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From Palm Oil By-Products to Biomedical Biosurfactants, A Review of Sophorolipid Bioproduction, Antimicrobial Mechanisms, Antibiofilm Activity, and Translational Opportunities

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Abstract

Sophorolipids are yeast-derived glycolipid biosurfactants whose chemical versatility and surface activity have stimulated interest in antimicrobial materials and biomedical formulations. Palm oil, palm olein, and palm fatty acid distillate offer potentially useful lipophilic fermentation inputs, but feedstock origin does not establish clinical performance or safety. This qualitative literature review critically integrates journal research published between 2020 and October 2026 across palm-derived bioproduction, molecular structure–activity relationships, antibacterial and antifungal action, biofilm disruption, medical-device coatings, nanocarriers, and translational constraints. An interpretive thematic synthesis distinguishes direct palm-feedstock studies from broader sophorolipid and biomedical evidence. Palm-derived fermentation is experimentally feasible, and selected preparations have inhibited fungal morphogenesis and biofilm-associated endpoints in vitro. Nevertheless, activity varies with congener profile, producer strain, test organism, exposure conditions, and formulation. Evidence for medically relevant antibiofilm materials and combination therapeutics is promising but remains predominantly preclinical, while direct clinical evidence for palm-derived products is insufficient. A safe-by-design translation pathway is proposed, integrating feedstock traceability, congener-resolved analytical specifications, clinically relevant biofilm models, mammalian exposure testing, manufacturing quality, and comparative environmental assessment. The most credible near-term opportunities lie in carefully evaluated topical or surface-associated applications rather than unqualified systemic therapeutic claims. Sophorolipids should be developed as defined biomedical material candidates, not treated as a universally effective class solely because of their renewable origin.

Keywords: Sophorolipids, Palm oil, Palm fatty acid distillate, Biosurfactants, Antimicrobial activity, Antibiofilm, Candida albicans, Biomedical materials, Microbial fermentation, Circular bioeconomy

JEL Classification: I15, L65, O13, Q53, Q56.

Introduction

Biomedical and Sustainability Context

Biofilm-associated infections expose an important mismatch between the performance of antimicrobial agents in a simplified laboratory environment and their performance when microorganisms colonize protected interfaces. Microbial cells within

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a biofilm encounter variable oxygen, nutrient and pH gradients, and extracellular polymeric substances complicate antimicrobial penetration and removal. For device-facing materials, successful design must therefore address the adhesion of microorganisms to a surface, the retention of viable cells after a cleaning event, and the compatibility of the proposed intervention with human tissues. Models that capture these features remain difficult to standardize, which complicates comparisons across technologies and encourages premature claims based on a single assay. These realities make bioactive but biocompatible interfacial molecules an appealing subject for critical study [7,51]. Conventional surfactants have useful wetting, dispersing and emulsifying functions, yet their suitability for healthcare depends on formulation concentration, duration of contact, biodegradation behaviour and interactions with tissues. Microbially synthesized biosurfactants broaden the range of possible chemistries beyond petroleum-derived surfactants and, in selected cases, can also interact with microbial envelopes. This does not mean that every biosurfactant is intrinsically harmless or that a biologically active surfactant will remain selective when placed on mammalian skin or implanted materials. Environmental biodegradability, cellular tolerability and clinical effectiveness are distinct claims requiring distinct evidence. More credible opportunities emerge when these dimensions are evaluated together, rather than when the word green is used as a substitute for toxicity or lifecycle measurements [3,37,52,53]. Sophorolipids are particularly relevant because several yeast platforms release them extracellularly and because the molecules have a sophorose headgroup attached to a hydroxylated fatty-acid chain. Structural variation generates acidic, lactonic, acetylated and other related forms with different solubility and interfacial properties. As a result, sophorolipid is not the name of one fixed molecular product. Fermentation usually creates a mixture, and changes in substrate, microbial genetics, process design or downstream fractionation can change the mixture's properties. The same feature that enables tailoring also introduces a major interpretive challenge, reported antibacterial activity cannot be generalized from one sample to a chemically different sample without direct testing [9,16,42,47,66]. The palm oil value chain supplies abundant lipid streams with different technical and economic characteristics. Refined palm oil and palm olein can provide relatively controlled lipophilic inputs, while Palm Fatty Acid Distillate (PFAD) represents a refinery co-product with potential for higher-value bioconversion. Other palm-processing residues can contribute nutrients after suitable treatment, although not all such residues are substitutes for the lipid fraction itself. Using a co-product may reduce dependence on refined inputs, but it can also introduce variability, pretreatment requirements and competing uses. Palm origin also raises land-use, chain-of-custody and counterfactual allocation questions. Accordingly, a credible circular-bioeconomy argument must compare actual environmental impacts, instead of assuming that transformation of a palm co-product is automatically sustainable [2,17,24,43].

Why A Critical Review is Needed

Direct experimental studies connect palm-derived inputs to sophorolipid biosynthesis and selected antimicrobial endpoints. One study produced a mixed sophorolipid preparation by cultivating Starmerella riodocensis on palm oil and glucose, then observed suppression of Candida albicans hyphal formation and biofilm-associated measures. Another used PFAD in a Starmerella bombicola fermentation study and evaluated antibacterial, antibiofilm and antifungal outcomes. These experiments are important proofs of feasibility, but their mixtures, recovery methods and test systems cannot by themselves establish therapeutic efficacy, dose suitability or product equivalence with sophorolipids derived from other oils. A source-aware synthesis must distinguish what those papers measured from the broader promise suggested by research on purified congeners, coatings or drug-delivery platforms [2,44]. The wider sophorolipid literature is developing in several directions at once, strain engineering, production intensification, congener separation, physicochemical modelling, microbe-specific inhibition, medical coating development and nanoscale delivery. Reviews increasingly describe biomedical potential, yet they often combine examples from different sources and product grades into one narrative category. A stricter interpretation is necessary because molecule selection, environmental design and host exposure may change the balance between antimicrobial effects and cytotoxicity. It is also necessary because applications range from comparatively accessible topical or anti-adhesive surfaces to systemic drug delivery, which involves substantially different safety and efficacy requirements. This review addresses that gap by joining fermentation provenance to a structure–property–function–safety framework [14,64,67,68].

Aim and Contribution

The aim is to evaluate under what circumstances sophorolipids derived from palm oil and its processing streams could form a credible basis for future antimicrobial and antibiofilm biomedical products. The review asks how substrate composition affects production and chemical identity, how molecular structure relates to antimicrobial action, what preclinical evidence supports biofilm-facing materials, and what production, toxicological and environmental work remains before translation. Its contribution is deliberately interpretive rather than statistical, it develops a set of decision principles for connecting upstream resource use with downstream biological credibility. A useful account must describe both favorable findings and limiting evidence, including species-dependent activity, inconsistent assays, host-cell effects and uncertain industrial economics [46,54,65].

Literature Review, Conceptual and Theoretical Foundations

Sophorolipid Chemistry, Congeners and Self-Assembly

The essential amphiphilic character of sophorolipids arises from the combination of a hydrophilic disaccharide and a relatively

hydrophobic lipid chain. In acidic sophorolipids the fatty-acid carboxyl group remains free, whereas in lactonic congeners an internal ester linkage generates a ring. Acetyl groups, chain length, saturation and linkage variants add additional degrees of freedom. These modifications influence aqueous solubility, adsorption, aggregation, packing and interaction with membranes. Consequently, apparent differences between acidic and lactonic preparations may partly reflect how the sample was dispersed and at what pH the assay was performed, rather than a simple hierarchy of inherent antibacterial power [5,9,42]. Colloidal behaviour connects chemical structures with biological exposure. A surfactant can exist as molecular monomers, assemblies and components bound to biological membranes, polymers or proteins. The concentration that reaches a bacterial envelope or penetrates an extracellular matrix therefore depends on its aggregation equilibrium and on the composition of its environment. Research on microbial bioamphiphile self-assembly describes how variations in headgroup and tail architecture change micelles, vesicles and other supramolecular organizations. More recent work with purified sophorolipids and phospholipid vesicles underscores that purity and structural type influence both assembled morphology and measured bioactivity. Biomedical formulation development must control these variables before it attributes an effect to a particular active molecule [4,5,46]. Component analysis is especially important when working with fermentation products. Modern chromatography and mass spectrometry can resolve many congeners that would be invisible in a basic gravimetric product-yield measurement. Naturally occurring sophorolipid glycerides and other unusual structural variants widen the analytical problem, while crystallization and separation can select particular families of congeners. A crude extraction mass cannot be equated with the mass of a single active component or with its biological potency. Meaningful studies should therefore report a product fingerprint, congener fractions, residual oil and processing impurities, with assay concentrations expressed in a transparent and reproducible manner [12,30,31,61].

