



Review Article

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Palm Kernel Oil in Wound Healing and Dermal Repair: Unveiling the Therapeutic Promise of *Elaeis Guineensis* Kernel Extracts Through Preclinical Evidence and Ethnopharmacological Insights — A Review

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Abstract

Palm Kernel Oil (PKO), derived from the seed endosperm of *Elaeis guineensis* Jacq. (Arecaceae), represents a bioactive-rich vegetable oil that has been employed for centuries in traditional wound care practices across West Africa and parts of Southeast Asia. Despite its long ethnopharmacological history, a consolidated scientific synthesis of PKO's therapeutic potential for wound healing and dermal repair is lacking in the current literature. This narrative review synthesizes preclinical evidence and ethnopharmacological insights concerning PKO's role in facilitating wound healing and dermal repair, integrating findings from phytochemistry, pharmacology, and traditional medicine. PKO's dominant bioactive constituents — particularly lauric acid (~44.5%), tocotrienols, phytosterols, and squalene — collectively mediate antimicrobial, anti-inflammatory, antioxidant, and pro-proliferative activities relevant to all four phases of wound healing: hemostasis, inflammation, proliferation, and remodeling. *In vivo* studies demonstrate that topical PKO, particularly Black Palm Kernel Oil (BPKO) and Tocotrienol-Rich Fractions (TRF), significantly accelerates wound closure, reduces microbial bioburden, enhances fibroblast density and neovascularization, and promotes re-epithelialization in rodent models. Ethnopharmacological evidence from Nigeria, Ghana, and other sub-Saharan African communities corroborates these scientific findings, validating the traditional use of PKO for ulcers, burns, boils, and infected wounds. The review highlights critical research gaps, including the lack of standardized PKO preparations, the scarcity of human clinical trials, and the heterogeneity in preclinical study designs. Future directions include the development of nano-delivery systems incorporating PKO bioactives, the standardization of clinical protocols, and the systematic ethnopharmacological documentation. PKO is a promising, accessible, and affordable option for evidence-based wound care — especially in resource-limited settings.

Keywords: Palm kernel oil, Wound healing, *Elaeis guineensis*, Lauric acid, Tocotrienol, Dermal repair, Ethnopharmacology, Antimicrobial, Anti-inflammatory, Preclinical evidence

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Introduction

Background and Rationale

Wound healing is one of the most intricate and vital physiological processes in vertebrate biology, involving a precisely orchestrated cascade of cellular, molecular, and vascular events that restore tissue integrity following injury. Globally, wounds — ranging from acute traumatic injuries and surgical incisions to chronic ulcers associated with diabetes and vascular insufficiency

— impose an enormous burden on healthcare systems and affected individuals alike. In 2022, global wound care expenditure was estimated at \$148.65 billion, a figure that reflects the clinical complexity and resource-intensive nature of contemporary wound management. In Low- and Middle-Income Countries (LMICs), this burden is compounded by limited access to advanced wound dressings, high costs of conventional treatments, and the growing challenge of antimicrobial resistance [1-3]. In this context, plant-derived oils and natural bioactive substances have experienced a



renaissance as complementary and alternative therapeutic agents for wound care. Vegetable oils, in particular, occupy a historically significant and scientifically emerging space in dermatological and wound-healing therapeutics. Among the most promising of these is Palm Kernel Oil (PKO), extracted from the endosperm of the seed of *Elaeis guineensis* Jacq., commonly known as the African oil palm. This oil is botanically and compositionally distinct from Crude Palm Oil (CPO), which is derived from the mesocarp of the palm fruit. PKO is characterized by a high content of Medium-Chain Fatty Acids (MCFAs), predominantly lauric acid and myristic acid, complemented by minor but pharmacologically significant components including tocotrienols, phytosterols, and squalene [4-7].

