novel treatments. The results of this investigation thus validate the plant's traditional usage for medicine.

Keywords: *Nauclea latifolia*, aqueous leaf extract, GC-MS analysis, phytochemical profiling

Introduction

Respiratory disease is a leading cause of morbidity and mortality in cattle and buffalo globally and is particularly burdensome in India, where the bovine respiratory disease complex (BRD) erodes production efficiency and animal welfare. Bovine respiratory disease (BRD) is the leading cause of morbidity and mortality in cattle feedlots, accounting for 60% to 90% of all morbidity and mortality in some cohorts (Blakebrough-Hall *et al.*, 2021) [1]. Indian epidemiology mirrors this significance respiratory disease accounts for roughly 18–22% of calf mortality and 15–20% of adult cattle losses annually (ICAR, 2023) [2]. In India, the buffalo dairy sector is frequently maintained in high-humidity, low-ventilation housing; these conditions, combined with overcrowding and climatic stressors, heighten susceptibility to respiratory pathogens and prolong recovery. Consequences include sustained drops in milk yield and growth, delayed maturity, repeated veterinary interventions, prolonged convalescence, and avoidable deaths in buffalo calves. Trade is additionally constrained by concerns over antimicrobial residues in meat and milk.

BRD is multifactorial. Viral priming, especially infection with bovine herpesvirus-1 (BoHV-1), bovine respiratory syncytial virus (BRSV), parainfluenza-3 (PI-3), and in mixed enteric-respiratory outbreaks, bovine coronavirus (BCoV), damages respiratory epithelium and blunts local immunity, creating a permissive niche for secondary bacterial invasion. The bacterial phase is dominated by *Mannheimia haemolytica*, *Pasteurella multocida*, and *Histophilus somni*. Leukotoxin from *M. haemolytica* lyses bovine neutrophils and drives fibrinous bronchopneumonia; *P. multocida* underpins pneumonic pasteurellosis and persistence; *H. somni* contributes to respiratory lesions and extra-pulmonary sequelae. Opportunists such as *Mycoplasma bovis* and *Trueperella pyogenes* complicate mixed infections. The pathophysiology typically proceeds from

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Stress-induced, cortisol-mediated immunosuppression to viral epithelial injury, followed by bacterial adherence, toxin-mediated damage, exuberant neutrophil influx and alveolar injury. Biofilm formation well described for *P. multocida* and *M. haemolytica* fosters antibiotic

tolerance and chronicity, culminating in high outbreak morbidity and case fatality with lasting penalties in feed conversion and milk output. Conventional countermeasures face constraints. Antimicrobial resistance is reported across BRD pathogens, with rising tolerance to macrolides, fluoroquinolones, and tetracyclines (Bismarck *et al.*, 2022) [4]. Biofilm-mediated tolerance further diminishes antibiotic efficacy, while residue risks challenge public health and export markets. Vaccines, though indispensable, often confer partial and strain-variable protection; delays to robust immunity leave young stock vulnerable, and real-world effectiveness is undermined by cold-chain lapses and booster noncompliance (Amat *et al.*, 2024) [5]. In low-resource settings, these limitations call for complementary, affordable, and sustainable tools. Within this context, herbal therapeutics have re-emerged as plausible adjuncts to integrated BRD control. Phytochemicals viz. phenolics, terpenoids, alkaloids, flavonoids, and tannins map directly onto BRD pathobiology, rapid bactericidal effects against Pasteurellaceae, antivirals that interrupt BoHV-1 entry or downstream inflammatory cascades, antibiofilm activities that disrupt persistence on airway mucosa, and immunomodulatory or antioxidant actions that temper tissue injury. Importantly, these mechanisms can be delivered through formats that target the upper airway, including essential-oil (EO) vapours and intranasal sprays.