Biosynthetic and Microbial Production Systems

Starmerella bombicola remains a central production platform because its sophorolipid pathway is tractable and its fermentation performance has received substantial study. The production network connects fatty-acid hydroxylation, sequential glycosylation, optional acetylation, transport and extracellular steps involved in lactonic-product formation. Recent pathway revisions emphasize that earlier simplified enzyme diagrams do not fully represent all intermediate forms and substrate preferences. Thus, a literature review that connects a desired bioactivity to a fermentation process should use updated biosynthetic concepts, rather than assuming a fixed linear route that yields a predetermined acidic-to-lactonic ratio [10,15,47,50]. Genetic and process engineering provide complementary routes for shaping the final product. Molecular approaches can adjust pathway activity, oxygen handling and congener selectivity, whereas fermentation design controls substrate availability, oxygen transfer, residence time, foaming and product recovery. Neither approach eliminates the need for a defined product target, the highest overall titer may not produce the congener mixture with the best antimicrobial selectivity. The correct industrial objective is therefore application-specific productivity of a characterized material meeting quality specifications, not simply maximal crude grams per litre. Recent reviews of pilot-scale advances and genetic engineering support this shift from volume-oriented to quality-oriented process development [47,67,68].

Palm Substrates and the Circular Bioeconomy

Palm oil, palm olein and PFAD are related but chemically and commercially distinct substrates. A triglyceride-rich oil requires metabolic access to fatty-acid chains, while fatty acid distillates often differ in free fatty-acid composition and contain variable minor components. In palm-oil and oleic-acid co-feeding, substrate blending improved production relative to a palm-olein comparator in a published fermentation study. PFAD-based work independently demonstrates that a refinery by-product can sustain sophorolipid production and that the recovered mixture may possess antimicrobial functionality. These findings justify research on palm-based platforms, but they do not prove that PFAD always outperforms refined palm streams or that its product profile is interchangeable with mixtures synthesized from soybean distillate or waste cooking oils [24,43]. Substrate valorization is broader than the price of a raw material. Industrial feedstocks require logistics, compositional specifications, storage stability, pretreatment and consistent dosing. Studies using food waste, alternative nitrogen sources and waste frying oil show the breadth of feasible circular inputs, while work on fermentation and downstream engineering demonstrates that the recovery train can shape operating costs. The environmental case must include electricity, carbon sources, solvent use, biomass allocation and treatment of residues. Relative sustainability is a comparative result, not an attribute guaranteed by microbial origin. A palm-based operation could plausibly improve resource productivity when responsibly sourced refinery streams are used, but the magnitude and distribution of benefits require process-specific assessment [17,29,41,62,65].

Mechanistic Concepts, Antimicrobial and Antibiofilm Action

Amphiphilic molecules can interact with the envelopes of microorganisms through adsorption, membrane partitioning and disruption of envelope-associated processes. Such explanations are plausible for sophorolipids and are supported by selected experimental observations, but activity varies across microbial species and congener families. The Gram classification of a bacterium is informative but insufficient to predict susceptibility, because membrane composition, stress responses, efflux and assay medium can change the outcome. Studies comparing purified lactonic sophorolipids across bacteria and assessing structure–activity relationships of modified esters provide evidence for dose- and chemistry-dependent effects. They also caution against treating

all sophorolipids as broad-spectrum antibiotics [35,45,63]. Biofilm control requires additional conceptual distinctions. Inhibiting initial adhesion, preventing mature biofilm formation, reducing crystal-violet-stained biomass, lowering metabolic signal and killing viable cells in a mature biofilm are different endpoints. A substance may disperse extracellular material without eliminating living bacteria, or inhibit fungal filamentation while retaining substantial cell viability. Because mature biofilms often show strong dependence on matrix chemistry and flow conditions, the same material can perform differently in a static microplate assay and on an implanted polymer under physiological fluid exposure. Interpretation is strongest when multiple endpoints agree and when the study distinguishes prevention from eradication [7,40,51].

Method, Qualitative Literature Review

Review Design and Epistemic Orientation

This study adopts an interpretive and critical qualitative literature review, designed to explain relationships and contradictions across disciplinary fields rather than estimate pooled effects. The approach draws on fermentation biotechnology, colloid science, microbiology, materials engineering, biomedical formulation and sustainability analysis. Peer-reviewed journal publications dated January 2020 to 22 October 2026 constitute the temporal evidence base. Articles were sought through concept-led scholarly searching and backward or forward citation tracing, prioritizing direct experiments and authoritative recent reviews. This is not a systematic literature review, no claim is made that all relevant records were captured, and PRISMA screening counts, meta-analytic effect estimates and exhaustive database coverage are intentionally absent [16,42,67]. The interpretive emphasis creates two important obligations. First, the strength of a claim depends on whether a study actually used palm-derived lipid material, a chemically similar but non-palm sophorolipid, or a contextual technology that merely informs potential biomedical design. Second, studies should be appraised by how closely their experimental situation resembles the proposed application. For example, the evidentiary weight of a Candida biofilm microplate experiment is different from that of a dynamic-catheter coating study, and both differ from a clinically tested wound product. Literature from distinct platforms may be juxtaposed to identify hypotheses, but such comparisons are not evidence that two products are therapeutically interchangeable [2,7,36].

Literature Identification, Inclusion and Critical Appraisal

Search concepts combined terms such as sophorolipid, sophorolipids, Starmerella bombicola, palm oil, palm olein, palm fatty acid distillate, fermentation, acidic, lactonic, antimicrobial, antibiofilm, Candida, device coating, wound dressing, nanocarrier, cytotoxicity and sustainability. The core material comprises journal research directly concerned with sophorolipids, carefully selected biofilm-method and biosurfactant studies provide necessary theoretical context. Articles were favoured when they reported identifiable authors, venues, publication dates, DOI records and interpretable methods. Conference abstracts, marketing claims and purely speculative applications were not treated as equivalent to primary experimental evidence. Citations were checked against DOI publisher pages when accessible, bibliographic inconsistencies from secondary lists were corrected using primary metadata [9,64,]. The evidence was organized using an analytic matrix rather than a numerical quality score. Matrix fields comprised feedstock, microorganism, fermentation design, recovery method, dominant structures, purity, target organism, experimental model, dose, comparator, endpoint, biocompatibility and translational relevance. Direct palm-based production with biological testing was designated Category A, other sophorolipid studies Category B, and complementary contextual evidence Category C. Methodological concerns—uncharacterized crude extracts, unclear units, single-endpoint biofilm measurements, inadequate host-cell controls or insufficient replication—were used to moderate interpretive confidence. The purpose was not to rank papers mechanically but to state exactly which inference each paper could support [31,43,65]. The publication cut-off was fixed at 22 October 2026 to prevent later publications from being retrospectively treated as available evidence. For recent primary studies, claims were tied to the experimentally tested preparation, including whether the lipid feedstock was palm-derived or another substrate, bibliographic details and DOI links were cross-checked against publisher or indexing records when available. This transparency is particularly important for fast-moving research on drug combinations and nanoassemblies, where an encouraging result under controlled laboratory conditions should not be mistaken for product approval or demonstrated clinical effectiveness [14,68].

Thematic Synthesis and Research Integrity

Initial deductive themes followed the feedstock-to-product-to-application chain. Inductive themes were then developed around disagreements over acidic versus lactonic potency, the relationship between surface activity and mammalian toxicity, and whether apparent biofilm effects represent dispersal or cell killing. Negative cases and gaps were retained rather than removed, because they are central to safe translational interpretation. An additional interdisciplinary lens considered whether an industrially promising feedstock remains attractive after purification, quality control, transportation and lifecycle impacts are included. The synthesis is therefore explanatory and conditional, it identifies mechanisms and plausible design pathways while explicitly separating measured effects from proposed future uses [37,51,66].

Results, Thematic Findings

Direct Evidence for Palm-Derived Sophorolipid Production

A first major finding is that palm-derived lipids have already been used successfully as fermentation inputs, the subject is not merely a proposal based on chemical similarity with other vegetable oils.