The global palm oil industry — encompassing both CPO and PKO — is one of the most economically significant agricultural sectors, with Indonesia and Malaysia together controlling approximately 77% of global palm oil exports. The market was valued at approximately USD 73.40 billion in 2024 and is projected to reach USD 110.67 billion by 2033. Beyond its industrial and nutritional value, palm kernel oil has maintained a central role in the ethnopharmacological practices of West African communities for generations, serving as a topical agent for wound treatment, skin care, and infection management [8]. Despite this dual profile of economic importance and traditional therapeutic use, the scientific literature lacks a comprehensive narrative synthesis that specifically addresses PKO's role in wound healing and dermal repair from a unified preclinical and ethnopharmacological perspective. Most existing reviews either focus broadly on palm oil (including CPO and RPO), address singular aspects such as antimicrobial properties, or limit discussion to neonatal skin care. There is an urgent need for an integrative narrative review that consolidates and critically interprets the available preclinical evidence and ethnopharmacological insights pertaining specifically to PKO in wound healing and dermal repair [9-12].

Urgency of the Study

The convergence of several contemporary health challenges underscores the urgency of this review. First, the global Antimicrobial Resistance (AMR) crisis has severely limited the efficacy of conventional topical antibiotics in wound management, making natural antimicrobial agents such as PKO increasingly relevant as alternative or complementary wound care solutions. Lauric acid, the principal fatty acid constituent of PKO (~44.5%), has demonstrated broad-spectrum antimicrobial activity against key wound pathogens, including *Staphylococcus aureus* and *Escherichia coli*, through mechanisms distinct from those of conventional antibiotics, thereby offering the potential to circumvent existing resistance pathways [13-15].

Second, the burden of chronic non-healing wounds — particularly those associated with diabetes mellitus, venous insufficiency, and pressure injuries — continues to grow globally. Natural bioactive compounds with anti-inflammatory, antioxidant, and pro-regenerative properties represent promising candidates for addressing the biological dysfunctions that underpin chronic

wound pathogenesis. PKO's tocotrienols and phytosterols are well-positioned to modulate oxidative stress and inflammatory signaling pathways implicated in the chronification of chronic wounds [16-18].

Third, in LMICs where oil palm is widely cultivated — particularly Nigeria, Indonesia, Malaysia, Ghana, and Côte d'Ivoire — PKO is an affordable, readily available natural resource whose pharmacological potential remains significantly underexploited in formal wound care protocols. Scientific validation of PKO's wound-healing activities would directly support the translation of PKO into evidence-based, cost-effective wound care products accessible to resource-limited populations [19-20].

Objectives and Research Questions

This Narrative Review Pursues Three Primary Objectives:

(1) to synthesize the phytochemical and bioactive compositional profile of PKO with specific relevance to wound healing and dermal repair; (2) to critically evaluate and integrate preclinical evidence — including *in vitro* and *in vivo* animal studies — supporting PKO's wound healing and dermal repair activities; and (3) to examine and validate ethnopharmacological insights concerning the traditional use of PKO for wound and skin conditions.

The Review Addresses Four Central Research Questions:

(RQ1) What is the bioactive compositional profile of PKO relevant to wound healing and dermal repair? (RQ2) What preclinical evidence supports PKO's therapeutic activities in wound healing? (RQ3) How do ethnopharmacological practices involving PKO align with and complement scientific evidence? (RQ4) What are the molecular and cellular mechanisms through which PKO bioactives facilitate wound healing and dermal repair?

Literature Review: Conceptual and Theoretical Framework

Palm Kernel Oil: Botanical Origin, Production, and Chemistry

Botanical Description of *Elaeis Guineensis*: *Elaeis guineensis* Jacq. is a monocotyledonous plant belonging to the family Arecaceae (formerly Palmae), originating from the tropical rainforest belt of West and Central Africa. The species is a stout, single-stemmed perennial tree that can reach 20–30 meters in height under optimal growth conditions. It bears dense clusters of fruits at its leaf axils, each fruit consisting of a fibrous mesocarp surrounding a hard endocarp (shell) enclosing the kernel (seed endosperm) — the source of PKO. The palm produces two distinct oils: CPO from the mesocarp and PKO from the kernel, the latter of which is rich in lauric acid [21-24]. *Elaeis guineensis* occupies a central position in the lives and economies of traditional societies across West Africa, where virtually every part of the plant has been assigned specific cultural, medicinal, and nutritional functions. In West African traditional medicine, the kernel oil is distinguished from mesocarp oil both compositionally and in its applications; PKO is preferentially used for skin care, wound dressing, and antimicrobial applications owing to its distinct fatty acid profile. The plant has

been extensively cultivated in Southeast Asia — particularly Malaysia and Indonesia — since the early 20th century, making it the world's highest-yielding oilseed crop [25-28].