Evidence from Herbal Medicines Relevant to BRD

Trachyspermum ammi (Ajwain)

The essential oil of Ajwain rich in thymol, carvacrol, and p-cymene demonstrates potent antimicrobial, antibiofilm, and quorum sensing inhibitory properties. In vitro studies show that ajwain oil has among the lowest minimum inhibitory concentrations (MICs) (~0.025%) against *Mannheimia haemolytica*, *Pasteurella multocida*, and *Histophilus somni*, with minimal cytotoxicity to bovine turbinates epithelial cells and negligible disruption of commensal flora (Amat *et al.*, 2019) [6]. Vapour-phase assays simulating respiratory tract conditions confirmed ajwain's superior performance against BRD pathogens (Amat *et al.*, 2017) [3]. Its inclusion in intranasal delivery frameworks is based on its antimicrobial, antibiofilm, and antiviral-surrogate activity and excellent mucosal tolerability (Amat *et al.*, 2024) [5]. A feedlot pilot study using an essential oil blend containing ajwain-like phenolics demonstrated a significant reduction in nasopharyngeal *Mannheimia haemolytica* loads without impacting feed intake, behaviour, hematology, or weight gain (Magossi *et al.*, 2024) [7]. These findings highlight ajwain can be used as frontline intranasal or vapour-based BRD interventions.

Syzygium aromaticum (Clove)

Clove essential oil dominated by eugenol and eugenyl acetate, exhibits strong antibacterial and antibiofilm activity. Comparative EO panels rank clove among the top performing essential oils against calf-origin *P. multocida* and *M. haemolytica* (Bismarck *et al.*, 2022) [4]. Mechanistically, eugenol causes rapid membrane disruption, ion leakage and metabolic collapse and also exhibiting biofilm-inhibitory effects. However, due to the phenolic nature of eugenol, clove oil can irritate mucosal tissues at higher doses. Therefore, it is best applied in multi-component EO blends where potency is balanced with safety (Amat *et al.*, 2024) [5]. Its strong efficacy makes it an essential supporting component in

intranasal BRD formulations.

Cinnamomum cassia/C. verum (Cinnamon)

Cinnamon oil is rich in cinnamaldehyde and eugenol (leaf fractions) is consistently identified as one of the most potent essential oils against *P. multocida* and *M. haemolytica*, achieving very low MIC/MBC values in calf-origin isolates (Bismarck *et al.*, 2022) [4]. Importantly, cinnamon retains its efficacy in vapour-phase assays, making it suitable for airway-targeted delivery (Amat *et al.*, 2017) [3]. It also disrupts bacterial biofilms, a critical advantage in chronic BRD infections. While cinnamaldehyde's mucosal sting limits its standalone use, cinnamon functions optimally as an anchor component within carefully formulated EO blends.

Cymbopogon citratus (Lemongrass)

Lemongrass oil, dominated by citral (geranial and neral) and limonene, displays potent antimicrobial activity with very low MICs against *P. multocida* and strong efficacy against *M. haemolytica* (Bismarck *et al.*, 2022) [4]. Lemongrass essential oil (*Cymbopogon flexuosus/citratus*) has established antimicrobial and anti-inflammatory properties in oromucosal applications, though its tolerability in intranasal use especially compared to phenolic-rich oils has not yet been evaluated (Kusuma *et al.*, 2024) [8]. In addition, lemongrass exhibits anti-inflammatory and antioxidant properties, which can help to reduce respiratory mucosal damage and support recovery during BRD episodes. Its inclusion in EO selection frameworks (Amat *et al.*, 2024) [5] underscores its dual advantage of potency and safety.

Coriandrum sativum (Coriander)

Coriander oil, containing linalool and γ -terpinene, provides moderate antibacterial potency but plays an important role in broadening antimicrobial coverage when combined with stronger essential oils. While its MIC values are slightly higher than those of cinnamon and lemongrass, coriander effectively inhibits *P. multocida* and *M. haemolytica* (Bismarck *et al.*, 2022) [4]. Its mild aroma and low mucosal irritation improve animal compliance, making coriander an excellent supportive component in intranasal blends (Amat *et al.*, 2019) [6].

