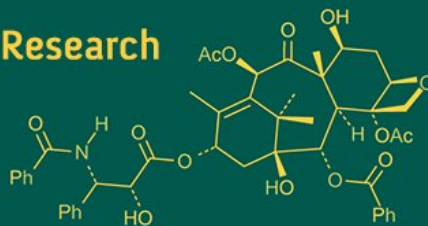


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Himalayan ayurvedic herbs with anti-inflammatory and antibacterial properties for mastitis management in Indian dairy animals

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Abstract

Mastitis remains one of the most economically important and therapeutically challenging diseases of dairy animals because it simultaneously reduces milk yield, alters milk quality, increases treatment costs and drives antimicrobial use at herd level (Kaseke *et al.*, 2023; Nelson *et al.*, 2024) ^[1, 2]. The growing concern over antimicrobial resistance, residue persistence, recurrent intramammary infection and consumer demand for safer food systems has renewed interest in medicinal plants and phytochemicals as adjuncts or alternatives in mastitis control programs (Kaseke *et al.*, 2023; Nelson *et al.*, 2024; Kaya *et al.*, 2024) ^[1, 2, 3]. Ayurveda and allied ethnoveterinary traditions are especially relevant in India because they preserve a long history of plant-based animal healthcare that can now be re-examined through contemporary phytochemical, microbiological and immunobiological frameworks (Nirmal *et al.*, 2025; Van Wyk and Prinsloo, 2020) ^[4, 5]. A recent South Asian review identified 83 herbs with anti-inflammatory significance for mastitis-oriented veterinary use, emphasizing flavonoids, polyphenols, terpenoids, alkaloids, vitamins and minerals as major functional classes of interest (Nirmal *et al.*, 2025) ^[4]. Meanwhile, systematic evidence from global bovine mastitis studies has shown that medicinal plants from at least 42 botanical families and 112 species have already been investigated for antibacterial activity against mastitis pathogens, although standardization remains inadequate (Kaseke *et al.*, 2023) ^[1]. This review synthesizes current knowledge on Himalayan and Ayurveda-linked medicinal herbs with anti-inflammatory and antibacterial promise for mastitis management in Indian dairy animals, with emphasis on pathobiological rationale, candidate species, phytochemical classes, translational limitations and research priorities for high-impact veterinary application (Nelson *et al.*, 2024; Kaya *et al.*, 2024) ^[2, 3].

Keywords: Antibacterials, antimicrobial, ethnomedicine, mastitis, phytochemicals

Introduction

Bovine mastitis is a multifactorial inflammatory disorder of the mammary gland that is usually associated with intramammary infection and remains a leading cause of economic loss in dairy systems worldwide (Kaseke *et al.*, 2023; Kaya *et al.*, 2024) ^[1, 3]. In India, the burden of mastitis is amplified by the coexistence of organized dairy farms, peri-urban dairies, and smallholder systems, where constraints in hygiene, diagnostics, treatment access and followup can prolong disease persistence and recurrence (Nirmal *et al.*, 2025; Kuralkar and Kuralkar, 2021) ^[4, 6]. Clinical mastitis causes visible udder inflammation and abnormal milk, whereas subclinical mastitis may remain undetected for long periods while still impairing milk production and increasing somatic cell count and pathogen shedding (Nelson *et al.*, 2024; Haxhijaj *et al.*, 2022) ^[2, 7]. The most frequently discussed bacterial agents in the recent mastitis literature include *Staphylococcus aureus*, *Escherichia coli*, streptococci, coagulase-negative staphylococci, and other environmental opportunists (Kaseke *et al.*, 2023; Dufour *et al.*, 2019) ^[1, 8].

