ANTI-INFLAMMATORY AND ANTIMICROBIAL EFFECTS OF LAVENDER OIL IN THE MANAGEMENT OF ORAL DISEASES

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Abstract

Lavender essential oil (Lavandula angustifolia) has gained growing interest in oral medicine due to its dual antimicrobial and anti-inflammatory mechanisms, which extend beyond the conventional scope of topical antiseptics. Its primary constituents, linalool and linalyl acetate, exert synergistic effects on microbial membrane integrity, biofilm adhesion, and inflammatory signaling, providing both pathogen suppression and modulation of the mucosal microenvironment. Evidence demonstrates clinical utility in the treatment of denture stomatitis, mucositis, peri-implant mucosal inflammation, and postoperative wound repair, especially when delivered through modern pharmaceutical systems, such as mucoadhesive hydrogels, chitosan scaffolds, or nanohydroxyapatite composites. These biomaterial-based formulations enhance mucosal retention, increase local bioavailability, and maintain sustained therapeutic concentrations. In addition, lavender's neuro-modulatory properties contribute to stress reduction and improved treatment tolerance, indirectly supporting mucosal healing in psychoneuroimmunologically mediated lesions. Its excellent safety profile and compatibility with regenerative dentistry principles position lavender as a bioadaptive therapeutic rather than a passive botanical extract. Together, the existing evidence suggests that lavender essential oil represents a promising adjunctive strategy in managing inflammatory and biofilm-associated oral pathologies, supporting a shift toward minimally invasive and integrative oral care.

Keywords: lavender essential oil, antimicrobial therapy, mucosal inflammation, biofilm modulation, oral wound healing, phytotherapeutics.

Introduction

Lavender essential oil (Lavandula angustifolia) has recently gained significant attention as a multifunctional phytotherapeutic agent in oral medicine due to its dual antimicrobial and anti-inflammatory profile. Its growing relevance in dentistry is supported by both in vitro and in vivo evidence demonstrating activity against key oral pathogens and the modulation of inflammatory pathways that contribute to mucosal breakdown and chronic infection. More critically, unlike conventional antimicrobials, lavender oil also exerts anti-adherence effects on prosthetic surfaces, a clinically important mechanism in reducing biofilm persistence on denture bases and other acrylic devices commonly colonized by oral pathogens [1].

The therapeutic potential of lavender oil extends beyond simple surface decontamination. When incorporated into polymeric biomaterials, particularly chitosan-based scaffolds, lavender oil enhances both their antimicrobial efficacy and their physicochemical behavior, suggesting an emerging role in muco-adhesive dressings and regenerative interfaces for inflamed or ulcerated oral mucosa [2]. These biomaterial-based formulations offer prolonged retention time within the oral cavity and enable sustained antimicrobial exposure, which is essential

DOI : 10.62610/RJOR.2025.3.17.23

in recurrent inflammatory disease of prosthetic or mucosal origin.

Recent systematic appraisals of essential oils within the context of the oral microbiome have emphasized lavender as a promising adjuvant capable of reducing pathogenic burden without excessively disrupting microbial homeostasis [3]. This ecological approach is of increasing interest given the limitations of conventional antiseptics, which either exhibit cytotoxicity at higher therapeutic thresholds or trigger microbial dysbiosia with consequent inflammatory relapse.

The transition from traditional phytotherapy to pharmaceutical-grade formulations has also stimulated the development of oromucosal delivery systems incorporating plant-derived actives, including lavender essential oil, which are designed to target infectious and inflammatory lesions of the oral cavity [4]. These innovative dosage forms allow localized delivery with optimized retention and bioavailability while minimizing systemic exposure.

Nanostructured biomaterials based on hydroxyapatite doped with lavender essential oil have further expanded their translational value by combining antimicrobial action with remineralizing and surface-protective effects [5]. Such hybrid constructs may prove clinically meaningful in peri-implant mucositis and early contaminative stages of peri-implant disease, where microbial biofilm and mucosal inflammation coexist and potentiate each other.

Beyond oral applications specifically, the broader wound-healing literature supports lavender's regenerative potential through synergistic antimicrobial and anti-inflammatory mechanisms, which reinforces its suitability for mucosal repair and post-inflammatory resolution in oral tissues [6]. These outcomes also align with the clinical need for topically active alternatives that can restore epithelial integrity while suppressing colonization.