Foeniculum vulgare (Fennel)

Fennel essential oil, enriched with trans-anethole and fenchone, exhibits significant inhibitory activity against *M. haemolytica*, *P. multocida* and *H. somni* at relatively low MICs while maintaining minimal cytotoxicity in bovine respiratory epithelial cells (Amat *et al.*, 2019) [6]. Although fennel is less potent compared to ajwain or cinnamon, it plays a crucial role as a tolerability-enhancing co-component in multi-oil blends. Its safety profile supports its inclusion as a secondary but essential element in EO-based respiratory formulations.

Mentha spp. (Peppermint)

Peppermint essential oil, containing menthol and menthone, provides moderate antimicrobial activity against *P. multocida* and *M. haemolytica* isolated from calves (Bismarck *et al.*, 2022) [4]. While less potent than phenolic-rich oils, peppermint enhances animal acceptance of intranasal sprays due to its cooling and soothing properties. Its addition to EO blends improves tolerability and compliance while contributing to overall antimicrobial activity (Amat *et al.*, 2024) [5].

Curcuma longa (Turmeric; Curcumin)

Curcumin, the principal bioactive compound in turmeric, has broad-spectrum therapeutic relevance in BRD. It was the first herb-derived compound demonstrated to block BoHV-1 viral entry in bovine MDBK cells, potentially mitigating viral priming in BRD pathogenesis (Zhu *et al.*, 2015) [9]. Additionally, nano-curcumin formulations have shown promising activity against cattle-origin *P. multocida* isolates, positioning it as a potential antibiotic alternative in the face of rising antimicrobial resistance (Bahr *et al.*, 2024) [10]. In buffaloes, curcumin supplementation improved antioxidant enzyme activity, enhanced cellular thermotolerance and reduced oxidative damage, indicating its role in supporting recovery during respiratory infections (Grewal *et al.*, 2022; Matin *et al.*, 2025) [11, 12].

Glycyrrhiza glabra (Licorice; Glycyrrhizin)

Licorice root contains glycyrrhizin, liquiritin, and glabridin which possess strong antiviral, anti-inflammatory, and antioxidant activities. In vitro, glycyrrhizin reduces BoHV-1 induced oxidative stress and suppresses NF- κ B and NLRP3 inflammatory pathways, while activating Nrf2/HO-1 antioxidant defenses in bovine MDBK cells (Guo *et al.*, 2023) [13]. In vivo guinea pig studies demonstrate glycyrrhizin's ability to mitigate BoAHV-1-associated lung injury, reinforcing its potential as an IBR-targeted adjunct within BRD control strategies (Guo *et al.*, 2024) [14].

Zingiber officinale (Ginger)

Ginger, containing gingerols and shogaols exhibits antioxidant, anti-inflammatory, and immunomodulatory effects. In Holstein calves, dietary supplementation of 1% ginger extract significantly enhanced antioxidant capacity, improved immune markers, and showed no adverse effects on hematological or biochemical parameters (Özkaya *et al.*, 2024). While direct anti-Pasteurellaceae studies in ruminants are limited, ginger strengthens host immunity and may reduce BRD severity when combined with pathogen targeted interventions such as EO intranasal blends.

