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Review Paper

Essential Oil-Loaded Microemulsion and Microemulgel Systems: Enhancing Antimicrobial Activity and Skin Delivery Using Lemongrass and Tulsi

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ABSTRACT

One big problem worldwide involves infections of the skin and deeper tissues caused by microbes - these hit hard in people with weak immune defenses, kids, older adults, or those managing long-term illnesses like diabetes. A growing number of resistant strains are making standard treatments, whether applied on the surface or taken internally, less reliable than before - this pushes science toward different ways to deliver medication effectively. Lately, plant extracts such as lemongrass (*Cymbopogon citratus*) and holy basil (*Ocimum sanctum*) caught interest - not because they're trendy, but because they fight many types of microbes through several pathways at once while coming from nature. Yet putting them into real-world treatment isn't straightforward; issues arise when trying to mix them with water, keep them stable over time, prevent evaporation, or avoid irritating the skin. To tackle that, researchers turned to tiny droplet carriers called microemulsions - and even thicker versions known as microemulgels - which may help carry these fragile substances where they're needed without losing potency. Tiny droplets help carry essential oils more effectively - improving how much dissolves, stays stable, and gets through the skin. By using surfactants, these carriers open pathways without harsh methods. Turning liquid forms into gels adjusts thickness, keeps the dose on the skin longer, slows release, and feels better during use. What's been studied includes how they're made, tested, checked for germ-fighting power, tracked across skin layers, and monitored over time. Data shows gel versions outperform older types, working stronger against microbes while staying gentle. They also protect active ingredients from breaking down early. Staying put on the surface means less frequent application, fewer side effects. Because delivery is steady, there's lower risk of resistance building up. Skin reactions tend to be milder than with raw oils or standard creams. People are

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more likely to stick with treatments that feel comfortable. These findings point toward one thing: plant-powered topicals can do more when designed precisely. Not every detail is settled yet. Research still needs real-world trials before wider use takes hold. Still, the direction looks viable - for now, it's about refining what already works.

INTRODUCTION

Global impact of microbial skin infections

Microbial skin infections remain a major global health challenge, particularly due to increasing antimicrobial resistance and limited effectiveness of conventional topical therapies. Across the world, infections tied to microbes on skin and deeper tissues pop up frequently - no matter if nations are rich or still growing. Bacteria, fungi, or sometimes both together cause issues ranging from impetigo and inflamed hair follicles to serious wound complications, burn-related cases, and foot sores in people with diabetes. Fungal types also play their part, showing up as surface rashes or more entrenched yeast-based illnesses. Kids, older adults, those managing blood sugar disorders, and anyone with a weakened defense system face higher odds of catching these. More frequent

illness follows - and daily living often takes a hit because of it ^[1]. Frequent on the skin, microbes don't just show up - they stick around, coming back even after seeming gone. When treatments fall short or aren't followed closely, bugs find ways to survive, helped along by clumsy medicine use. Sometimes beginning as minor irritations, these spots open doors wider, letting infections dive deeper into the body. Because of this drift from surface to system, handling them well isn't optional - it shapes outcomes far beyond the initial rash or sore ^[1,4]. What's happening with germs these days makes healing skin issues tougher than before. Bacteria like *Staphylococcus aureus*, along with certain strains of *E. coli* and various *Candida* types, are adapting in ways that dodge medicine's reach - breaking drugs down through enzymes or pumping them out using specialized channels. Changes in their internal targets also play a role; so does wrapping themselves in protective layers known as biofilms. As a result, standard treatments often don't work nearly as well as they once did. Recovery takes longer because of it. Medical care becomes more expensive, while unsuccessful outcomes happen more frequently ^[2,3].