An additional therapeutic advantage is the synergistic enhancement of conventional antimicrobial efficacy when lavender is co-administered with standard agents [7]. This combination strategy is clinically relevant in managing colonization by opportunistic or partially resistant pathogens frequently encountered in the oral environment, especially in denture wearers and immunologically fragile patients.

Lavender has also demonstrated indirect but clinically valuable psychophysiological benefits through anxiolytic properties relevant to dental care settings, especially in pediatric and anxious adults, where psychological distress amplifies pain perception and inflammatory stress responses [8]. While anxiolysis is not itself anti-inflammatory, it may contribute to favorable treatment compliance and improved overall mucosal healing.

At the cellular level, its anti-inflammatory activity has been mechanistically linked to the downregulation of key pro-inflammatory mediators produced by macrophages and immunoreactive epithelial cells, supporting its relevance in inflammatory oral pathologies where innate immune dysregulation plays a central role [9]. This molecular attenuation of cytokine signaling complements its antimicrobial spectrum, providing a dual-action therapeutic profile.

Moreover, preclinical research supports not only its anti-inflammatory properties but also its analgesic and antioxidant effects, which together enhance local pain control and reduce oxidative tissue stress, thus optimizing the inflammatory microenvironment and facilitating mucosal restitution [11].

Taken together, the available evidence positions lavender essential oil as a promising adjunctive therapeutic agent in the management of oral infectious–inflammatory conditions. Its ability to reduce microbial adhesion, modulate inflammatory mediators, enhance

DOI : 10.62610/RJOR.2025.3.17.23

biomaterial bioactivity, and indirectly improve patient tolerance defines a multifaceted pharmacological profile with strong translational relevance for dentistry. This scientific foundation supports a deeper exploration of its chemical composition, mechanistic pathways, and formulation strategies, which will be discussed in the subsequent sections of this review.

Chemical composition

Lavender essential oil consists primarily of monoterpenes and monoterpenoid esters, among which linalool and linalyl acetate account for the majority of its pharmacological activity. The quantitative ratio between these two constituents is critical to its biological profile, with higher linalyl acetate concentrations correlating with enhanced anti-inflammatory potency, while linalool exerts stronger antimicrobial and neuro-modulatory effects [12]. This duality explains the pleiotropic actions of lavender oil observed in oral applications and supports its relevance as both a direct antimicrobial and an indirect regulator of inflammatory cascades.

Image 1. Linalool as a bioactive component of lavender essential oil in oral inflammation

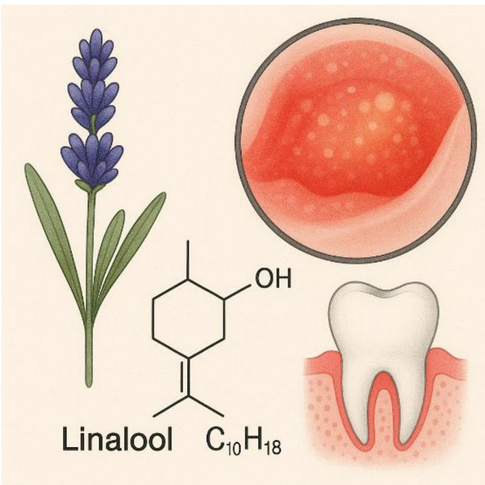

Image 1. Linalool, the main monoterpene of lavender essential oil, contributes to oral mucosal protection through its anti-inflammatory and antimicrobial activity. By modulating cytokine expression and disrupting microbial adhesion, it supports epithelial healing and reduces inflammatory burden in oral lesions.

Beyond the two major constituents, minor but functionally relevant components such as borneol, terpinen-4-ol, lavandulol, and lavandulyl acetate contribute synergistically to membrane destabilization in microbial cells and modulation of cellular oxidative balance [13]. These secondary compounds enhance the permeability of microbial membranes and facilitate the intracellular penetration of the active monoterpenes, amplifying antimicrobial efficacy without requiring high concentrations that might compromise mucosal tolerance.

Chemical profiling studies further indicate that the phenophase of lavender harvesting significantly influences its bioactive composition. Essential oil extracted during the flowering phase is richer in oxygenated monoterpenes, particularly linalool derivatives, which have demonstrated more pronounced immunomodulatory effects on inflammatory macrophage signaling [14]. This compositional variability has meaningful implications for pharmaceutical standardization, particularly for oral topical delivery systems intended to achieve reproducible therapeutic outcomes.