Current mastitis control still relies heavily on antibiotics, intramammary infusion, dry-cow therapy, hygiene management, and supportive care, yet these measures have notable limitations in chronic, recurrent, resistant, or subclinical infections (Nelson *et al.*, 2024; Casseri *et al.*, 2022) ^[2, 9]. Antimicrobial resistance and residue concerns have further intensified the search for non-antibiotic therapeutics, especially plant-derived products with multitarget antimicrobial and anti-inflammatory potential (Dyson *et al.*, 2022; Sharun *et al.*, 2021) ^[10, 11]. This interest is not merely pharmacological but also strategic, because modern

Mastitis management increasingly values ecological sustainability, One Health alignment and culturally acceptable low-cost interventions for field settings (Kaya *et al.*, 2024; Nirmal *et al.*, 2025) [3, 4]. Within this context, Himalayan Ayurvedic herbs deserve focused review because the Himalayan region is a major reservoir of medicinal flora and Ayurveda provides an interpretive framework for their antiinflammatory, wound-healing, antioxidant and antimicrobial use in livestock disorders (Nirmal *et al.*, 2025; Kala *et al.*, 2006) [4, 12].

Rationale for a Himalayan ayurvedic approach

Recent reviews have already established that medicinal plants and plant-derived products are relevant to bovine mastitis management, but the literature remains fragmented across ethnoveterinary reports, phytochemical screenings, *in vitro* antimicrobial studies, and limited clinical observations (Kaseke *et al.*, 2023; Nelson *et al.*, 2024) [1, 2]. A Himalayan Ayurvedic framing is scientifically valuable because it links three evidence streams that are often treated separately: traditional veterinary knowledge, phytochemical richness of high-altitude medicinal flora, and urgent need for validated adjuncts in mastitis care (Nirmal *et al.*, 2025; Kaya *et al.*, 2024) [4, 3]. This framing is also regionally appropriate for India, where Ayurveda remains a living medical system and where Himalayan botanicals retain high cultural and commercial relevance in both human and veterinary practice (Dawa *et al.*, 2018; Sureshbabu *et al.*, 2020) [13, 14]. High-impact veterinary journals increasingly favor such translational syntheses when they combine ethnomedical depth with rigorous caution about evidence quality, standardization, and clinical applicability (Kaya *et al.*, 2024; Kaseke *et al.*, 2023) [3, 1].

Mastitis in Indian animals

Mastitis remains a major health and production problem in Indian dairy animals because it affects milk yield, milk quality, animal welfare, and farm profitability (Kaseke *et al.*, 2023; Kaya *et al.*, 2024) [1, 3]. The burden is amplified by the coexistence of organized farms, peri-urban dairies and smallholder systems, where hygiene, diagnostics, and treatment followup may be inconsistent (Nirmal *et al.*, 2025; Kuralkar and Kuralkar, 2021) [4, 6]. Clinical mastitis produces visible udder inflammation and abnormal milk, while subclinical mastitis may persist for long periods and still raise somatic cell count and pathogen shedding (Nelson *et al.*, 2024; Haxhij *et al.*, 2022) [2, 7]. Common mastitis pathogens include *Staphylococcus aureus*, *Escherichia coli*, streptococci, and coagulase-negative staphylococci, which makes pathogen diversity another reason conventional single-target control is often insufficient (Kaseke *et al.*, 2023; Dufour *et al.*, 2019) [1, 8]. The pathology of mastitis involves bacterial invasion, host recognition of pathogen-associated molecular patterns, cytokine release, leukocyte infiltration, oxidative stress, tissue injury, vascular leakage, and disturbed secretory function of the mammary epithelium (Nelson *et al.*, 2024; Haxhij *et al.*, 2022) [2, 7]. Therefore, mastitis cannot be viewed only as a microbiological problem, because inflammatory amplification and collateral tissue damage contribute directly to pain, fibrosis, altered milk composition, and delayed cure (Nirmal *et al.*, 2025; Kaya *et al.*, 2024) [4, 3]. This pathophysiological complexity explains why herbs with dual antibacterial and anti-inflammatory effects are more attractive than agents that

only suppress bacterial growth *in vitro* (Nelson *et al.*, 2024; Kaseke *et al.*, 2023) [2, 1]. It also explains why phytochemicals such as flavonoids, tannins, terpenoids, alkaloids, and phenolic acids are repeatedly highlighted in mastitis-oriented literature, since these classes frequently act on oxidative stress, membrane integrity, inflammatory mediators, quorum sensing, and biofilm formation (Nirmal *et al.*, 2025; Vaou *et al.*, 2021) [4, 15].