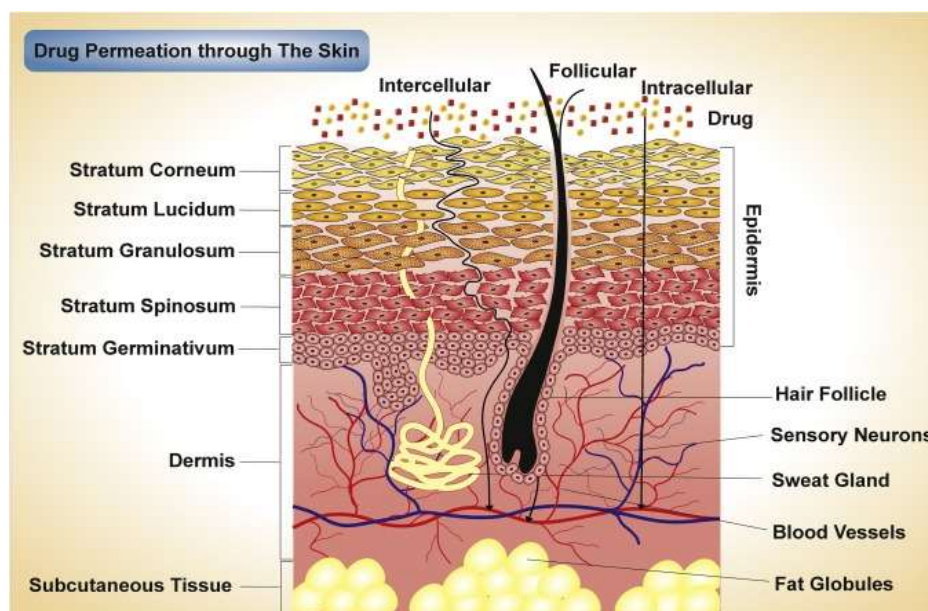


Figure 1. Skin Penetration Pathway of Microemulgel System ^[71]

1.2. Importance of Topical Drug Delivery Systems

Putting medicine right where it's needed - on the skin - can be more effective than taking pills or injections. Direct application means stronger doses at the infected spot without flooding the whole body. That often leads to fewer side effects elsewhere. Since the treatment stays mostly on the surface, the liver doesn't break it down before it works. Bypassing that step helps maintain potency exactly where required. For skin issues caused by microbes, this method fits well with how treatments should act locally ^[4,5]. One key advantage of applying medication directly to the skin lies in how consistently patients stick with treatment. These kinds of medicines usually go on without discomfort, require little effort, or cause irritation - making them practical for ongoing use. For conditions like recurring or persistent skin issues, that ease matters even more, since therapy can stretch over months or years. What also helps is the ability to tweak how these products look and feel; smoother textures or less noticeable residues tend to encourage people to keep using them ^[5,11]. Even with clear benefits, getting drugs through the skin runs into trouble because of its built-in defenses. Sitting at the surface, the stratum corneum blocks most invaders - its tightly arranged cells surrounded by fatty layers make passage tough. Because of this shield, plenty of medicines struggle to get through, especially those that are large or repel water. As a result, not enough active compound reaches below-the-surface targets, weakening treatment effects ^[6,7]

1.3. Limitations of Conventional Topical Formulations.

Most standard skin treatments - like creams, ointments, lotions, or pastes - are common in medicine, yet don't always work well. Greasiness tends to stick around with ointments and creams,

making them unpleasant cosmetically, so people use them less often than needed. Even though lotions feel lighter, they flow too easily and won't stay put on the skin. Because they slide off fast, the treatment doesn't last long enough for steady results ^[8-10]. Few patients find traditional topical treatments easy to use, partly because these systems struggle to dissolve substances that don't mix well with water. Since many antimicrobials and plant-derived components - like essential oils - have low solubility in water, blending them into water-driven products becomes tricky. Without proper integration, active ingredients end up sparsely packed, inconsistently spread, or released irregularly ^[9,10]. Facing frequent instability, traditional preparations often end up separating into phases or breaking down - active components lose potency over time on the shelf. Such drawbacks point toward a quiet necessity: smarter ways to deliver drugs through the skin. Systems stepping beyond old limits could boost how well medicines dissolve, hold steady longer without degrading, stick around in skin tissue, while releasing medication at a measured pace ^[10,11]

1.4. Essential Oils as Natural Antimicrobial Agents

From plant bits like petals, peels, or roots, tiny fragrant fluids emerge - known as essential oils. These liquids carry shifting blends of natural compounds: some built on alcohol backbones, others rich in ketones, phenols, or terpene chains. Centuries ago, healers reached for them when dealing with sore skin, swelling, or stubborn bugs invading the body ^[12,13]. Essential oils aren't new, but science has taken a closer look at them lately - mostly because they can tackle bacteria, fungi, and even viruses in varied ways. Coming straight from plants, these compounds break down naturally over time, which adds to their appeal compared to lab-made options. What stands out is how they



don't rely on just one pathway to work; instead, they interact with multiple biological targets. This complexity might explain why researchers see potential in using them alongside conventional treatments. With drug-resistant microbes becoming more common, such plant-based solutions enter the conversation - not as replacements, but as possible support tools [13,14]. What makes essential oils act against microbes? Mainly how they work on the outer layer of microbial cells. Because these oil parts mix well with fats, they slip into the cell's fatty barrier. This intrusion shakes up the membrane's stability - making it leaky. Once compromised, internal materials seep out. That often ends in cellular collapse. Beyond physical disruption, some compounds mess with proteins that drive chemical reactions inside the cell. They may throw off energy production or disturb how charged particles move across membranes [15]. Fewer chances of microbes adapting emerge because essential oils hit multiple targets at once - unlike standard antibiotics that focus on just one path. These natural extracts don't only disturb cell membranes; they also interfere with bacterial