The antioxidant properties of lavender essential oil are also chemically driven by the same terpene derivatives, which act as direct free radical scavengers and modulators of redox-sensitive inflammatory pathways [15]. These molecular properties contribute to mucosal protection by limiting oxidative tissue injury, a frequent co-factor in oral inflammatory disease.

Several studies have evaluated lavender as part of combination formulations, where its chemical constituents potentiate other plant

DOI : 10.62610/RJOR.2025.3.17.23

compounds or pharmaceutical actives. In the context of oral pathology, co-formulation with other antioxidants or antimicrobial scaffolds has improved both tissue bioavailability and retention in inflammatory microenvironments. This synergy is not merely additive but biochemical, as linalool increases membrane fluidity and allows greater intracellular transport of accompanying anti-infective molecules [16].

Differences in extraction method and thermal handling further alter the proportion of volatile esters and free terpenes, which can shift clinical efficacy. Cold-extraction yields maximize ester preservation, associated with anti-inflammatory action, whereas steam distillation increases free linalool concentration and favors antimicrobial outcomes [17]. The specific extraction conditions, therefore, serve as a strategic lever for therapeutic targeting, depending on whether the intended primary indication is microbial suppression or inflammation control.

The chemical versatility of lavender oil explains its adaptability to different pharmaceutical platforms used in oral medicine, including hydrogels, mucoadhesive sponges, and nanoparticulate carriers. When contextualized with prior findings regarding its antimicrobial adhesion-blocking effect and biomaterial integration, the compositional profile of lavender emerges not as a simple mixture of terpenes but as a structurally coherent set of molecules operating through interdependent biochemical mechanisms [1–5].

Table 1. Major and minor constituents of lavender essential oil and their oral therapeutic relevance

Chemical constituent	**Class**	**Primary pharmacological role**	**Mechanism of relevance in oral applications**	**References**
Linalool	Monoterpene alcohol	Antimicrobial, neuro-modulatory	Disrupts microbial membrane integrity, enhances permeability, and contributes to anxiolytic effect.	[12][13][17]
Linalyl acetate	Monoterpenoid ester	Anti-inflammatory	Downregulates pro-inflammatory cytokines, enhances mucosal tolerance	[12][14]
Borneol	Monoterpene alcohol	Synergistic antimicrobial	Increases membrane fluidity and improves penetration of active terpenes	[13]
Terpinen-4-ol	Monoterpene alcohol	Redox-modulation	Antioxidant protection and stabilization of the epithelial barrier under oxidative stress	[13][15]
Lavandulol	Oxygenated monoterpene	Mucosal restoration support	Contributes to epithelial repair and membrane stabilization	[13]
Lavandulyl acetate	Monoterpenoid ester	Co-adjuvant anti-inflammatory	Enhances linalyl acetate activity in cytokine suppression	[13][14]
Total oxygenated monoterpenes	Complex terpene fraction	Immunomodulation	Higher levels during the flowering phenophase improve anti-inflammatory signaling in macrophages.	[14][15]
Volatile ratio (linalool: linalyl acetate)	Functional chemical balance	Defines therapeutic direction	Higher linalyl acetate → anti-inflammatory dominance; higher linalool → antimicrobial emphasis	[12][17]

DOI : 10.62610/RJOR.2025.3.17.23

Table 1 summarizes the principal bioactive constituents of lavender essential oil and their mechanisms of action relevant to oral applications, illustrating how compositional variability determines therapeutic orientation between antimicrobial and anti-inflammatory pathways across contemporary delivery systems.

Anti-inflammatory mechanisms

Lavender essential oil exhibits multiple anti-inflammatory mechanisms relevant to oral mucosal pathology, operating through both nociceptive modulation and downregulation of innate immune mediators. Experimental models investigating its topical analgesic action before dental anesthesia have demonstrated a significant reduction in pain perception, attributed to transient receptor potential (TRP) channel desensitization and interference with peripheral nociceptor signaling [18]. This peripheral neuromodulation indirectly attenuates inflammatory amplification driven by nociceptive feedback.

In addition to its analgesic effects, lavender mediates cytokine suppression through macrophage and epithelial cell signaling pathways, decreasing IL-6, TNF-α, and COX-2 expression, which collectively reduces leukocyte recruitment and oxidative burden within inflamed tissues [19]. Such modulation is essential in conditions like recurrent mucosal irritation, prosthetic trauma, or inflammatory peri-implant disease, where persistent innate immune activation drives tissue degradation.