Evidence base for medicinal plants in bovine mastitis

A systematic review published in 2023 examined 45 studies and reported 112 medicinal plant species from 42 families that had been investigated against mastitis-associated bacteria, demonstrating the breadth of global interest in plant-derived antibacterials for udder infections (Kaseke *et al.*, 2023) [1]. The same review noted that India was among the leading countries represented in this evidence base, underscoring the importance of the Indian traditional medicine context for future veterinary bioprospecting (Kaseke *et al.*, 2023) [1]. The most commonly targeted pathogens across these studies were *S. aureus* and *E. coli*, which is consistent with their importance in contagious and environmental mastitis, respectively (Kaseke *et al.*, 2023; Dufour *et al.*, 2019) [1, 8]. However, that review also emphasized major methodological variability in plant part selection, extraction solvent, assay choice, phytochemical characterization, and toxicity assessment, making direct comparison difficult (Kaseke *et al.*, 2023) [1].

More recent reviews have expanded the interpretive lens by emphasizing antiinflammatory, dietary, and immunomodulatory medicinal plants rather than considering antibacterial screening alone (Nelson *et al.*, 2024; Kaya *et al.*, 2024) [2, 3]. This conceptual shift is important because reduction of inflammatory damage may improve udder function even when bacteriological elimination is incomplete, especially in subclinical or recurrent disease (Nelson *et al.*, 2024; Nirmal *et al.*, 2025) [2, 4]. The emerging consensus is that phytotherapeutics are most promising when integrated into broader mastitis control programs involving hygiene, early diagnosis, prudent antibiotic use, and herd management rather than promoted as simplistic replacements for all conventional therapy (Kaya *et al.*, 2024; Casseri *et al.*, 2022) [3, 9].

Himalayan Ayurvedic herbs of interest

Curcuma longa

Curcuma longa is central to Ayurveda and remains one of the most important herbs in Indian ethnoveterinary mastitis practice because curcuminoids and associated constituents possess anti-inflammatory, antioxidant and broad antimicrobial effects (Nirmal *et al.*, 2025; Nelson *et al.*, 2024) [4, 2]. Turmeric frequently appears in polyherbal mastitis preparations used in field conditions, particularly in combinations with aloe, oils, lime and other supportive ingredients (Ethno veterinary practices, 2024; Evaluation of ethnoveterinary polyherbal adjunct therapy, 2025) [16, 17]. Curcumin has been widely studied beyond mastitis for its effects on inflammatory transcription pathways, oxidative injury and tissue protection, which strengthens its biological plausibility in udder inflammation (Nelson *et al.*, 2024; Jurenka, 2009) [2, 18]. In mastitis-oriented reviews, turmeric is best regarded as a multitarget anti-inflammatory adjunct with supportive antimicrobial value rather than a universally

validated single-agent cure (Nirmal *et al.*, 2025; Kaya *et al.*, 2024) ^[4, 3].

Withania somnifera

Withania somnifera is an important Ayurvedic rasayana herb with immunomodulatory and anti-inflammatory effects that make it relevant to mastitis, especially where stress, immune dysregulation, and chronic inflammation contribute to poor udder recovery (Nirmal *et al.*, 2025; Gupta and Rana, 2007) ^[4, 19]. ICAR-linked work on the immunotherapeutic role of *W. somnifera* in bovine mastitis supports the concept that host-directed phytotherapy deserves greater attention in veterinary medicine (ICAR source on *Withania somnifera*, 2020) ^[20]. The strength of ashwagandha lies less in direct bactericidal action and more in modulation of host defense, inflammatory balance, and recovery pathways (Nelson *et al.*, 2024; Nirmal *et al.*, 2025) ^[2, 4]. For this reason, it is especially suited to adjunctive frameworks rather than stand-alone antimicrobial positioning (Kaya *et al.*, 2024; Kuralkar and Kuralkar, 2021) ^[3, 6].