communication and slimy layer buildup, processes tied closely to how harmful or stubborn certain strains become [14,15]. Fragile stability and low water compatibility make essential oils tricky to use in medicine - even though they can fight microbes well. Evaporating fast isn't helpful; neither is their tendency to break down when exposed to air. Strong scents turn some people off, while concentrated forms may irritate skin. Without steady delivery systems, benefits fade quickly using standard methods [12,16]. Solving these issues isn't possible without proper delivery methods - ones that hold essential oils steady while easing them through the skin with less chance of discomfort. Instead of spreading uncontrollably or breaking down fast, they need guidance; stability matters just as much as timing. Lately, tiny transport units like microemulsions and gel-like variants have stepped into focus, quietly proving useful where older forms failed. Their small scale seems to help, letting ingredients move deeper without abrupt reactions. Researchers now see them as practical routes forward - not perfect, yet working better than many expected.

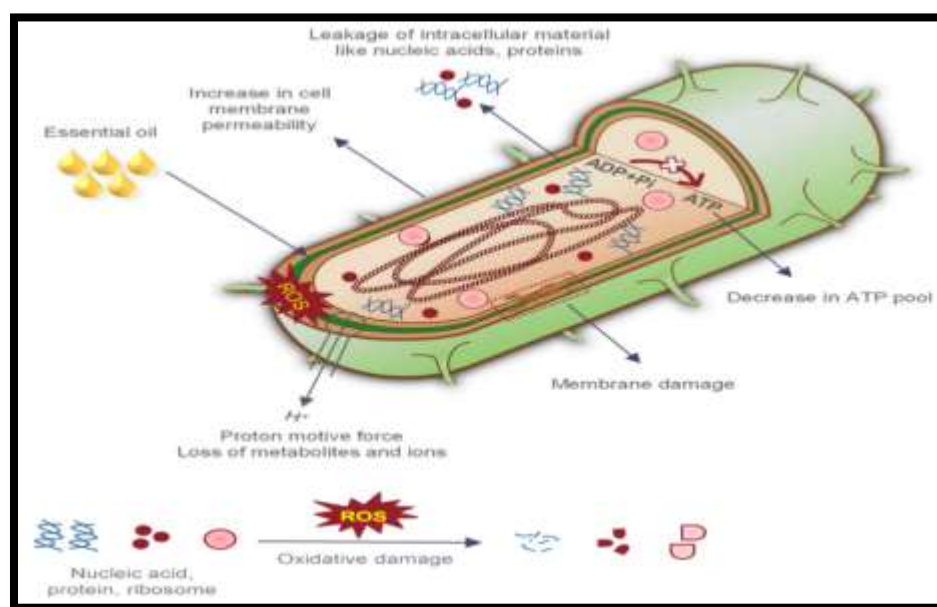


Figure 2. Mechanism of Antimicrobial Action of Essential Oil-Loaded Microemulsions [71]

1.5. Microemulsions as Advanced Drug Delivery Systems.

5.1 Microemulsions what they are and how they come together

Far from needing intense energy, these clear mixtures come together on their own - oil, water, a surfactant, sometimes an extra helper molecule - all held in balance by physics rather than force. Stability here isn't forced; it's built into the system, making them last without breaking down. Because they're uniform and see-through, light passes through without scattering, hinting at just how tiny their structures really are. Droplets measure mere billionths of a meter across, creating vast contact zones between phases. That massive boundary space turns out to be useful when packing drugs inside - they dissolve more easily, move faster ^[16,17]. What makes microemulsions work well for carrying essential oils? These systems handle oil-loving substances with ease. Solubility gets a boost, while fragile aromatic parts stay shielded from breaking down. Skin absorption tends to increase, partly because surfactants - and their helpers - nudge open pathways in the outer layer of skin by rearranging its natural fats ^[17,18]. Apart from their benefits, microemulsions often flow too easily - making them slip off the applied area before fully interacting with the skin. Because they don't stick around long, their healing potential weakens over short periods. Such behavior calls for structural tweaks so they perform better during surface delivery ^[16,18]. A mix of microemulsions trapped inside a gel network creates what's called a microemulgel - essentially, tiny droplets suspended within a thicker base. By blending these liquid pockets into a structured matrix through gelling substances, one gets a system that carries benefits from both forms. While the inner phase helps dissolve drugs more effectively and pushes them across skin layers, the outer gel adds thickness, stickiness to tissue, and