The palm oil–glucose system developed for Starmerella riodocensis yielded a mixed acidic/lactonic preparation and was experimentally linked with inhibition of Candida albicans morphogenesis and biofilm-related measurements. Yet the biological observations concerned that organism, its recovered material and the selected in vitro methods. The results do not establish whether every palm-derived sophorolipid mixture would share its profile, nor whether the same outcomes occur in human tissue. Direct provenance strengthens the relevance of the experiment while making its boundaries more important, because the translation claim should remain attached to the tested material [2]. A complementary line of direct evidence comes from palm fatty acid distillate. In the PFAD study, the reported crude sophorolipid production from palm distillate exceeded the sunflower-oil comparator, although soybean fatty acid distillate produced a still higher yield under the selected conditions. The extracted materials were also investigated against bacterial and fungal targets, supporting the practical idea that refinery streams can be bioconverted into a functionally interesting product. It would nonetheless be misleading to present these yield differences as universal feedstock rankings, because results arise from a specific organism, composition, process and assay. A useful next step would be replicated, controlled comparisons among palm olein, refined palm oil, PFAD and well-characterized waste streams using identical fermentation and purification protocols [44]. The dual-lipophilic-substrate work adds an industrial process perspective. Co-feeding palm oil with oleic acid improved reported productivity and yield relative to palm olein alone, showing that feedstock design can influence biosurfactant synthesis rather than merely supply inexpensive carbon. Palm-processing streams could therefore be chosen for targeted ratios of fatty-acid precursors, but the selection must be informed by the actual fatty-acid profile and by economics of additional inputs. Comparisons with fried-waste-oil fermentation suggest broad substrate flexibility rather than proof of chemical equivalence. Waste-lipid oxidation, moisture, contaminants and trace composition can influence reproducibility, analytical recovery and the acceptability of a future medical-grade product [24,29,65].

Figure 1 summarizes how evidence requirements change across the palm-feedstock, fermentation, molecular-specification and biomedical-testing stages. The associated decision gates underscore that successful bioconversion is necessary but insufficient for claims about medical-device safety, therapeutic selectivity or comparative environmental performance [2,43] (Figure 1).

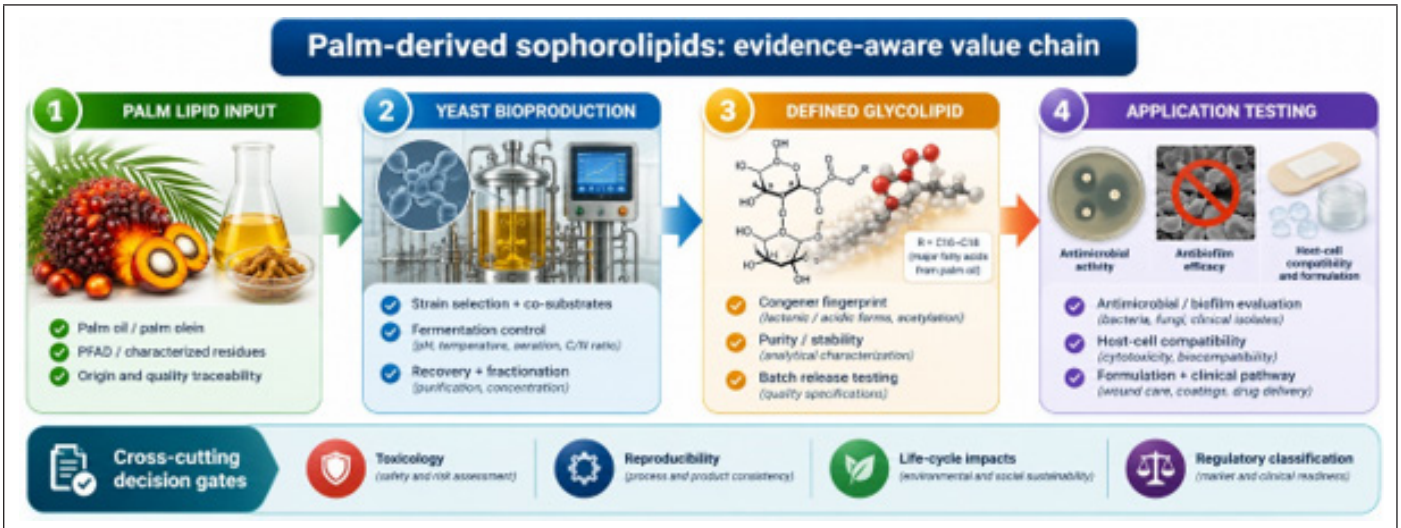


Figure 1: Evidence-aware feedstock-to-biomedical value chain (author-developed conceptual synthesis).

Figure 1 calls out the evidence-aware pathway from a palm-derived lipid fraction to a potential biomedical product. Its most important feature is the explicit quality and safety gate between fermentation output and biomedical claims. An upstream proof of production establishes technical feasibility, while a congener-resolved product fingerprint and relevant biological testing are still required before any therapeutic or device use can be justified. The framework also shows that environmental and chain-of-custody evaluation should accompany processing rather than be added retrospectively as a marketing justification [2,44,67].

Process Engineering and Quality by Design

The production literature converges on an important principle, microbial performance and material specification must be optimized together. Oxygen transfer, lipid feeding, nitrogen availability, product accumulation and downstream recovery can affect both total material recovery and the balance of molecular forms. Investigations into alternative nitrogen sources demonstrate that agricultural side-streams may support fermentation and that medium composition can shape the dominant congener.

Separately, process-intensification studies and contemporary pilot-scale reviews highlight the importance of recovery strategies capable of limiting productivity losses and inconsistent crude-product characterization. For biomedical uses, the downstream process cannot be viewed solely as a cost centre, because it determines residual solvent, residual lipid, microbiological purity and the repeatability of subsequent safety studies [17,67]. Recent molecular work complicates the assumption that the dominant product forms are fixed outputs of conventional pathway steps. Revision of the lactone-esterase role and related biosynthetic insights provides a stronger basis for rational pathway engineering. Research on the transportome also points to cellular export as a relevant production variable, while engineering reviews outline ways to change titers and selectivity. An application-oriented development programme should specify the intended congener or well-defined congener distribution first, then choose fermentation and separation approaches consistent with that target. Otherwise, apparent improvements in biomass conversion can produce a poorly standardized biological product, which is unacceptable for comparative toxicity assessment or eventual regulatory submissions [10,15,50,68]. An additional finding concerns structural analytics. Analytical studies of natural congeners and purification methods show that sophisticated fractionation can distinguish molecular forms whose properties need not match those of the unfractionated crude extract. Purified materials enable interpretable structure–activity experiments, whereas mixed materials may preserve economically important synergistic interactions. These options need not be framed as a contest between scientific purity and commercial feasibility, developers may use purified congeners for mechanistic validation and then determine whether a reproducible controlled mixture delivers adequate biological performance. The crucial requirement is that batch specifications capture what matters for efficacy and exposure safety, including the degree of lactonization, acetylation, fatty-acid distribution and contaminants [12,30,31,61].

Antibacterial Action and Species-Dependent Susceptibility

Bacterial evidence is encouraging but uneven across organisms. A comparison of lactonic sophorolipid inhibitory effects reported substantial activity against selected pathogens while also showing that some organisms were less susceptible under the tested conditions. Work evaluating specific congeners against Clostridium perfringens provides another example of organism-dependent potency, but its animal-health context is not identical to treatment of a human wound. Production from alternative by-products and studies using unconventional yeasts further suggest that biological spectrum changes with the recovered mixture. These findings make a single label such as broad-spectrum antimicrobial scientifically unhelpful unless it is supported by a specified pathogen panel, standardized concentrations and host-cell selectivity data [35,45,56]. Biophysical interaction studies help explain why the pattern is not uniform. Acidic sophorolipids can associate with phospholipid membranes, and chain length, polarity and structural modification alter the manner of association. A surface-active molecule may perturb microbial envelopes, but it may also interact with mammalian membranes under other exposure conditions. Work on structure-dependent skin-cell effects and synthetic derivatives reinforces the importance of comparing microbial growth inhibition with host-cell viability across the same concentration range. Antibacterial effectiveness without an adequate biological selectivity window is not a viable therapeutic result. It is more informative to report a concentration-response surface across organism, molecular identity and test matrix than to declare one sophorolipid subclass categorically superior [1,20,44,63]. Modified sophorolipids offer a means of engineering activity, but chemical modification introduces additional safety responsibilities. Amide functionalization, chemical tuning of microbial glycolipids and ester-derivative structure–activity studies show that native physicochemical characteristics can be systematically altered. This creates opportunities to increase potency against particular pathogens or improve solution behaviour. At the same time, a derivative is not equivalent to its parent molecule merely because it retains the sophorose backbone. New functional groups can change persistence, mammalian toxicity and environmental behaviour, requiring a renewed assessment rather than an assumed transfer of the safety profile associated with native fermentation products [11,44,63].