Azadirachta indica

Azadirachta indica is repeatedly cited in mastitis-related plant literature and was among the most frequently referenced species in the 2023 systematic review of medicinal plants tested against bovine mastitis pathogens (Kaseke *et al.*, 2023) ^[1]. Neem contains limonoids, flavonoids, tannins, and other bioactive compounds associated with antibacterial, anti-inflammatory, and wound-healing properties in broader pharmacological research (Biswas *et al.*, 2002; Nelson *et al.*, 2024) ^[21, 2]. Its appeal in veterinary practice comes from strong traditional acceptability, widespread availability in India, and broad-spectrum reputation in both ethnomedicine and livestock health management (Nirmal *et al.*, 2025; Kuralkar and Kuralkar, 2021) ^[4, 6]. Nonetheless, neem-based mastitis recommendations should still distinguish between ethnoveterinary use, *in vitro* evidence, and controlled clinical proof, because those levels of evidence are not interchangeable (Kaya *et al.*, 2024; Kaseke *et al.*, 2023) ^[3, 1].

Ocimum teuflorum

Ocimum tenuiflorum or tulsi is another major Ayurvedic herb with recognized antioxidant, immunomodulatory, and antimicrobial activities that make it attractive in the context of mastitis biology (Pattanayak *et al.*, 2010; Nirmal *et al.*, 2025) ^[22, 4]. Tulsi phytochemicals include eugenol-rich aromatic fractions, terpenoids, and phenolics that may contribute to antimicrobial and anti-inflammatory action (Nelson *et al.*, 2024; Pattanayak *et al.*, 2010) ^[2, 22]. Its direct mastitis-specific evidence remains less extensive than its broader pharmacological profile, which means tulsi should currently be presented as a plausible supportive candidate rather than a fully validated mastitis therapy (Kaya *et al.*, 2024; Kaseke *et al.*, 2023) ^[3, 1]. This distinction is important for a high-impact review because overstatement of traditional herbs without disease-specific validation weakens scientific credibility (Vaou *et al.*, 2021; Kaya *et al.*, 2024) ^[15, 3].

Aloe vera

Aloe vera is widely used in topical and polyherbal udder applications in Indian ethnoveterinary settings and appears

prominently in practical mastitis discussions because of its soothing, wound-healing, anti-inflammatory, and adjunct antimicrobial properties (Ethno veterinary practices, 2024; Management of Mastitis Using Trans-Disciplinarily Validated Ethno, 2023) ^[16, 23]. Aloe-based combinations with turmeric and alkaline ingredients have been repeatedly discussed as field-level remedies, reflecting a translational bridge between traditional practice and veterinary extension (Ethno veterinary practices, 2024; Efficacy of ethno veterinary medicine, 2023) ^[16, 24]. Although aloe is not a classical Himalayan species, its continued clinical use in India makes it impossible to exclude from a review intended for veterinary applicability (Nirmal *et al.*, 2025; Kaya *et al.*, 2024) ^[4, 3]. Its strongest role is likely in local anti-inflammatory support and tissue comfort rather than as a robust, independently validated intramammary antibacterial (Nelson *et al.*, 2024; Management of Mastitis Using Trans-Disciplinarily Validated Ethno, 2023) ^[2, 23].

Tinospora cordifolia

Tinospora cordifolia is highly valued in Ayurveda for immunomodulatory and antiinflammatory effects and is therefore relevant to mastitis, a disease where host response strongly influences outcome (Saha and Ghosh, 2012; Nirmal *et al.*, 2025) ^[25, 4]. Guduchi has broader pharmacological support for antioxidant and inflammatory modulation, which strengthens its plausibility as a supportive herb in bovine udder disease (Nelson *et al.*, 2024; Saha and Ghosh, 2012) ^[2, 25]. However, mastitis-specific bovine evidence remains relatively sparse, so its current placement should be within the “priority candidate” category rather than the “clinically established” category (Kaya *et al.*, 2024; Kaseke *et al.*, 2023) ^[3, 1]. Such categorization helps align traditional enthusiasm with evidence-based reporting standards expected by peer-reviewed clinical journals (Kaya *et al.*, 2024; Casseri *et al.*, 2022) ^[3, 9].