ease of spreading. Because of this pairing, medicines applied on the surface stay longer where needed. Release happens gradually rather than all at once, reducing sudden peaks in absorption. Stability tends to improve when compared to simpler preparations like lotions or solutions. Users often find these systems lighter, less oily, visually cleaner. Acceptance goes up - not because they're flashy, but due to comfort during extended use. Evidence points toward better performance than standard creams or ointments in certain cases. A fresh look at fighting microbes shows promise when essential oils are packed into microemulgels. These tiny droplets, small enough to hug bacterial surfaces tightly, slip through barriers more easily than older forms. Instead of spiking and fading, the medicine seeps out slowly thanks to the gel holding it in place. That steady flow keeps levels high where needed - right at the infection. Because it lasts longer, fewer applications do the job. Together, these effects sharpen the attack on pathogens while cutting down how often you need to reapply ^[19,20]. Moisture buildup in the outer skin layer, along with loosened lipid organization, helps microemulgels push drugs deeper into the skin. These gels can temporarily disturb the spaces between lipids - opening pathways without lasting damage. Sometimes, essential oils join in, slipping through alongside medication thanks to their own penetrating qualities. Their presence often boosts how much medicine gets absorbed, nudging effectiveness a little higher ^[6,7,18]. What keeps essential oils intact? A shield-like setup within microemulgels blocks oxygen exposure plus evaporation. Slow dispersal of active ingredients tends to lower skin reactions - this matters when treatment goes on for weeks or months. Texture and feel play a bigger role than expected; people stick with treatments that don't sting, tingle, or leave residue behind ^[11,20]. A shift is now visible - scientists are turning more toward plant-derived



oils, testing them within microemulsion gels that could replace lab-made antimicrobials. These natural setups draw attention because they're kinder to ecosystems while still fighting microbes effectively. With better nano-engineering tools emerging, fine-tuning such products becomes less guesswork. Design strategies built around consistent quality help shape reliable outcomes during development. As techniques evolve, so does potential for safer, scalable solutions rooted in nature rather than chemical labs ^[9,10,20]. Aiming beyond standard approaches, this study explores microemulsions and their gel forms loaded with essential oils - focusing on boosting both antibacterial effects and skin penetration. By shifting away from traditional topical methods, which often fall short, the approach seeks to refine treatment for common skin-related microbial issues ^[8-10,19]. Instead of relying on outdated formats, it tests how fluid nanostructures combined with natural oils might offer better performance. Through these adjustments, barriers in delivery and effectiveness could be reduced, potentially leading to more consistent results where others have struggled ^[8-10,19].

2. COMPREHENSIVE REVIEW OF METHODS

2.1 Lemongrass and tulsi essential oils in microemulsion and microemulgel systems

A starting point often involves choosing plants carefully - especially when crafting herbal treatments. Take lemongrass, known scientifically as *Cymbopogon citratus*; its role in folk medicine stands alongside verified effects against microbes. Then there's Tulsi, or *Ocimum sanctum*, commonly used in healing traditions with a track record for safe external use. Evidence from both ancient Ayurvedic texts and recent studies supports their relevance in addressing skin inflammation and infections caused by

microorganisms ^[21,22]. Leaves, gathered from verified plants, go through careful washing - this clears off dirt and unwanted bits. Drying them away from direct sun helps hold onto sensitive compounds that heat might break down. Once dried, the material gets reduced in size, turning into a rough powder. A trained expert checks the plant identity, making sure it's correctly named. For future reference, sample specimens find their place in an established herbarium, supporting consistency and credibility in research ^[23]. Boiling chopped lemongrass - fresh or dried - in water kicks off the hydrodistillation process. Steam carries the plant's aromatic compounds upward, where they cool and turn back into liquid inside a Clevenger-style setup. This collected fluid splits naturally into two phases: one oily, one watery. What floats on top - the essential oil - is drawn off carefully after drying with sodium sulfate. To slow down chemical breakdown from oxygen exposure, it's tucked away in cold storage. Though variations exist, this approach appears frequently across studies focused on pulling oil from lemongrass ^[24,25]. A distinct approach delivers oil high in citral - this compound largely drives lemongrass's ability to inhibit microbes. Simplicity gives hydrodistillation an edge; because results stay consistent and reliance on chemical solvents stays low, it fits well within cosmetic and medicinal production frameworks ^[26]. Starting off with fresh tulsi leaves, one way to pull out the essence involves water-based distillation or soaking in alcohol. Alcohol at concentrations between 70% and 95% tends to work well when keeping heat-sensitive elements like eugenol intact. This method - left undisturbed for some time - allows slow release of active components into solution. Once done, the liquid gets strained through fine material to remove plant bits. From there, lowering the pressure helps evaporate excess solvent without applying high heat. What remains is a more potent version of the original mix. Finally,



sealing it in closed bottles keeps quality stable over time ^[27,28]. Even though Soxhlet pulls out more material, the extended heat can break down delicate compounds. Because of this, cooler methods tend to be chosen when making products applied to skin - especially if keeping natural effects matters ^[29]. A closer look at lemongrass and tulsi reveals distinct profiles when used in microemulgel setups ^[71]. While one relies heavily on citral - made up of geranial and neral - the other centers on eugenol, along with some methyl eugenol. Membrane disruption marks how lemongrass tackles microbes. In contrast, tulsi interferes through different biochemical pathways. Each plant brings a unique chemical footprint. These differences shape their behavior inside delivery systems. Stability, solubility, and release patterns shift accordingly. Not every compound behaves the same under identical conditions. Small variations in structure lead to functional changes. Observing them together highlights more than individual traits