Azadirachta indica (Neem)

Neem leaves and bark contain azadirachtin, nimbolide, and quercetin, compounds with antibacterial, antibiofilm, and immunomodulatory properties. Methanolic neem (*Azadirachta indica*) leaf extract significantly inhibits biofilm formation by multiple Gram-negative and Gram-positive pathogens—including *Serratia marcescens* (83.8% inhibition at 100 μ g/mL) and *Klebsiella pneumoniae* (73.1%)—via mechanisms such as DNA gyrase inhibition, supporting its potential as a natural adjunct in targeting biofilm-driven chronic BRD lesions (Mahmoud *et al.*, 2024) [15]. In vitro research shows that neem (*Azadirachta indica*) leaf ethanolic extract has bactericidal activity against multidrug-resistant *P. multocida* though in poultry models rather than goats highlighting its potential for further evaluation in BRD-related pathogens (Ali *et al.*, 2021) [16]. Furthermore, neem enhances antioxidant enzyme activity and modulates cytokine responses, potentially reducing respiratory inflammation (Rahman *et al.*, 2023). Despite limited field-based data in cattle and buffalo, neem remains a high-value exploratory adjunct in BRD control and a strong herb for inclusion in EO-based blends.

Terminalia chebula (Haritiki)

Terminalia chebula is rich in hydrolysable tannins, including chebulagic acid and chebulinic acid which possess potent antioxidant, immunomodulatory, and antimicrobial

actions. In goats, supplementation with *Terminalia chebula* meal significantly improved rumen fermentation efficiency, enhanced nitrogen retention, and reduced protozoal populations changes that may contribute to improved systemic immune resilience (Gunun *et al.*, 2022) [17]. These findings suggest that *Terminalia* may indirectly strengthen respiratory defense mechanisms during BRD outbreaks. However, cattle and buffalo specific respiratory trials are required to confirm its direct benefits.

Plectranthus amboinicus (Indian Borage)

Plectranthus amboinicus essential oil contains carvacrol and thymol with chemotypedependent antibacterial and antibiofilm effects. In vitro research showed that *Plectranthus amboinicus* essential oil—and its dominant compound carvacrol—effectively inhibited oxacillin and vancomycin-resistant *S. aureus*, including disruption of established biofilms (Vasconcelos *et al.*, 2017) [18]. In parallel, lamb feeding trials using *Coleus amboinicus* supplementation demonstrated safety, enhanced rumen fermentation, reduced methane production, and improved meat fatty-acid profile (Yanza *et al.*, 2022) [19]. Although direct BRD efficacy studies in cattle and buffalo are limited, Indian borage represents a safe, well-tolerated and promising adjunct for respiratory formulations.

Justicia adhatoda (Vasaka)

Justicia adhatoda (Vasaka) is a classical respiratory botanical whose primary alkaloids—vasicine and vasicinone—exert proven bronchodilator and antitussive effects. Traditionally used in Ayurvedic treatments for asthma, bronchitis, and cough (Sobia, 2020; Singh, 2024), its utility extends to modern formulations in Europe such as Kan Jang and SalusTuss for cough and bronchitis (Singh, 2024). While direct studies in cattle or buffalo respiratory disease models are lacking, its long history as a respiratory therapeutic underscores its potential. Moreover, *Justicia* leaf extracts have been used to bio-synthesize TiO₂ nanoparticles with antibacterial and photocatalytic activity suggesting innovative delivery modalities (Rajan & Somasundaram, 2025). Overall, vasaka remains a promising symptomatic adjunct an anti-bronchospasm or expectorant component to complement pathogen-targeted therapies pending RCTs in large ruminants.

Tinospora cordifolia (Guduchi)

Tinospora cordifolia (Giloy) is a potent immunomodulator and antioxidant, traditionally revered in Ayurveda. In dairy cows, supplementation (100 mg/kg BW) for five days enhanced phagocytic function of polymorphonuclear cells and innate immune responses, suggesting a stronger barrier against infections (Gupta *et al.*, 2016; 2025) [20]. In goats, combinations with CpG oligonucleotides improved resistance to viral challenge through enhanced B- and T-cell proliferation (Sachan *et al.*, 2019). A 50% hydromethanolic extract in chicken lymphocytes boosted lymphocyte proliferation and antioxidant capacity (Pragati Patel, 2024) [21]. These data across species support Guduchi's role as a vaccine adjuvant or resilience-promoting additive, particularly valuable in BoHV-1-primed BRD systems, though BRD-specific trials in cattle or buffalo are still needed.