Berberis aristata

Berberis aristata is an especially relevant Himalayan Ayurvedic herb because it combines high regional identity with alkaloid-rich phytochemistry, particularly berberine-related constituents known for antibacterial potential in broader infectious disease literature (Nirmal *et al.*, 2025; Imenshahidi and Hosseinzadeh, 2016) ^[4, 26]. Berberine-containing plants are of interest for mastitis because they may exert overlapping antibacterial, anti-inflammatory, and anti-biofilm effects, although direct bovine mastitis validation remains limited (Nelson *et al.*, 2024; Vaou *et al.*, 2021) ^[2, 15]. For a Himalayan-centered review, daruharidra is therefore a strategically important species to highlight as a high-value research candidate for future mastitis screening programs (Nirmal *et al.*, 2025; Kaya *et al.*, 2024) ^[4, 3]. Emphasizing such species can help shift veterinary bioprospecting from generic herbal catalogues toward regionally meaningful medicinal plants with plausible translational value (Kala *et al.*, 2006; Dawa *et al.*, 2018) ^[12, 13].

Nardostachys jatamansi

High-altitude Himalayan medicinal plants such as *Nardostachys jatamansi* deserve attention because their secondary metabolite profiles are often rich in sesquiterpenes and other antiinflammatory aromatic constituents (Nirmal *et al.*, 2025; Singh *et al.*, 2017) ^[4, 27].

Although direct mastitis-specific testing is still scarce, such herbs are scientifically relevant because essential oil and terpene-rich botanicals have shown promise against mastitis pathogens in other plant systems (Kaseke *et al.*, 2023; Álvarez-Martínez *et al.*, 2021) [1, 28]. Their present role in the literature is therefore hypothesis-generating rather than clinically validated, but that still makes them worth including in a forward-looking review (Kaya *et al.*, 2024; Nirmal *et al.*, 2025) [3, 4]. High-impact reviews often gain value by identifying these research-priority species and clarifying why they matter mechanistically and regionally (Vaou *et al.*, 2021; Sureshbabu *et al.*, 2020) [15, 14].

Phytochemical classes relevant to mastitis control

Phenolics and flavonoids are among the most important phytochemical groups in mastitis-oriented herbal research because they frequently contribute to antibacterial, antioxidant, membrane-active, and anti-inflammatory effects (Nirmal *et al.*, 2025; Nelson *et al.*, 2024) [4, 2]. A 2026 study on medicinal plant extracts and their combinations against mastitis pathogens reported that total phenolic and flavonoid content correlated positively with antimicrobial activity, reinforcing the view that these classes are useful indicators in phytotherapeutic screening (Hulea *et al.*, 2026) [29]. This finding is consistent with earlier observations that crude extracts with rich polyphenolic composition often retain higher biological activity than isolated fractions, possibly because of synergistic interactions (Álvarez-Martínez *et al.*, 2021; Williamson, 2001) [28, 30]. Such synergy is directly relevant to Ayurveda, where multi-component formulations are traditionally favored over single-molecule reductionism (Nirmal *et al.*, 2025; Management of Mastitis Using Trans-Disciplinarily Validated Ethno, 2023) [4, 23].

Terpenoids and essential-oil components are also important because many studies of mastitis-active plants have identified thymol, carvacrol, eugenol, cineole, citral, and related volatile compounds as major antibacterial contributors (Kaseke *et al.*, 2023; Bachir and Benali, 2012) [1, 31]. Essential oils may act through membrane disruption, leakage of intracellular components, interference with biofilm formation, and broader stress on microbial survival systems (Aiemsard *et al.*, 2011; Vaou *et al.*, 2021) [32, 15]. Alkaloids such as berberine-rich fractions are attractive because they can combine antibacterial activity with anti-inflammatory signaling effects, though bovine mastitis-specific evidence remains incomplete (Imenshahidi and Hosseinzadeh, 2016; Nelson *et al.*, 2024) [26, 2]. Tannins, saponins, and related metabolites may contribute additional antimicrobial and immunomodulatory functions, but comparative veterinary evidence remains methodologically inconsistent across plant species and assays (Kaseke *et al.*, 2023; Abubakar and Haque, 2020) [1, 33].