Lavender also exerts anxiolytic regulation of the hypothalamic pituitary adrenal axis, which produces secondary anti-inflammatory effects by reducing salivary cortisol levels, thereby attenuating stress-driven inflammatory exacerbation in the oral cavity [20]. This psychoneuroimmunological pathway is clinically relevant in patients with heightened inflammatory reactivity or treatment-related anxiety.

Table 2. Mechanisms underlying the anti-inflammatory action of lavender essential oil in oral pathology

Mechanistic domain	**Primary target**	**Biological effect**	**Clinical relevance**	**References**
Peripheral neurosensory modulation	TRP ion channels	Reduced nociceptive signalling and local hyperalgesia	Diminished pain-driven inflammatory amplification	[18]
Cytokine pathway regulation	Macrophages / epithelial cells	Downregulation of IL-6, TNF-α, COX-2	Lower leukocyte recruitment and tissue burden	[19]
Neuroendocrine axis modulation	HPA axis	Reduced cortisol-associated inflammatory stress	Psychoneuroimmunological stabilization of the mucosa	[20]
Systemic inflammatory tone modulation	Sleep / autonomic balance	Improved tissue recovery and healing	Enhanced epithelial restitution	[21]
Host-microenvironment stabilization	Mucosal barrier regulation	Synergistic antimicrobial + anti-inflammatory effect	Sustained mucosal protection	[22]

DOI : 10.62610/RJOR.2025.3.17.23

Table 2 synthesizes the principal biological pathways through which lavender essential oil modulates inflammatory responses in the oral mucosa, demonstrating its dual biochemical and neurosensory activity and clarifying how these mechanisms translate into clinically relevant therapeutic outcomes.

Randomized trials have further shown beneficial regulatory effects on systemic inflammatory tone and sleep-associated recovery processes, indirectly supporting mucosal regeneration and epithelial restabilization [21]. When integrated into dental care as adjunctive therapy, these mechanisms complement its previously demonstrated antimicrobial and membrane-stabilizing properties [1–5].

Overall, lavender's anti-inflammatory action is both biochemical (cytokine suppression, oxidative modulation) and neurosensory (analgesic and anxiolytic), defining a multifactorial therapeutic profile that addresses not only microbial burden but also the inflammatory microenvironment sustaining mucosal pathology [22].

Antimicrobial activity

The antimicrobial efficacy of lavender essential oil derives from multiple complementary mechanisms that disrupt microbial viability, colonization, and persistence rather than relying on a single bactericidal pathway. The primary mode of action involves alteration of membrane permeability, mediated predominantly by linalool's lipophilic insertion into phospholipid bilayers, which induces leakage of intracellular contents and destabilization of cell wall integrity [1]. This membrane-disruptive effect is particularly relevant in oral pathogens that form dense biofilms.

A second major antimicrobial mechanism is interference with microbial adhesion and early biofilm maturation. Lavender oil has demonstrated a significant anti-adherence effect on denture base resin, reducing colonization density and biofilm resilience under conditions that replicate intraoral surfaces [1]. By impairing the initial stages of surface attachment, lavender functionally reduces virulence potential even before direct microbial killing occurs.

When incorporated into biomaterial carriers such as chitosan matrices, lavender oil shows amplified antimicrobial effects due to prolonged mucosal contact time and sustained release kinetics [2]. This embedded delivery improves efficacy against biofilm-forming organisms by maintaining inhibitory concentrations at the host–surface interface.

Additionally, lavender exerts synergistic antimicrobial enhancement when combined with conventional agents, decreasing the minimum inhibitory concentration of standard antiseptics and antifungals [7]. Such synergy is particularly important in dentistry, where resistance patterns and biofilm tolerance reduce monotherapy responsiveness.

At a microenvironmental level, suppression of inflammation indirectly supports antimicrobial efficiency by diminishing exudative substrates that fuel microbial persistence [9]. This interaction illustrates that lavender's antimicrobial profile is not isolated from its immunomodulatory activity but instead functions as part of a broader bioactive network.

These converging mechanisms, membrane destabilization, anti-adhesion, synergy with carriers, and immunologic modulation position lavender essential oil as a multifunctional antimicrobial adjuvant in oral therapeutics. Its capacity to influence both microbial viability and pathogenic behavior distinguishes it from standard antiseptics and supports ongoing integration into oral biomaterials and topical formulations [3-6].