2.2 Enzyme inhibition and biofilm suppression

Though effective against Gram-positive microbes, its performance slips when tackling Gram-negative strains. Fungi show varying levels of susceptibility across test environments. One major drawback stands out - the compound evaporates quickly when exposed. Chemical breakdown follows close behind under normal storage conditions. Instability limits practical use despite broad coverage. Volatility further reduces shelf life without proper sealing

2.3 Poor aqueous solubility and potential skin irritation

Benefit in microemulgel Improved stability and enhanced skin penetration Sustained release with improved safety , A single blend brings together effects that hit microbes harder. When compounds

interact, their impact can exceed expectations. Resistance becomes less probable as a result of this joint action. A first look at plant compounds checks for key natural chemicals - things like terpenoids, phenols, flavonoids, alkaloids, or glycosides. Their role often ties to fighting microbes or easing inflammation, which hints at practical uses later on ^[22,30]. With these findings, researchers gain footing for deeper study into how extracts might be turned into treatments. Starting off, gas chromatography paired with mass spectrometry helps uncover what chemicals make up essential oils. Moving to lemongrass, its oil mainly features citral - split into geranial and neral forms. In contrast, tulsi oil packs a mix dominated by eugenol, along with some methyl eugenol and β -caryophyllene. These compounds are pinned down using retention index values matched against known spectra in digital libraries ^[24,31]. Choosing ingredients for microemulsion setups isn't random - each component plays a role. Oil phase often comes from lemongrass or tulsi essential oils, both natural yet effective. Instead of harsh chemicals, milder options like Tween 80 or Cremophor RH-40 step in as surfactants; they're less irritating, better tolerated by skin. To help things mix more smoothly, substances such as propylene glycol or PEG-400 join in - not main actors, but crucial supporters. Their job? Lowering surface resistance so droplets form smaller, steadier structures. Research backs this combination, showing improved stability when these agents work together. Starting off, pseudo-tertiary phase maps rely on water titration to pinpoint where microemulsions form. Clearness, even mixing, and resistance to separation guide the assessment across differing proportions of oil, surfactant-cosurfactant blend, and water. Instead of guessing, researchers use these visual tools to land on formulas that hold together well while carrying substantial amounts of active substance ^[34,35]. A typical starting point involves mixing essential oil



into an oily base before bringing in both surfactant and its supporting co-surfactant. With steady agitation, water is introduced slowly, drop after drop, guiding the mix toward clarity and uniformity. What emerges is a stable, transparent blend - self-assembled without force or external energy input. This natural structuring means no intense machinery steps in during creation. A shift from liquid to semi-solid forms happens when chosen microemulsions blend into gel matrices, creating microemulgels. By slowly adding the microemulsion into a pre-formed base - where polymers like Carbopol 934 or HPMC have swelled and turned transparent - a stable mixture emerges. Neutralization helps the gel reach the right clarity before integration. Once combined, the resulting formulation sticks around on skin longer than fluids alone. Drug delivery becomes steadier, less abrupt. Structural tweaks at each stage influence how smoothly substances move out over time ^[32,37].

Average droplet dimensions, uniformity of particle distribution, and surface charge are assessed via dynamic light scattering - this helps confirm both nano-range sizing and formulation durability. Skin-like acidity levels, kept between 5.5 and 6.5, guide pH adjustments. Flow behavior and how smoothly it coats surfaces are examined to reflect real-use handling and user comfort ^[33,38]. Testing how drugs leave a solution happens outside living organisms, often through tools like Franz diffusion chambers paired with artificial barriers. Insights

emerge when comparing delivery patterns of microemulgels carrying essential oils against standard versions - revealing differences in timing and flow. Such setups help track how steadily active components exit their carriers over time. Findings align with earlier observations noted by researchers examining similar systems ^[36,39]. Penetration behavior often gets tested through lab models involving removed skin - either from animals or deceased humans. These setups help track how much medicine moves into the skin layer and where it stays. When microemulgels enter the picture, movement tends to increase. Tiny droplet size plays a role here. So does the presence of certain surface-active compounds that ease entry ^[35,40]. Began with assessing microbial response through agar-based well tests, alongside disk methods, MIC determinations, also biofilm disruption trials. What stands out is how lemongrass paired with tulsi in microemulgel form pushes further into pathogens - likely from deeper tissue access and a slower leak of key compounds. Looking at stability, researchers check how products hold up over time - using both faster tests and real-time storage - to track changes like color shifts, layering, acidity levels, or active ingredient breakdown. When it comes to safety, findings show these microemulgel systems tend to be gentler on skin, mainly because they manage how fast essential oils come out ^[37,38].