Piper longum (Pippali)

Piper longum has been employed in herbal medicine for centuries to manage respiratory ailments such as bronchial asthma, cough, and bronchitis (Kumari, 2012; Singh, 1992).

Its fruit extracts exhibit anti-asthmatic activity by prolonging latency in histamine-induced bronchospasm in guinea pigs, indicating H₁ receptor antagonism (Pandi *et al.*, 2012). Additionally, piperine its key alkaloid acts as a respiratory stimulant at low doses, countering opioid-induced respiratory depression in animal models (Srivastava *et al.*, 2010). These findings suggest that Pippali could serve as a supportive bronchodilatory adjunct in respiratory distress settings though no ruminant-specific BRD data are yet available.

***Ocimum sanctum* (Tulsi)**

Ocimum sanctum (tulsi) is traditionally known for its immunostimulant, antimicrobial, and adaptogenic actions (Makams blog, 2024). In buffaloes, inclusion in a polyherbal “antistressor” blend enhanced total leukocyte and

lymphocyte counts, elevated antioxidant enzyme (glutathione peroxidase) levels, and lowered cortisol, indicating systemic resilience enhancement during heat stress (Sivajothi *et al.*, 2018). In dairy cows, tulsi essential oil used as a post-milking teat spray significantly reduced bacterial counts on teat skin and milk over two weeks, suggesting potential for controlling mastitis and by extension airway-relevant pathogens (Divyalakshmi *et al.*, 2025). Tulsi’s restoration of hematological and hepatic markers in meloxicam-induced toxicity in rodents further underscores its cytoprotective potential (Mahaprabhu *et al.*, 2011). Together, these findings support tulsi’s role as a supportive feed additive enhancing systemic immunity, stress resilience, and mucosal health, meriting exploration for respiratory health programs in cattle and buffalo.

Table 1: Categorization of Herbal Therapeutics for Bovine Respiratory Diseases Based on Mechanisms of Action and Supporting Studies