Fungal Morphogenesis and Biofilm Control

The fungal evidence is especially relevant to the palm-derived research question. The palm oil-based Starmerella riodocensis preparation inhibited Candida albicans hyphal development and measured biofilm formation, establishing a direct link between a palm-based feedstock and an antifungal endpoint. Other work describes a curcumin–sophorolipid nanocomplex that also inhibited C. albicans filamentation and biofilm development, and derivative chemistry has been explored to disrupt fungal mitochondrial function and induce oxidative stress. Together, these studies justify mechanistic hypotheses concerning developmental pathways, membrane interactions and stress responses. However, native material, chemical derivative and multi-component nanocomplex remain separate interventions, and their observed effects cannot be pooled as though they reflected the same active dose [2,6,48]. Additional work on Trichophyton and spoilage fungi extends the biological spectrum. A dermatophytosis-focused study reported preclinical activity, while investigations of food-spoilage fungi illustrate how growth conditions and fungal species change susceptibility. These studies help define the field's biological diversity but must be translated cautiously, agricultural fungal suppression, food safety and human mucocutaneous therapy expose different tissues, microbiota and risk profiles. The possibility of topical use is scientifically attractive because exposure can be localized and monitored, but actual wound infection models must still resolve host-cell effects, duration of activity, product stability and changes in tissue repair [23,55]. Two 2026 studies extend the

evidence for combining sophorolipids with established antifungal drugs. One investigated soybean-meal-derived Starmerella riodocensis products with amphotericin B and itraconazole, reporting reduced Candida albicans biofilm endpoints and altered expression of virulence-associated genes, a related study evaluated azole combinations against preformed biofilms. These findings support a focused combination-therapy hypothesis but remain non-palm, preclinical evidence, and assay-specific improvements should not be presented as proof of clinical synergy across patients or formulations [26,27].

Biofilm research also points toward combinations rather than simple replacement of conventional antimicrobials. The acidic sophorolipid–antimicrobial-peptide formulation literature investigates complementary actions, and other studies examine pairings with antibiotics or lactic acid. Synergistic results should be expressed with proper dose–response and combination measurements, not inferred solely from a stronger effect of a mixture than either unoptimized component. The term antibiofilm is likewise too broad when studies fail to distinguish initial adhesion reduction, growth inhibition, mature-biofilm biomass loss and viable-cell eradication. A clinical materials researcher needs each endpoint separately, ideally linked to imaging and cultures under fluid-exposure conditions that resemble the intended site [28,54,59]. Figure 2 organizes molecular variation alongside proposed interfacial mechanisms and their distinct measurement requirements. The arrows represent experimentally testable links rather than established causal equivalence among all sophorolipid congeners, and the validation panel separates biofilm suppression from mature-biofilm eradication and host-cell tolerability [5,14] (Figure 2).

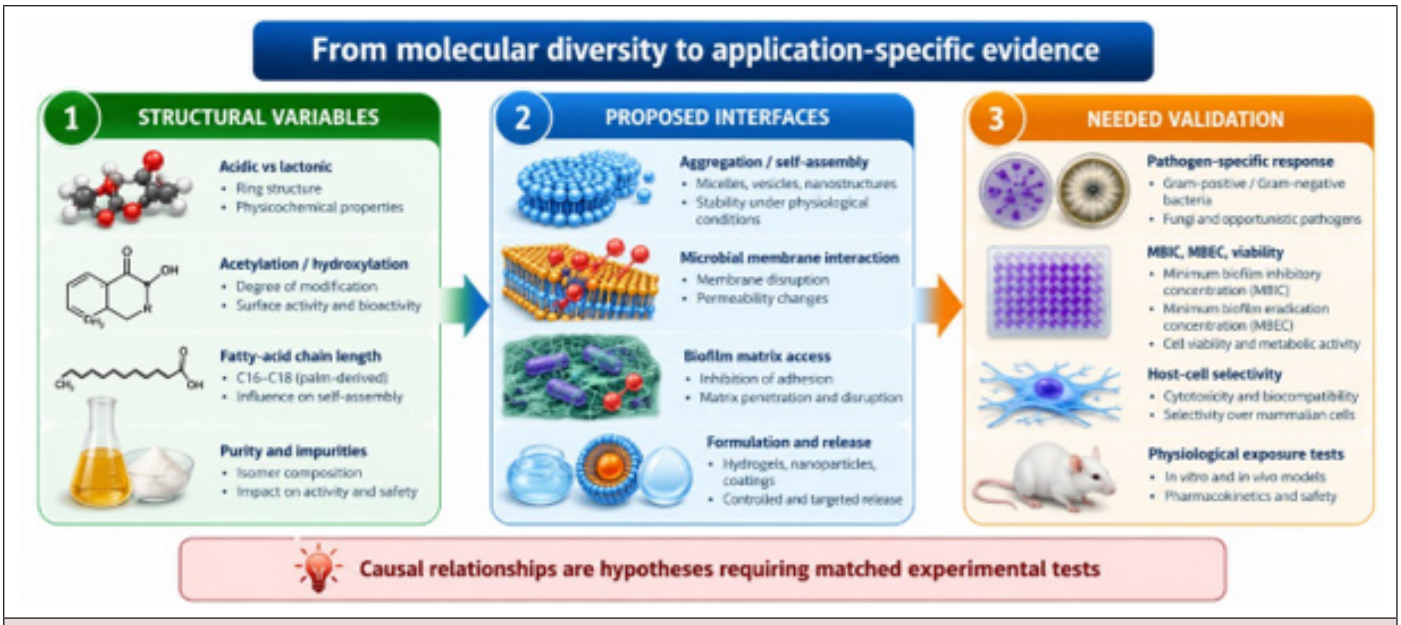


Figure 2: Structure-to-function relationships and experimental validation gates (author-developed conceptual synthesis).

Figure 2 illustrates why sophorolipid molecular architecture should be positioned between fermentation and any biological efficacy claim. The arrows intentionally represent testable hypotheses, not universally established pathways. A sample with greater apparent hydrophobicity may show stronger activity in a given assay while also creating solubility and host-cell compatibility problems, a water-soluble sample may behave differently in an extracellular matrix. The conceptual model therefore recommends matched physicochemical, microbial and mammalian experiments before a mechanistic or safety conclusion is drawn [5,9,20].

Biofilms on Medical Surfaces and Mixed Microbial Communities

Device-relevant studies reveal a distinct and practically important research niche. Sophorolipids have been investigated on medical-grade silicone, a material with obvious relevance to healthcare surfaces, and other work addresses strategies for reducing Staphylococcus aureus catheter-associated contamination through anti-adhesive or release-based approaches. These studies do not amount to evidence of infection prevention in implanted patients, but they identify materials and endpoints closer to healthcare operation than generic planktonic MIC screens. Device-coating strategies should be tested for coating retention, sterilization stability, repeated conditioning, protein fouling and mechanical durability as well as microbiological performance, because such properties determine whether a laboratory surface effect remains useful [7,36]. The experimental challenge becomes greater with multi-species communities. Work on Candida–Staphylococcus dual-species biofilms demonstrate that interactions between fungal and bacterial cells may complicate removal strategies.

Research on the combined use of sophorolipids with other surfactants for Pseudomonas aeruginosa biofilm disruption shows that the formulation environment can materially affect the result. Studies on printed biosurfactant–chitosan coatings further expand possibilities for localized surface design, although the antimicrobial component and the printing matrix must each be characterized. Together, these findings suggest a feasible near-term emphasis on ex vivo device-surface trials and mixed-species flow models, where efficacy and material stability can be jointly observed [8,38,39].

Nanocarriers, Self-Assembled Formulations and Other Biomedical Directions

Nanostructured sophorolipid systems provide a bridge between interfacial chemistry and targeted exposure. Sophorolipid micelles have been used to encapsulate glabridin and honokiol in biofilm-oriented research, illustrating an attempt to improve penetration of poorly soluble active molecules into extracellular matrices. Self-assembled sophorolipid–eugenol nanoemulsions supply another example of combined activity. These studies demonstrate formulation feasibility and biological potential in selected models, not the clinical readiness of a palm-derived drug. The relevant comparison for future studies is not simply a loaded nanocarrier versus no treatment, it should include the cargo alone, carrier alone, free mixture, established standard treatment and a matched host-cell toxicity analysis [18,32,33]. An additional 2026 experimental report examined sophorolipid-based niosomes containing ciprofloxacin against resistant Staphylococcus aureus isolates. For one tested MRSA strain, the reported minimum inhibitory concentration was 5 micrograms per millilitre for a positively charged drug-loaded formulation compared with 40 micrograms per millilitre for free ciprofloxacin, illustrating the potential importance of formulation engineering. Because those vesicles contained auxiliary charge-modifying ingredients and were not derived from a specified palm feedstock, the result supports a formulation-specific hypothesis rather than evidence that unformulated palm-derived sophorolipids would produce the same antibacterial effect [25]. The literature on particle-stabilizing and nanoparticle-associated sophorolipids widens the design space. Gold nanoparticle systems have been studied against Vibrio cholerae, while sophorolipid-mediated silver nanoparticles have been investigated in antimicrobial composite films. These results illustrate a potential dual role in nanomaterial stabilization and microbial interaction. Nevertheless, a metal-containing nanoparticle's biological action cannot automatically be assigned to the sophorolipid shell, and the toxicology of nanoparticles differs materially from that of free biosurfactant. Such systems require separate characterization of particle size, dissolution, metal exposure and cellular response, especially if they are proposed for chronic wound use or contact with sensitive tissues [57,58,60].