Table 1. Comparative Role of Lemongrass and Tulsi in Microemulgel Systems^[72]

Feature	Lemongrass (<i>Cymbopogon citratus</i>)	Tulsi (<i>Ocimum sanctum</i>)
Major actives	Citral (geranial, neral)	Eugenol, methyl eugenol
Antimicrobial mechanism	Membrane disruption	Enzyme inhibition, biofilm suppression
Spectrum	Bacteria & fungi	Bacteria & fungi
Limitation (free oil)	Volatility, instability	Poor solubility, irritation



Benefit in microemulgel	Improved stability & penetration	Sustained release & safety
Combined advantage	Synergistic antimicrobial action	Reduced resistance development

3. SUMMARY OF OUTCOMES

A closer look at lemongrass (*Cymbopogon citratus*) and tulsi (*Ocimum sanctum*) reveals how their essential oils perform when delivered via microemulsion or microemulgel - systems engineered to enhance effectiveness on the skin. These modern approaches outshine traditional methods, particularly in fighting microbes, entering tissue layers, resisting breakdown over time, and aligning with user comfort [41,44,46]. Looking across multiple analyses, it's clear lemongrass and tulsi oils work against a range of microbes - both Gram-positive and Gram-negative bacteria, along with fungi. When packed into microemulsions, their potency rises noticeably, thanks to tiny droplets enabling tighter contact with microbial surfaces. This close proximity tends to destabilize cell membranes more effectively, boosting pathogen breakdown. Turning these systems into gels slows release, extending how long they stay active where needed [41-43,47]. What happens when essential oils meet microemulsions? Their usual volatility and dislike for water become less of an issue. These tiny droplet systems help dissolve active parts - like citral or eugenol - more effectively. Exposure to air or light doesn't break them down as quickly anymore. Turn that liquid setup into a gel-like form, and things get even steadier. Phase splits and evaporation slow down while sitting on the shelf. Protection gets stronger without needing extra chemicals. The structure just works better over time [44,46,50]. Apart from typical formulations like creams or gels, microemulsions move more effectively through skin layers. Their tiny droplets, minimal surface resistance, because of certain

stabilizing agents, help cross the outer barrier with less hindrance. When turned into gel forms, these systems stick longer on the skin - thanks to thicker consistency and mild clinging behavior. That thickness slows release, which means active ingredients stay where needed, working over extended periods [45,46,50]. Microemulgel systems tend to release medication more gradually than basic microemulsions do. Because the gel component hinders fast diffusion, drugs exit at a steadier pace - keeping levels high enough to fight microbes for longer stretches. As a result, patients may need fewer applications throughout therapy, which often helps them stick to their regimen more consistently [44,46,47]. Applying essential oils straight to skin at strong doses can lead to discomfort or allergic reactions. When these oils are tucked into microemulsions or microemulgels, they're less likely to irritate - thanks to slower release and less raw exposure. The way these mixtures interact with skin seems gentler, partly because their pH lines up well with natural skin conditions. Tests so far suggest a low risk of irritation, backing earlier findings [46,50]. What makes microemulgels stand out isn't just how they feel - light, non-sticky, simple to rinse off - but how that feeling influences real-world use. Their ease of application and skin-friendly touch often means people stick with treatment longer. Unlike heavier ointments or creamy formulations, these gels tend to be preferred in daily routines, especially when therapy extends over weeks or months [46,50]. What if everyday plant extracts could slow down superbugs? Compounds from lemongrass and holy basil interfere with bacterial membranes while messing up their internal chemistry - hitting multiple weak spots at once



makes it harder for microbes to adapt. When packed into tiny delivery vehicles like nanoparticles, these oils work even better, staying active longer where needed. This combo might one day support skin treatments aimed at stubborn infections that resist conventional drugs ^[41–43,48,49]. A fresh look at how medicines reach the skin shows that tiny droplets carrying lemongrass or tulsi oils might be onto something useful. Stability climbs when these oils are tucked into microemulsions instead of left on their own. Getting active ingredients through the skin improves, thanks to the design of these gels and liquids. Patient comfort tends to follow suit - less irritation, easier use. Antimicrobial power doesn't fade; in many cases, it gets sharper. Old-style creams and loose oils face hurdles these new forms simply bypass. Research numbers back this up, pointing to consistent gains across tests ^[44–47,50].