Antibacterial evidence against mastitis pathogens

The antibacterial literature on bovine mastitis herbs is substantial but heterogeneous, with evidence ranging from agar diffusion studies and minimum inhibitory concentration assays to anti-biofilm evaluations and limited formulation testing (Kaseke *et al.*, 2023; Vaou *et al.*, 2021) [1, 15]. The dominance of *S. aureus* and *E. coli* in these studies reflects their clinical relevance and the persistent need for agents active against both Gram-positive and Gram-negative mastitis organisms (Dufour *et al.*, 2019; Kaseke *et al.*, 2023) [8, 1]. A 2017 study on plant-based products tested on

pathogens isolated from mastitis milk demonstrated measurable inhibition across multiple preparations and highlighted the potential superiority of some combinations relative to individual plant extracts (Aleksic *et al.*, 2017) [34]. A 2026 *in vitro* study further reported that selected medicinal plant extracts and their combinations exhibited broad-spectrum inhibition and that combinations could preserve strong antimicrobial effects across different mastitis organisms (Hulea *et al.*, 2026) [29].

Earlier Indian and related studies also support the concept that crude plant extracts rich in tannins, flavonoids, saponins, and alkaloids can inhibit mastitis-associated bacteria under *in vitro* conditions (Dharajiya *et al.*, 2012; Awandkar *et al.*, 2012) [35, 36]. Screening work against *S. aureus* isolates from bovine mastitis has likewise shown that medicinal plants can provide a reservoir of antibacterial leads relevant to intramammary infection biology (Bussmann *et al.*, 2010; Kaseke *et al.*, 2023) [37, 1]. However, disc diffusion zones and MIC values do not automatically predict therapeutic success in a lactating udder, where milk composition, tissue penetration, inflammation, pH, biofilm formation, and local immune response all shape outcome (Casseri *et al.*, 2022; Kaya *et al.*, 2024) [9, 3]. A high-impact review must therefore interpret *in vitro* antibacterial evidence as necessary but insufficient for clinical endorsement (Vaou *et al.*, 2021; Kaya *et al.*, 2024) [15, 3].

Anti-inflammatory and immunomodulatory evidence

The anti-inflammatory dimension of herbal mastitis management has gained sharper attention in recent literature because mastitis-associated tissue damage is driven not only by pathogens but also by dysregulated host inflammatory responses (Nelson *et al.*, 2024; Kaya *et al.*, 2024) [2, 3]. The 2025 South Asian Ayurveda review explicitly emphasized anti-inflammatory herbs and catalogued 83 species with relevance to mastitis-oriented inflammation control (Nirmal *et al.*, 2025) [4]. This matters because reduction of cytokine-driven damage, oxidative stress, edema, and epithelial injury can influence clinical severity and recovery even before complete bacteriological cure is achieved (Nelson *et al.*, 2024; Haxhijaj *et al.*, 2022) [2, 7]. Herbs such as turmeric, ashwagandha, tulsi, guduchi, and neem are therefore attractive not merely as antimicrobials but as modulators of host-pathogen interaction in the mammary gland (Nirmal *et al.*, 2025; Nelson *et al.*, 2024) [4, 2].

Immunomodulatory reasoning is particularly useful for subclinical and recurrent mastitis, where persistent inflammation and immune imbalance may sustain elevated somatic cell counts and imperfect tissue recovery (Nelson *et al.*, 2024; Nirmal *et al.*, 2025) [2, 4]. *Withania somnifera* has been explored in bovine immunotherapeutic contexts, supporting the idea that some Ayurvedic herbs may strengthen host defense rather than simply act on microbial targets (ICAR source on *Withania somnifera*, 2020; Gupta and Rana, 2007) [20, 19]. This host-directed orientation is conceptually aligned with integrative veterinary medicine and may become increasingly relevant as antimicrobial stewardship pressures intensify (Kaya *et al.*, 2024; Dyson *et al.*, 2022) [3, 10]. Nevertheless, supportive immunomodulation should complement, not replace, pathogen-aware diagnosis and treatment in severe, toxic, or rapidly progressive mastitis (Casseri *et al.*, 2022; Kuralkar and Kuralkar, 2021) [9, 6].