Beyond antimicrobial applications, sophorolipids are being studied in antiproliferative, anti-inflammatory and formulation contexts. PEGylated polymer-based encapsulation, breast-cancer model investigations and cell-line experiments show biological activity that might support additional lines of research. Inflammation-related cell experiments and cell-cryopreservation studies similarly illustrate that biomedical utility could extend beyond direct pathogen suppression. The appropriate review interpretation is that these constitute independent exploratory evidence streams, not proof that one palm-derived sophorolipid product can function simultaneously as an antibiotic, anticancer agent, wound-healing drug and safe delivery excipient. Such convergence remains a hypothesis to be tested in carefully defined systems [22,40,49,69].

Toxicology, Commercial Readiness and Sustainable Sourcing

A recurring limitation is the tendency to conflate eco-friendly production with biomedical safety. Toxicity research has compared acidic sophorolipids with other biosurfactants in selected cell lines and has found differential cellular responses, but this cannot establish compatibility across all human tissues or exposure durations. Other analyses of sophorolipid derivatives indicate that changes in molecular substituents may create additional toxicological hazards. The need for congener-specific safety testing is heightened when a biomedical product uses industrial co-products, because chemical residues and batch-to-batch variability are independent factors that may confound biological responses. A responsible study should specify cytotoxicity assay interference, hemocompatibility when relevant, sensitization or irritation for contact materials, and long-term exposure potential [1,3,34]. The production literature indicates credible routes toward scale-up, but also identifies costs and constraints. Recent reviews of industrial production emphasize strain performance, fermentation design, alternative feedstocks and downstream purification, while work on food waste and mixed oil residues shows how a circular input can be exploited technically. A comprehensive cost comparison must account for feedstock prices, transport, energy, sugar and nitrogen consumption, solvent recovery, purification yield, batch testing and product rejection rates. The use of palm oil as a substrate may be commercially attractive in palm-producing countries, but product-grade requirements for healthcare could absorb much of any initial feedstock cost advantage. Environmental assessment also needs allocation of impacts among co-products and a credible alternative fate for PFAD [29,41,62,67].

Discussion and Analysis

Answering the Feedstock-to-Function Question

The evidence supports a qualified affirmative answer to the question of whether palm-based sophorolipids represent a viable research platform for biomedical biosurfactants. Palm oil and PFAD can support fermentation, and selected palm-derived extracts have displayed antimicrobial or antibiofilm activity in laboratory assays. It does not follow, however, that palm origin endows a unique antibacterial advantage. In the absence of

matched congener-resolved comparisons, the causal determinants of biological performance remain difficult to distinguish from production organism, extraction method, formulation and target-cell susceptibility. The appropriate unit for translational decision-making is therefore a chemically specified product made under a defined process, with its provenance recorded as one important attribute among several [2,24,43]. This perspective helps explain some apparent disagreements in the literature. A more lactonic preparation may perform well in a particular bacterial inhibition experiment because of its interfacial and partitioning behaviour, whereas an acidic preparation may be preferable in an aqueous carrier, on a coated surface or where host-cell compatibility is the main constraint. Such differences need not imply that one category of sophorolipid is always stronger or safer. An informative design would compare chemically characterized acidic and lactonic fractions side by side, equalize conditions where practical, and report dissolved versus aggregate-associated concentrations. It would then test whether the observed microbial selectivity survives exposure to serum proteins, wound fluid, extracellular matrix components and relevant mechanical stresses [3,5,20,45].

Assessing what Antimicrobial Mechanisms Actually Establish

Membrane interaction provides a plausible unifying hypothesis, but it cannot explain every reported outcome without complementary data. Sophorolipid molecules can change interfacial organization, and modifications of the lipid chain or polar substituents may alter microbial susceptibility. At the same time, formulation-driven delivery can improve access of an entirely different active molecule to a biofilm. Photodynamic conjugate research, including sophorolipid–toluidine blue systems, illustrates the latter possibility, light activation and photosensitizer chemistry must be distinguished from intrinsic activity of the glycolipid itself. Similarly, cosmetic formulations that combine sophorolipids with palmarosa essential oil demonstrate practical multifunctionality but do not isolate the contribution of each component without appropriate controls. Mechanism claims should reflect the actual intervention [11,19,21]. A robust experimental sequence would begin with defined isolated congeners or reference mixtures and validated MIC testing against a clinically relevant pathogen panel. It would then move to time-kill analysis and microscopy or membrane-permeability measurements, followed by separate biofilm-formation and established-biofilm experiments. Biomass measurement, ATP or metabolic assessment, viable colony counts and confocal imaging should be used as complementary rather than interchangeable indicators. Finally, tests on relevant tissues or devices must determine whether the exposure required for antibiofilm activity is tolerated by mammalian cells. A large reduction in crystal-violet staining alone is not equivalent to microbial eradication, and a favorable mammalian cell viability percentage over one short exposure does not replace longer-term toxicology [7,14,36,51].

Prioritizing Biomedical Applications According to Evidence Readiness

Near-term development should focus on applications that can be tested in defined local conditions and for which the intended mechanism is mainly anti-adhesive or surface-associated. Sophorolipid-modified silicone, catheter-facing coatings and other contact surfaces are plausible candidates, provided they undergo simulated-use assessment for stability, biofilm prevention and safety. The analytical focus should be the complete material, including coating substrate, carrier, antimicrobial component and release profile. For any device, sterilization compatibility, shelf life and durability may be just as important as a short-lived antimicrobial effect in a static assay. Research on silicone surfaces, catheter infection strategies and printed chitosan coatings creates a reasonable preclinical foundation for these experiments, while still falling short of clinical infection-prevention evidence [7,36,38]. Topical wound-care formulations are a second research priority, particularly where local antimicrobial exposure can be combined with moisture control, handling properties and tissue compatibility. However, wound management is not achieved merely by reducing one laboratory pathogen, a useful dressing must also preserve tissue regeneration, avoid excessive inflammation, and perform under protein-rich exudate conditions. Sophorolipid–peptide combinations and antifungal nanocomplexes provide formulation precedents, but an experimental wound dressing should be judged against clinically relevant comparators and controls that separate carrier effects from active-agent effects. Local exposure may simplify some systemic safety questions, yet sensitization, irritation, delayed repair and changes to normal skin microbiota remain relevant [1,48,54]. Drug delivery and intracellular or systemic therapeutic claims require a substantially higher evidentiary standard. Micellar encapsulation of honokiol or glabridin can support the feasibility of carrying an active substance into challenging biological environments, but these systems must demonstrate reproducible pharmacokinetics, tissue distribution, clearance and appropriate exposure margins before clinical relevance can be asserted. Likewise, antitumor findings in cell and animal models are not evidence that a palm-derived sophorolipid is a proven cancer treatment. A novel 2026 report on sophorolipid–phospholipid hybrid vesicles illustrates the rapid development of the field, yet it also emphasizes the roles of purification and structural specificity. This is a platform opportunity, not a clinical endpoint [22,32,33,46]. This formulation dependence is also apparent when comparing recent niosome and micelle research, the observed biological response may emerge from drug loading, particle charge, release kinetics and carrier composition rather than from sophorolipid exposure alone. Future studies should report an explicit control hierarchy encompassing unloaded carrier, free drug, a physical drug–carrier mixture and a benchmark formulation, alongside kinetic release and host-cell safety measurements. Such designs would make advances in biofilm penetration more causally

interpretable and reduce overstatement of biomedical readiness [25,33].

The Translational Evidence Hierarchy

A three-tier evidence hierarchy offers a practical way to organize the literature. Tier 1 comprises direct palm-feedstock experiments that demonstrate bioconversion and selected in vitro biological effects. Tier 2 includes broader sophorolipid research on purified congeners, combinations, materials and organism-specific mechanisms, which informs hypotheses but does not prove equivalence of palm-derived products. Tier 3 comprises contextual biofilm science, environmental assessment, quality requirements and supporting biomedical technologies. This hierarchy is not a numerical effectiveness ranking; it is a guardrail against crossing the boundary from observed substrate feasibility into untested clinical claims. It also highlights why high-quality negative or null results should be welcomed, they narrow the acceptable space of product composition, organisms and indications [2,43,51].

Figure 3 compares four development pathways through their existing preclinical evidence and still-missing validation steps. It is designed to clarify where application-specific experiments are required, not to assign quantitative effectiveness rankings or imply clinical endorsement of any formulation [7,46] (Figure 3).