Herb (Scientific Name)	Key Bioactive Compounds	Primary Mechanism of Action	Effect on BRD Pathogens / Host Immunity	Supporting Studies
<i>Trachyspermum ammi</i> (Ajwain)	Thymol, carvacrol, p-cymene	Antibacterial, antibiofilm, quorum-sensing inhibition	Potent activity vs. <i>M. haemolytica</i> , <i>P. multocida</i> , <i>H. somni</i> ; low MIC (~0.025%)	Amat <i>et al.</i> , 2019; Bismarck <i>et al.</i> , 2022 ^[4] ; Magossi <i>et al.</i> , 2024
<i>Syzygium aromaticum</i> (Clove)	Eugenol, eugenyl acetate	Antibacterial, antibiofilm, membrane disruption	Strong inhibition of <i>P. multocida</i> and <i>M. haemolytica</i> ; complementary in EO blends	Bismarck <i>et al.</i> , 2022 ^[4] ; Amat <i>et al.</i> , 2024
<i>Cinnamomum cassia/verum</i> (Cinnamon)	Cinnamaldehyde, eugenol	Antibacterial, antibiofilm, vapour-phase inhibition	Top-ranking oil vs. <i>P. multocida</i> ; effective in vapour assays simulating airway exposure	Amat <i>et al.</i> , 2017; Bismarck <i>et al.</i> , 2022 ^[4]
<i>Cymbopogon citratus</i> (Lemongrass)	Citral, limonene	Antibacterial, anti-inflammatory	Low MICs vs. <i>P. multocida</i> ; mucosal tolerability favours intranasal delivery	Bismarck <i>et al.</i> , 2022 ^[4] ; Amat <i>et al.</i> , 2024
<i>Coriandrum sativum</i> (Coriander)	Linalool, γ -terpinene	Antibacterial, supportive blend synergy	Moderate activity vs. <i>P. multocida</i> and <i>H. somni</i> ; improves palatability	Bismarck <i>et al.</i> , 2022 ^[4] ; Amat <i>et al.</i> , 2019
<i>Foeniculum vulgare</i> (Fennel)	Trans-anethole, fenchone	Antibacterial, mucosal safety enhancer	Inhibits <i>M. haemolytica</i> , <i>P. multocida</i> , <i>H. somni</i> ; broadening EO blend tolerance	Amat <i>et al.</i> , 2019
<i>Mentha</i> spp. (Peppermint)	Menthol, menthone	Antibacterial, mucolytic, soothing effect	Mid-tier efficacy vs. <i>P. multocida</i> ; improves intranasal spray acceptance	Bismarck <i>et al.</i> , 2022 ^[4] ; Amat <i>et al.</i> , 2024
<i>Curcuma longa</i> (Turmeric)	Curcumin, demethoxycurcumin	Antiviral, antioxidant, anti-inflammatory	Blocks BoHV-1 entry; nano-curcumin active vs. <i>P. multocida</i> ; boosts buffalo antioxidant status	Zhu <i>et al.</i> , 2015 ^[9] ; Bahr <i>et al.</i> , 2024 ^[10] ; Grewal <i>et al.</i> , 2022
<i>Glycyrrhiza glabra</i> (Licorice)	Glycyrrhizin, liquiritin, glabridin	Antiviral, anti-inflammatory, antioxidant	Reduces BoHV-1 oxidative stress via NF- κ B/NLRP3 suppression; activates Nrf2 pathways	Guo <i>et al.</i> , 2023 ^[13]
<i>Zingiber officinale</i> (Ginger)	Gingerols, shogaols	Immunomodulatory, antioxidant, anti-inflammatory	Enhances antioxidant status and immune markers in calves; supportive role in BRD	Özkaya <i>et al.</i> , 2024
<i>Azadirachta indica</i> (Neem)	Azadirachtin, nimbolide, quercetin	Antibacterial, antibiofilm, anti-inflammatory	Inhibits <i>P. multocida</i> biofilms; suppresses MDR strains relevant in small-ruminant pneumonia	Ali <i>et al.</i> , 2021 ^[16] ; Mahmoud <i>et al.</i> , 2024 ^[15]
<i>Terminalia chebulai</i> (Haritiki)	Chebulagic acid, chebulinic acid, gallic acid	Antioxidant, immunomodulatory, rumen support	Improves rumen fermentation, nitrogen retention, and immunity; indirectly supports respiratory resilience	Gunun <i>et al.</i> , 2022 ^[17]
<i>Plectranthus amboinicus</i> (Indian Borage)	Carvacrol, thymol	Antibacterial, antibiofilm, fermentation enhancer	Inhibits biofilms in vitro; improves rumen fermentation and meat quality in lambs	Vasconcelos <i>et al.</i> , 2017 ^[18] ; Yanza <i>et al.</i> , 2022 ^[19]
<i>Justicia adhatoda</i> (Vasaka)	Vasicine, vasicinone	Bronchodilator, expectorant, mucolytic	Polyherbal trials show improved respiratory scores; bronchodilatory phytochemicals aid mucus clearance	Ramesh <i>et al.</i> , 2022 ^[22] ; Sobia <i>et al.</i> , 2020
<i>Tinospora cordifolia</i> (Guduchi)	Tinosporide, alkaloids, polysaccharides	Immunomodulatory, antioxidant, adjuvant potential	Enhances leukocyte activity, immunoglobulin levels, and lymphocyte proliferation; promising as a vaccine adjuvant	Gupta <i>et al.</i> , 2016; Sachan <i>et al.</i> , 2019
<i>Piper longum</i> (Pippali)	Piperine, piperlongumine	Bronchodilator, anti-inflammatory, respiratory stimulant	Reduces airway hyperresponsiveness in histamine-induced bronchospasm models; plausible supportive use in BRD	Pandit <i>et al.</i> , 2012; Srivastava <i>et al.</i> , 2010
<i>Ocimum sanctum</i> (Tulsi)	Eugenol, rosmarinic acid, ursolic acid	Antioxidant, immunomodulatory, adaptogenic	Enhances leukocyte counts, boosts antioxidant enzymes, and improves resilience under stress; supports BRD recovery	Sivajothi <i>et al.</i> , 2018; Divyalakshmi <i>et al.</i> , 2025