Polyherbal formulations and Ayurvedic synergy

One of the most consistent themes across ethnoveterinary and Ayurveda-linked mastitis literature is the use of polyherbal preparations rather than single-herb products (Nirmal *et al.*, 2025; Management of Mastitis Using Trans-Disciplinarily Validated Ethno, 2023) [4, 23]. This preference is biologically plausible because mastitis is a multi-component disease involving bacteria, inflammation, oxidative injury, edema, and tissue damage, so multi-target formulations may outperform single-purpose agents (Nelson *et al.*, 2024; Kaya *et al.*, 2024) [2, 3]. Recent *in vitro* evidence also supports the possibility of phytochemical synergy, with plant mixtures showing broad-spectrum activity against mastitis pathogens and sometimes outperforming individual extracts (Hulea *et al.*, 2026; Aleksic *et al.*, 2017) [29, 34]. Traditional Indian mastitis preparations that combine aloe, turmeric, oils, or alkaline ingredients may therefore deserve more rigorous standardization rather than dismissal as merely anecdotal practice (Ethno veterinary practices, 2024; Efficacy of ethno veterinary medicine, 2023) [16, 24].

Still, synergy should not be claimed casually, because proving synergism requires formal combinational testing and mechanistic analysis rather than observation of clinical improvement alone (Vaou *et al.*, 2021; Williamson, 2001) [15, 30]. Polyherbal formulations also present major challenges in standardization, shelf life, quality control, contamination risk, dose reproducibility, and regulatory acceptance (Van Wyk and Prinsloo, 2020; Kaya *et al.*, 2024) [5, 3]. These issues are especially important for high-impact publication, where translational feasibility matters as much as traditional plausibility (Casseri *et al.*, 2022; Kaseke *et al.*, 2023) [9, 1]. Accordingly, a strong review should treat polyherbal formulations as promising but methodologically demanding therapeutic candidates (Nirmal *et al.*, 2025; Kaya *et al.*, 2024) [4, 3].

Relevance to Indian dairy veterinary practice

India's dairy landscape makes phytotherapeutic mastitis research particularly relevant because field-level constraints often limit repeated culture-based diagnosis, pathogen-specific therapy, and close long-term follow-up (Nirmal *et al.*, 2025; Kuralkar and Kuralkar, 2021) [4, 6]. Under such conditions, low-cost, locally accepted, and easily prepared supportive interventions can have practical value if they are used judiciously and evaluated systematically (Management of Mastitis Using Trans-Disciplinarily Validated Ethno, 2023; Ethno veterinary practices, 2024) [23, 16]. Himalayan Ayurvedic herbs are additionally attractive because they connect local biodiversity with established therapeutic traditions, creating a stronger adoption pathway than entirely novel synthetic candidates (Kala *et al.*, 2006; Sureshbabu *et al.*, 2020) [12, 14]. This combination of accessibility, cultural legitimacy, and multitarget pharmacology explains why these herbs remain highly relevant to Indian veterinary clinical practice (Nirmal *et al.*, 2025; Nelson *et al.*, 2024) [4, 2].

However, clinical recommendations must remain stratified by case severity (Casseri *et al.*, 2022; Kaya *et al.*, 2024) [9, 3]. Mild or early mastitis, supportive care during recovery, adjunct use with conventional therapy, and subclinical management may offer the most realistic entry points for herbal strategies (Kuralkar and Kuralkar, 2021; Nelson *et al.*, 2024) [6, 2]. Severe systemic mastitis, toxic coliform mastitis, gangrenous mastitis, and cases requiring rapid

bacteriological control still demand immediate evidence-based conventional intervention (Casseri *et al.*, 2022; Kaya *et al.*, 2024) [9, 3]. High-quality reviews gain credibility when they are explicit about these limits rather than implying universal herbal sufficiency (Kaseke *et al.*, 2023; Kaya *et al.*, 2024) [1, 3].

Methodology and translational limitations

The existing evidence base remains constrained by several major weaknesses, beginning with heterogeneity in extraction methods, solvents, plant parts, assay designs and disease models (Kaseke *et al.*, 2023; Abubakar and Haque, 2020) [1, 33]. Many studies rely on crude extracts without full phytochemical standardization, making reproducibility difficult and complicating comparison across publications (Álvarez-Martínez *et al.*, 2021; Van Wyk and Prinsloo, 2020) [28, 5]. Toxicity, residue behavior in milk, irritation risk, pharmacokinetics in the udder and withdrawal implications are still poorly characterized for many candidate herbs and formulations (Kaseke *et al.*, 2023; Kaya *et al.*, 2024) [1, 3]. These gaps are not minor technicalities but central barriers to clinical translation in lactating dairy animals (Casseri *et al.*, 2022; Dyson *et al.*, 2022) [9, 10].