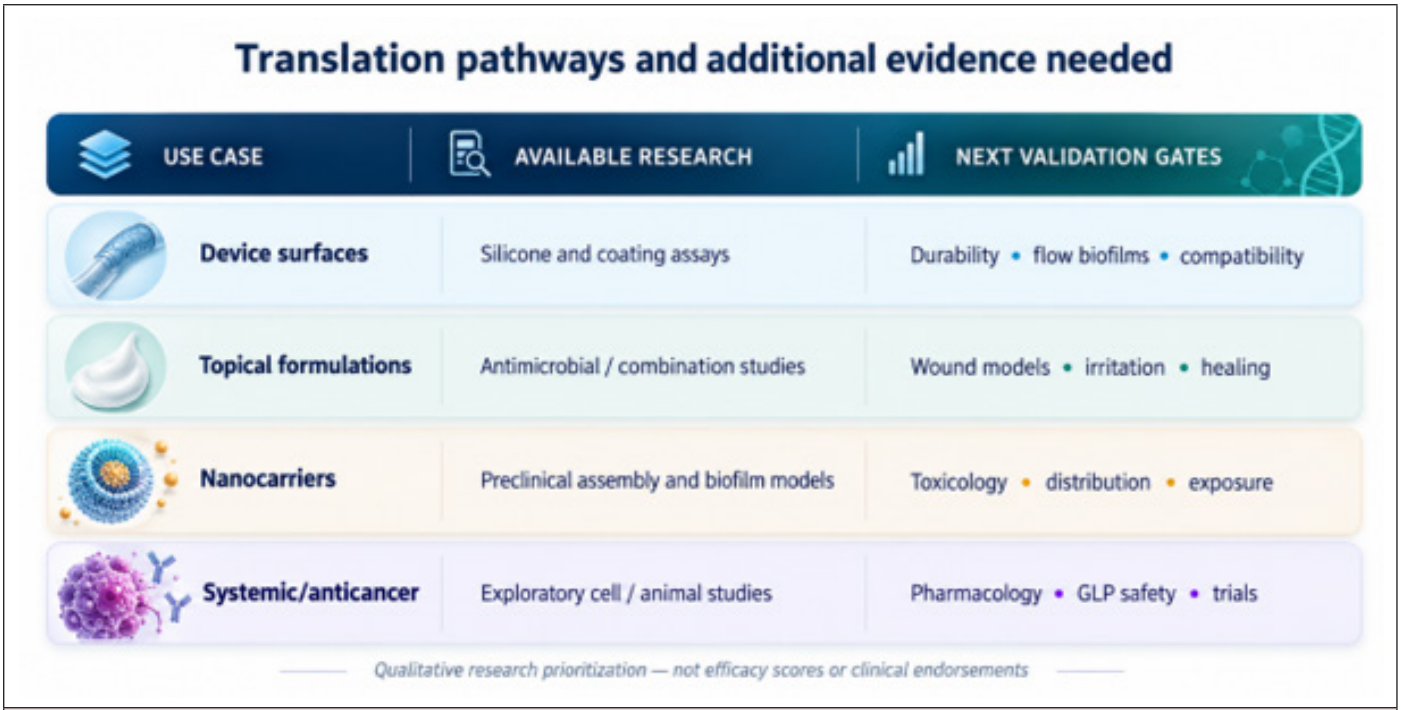


Figure 3: Qualitative translational readiness pathways, not quantitative efficacy ratings (author-developed conceptual synthesis).

Figure 3 maps the principal biomedical opportunities against a qualitative translation pathway. The left-to-right movement identifies additional data requirements—defined chemistry, appropriate biological models, safety testing, realistic materials performance and regulated clinical evaluation—rather than depicting measured numerical effectiveness. Surface-coating and topical research are placed nearer to practical preclinical development because directly relevant laboratory evidence exists, while systemic and anticancer pathways are shown as more exploratory. This distinction helps allocate research resources without diminishing the scientific importance of high-risk, long-horizon delivery research [7,22,36,46].

A Coordinated Testing and Manufacturing Agenda

To translate the evidence, investigators should agree on a target-product profile before optimizing production. For a topical antimicrobial ingredient, such a profile might specify preferred congener ranges, upper limits on fermentation contaminants, aqueous stability, acceptable cytotoxicity under the intended contact duration, stability in a selected carrier, and a standardized relevant pathogen panel. For a device coating, the profile would additionally define coating integrity, release kinetics, sterilization tolerance and simulated-use performance. Analytical release tests should go beyond total glycolipid weight and generic surface tension. Reproducible LC–MS fingerprints, residual-oil assessment and meaningful biological potency assays would reduce the risk of treating two dissimilar fermentation products as interchangeable [12,31,61]. The environmental and commercial agenda needs comparable discipline. PFAD may be a compelling substrate from a valorization perspective, yet it has existing economic uses, and its sustainable allocation depends on the actual supply-chain context. A credible comparison should evaluate refined palm

oil, PFAD and alternative waste lipid inputs through the same system boundary, while considering the counterfactual fate of each resource. Greenhouse gas burdens, energy use, solvent management, waste handling, transport and land-related impacts should be transparent. When environmental uncertainty remains large, it is more scientifically sound to present scenario ranges than a definitive green-product label. Biomedical value should not excuse misleading sustainability claims, just as a favourable lifecycle estimate cannot establish biomedical safety [17,29,37,52]. Collaboration between palm processors, fermentation specialists, analytical chemists, microbiologists, clinicians and regulators is consequently necessary from an early stage. Processing partners can provide representative feedstock variability data, while bioprocess teams can create manufacturing consistency, laboratories can then test defined material lots across organism and host-cell systems. Health specialists should specify use contexts and clinically meaningful comparators before large-scale animal programmes begin. Regulators or standards experts can help determine whether a proposed product is likely to be considered a device, drug, excipient or combination, because each classification changes the testing pathway. A staged collaboration programme would prioritize reproducibility and traceable decision gates rather than promising clinical approval based on promising microplate experiments [14,68,69].

Limitations and Theoretical Contribution

This qualitative review has several limitations. Its interpretive search strategy is not exhaustive, the literature is heterogeneous, and results obtained with different sophorolipid structures, microorganisms, concentrations and endpoints cannot be pooled into reliable quantitative comparative effects. There are relatively few studies connecting an explicitly palm-derived input to a fully characterized biomedical formulation and a realistic in vivo infection model. Moreover, rapid advances in 2025–2026 mean that individual technological claims should be reconfirmed during final submission. These limitations do not invalidate the literature's findings, they define the appropriate confidence of the conclusions and motivate reproducible head-to-head comparisons [14,46,66]. The review's conceptual contribution is the integration of a feedstock–congener–interface–biological-selectivity–translation chain with sustainability and governance criteria. It reframes sophorolipids as differentiated, application-specific material candidates rather than an automatically beneficial chemical category. The framework also suggests a broader lesson for bio-based biotechnology, value creation begins with resource transformation but only becomes clinically meaningful when product identity, biological effect and safety are coherently linked. A circular source can be an advantage, but neither a green feedstock nor an attractive fermentation titer substitutes for standardized quality and clinically relevant evidence. This integrated account offers a practical foundation for designing the next generation of palm-based biosurfactant research [13,16,42].

Conclusion

Palm oil, palm olein and palm fatty acid distillate offer plausible fermentation inputs for sophorolipid production, while selected laboratory studies establish potential antimicrobial and antibiofilm activity. Their significance lies in the combination of demonstrated bioconversion feasibility and a chemically adaptable glycolipid platform. Nevertheless, the evidence remains primarily preclinical, and the properties of one sophorolipid mixture cannot be assumed for another material with a different congener profile or manufacturing history. The strongest conclusions concern technical feasibility, mechanism-informed research opportunities and the need for product-specific characterization rather than proven clinical effectiveness. The most actionable biomedical directions are controlled anti-adhesive coatings, carefully formulated topical materials and combination systems whose effects can be separated through appropriate experimental controls. Future research should use chemically characterized batches, relevant mixed-species and mature-biofilm models, viable-cell and imaging endpoints, exposure-specific mammalian safety tests and realistic comparators. Progression toward systemic delivery or antitumor treatment requires additional pharmacological, toxicological and clinical evidence. The choice of indication should be driven by achievable selectivity and exposure control rather than by broad lists of possible applications. A responsible development roadmap must also integrate substrate traceability, quality-by-design manufacturing, comparative techno-economic analysis, lifecycle assessment and early regulatory classification. For palm-producing economies, this creates an opportunity to move from low-value lipid streams toward high-value biotechnology without neglecting environmental and social consequences. The central recommendation is to treat sustainability, material identity, antimicrobial performance and patient safety as four linked but independently verifiable requirements. Such a programme would advance palm-derived sophorolipids through credible evidence rather than promotional generalization.

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Conflict of Interest

None.