4. RESEARCH GAPS

4.1. Gap Between Antimicrobial Screening and Advanced Topical Delivery Systems

Most studies on lemongrass (*Cymbopogon citratus*) and tulsi (*Ocimum sanctum*) primarily focus on in-vitro antimicrobial screening of free essential oils or crude extracts. Although these studies confirm antimicrobial potential, they do not sufficiently address formulation-related challenges such as volatility, instability, poor aqueous solubility, and limited skin penetration. The translation of antimicrobial screening into optimized topical delivery systems like microemulsions and microemulgels remains inadequate ^[51,52].

4.2. Limited Combined Use of Lemongrass and Tulsi Essential Oils

Existing literature largely investigates lemongrass and tulsi as individual antimicrobial agents.

Despite evidence suggesting complementary mechanisms of action of citral and eugenol, there is a lack of systematic studies evaluating their combined incorporation into a single microemulsion or microemulgel system. This limits understanding of potential synergistic antimicrobial effects ^[53].

4.3. Insufficient Emphasis on Microemulgel-Based Skin Retention

While microemulsions are widely reported to enhance solubility and antimicrobial efficacy of essential oils, their low viscosity results in poor skin retention. Many studies fail to convert optimized microemulsions into microemulgels, which provide improved residence time and controlled release. Comparative evaluations between microemulsions and microemulgels for lemongrass and tulsi remain limited ^[54,55].

4.4. Lack of Standardized Formulation and Evaluation Protocols

Considerable variability exists in formulation components, including surfactant type, oil concentration, and evaluation parameters. Differences in antimicrobial test organisms, diffusion techniques, and permeation models hinder reproducibility and cross-study comparison. The absence of standardized formulation and evaluation protocols limits systematic development of essential oil-based microemulgel systems ^[56].

4.5. Limited Ex-Vivo and In-Vivo Skin Delivery Evidence

Although enhanced antimicrobial activity of encapsulated essential oils has been reported, robust ex-vivo skin permeation and dermal retention studies are scarce, particularly for tulsi-based formulations. Furthermore, most studies



remain confined to in-vitro investigations, with insufficient in-vivo validation of skin safety, irritation potential, and therapeutic efficacy ^[57,58].

4.6. Inadequate Stability and Volatile Retention Studies

Essential oils are highly volatile and prone to oxidative degradation. While nano-encapsulation strategies have demonstrated improved stability, long-term and accelerated stability studies of essential oil-loaded microemulgel systems are limited. Insufficient data are available on volatile loss, phase separation, and chemical stability under storage conditions ^[59].

4.7. Limited Evidence on Antimicrobial Resistance Mitigation

Although essential oils act via multi-target mechanisms, few studies have explored their role in reducing antimicrobial resistance when delivered through sustained-release topical systems. The potential of microemulgel-based localized delivery to prevent sub-therapeutic exposure and resistance development remains underexplored ^[52,60].

5. FUTURE SCOPE

The encouraging findings reported for lemongrass (*Cymbopogon citratus*) and tulsi (*Ocimum sanctum*) essential oil-loaded microemulsion and microemulgel systems open several promising avenues for future research and development in topical antimicrobial therapy ^[61,62].

5.1. Creating combined herbal microemulgels

A fresh look at blending lemongrass and tulsi into a microemulgel could reveal how citral and eugenol work together against microbes. These mixed herbal setups might hit harder on pathogens while using less of each oil. Lower concentrations

often mean gentler effects on skin - something simpler formulas don't always manage. Earlier results hint that combining plant actives brings more than just additive benefits ^[63,64].

5.2. Application of Quality by Design (QbD) and DoE Approaches

A fresh look at formulation work shows how blending QbD principles with DoE methods shifts the focus toward structured improvement - tweaking elements like oil levels, surfactant balance, or droplet dimensions isn't left to chance. Instead, patterns emerge through planned variation, shaping viscosity and delivery behavior more predictably. Outcomes tend to hold up better under scale-up stress, meet tighter consistency standards, while also lining up well with regulatory expectations ^[65].

5.3. Advanced Skin Permeation and Deposition Studies

To grasp how essential oils move through skin and where they settle, upcoming studies might use real human tissue samples alongside advanced imaging methods ^[66]. Confocal microscopy could reveal details about absorption routes - especially around hair follicles. Examining microemulgels this way may clarify their delivery efficiency. Insights into how much oil stays within skin layers should emerge from such approaches.

5.4. Long-Term Stability and Shelf-Life Evaluation

Stability over time? That's where focus shifts - tracking how these microemulgels hold up when stored for extended periods. Changes in texture, smell, or effectiveness need watching under normal shelf conditions. Accelerated tests help predict what happens down the line without waiting years. Volatile components tend to fade;



keeping them intact matters. Antimicrobial strength shouldn't drop off either. Packaging plays a role - not every container interacts well with oils. Real-world storage environments shape results more than lab simulations. Compatibility between material and formula can make or break longevity. Evidence from repeated trials builds confidence in lifespan estimates [67].