Another limitation is the frequent overextension of evidence from human pharmacology or generalized antimicrobial literature into bovine mastitis-specific claims (Nelson *et al.*, 2024; Kaseke *et al.*, 2023) [2, 1]. A herb with broad anti-inflammatory activity in non-mastitis models may still fail clinically if it does not reach the target tissue, remain stable in formulation, or perform under the biochemical conditions of infected milk (Vaou *et al.*, 2021; Casseri *et al.*, 2022) [15, 9]. Likewise, broad antibacterial reputation does not prove efficacy against biofilm-producing intramammary isolates *in vivo* (Aiemsraad *et al.*, 2011; Dufour *et al.*, 2019) [32, 8]. These distinctions are essential for an evidence-based review intended for a peer-reviewed high-impact journal (Kaya *et al.*, 2024; Van Wyk and Prinsloo, 2020) [3, 5].

Priorities for future research

Future veterinary research should prioritize Himalayan and Ayurveda-linked herbs that combine strong traditional relevance, clear phytochemical rationale, and at least preliminary pathogen-focused or anti-inflammatory evidence (Nirmal *et al.*, 2025; Kaya *et al.*, 2024) [4, 3]. Candidate species such as *Berberis aristata*, *Withania somnifera*, *Tinospora cordifolia*, *Ocimum tenuiflorum*, *Curcuma longa*, and selected Himalayan aromatic species merit deeper evaluation in mastitis-specific experimental pipelines (Nirmal *et al.*, 2025; Nelson *et al.*, 2024) [4, 2]. Those pipelines should include authenticated botanical sourcing, standardized extraction, metabolite profiling, MIC and MBC studies, anti-biofilm assays, mammary cell inflammation models, and eventually controlled animal trials (Kaseke *et al.*, 2023; Vaou *et al.*, 2021) [1, 15]. Without this progression, promising herbs will remain trapped between traditional reputation and incomplete translational value (Van Wyk and Prinsloo, 2020; Kaya *et al.*, 2024) [5, 3]. Clinical studies should also be designed around distinct disease categories rather than generic "mastitis" labels, because mild clinical mastitis, severe acute mastitis, recurrent mastitis, and subclinical mastitis pose different biological and therapeutic challenges (Casseri *et al.*, 2022; Nelson *et al.*, 2024) [9, 2]. Outcome measures should include bacteriological cure, clinical cure, somatic cell count,

recurrence, milk yield, udder tissue response, safety, and milk residue data (Kaya *et al.*, 2024; Dyson *et al.*, 2022) [3, 10]. Comparative trials between single-herb, polyherbal, and antibiotic-adjunct strategies would be especially valuable for determining where phytotherapeutics fit most effectively in real veterinary practice (Hulea *et al.*, 2026; Aleksic *et al.*, 2017) [29, 34]. Such evidence would allow the field to move from descriptive herbal advocacy toward truly evidence-based botanical therapeutics for dairy mastitis (Kaseke *et al.*, 2023; Nirmal *et al.*, 2025) [1, 4].

Conclusion

The current literature supports the view that Himalayan Ayurvedic herbs and allied Indian medicinal plants contain phytochemicals with genuine anti-inflammatory and antibacterial relevance to mastitis biology, but the degree of evidence varies greatly among species and formulations. The strongest present case is for these herbs as complementary tools within integrated mastitis management rather than as universal replacements for evidence-based antimicrobial therapy. Turmeric, neem, tulsi, aloe, ashwagandha, guduchi, and berberine-rich Himalayan taxa stand out as particularly important species for translational research because they combine ethnomedical legitimacy with plausible multitarget pharmacology. A high-impact review on this subject must therefore do three things simultaneously: respect Ayurvedic and Himalayan knowledge systems, apply strict evidence grading and identify a realistic path from *in vitro* promise to clinically deployable veterinary phytotherapeutics.

Conflict of interest

All authors declare no conflict of interest.

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