References

1. Adu SA, Matthew ST, Patrick JN, Roger Marchant, Ibrahim MB, et al. (2022) Biosurfactants as anticancer agents: glycolipids affect skin cells in a differential manner dependent on chemical structure. Pharmaceutics 14(2): 360.
2. Alfian AR, Kwanrutai W, Chayaphathra S, Nitnipa S (2022) Production of new antimicrobial palm oil-derived sophorolipids by the yeast Starmerella riodocensis sp nov against Candida albicans hyphal and biofilm formation. Microbial Cell Factories 21(1): 163.
3. Araki M, Erika K, Yoshihiko H, Misa M (2024) The lower toxicity and wider safety range of acidic sophorolipid compared to surfactin and

rhamnolipid as biosurfactants toward the HaCAT THP 1 and RAW 264 7. BPB Reports 7(2): 56-60.

4. Baccile N, Chloé S, Alexandre P, Silvia ADC (2021) Self-assembly interfacial properties interactions with macromolecules and molecular modelling and simulation of microbial Bio based amphiphiles biosurfactants A tutorial review. Green Chemistry.
5. Baccile N, Alexandre P, Patrick LG, Petra P, Melike P, et al. (2023) Aqueous self-assembly of a wide range of sophorolipid and glucolipid microbial bioamphiphiles biosurfactants considerations on the structure-properties relationship. Colloids and Surfaces a Physicochemical and Engineering Aspects.
6. Basotra SD, Yachna K, Mansi V, Arpit T, Deepak S, et al. (2024) ASLdC3 a derivative of acidic sophorolipid disrupts mitochondrial function induces ROS generation and inhibits biofilm formation in Candida albicans. ACS Infectious Diseases 10(9): 3185-3201.
7. Ceresa C, L Fracchia, M Williams, I M Banat, MADD Rienzo, et al. (2020) The effect of sophorolipids against microbial biofilms on medical grade silicone. Journal of Biotechnology 309: 34-43.
8. Ceresa C, Maurizio R, Francesco T, Devid M, Emanuele F, et al. (2021) Inhibitory effects of lipopeptides and glycolipids on C albicans Staphylococcus spp dual species biofilms. Frontiers in Microbiology 11: 545654.
9. Cho WY, Jeck FN, Wei HY, Bey HG (2022) Sophorolipids-Bio Based Antimicrobial Formulating Agents for Applications in Food and Health. Molecules 27(17): 5556.
10. Claus S, Sylwia J, Liam DHE, Inge VB (2022) Exploring the transportome of the biosurfactant producing yeast Starmerella bombicola. BMC Genomics 23(1): 22.
11. Cui T, Lianpeng G, Mengqian Z, Li L, Xuwei L, et al. (2024) Amide modification of glycolipid biosurfactants as promising biocompatible antibacterial agents. Journal of Agricultural and Food Chemistry 72 (12): 6302–6314.
12. Dardouri M, Rita MM, Johannes F, Judite C, Isabel ACR, et al. (2021) Seeking faster alternative methods for glycolipid biosurfactant characterization and purification. Analytical and Bioanalytical Chemistry 413(16): 4311-4320.
13. Veerle DC, Sophie LKWR, Martijn GC, Sofie LDM, Wim KS (2021) Elucidation of the Natural Function of Sophorolipids Produced by Starmerella bombicola. Journal of Fungi 7(11): 917.
14. Dhadwal S, Shristi H, Mary C, Ibrahim MB (2024) Sophorolipid An Effective Biomolecule for Targeting Microbial Biofilms. Current Microbiology 81(11): 388.
15. Diao Z, Sophie LKWR, Goedele L, Jan G, Isabel V, et al. (2024) Revision of the sophorolipid biosynthetic pathway in Starmerella bombicola based on new insights in the substrate profile of its lactone esterase. Biotechnology for Biofuels and Bioproducts 17(1): 89.
16. Dierickx S, Martijn C, Jelle R, Veerle DC, Sofie L, et al. (2022) From bumblebee to bioeconomy recent developments and perspectives for sophorolipid biosynthesis. Biotechnology Advances.
17. Eras Muñoz E, Phavit W, Benjamin I, James W, Teresa G, et al. (2024) Screening of alternative nitrogen sources for sophorolipid production through submerged fermentation using Starmerella bombicola. Waste Management.
18. Fan L, Wei S, Xiaoqian Z, Suqun Y, Yongsheng Z, et al. (2024) Self Assembly of sophorolipid and eugenol into stable nanoemulsions for synergetic antibacterial properties through alerting membrane integrity. Colloids and Surfaces B Biointerfaces 234: 113749.
19. Filipe GA, Briane GB, Cristiani B, Marcelly CG, Renata KTK, et al. (2022) Development of a multifunctional and selfpreserving cosmetic formulation using sophorolipids and palmarosa essential oil against acne causing bacteria. Journal of Applied Microbiology 133(3): 1534-1542.
20. Franco MPR, Julia O, Silvio SDS, Antonio O (2021) Interaction of an acidic sophorolipid biosurfactant with phosphatidylcholine model membranes. Colloids and Surfaces B Biointerfaces 207: 112029.
21. Gu X, Lixian X, Haoyang Y, Cailing L, Juan Z et al. (2023) Sophorolipid-toluidine blue conjugates for improved antibacterial photodynamic therapy through high accumulation. RSC Advances.
22. Haggag Y, Mohamed E, Mohamed ET, Ibrahim MB, Paul M, et al. (2020) Nanoencapsulation of sophorolipids in PEGylated poly lactide-co-glycolide as a novel approach to target colon carcinoma in the murine model. Drug Delivery and Translational Research 10(5): 1353–1366.
23. Hipólito A, Ricardo AAS, Talita OC, Victória AIS, Ismael RA, et al. (2020) Evaluation of the antifungal activity of sophorolipids from Starmerella bombicola against food spoilage fungi. Biocatalysis and Agricultural Biotechnology.
24. Hirata Y, Keisuke I, Akiko U, Glen LQ (2021) Enhanced sophorolipid production and effective conversion of waste frying oil using dual lipophilic substrates. Bioscience Biotechnology and Biochemistry 85(7): 1763-1771.
25. Jain A, Navjot K, Shobit A, Hemraj N, Mani SB (2026) Enhanced antimicrobial activity of ciprofloxacin encapsulated in sophorolipid based nano-assemblies against ciprofloxacin-/methicillin-resistant Staphylococcus aureus (MRSA). Pharmaceutics 18(1): 104.
26. Jayasekara LACB, Kwanrutai W, Jirayut E, Kanokwan P, Chutikarn B, et al. (2026a) Clearing Candida biofilms using combined antimicrobial sophorolipids with amphotericin B and itraconazole. FEMS Yeast Research 26: foag021.
27. Jayasekara LACB, Kwanrutai W, Chutikarn B, Nitnipa S (2026b) Overcoming Candida albicans biofilm drug resistance via azole-sophorolipid synergy. Scientific Reports 16(1): 5963.
28. Juma A, Patrick L, Alistair BJS, Jason M, Barry MGOH, et al. (2020) Microscopic investigation of the combined use of antibiotics and biosurfactants on methicillin resistant Staphylococcus aureus. Frontiers in Microbiology 11: 1477.
29. Kim JH, Yu RO, Juyoung H, Jaeryeon K, Hyeri K, et al. (2021) Valorization of waste-cooking oil into sophorolipids and application of their methyl hydroxyl branched fatty acid derivatives to produce engineering bioplastics. Waste Management 124: 195-202.
30. Kobayashi Y, Qiushi L, Kazunori U, Makoto H, Tomotake M, et al. (2023) Isolation and characterization of novel naturally occurring sophorolipid glycerides. Bioresource Technology Reports.
31. Kobayashi Y, Qiushi L, Kazunori U, Makoto H (2024) Updated component analysis method for naturally occurring sophorolipids from Starmerella bombicola. Applied Microbiology and Biotechnology.
32. Lin S, Xiaojuan L, Wei Z, Gang S, Haohuan L, et al. (2024) Encapsulation nanoarchitectonics of glabridin with sophorolipid micelles for addressing biofilm hazards via extracellular polymeric substance permeation and srtA gene suppression. Ecotoxicology and Environmental Safety 286: 117150.
33. Lin S, Xiaojuan L, Wei Z, Gang S, Tim TN, et al. (2025) Enhanced penetration and biofilm eradication by sophorolipid micelles encapsulating Honokiol: a comprehensive solution for biofilm-associated lung infections. Journal of Nanobiotechnology 23(1): 76.
34. Liwarska BE, Christian VS, Elisabeth IPD, Kevin MVG (2021) Endocrine disrupting potency and toxicity of novel sophorolipid quaternary ammonium salts. Ecotoxicology 30(4): 658-666.
35. Ma X, Tong W, Hui MZ, Jun QS, Mei J, et al. (2022) Comparison of inhibitory effects and mechanisms of lactonic sophorolipid on different pathogenic bacteria. Frontiers in Microbiology 13: 929932.