5.5. Extended Safety, Toxicity, and Irritation Assessment

Few assume that plant-based means risk-free - yet thorough checks on long-term skin exposure remain sparse. Repeated contact could reveal hidden reactions, urging deeper study into how these oils affect tissue over time. Chronic use, particularly when treating persistent conditions, demands clearer evidence on irritation potential. Sensitization risks aren't fully mapped either, even though daily application is common. Without structured toxicology follow-ups, uncertainties linger just beneath the surface. Research gaps like these quietly challenge assumptions about safety. A closer look may reshape expectations around so-called gentle remedies.

5.6. Investigation of Antimicrobial Resistance Mitigation

Looking into how we might slow antimicrobial resistance, one path worth exploring is sustained-release microemulgel systems. These could help by avoiding low-level drug exposure - something that often fuels resistant strains. Another angle: their possible role in blocking biofilms, where microbes toughen up and evade treatment. Evidence hints at benefits, yet deeper research remains necessary to confirm real-world impact [61,69].

5.7. Expansion to Targeted Dermatological Applications

Looking into specific skin issues, lemongrass and tulsi microemulgels might play a role in managing acne or fungal infections like dermatophytosis. Conditions such as diabetic foot ulcers or contaminated wounds could also respond, depending on how the formula is adjusted. Skin type matters - so does the kind of microbes present - and fine-tuning the blend may improve outcomes [70].

5.8. Scale-Up, Industrial Manufacturing, and Regulatory Translation

Ahead of market entry, questions around large-scale production need exploring - how formulas behave when made in bulk isn't always predictable. Turning lab results into factory output involves rethinking mixing methods, storage conditions, even packaging lines. Guidelines for medicines and skincare don't always match up, creating hurdles that slow down approval pathways. Bridging these gaps means adjusting formulations while staying within legal boundaries set by health authorities. Progress hinges less on innovation alone, rather on how well each step aligns with real-world constraints [65,67].

5.9. Integration into Advanced and Smart Delivery Platforms

Putting microemulgels loaded with essential oils into advanced setups - like responsive gels or adhesive patches - opens paths toward more precise delivery. These systems can react to environmental cues, releasing their contents where needed most. Wound coverings infused this way might support better targeting of microbes. Small changes in pH or temperature could trigger release, making timing and location more predictable. Research hints at stronger performance when such carriers adapt on-site [66,70].



5.10. Clinical Validation and Patient-Centric Studies

Trials involving real patients help confirm whether a treatment works safely - and if people actually find it tolerable over time. These insights connect bench findings to actual medical use, grounding innovation in practical outcomes^[62,68]

CONCLUSION

Even now, infections on the skin caused by microbes remain tough to tackle worldwide - not just because they pop up so often, but also since repeat cases are common and more bugs resist treatment. While standard creams or ointments get used a lot, they don't always work well - penetration into deeper layers can be weak, medicines may not stay put, greasy ingredients struggle to dissolve, shelf life tends to shorten, plus people skip applications. Because of these hiccups, better ways to deliver drugs through the skin have become hard to ignore. Fresh from lemongrass and tulsi plants, certain oils show real potential against microbes - not just because they hit a wide range, but also due to how they work on multiple fronts while sidestepping common resistance issues. Still, putting them to use in medicine hits a wall: they don't mix well with water, tend to evaporate quickly, break down under stress, and sometimes irritate the skin if applied directly. One way around these problems? Wrapping the oils into tiny droplets using microemulsions or gel-like carriers called microemulgels - structures that stabilize the compounds, improve delivery, and smooth out harsh effects. What happens when tiny droplets carry essential oils? They move more easily into the skin, stay stable, because surfactants help them slip through barriers. Turning these systems into gel-like forms brings extra benefits - think thicker texture, longer contact time on skin, slower ingredient release, a smoother feel during use. Using both lemongrass and tulsi oils in such gels

shows stronger germ-fighting power than standard creams or raw oils. These versions also penetrate deeper, last longer on the skin surface, hold up better over time, while causing less discomfort. How do researchers check this? By testing how each part behaves - from mix design to real-world performance - all pointing toward improved outcomes without harsh reactions. Few things stand out like how microemulsions and their gel forms carry essential oils safely onto the skin. While tackling stubborn microbes, these delivery methods show clear benefits over conventional options. One key advantage lies in their ability to enhance penetration without irritation. Because they're easy to apply and well tolerated, patients tend to stick with treatment longer. With rising interest in plant-derived remedies, such systems fit naturally into evolving skincare strategies. Progress here doesn't just stop at labs - real-world use becomes more feasible with each study. Looking ahead, further testing could bridge gaps between herbal actives and practical medicine. What begins as a lab formulation may eventually shape everyday dermatological care.

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