DOI : 10.62610/RJOR.2025.3.17.23

Clinical applications in oral pathology

Lavender essential oil has progressively emerged as a clinically relevant adjuvant in the management of oral inflammatory and infectious conditions due to its simultaneous antimicrobial, anti-inflammatory, reparative, and neuromodulatory properties. Its value in clinical dentistry lies not merely in microbial suppression but rather in its capacity to alter the pathological microenvironment that sustains mucosal injury, dysbiosis, prosthetic intolerance, and recurrent inflammation. Unlike traditional antiseptics, whose activity is largely unidirectional and frequently cytotoxic at higher concentrations, lavender demonstrates a multimodal mechanism that confers broader therapeutic reach with improved tissue compatibility and patient tolerance.

In the context of mucositis and trauma-induced oral inflammation, lavender contributes to epithelial restitution by modulating inflammatory signaling cascades and providing analgesic benefit through peripheral neurosensory modulation [18]. These effects are particularly useful in patients presenting with early-stage mucosal breakdown, frictional lesions from ill-adapted prostheses, or parafunctional microtrauma. Oromucosal sprays containing lavender facilitate direct mucosal deposition, allowing a rapid onset of action while bypassing systemic exposure that might otherwise limit tolerability [4]. The reduction in cytokine burden not only inhibits lesion progression but also creates a more favorable environment for epithelial regeneration.

A central area of clinical relevance is denture stomatitis, a condition in which microbial colonization and inflammatory damage are tightly coupled. Lavender interferes with biofilm initiation by limiting adhesion of Candida species to polymethylmethacrylate surfaces [1], an essential step in disrupting chronic recolonization cycles that typically follow conventional hygiene measures. When combined with chitosan-based matrices, its therapeutic impact is amplified by sustained release, prolonged mucosal contact, and improved carrier biocompatibility [2], which together support a more stable, inflammation-resistant mucosal surface. This contrasts with routine antifungal rinses that achieve transient microbial reduction without correcting biofilm adhesion kinetics.

In peri-implant mucositis, lavender's role extends beyond microbiological suppression into preservation of peri-implant soft tissue integrity. Formulations incorporating lavender into nanostructured hydroxyapatite have demonstrated dual benefits, impeding early-stage microbial biofilm development while promoting cellular compatibility at the peri-implant interface [5]. This combined approach is valuable because peri-implant inflammation is not merely a function of microbial excess, but reflects a dysregulated immune response at the biomaterial-tissue junction. By stabilizing both the microbial and inflammatory dimensions of the lesion, lavender reduces the likelihood of progression toward peri-implantitis.

Postoperative wound healing is another domain in which lavender has translational benefit. Its antioxidant and angiogenesis-supportive actions modulate the tissue microenvironment after injury, accelerating re-epithelialization and lowering oxidative stress that otherwise impairs granulation and mucosal maturation [6]. In this respect, lavender-containing hydrogels or films may represent gentle yet effective alternatives to conventional anti-inflammatory pharmaceuticals, especially in patients at risk of delayed wound healing or steroid-induced mucosal atrophy.

Lavender's clinical utility also extends to recurrent aphthous lesions and stress-mediated mucosal disorders.

DOI : 10.62610/RJOR.2025.3.17.23

Although such lesions are not primarily infectious, they are perpetuated by pro-inflammatory cytokine cascades and a disturbed oxidative balance, both of which are attenuated by lavender's immunomodulatory properties [19]. Moreover, its anxiolytic effects confer a secondary layer of therapeutic relevance, as psychological stress is a known amplifier of mucosal inflammation and epithelial vulnerability [20]. Through modulation of the hypothalamic–pituitary–adrenal axis, lavender helps stabilize neuro-immunological reactivity, indirectly improving mucosal resilience and reducing recurrence frequency.

The broader implication of these findings is that lavender does not act as a simple topical antiseptic, but as a bioadaptive therapeutic agent capable of restructuring the pathological context in which inflammation and microbial persistence interact. It strengthens mucosal defense while discouraging colonization, creating conditions for restoration rather than suppression alone. Its favorable safety profile also encourages repeated or prolonged use, which is critical in chronic oral conditions where maintenance therapy defines long-term outcomes.