Intranasal essential-oil delivery: from concept to application

Vapour-phase systems and broth microdilution tailored to BRD bacteria, combined with antibiofilm testing and bovine-cell safety, have enabled rational selection of oils frequently ajwain, cinnamon leaf, citral-rich lemongrass, fennel, and related phenolic profiles for intranasal sprays (Amat *et al.*, 2017; Amat *et al.*, 2019; Amat *et al.*, 2024) ^[3, 6, 5]. A single intranasal dose of an essential-oil (EO) spray comprising ajowan, thyme, fennel, cinnamon leaf, and citronella moderately reduced nasopharyngeal *Mannheimia* abundance in feedlot cattle, without affecting performance or immune metrics, thereby motivating future multi-dose, dose-response randomized trials focused on morbidity, retreatment, mortality, and harvest lung-score endpoints (Magossi *et al.*, 2024) ^[7].

Practical integration as veterinary adjuncts

Herbal interventions should complement, not replace, vaccination, metaphylaxis, and stockmanship. On arrival, intranasal EO blends anchored by high-potency components (cinnamon, lemongrass, ajwain) and balanced with fennel, peppermint, or coriander for tolerability can be layered onto existing programs, with attention to mucosal tolerance and chemotype standardization (Amat *et al.*, 2019; Amat *et al.*, 2024) ^[6, 5]. Antiviral phytochemicals such as curcumin and glycyrrhizin are conceptually suited to IBR-risk windows but should advance under controlled studies until field dosing, safety, residues, and withdrawal times are defined (Zhu *et al.*, 2015; Guo *et al.*, 2023) ^[9, 13]. Supportive nutritional supplementation with ginger extract and tannin-rich botanicals can enhance immune resilience and rumen function, but they do not substitute for pathogen-directed control measures (Gunun *et al.*, 2022) ^[17]. Programs should record BRD incidence, retreatments, case fatality, antimicrobial use, and average daily gain when piloting EO adjuncts.

Evidence gaps and research priorities

Priorities include buffalo-specific trials under natural exposure; dose-response and multidose intranasal schedules with pharmacodynamic readouts on nasopharyngeal microbiota and biofilms; randomized evaluations of curcumin and glycyrrhizin in BoHV-1-vaccinated systems with full safety and residue profiling; chemotype standardization and batch quality assurance; testing against multidrug-resistant *Mannheimia/Pasteurella* with synergy analyses alongside macrolides and β -lactams; and regulatory dossiers addressing food-animal carriers, anti-irritant excipients, and residues.

Conclusion

Essential-oil driven antibacterial strategies centred on ajwain, cinnamon, lemongrass, coriander, clove, fennel, and peppermint show the strongest and most consistent *in-vitro* evidence against BRD bacteria, now supported by an intranasal feasibility signal in cattle. Curcumin and glycyrrhizin provide credible bovine-cell antiviral mechanisms against BoHV-1, while ginger and tannin-rich *Terminalia* offer host-defence support. To translate these into practice, the field needs dose-defined, multi-dose randomized trials in calves and buffalo that integrate herbal adjuncts with standard BRD control and quantify clinical benefit, antimicrobial use reduction, safety, and residues.

With these data, herbal therapeutics can be positioned as sustainable, antibiotic-sparing components of modern respiratory health programs in ruminants.

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