36. Mendes RM, Ana PF, Filomena AC, Maissa D, Bruna C, et al. (2021) Fighting S. aureus catheter-related infections with sophorolipids: electing an antiadhesive strategy or a release one?. Colloids and Surfaces B Biointerfaces 208: 112057.

37. Nagtode VS, Clive C, Haya KAY, Suraj NM, Srushti MT, et al. (2023) Green surfactants (biosurfactants): a petroleum-free substitute for sustainability-comparison applications market and future prospects. ACS Omega 8(13): 11674-11699.

38. Narciso F, Sara C, Nuno M, Madalena L, Victor M, et al. (2023) 3D-printed biosurfactant-chitosan antibacterial coating for the prevention of silicone-based associated infections. Colloids and Surfaces B Biointerfaces 230: 113486.

39. Nguyen TNT, Toshiki N, Masanori T, Nobuhiko N, Andrew SU (2020) Synergy between sophorolipid biosurfactant and SDS increases the efficiency of P. aeruginosa biofilm disruption. Langmuir 36(23): 6411-6420.

40. Nguyen TNT, Yuki S, Motoki T, Masashi Y, Yoshihiko H (2025) Potential application of acid-form sophorolipids in cell cryopreservation. Cryobiology 119: 105228.

41. Oiza N, Javier Moral Vico, Antoni Sanchez, Teresa Gea Leiva (2024) Enhanced anaerobic digestion of food waste using purified lactonic sophorolipids produced by solid-state fermentation of molasses and oil waste: A circular approach. Journal of Cleaner Production.

42. Pal S, Niloy Chatterjee, Arun K Das, David Julian McClements, Pubali Dhar, et al. (2023) Sophorolipids: A comprehensive review on properties and applications. Adv Colloid and Interface Sci 313: 102856.

43. Pal S, Niloy Chatterjee, Sagnik Sinha Roy, Brajadulal Chattopadhyay, Krishnendu Acharya, et al. (2024) Valorization of oil refinery by-products: production of sophorolipids utilizing fatty acid distillates and their potential antibacterial, anti-biofilm, and antifungal activities. World J Microbiol Biotechnol 40(11): 344.

44. Pala M, Martijn G Castelein, Camille Dewaele, Sophie L K W Roelants, Wim K Soetaert, et al. (2024) Tuning the antimicrobial activity of microbial glycolipid biosurfactants through chemical modification. Front Bioeng Biotechnol 12: 1347185.

45. Park I, Sungtaek Oh, Hyoyoun Nam, Pietro Celi, Hyun S Lillehoj, et al. (2022) Antimicrobial activity of sophorolipids against Eimeria maxima and Clostridium perfringens, and their effect on growth performance and gut health in necrotic enteritis. Poult Sci 101(4): 101731.

46. Perinelli DR, Teresa Gea, Alexia Barbarossa, Junbiao Wang, Marco Cespi, et al. (2026) From sustainable fermentation to smart nanocarriers: Sophorolipid-phospholipid hybrid vesicles with antibacterial and antiproliferative activity. Journal of Drug Delivery Science and Technology.

47. Qazi MA, Qinhong Wang, Zongjie Dai (2022) Sophorolipids bioproduction in the yeast Starmerella bombicola: Current trends and perspectives. Bioresour Technol 346: 126593.

48. Rajasekar V, Priti Darne, Asmita Prabhune, Richard Y T Kao, Adline Princy Solomon, et al. (2021) A curcumin-sophorolipid nanocomplex inhibits Candida albicans filamentation and biofilm development. Colloids Surf B Biointerfaces 200: 111617.

49. Roberge CL, Rebecca T Miceli, Lillian R Murphy, David M Kingsley, Richard A Gross, et al. (2023) Sophorolipid candidates demonstrate cytotoxic efficacy against 2D and 3D breast cancer models. J Nat Prod 86(5): 1159-1170.

50. Roelants SLKW, Stijn Bovijn, Elvira Bytyqi, Nicolas de Fooz, Goedele Luyten, et al. (2024) Bubbling insights: unveiling the true sophorolipid biosynthetic pathway by Starmerella bombicola. Biotechnol for Biofuels and Bioprod 17(1): 113.

51. Rumbaugh KP, Whiteley M (2025) Towards improved biofilm models. Nat Rev Microbiol 23(1): 57-66.

52. Sarubbo LA, Maria da Gloria C Silva, Italo José B Durval, Káren Gercyane O Bezerra, Beatriz G Ribeiro, et al. (2022) Biosurfactants: production, properties, applications, trends, and general perspectives. Biochemical Engineering Journal.

53. Sałek, K. Stephen R Euston, Tomasz Janek (2022) Phase behaviour, functionality, and physicochemical characteristics of glycolipid surfactants of microbial origin. Front Bioeng Biotechnol 10: 816613.

54. Seena S, Rafaela Ferrão, Melike Pala, S L K W Roelants, Wim Soetaert, et al. (2023) Acidic sophorolipid and antimicrobial peptide-based formulation as antimicrobial and antibiofilm agents. Biomater Adv 146: 213299.

55. Sen S, Siddhartha Narayan Borah, Raghuram Kandimalla, Arijit Bora, Suresh Deka (2020) Sophorolipid biosurfactant can control cutaneous dermatophytosis caused by Trichophyton mentagrophytes. Front Microbiol 11: 329.

56. Sen S, Siddhartha Narayan Borah, Hemen Sarma, Arijit Bora, Suresh Deka, et al. (2021) Utilization of distillers dried grains with solubles as a cheaper substrate for sophorolipid production by Rhodotorula babjevae YS3. Journal of Environmental Chemical Engineering 9(4).

57. Shikha S, Saumya Raychaudhuri, Mani Shankar Bhattacharyya (2020) Facile one pot greener synthesis of sophorolipid capped gold nanoparticles and its antimicrobial activity having special efficacy against Gram negative Vibrio cholerae. Scientific Reports 10(1).

58. Shikha, Vineet Kumar, Ankita Jain, Dipak Dutta, Mani Shankar Bhattacharyya, et al. (2023) Unraveling the mechanistic insights of sophorolipid-capped gold nanoparticle-induced cell death in Vibrio cholerae. Microbiolo Spectr 11(6): e0017523.

59. Silveira VAI, Renata Katsuko Takayama Kobayashi, Admilton Gonçalves de Oliveira Junior, Mario Sérgio Mantovani, Gerson Nakazato l, et al. (2021) Antimicrobial effects of sophorolipid in combination with lactic acid against poultry-relevant isolates. Braz J Microbiol 52(4): 1769-1778.

60. Silveira VAI, BG Bigotto, MC Gonçalves, C Baldo, S Mali, et al. (2024) Sophorolipid-mediated green synthesis of silver nanoparticles for antimicrobial starch nanocomposite films. Journal of Applied Polymer Science.

61. Solaiman DKY, Richard DA, Alberto N, Nicole C (2020) Low-temperature crystallization for separating monoacetylated long-chain sophorolipids: characterization of their surface-active and antimicrobial properties. Journal of Surfactants and Detergents.

62. To MH, Huaimin W, Yahui M, Guneet K, Sophie LKWR, et al. (2023) Optimal preparation of food waste to increase its utility for sophorolipid production by Starmerella bombicola. Bioresource Technology 379: 128993.

63. Totsingan F, Fei L, Richard AG (2021) Structure-activity relationship assessment of sophorolipid ester derivatives against model bacteria strains. Molecules 26(10): 3021.

64. Wang H, J Chen, X Liu (2023) A review on antimicrobial activity, anti-biofilm and synergistic effects of sophorolipids since their discovery. Applied Biochemistry and Microbiology.

65. Wang H, Ruifang G, Xin S, Xiangdong Y, Xiuli C, et al. (2024) Study on the production of Sophorolipid by Starmerella bombicola yeast using fried waste oil fermentation. Bioscience Reports 44(2): BSR20230345.

66. Wang H (2026) Sophorolipids: multifunctional microbial glycolipids with diverse bioactivities and applications. Biotechnology for Biofuels and Bioproducts.

67. Wongsirichot P, Winterburn J (2025) Recent advances in sophorolipid production: From laboratory to pilot scale and beyond. Journal of Cleaner Production.

68. Wongsirichot P, Gerard CB, Rebecca D, Javier GC, Robin H, et al. (2026) Current status of genetic engineering for sophorolipids production. Critical Reviews in Biotechnology.

69. Xu R, Ling M, Timson C, Jing W (2022) Sophorolipid suppresses LPS-induced inflammation in RAW264.7 cells through the NF-κB signaling pathway. Molecules 27(15): 5037.