Table 3. Clinical applications of lavender essential oil in oral pathology

Clinical indication	*Therapeutic target*	*Formulation used*	*Mechanistic outcome*	*References*
Mucositis / traumatic lesions	Inflammation + pain mediation	Oromucosal spray	Reduces cytokine signaling and neurosensory drive	[4][18]
Denture stomatitis	Candida adhesion/ biofilm	Chitosan-based mucoadhesive	Anti-adherence and prolonged antimicrobial exposure	[1][2]
Peri-implant mucositis	Biofilm initiation at the implant interface	Lavender-enriched nanohydroxyapatite	Dual antimicrobial + soft tissue stabilization	[5]
Postoperative wound healing	Oxidative stress + epithelial delay	Hydrogels/biofilm dressings	Enhanced re-epithelialization and angiogenesis	[6]
Recurrent aphthous / stress-related lesions	Neuroimmune dysregulation	Topical + aromatherapy	Cytokine reduction and HPA-axis modulation	[19][20]

Table 3 summarizes the most relevant oral pathologies in which lavender essential oil demonstrates therapeutic activity, linking clinical indication with delivery system and mechanistic rationale to highlight its role as a multimodal and bioadaptive adjuvant therapeutic.

Modern pharmaceutical formulations

The translation of lavender essential oil into clinical oral therapeutics has been significantly enhanced by advances in pharmaceutical delivery systems designed to overcome volatility, rapid clearance, and limited mucosal residence time. Contemporary formulations aim not only to preserve the integrity of its bioactive constituents but also to ensure prolonged contact with inflamed or colonized oral surfaces, which is essential for meaningful therapeutic impact. Oromucosal sprays represent one of the most clinically

DOI : 10.62610/RJOR.2025.3.17.23

accessible systems, allowing uniform deposition across large mucosal areas with rapid onset of anti-inflammatory and analgesic action, particularly in mucositis and trauma-associated lesions where broad field coverage is advantageous [4]. However, sprays alone provide transient exposure, which has stimulated the development of slow-release carriers.

Mucoadhesive biomaterials such as chitosan sponges integrate lavender oil into a polymeric framework capable of adhering to mucosal tissue, gradually releasing active compounds while simultaneously supporting surface regeneration. These scaffolds demonstrate dual benefit, antimicrobial protection and biomechanical stabilization of the healing interface, making them suitable for prosthetic trauma, denture stomatitis, and postoperative soft-tissue management [2]. In parallel, nanohydroxyapatite delivery systems have emerged as a strategic approach for peri-implant soft-tissue stabilization, exploiting the biomimetic affinity of hydroxyapatite for oral mucosa while incorporating lavender to prevent early biofilm formation [5]. This synergy extends the role of lavender from a topical antiseptic into a surface-protective co-adjuvant in implant maintenance.

However, the clinical use of lavender essential oil remains limited by compositional variability related to botanical origin and extraction process, the lack of consistent pharmacological standardization, and occasional allergic reactions, factors that warrant caution and call for further safety and efficacy studies.

Conclusions

Lavender essential oil represents a clinically relevant adjunct in the management of oral diseases due to its unique combination of antimicrobial, anti-inflammatory, antioxidant, and neuromodulatory properties. Unlike conventional antiseptics that act through a single cytotoxic mechanism, lavender exerts a bioadaptive influence on the oral microenvironment, reducing microbial adhesion, modulating cytokine expression, and supporting epithelial regeneration. Modern pharmaceutical systems such as sprays, hydrogels, mucoadhesive scaffolds, and nanostructured biomaterials have expanded their therapeutic applicability by prolonging contact time and enhancing tissue compatibility. These advances position lavender not as a complementary product of purely botanical interest, but as a bioactive therapeutic compound with translational potential in peri-implant care, mucositis management, denture stomatitis, and stress-related mucosal lesions. Its dual action on host tissue and pathogen biology supports a precision-based approach to oral inflammation, aligning with minimally invasive and regenerative strategies in contemporary dentistry. Lavender essential oil therapy shows particular clinical relevance in the management of oral mucositis, gingivitis, and aphthous stomatitis, where its anti-inflammatory and antimicrobial effects are best supported by scientific evidence, especially in the form of sprays, gels, and bioactive nanocomposites. Lavender thus holds significant promise as a future component of integrative oral therapeutics.

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DOI : 10.62610/RJOR.2025.3.17.23