Extraction, Processing, And Grades of PKO: The extraction of PKO involves mechanical pressing or solvent extraction of the kernel after separation from the palm fruit mesocarp. The resulting oil may be processed to varying degrees, yielding crude palm kernel oil (CPKO), refined, bleached, and deodorized palm kernel oil (RBD-PKO), and uniquely pharmacologically rich black palm kernel oil (BPKO). BPKO, obtained through traditional hot-pressing without further refinement, retains higher concentrations of bioactive phenolics, tocotrienols, and other antioxidant compounds than refined variants. The extraction temperature significantly influences the bioactive profile: Hot-Pressed PKO (HPPKO) and Cold-Pressed PKO (CPPKO) differ substantially in their GC-MS profiles and pharmacological activities [29].

Fatty Acid Profile and Phytochemical Composition: The fatty acid composition of Malaysian CPKO reveals a dominance of saturated MCFAs, with lauric acid (C12:0) constituting approximately 44.5%, myristic acid (C14:0) at 16.9%, palmitic acid (C16:0) at 9.4%, and oleic acid (C18:1) at approximately 18.0%. This MCFA-rich profile — with over 85% saturated fatty acids — distinguishes PKO from most other vegetable oils and constitutes the primary basis for its antimicrobial activity. The favorable positioning of lauric acid at the sn-2 position of triglycerides in PKO further enhances its bioavailability and antimicrobial potency [30-32]. Beyond its fatty acid composition, PKO contains biologically significant quantities of tocotrienols (predominantly α -, γ -, and δ -tocotrienols), tocopherols, phytosterols (β -sitosterol, campesterol, stigmasterol), and squalene. Phytochemical analyses have also identified saponins, phenolics, tannins, alkaloids, and flavonoids in PKO extracts, which collectively contribute to its antimicrobial, antioxidant, and anti-inflammatory activities. These bioactive constituents, individually and synergistically, provide the pharmacological basis for PKO's wound healing activities [33-35].

Wound Healing: Pathophysiology and Mechanisms

Phases of Wound Healing: Wound healing is a complex, dynamic, and tightly regulated biological process conventionally described as proceeding through four overlapping and sequential phases: hemostasis, inflammation, proliferation, and remodeling. The hemostasis phase, occurring within minutes of injury, involves platelet aggregation, activation of the coagulation cascade, and formation of a fibrin clot that serves as a temporary physical barrier and structural scaffold for subsequent cellular events. Platelets release critical growth factors, including Platelet-Derived Growth Factor (PDGF), Transforming Growth Factor-Beta (TGF- β), and Vascular Endothelial Growth Factor (VEGF), initiating the recruitment of immune cells to the wound site [36-38]. The inflammatory phase (days 1-3 in acute wounds) involves the recruitment and activation of neutrophils, monocytes, and macrophages to the wound site. Neutrophils provide the first line of antimicrobial defense through phagocytosis and the

production of Reactive Oxygen Species (ROS). At the same time, macrophages orchestrate the transition between inflammation and proliferation through polarization from the pro-inflammatory M1 phenotype to the pro-regenerative M2 phenotype. Dysregulation of the inflammatory phase — particularly when pro-inflammatory cytokines (TNF- α , IL-1 β , IL-6) remain persistently elevated — contributes to wound chronification [39-41]. The formation of granulation tissue, angiogenesis, wound contraction, and re-epithelialization characterizes the proliferative phase (days 4-12). Fibroblasts migrate into the wound bed and synthesize collagen (initially type III, later replaced by type I during remodeling), while keratinocytes migrate from wound edges to re-form a functional epidermis. The final remodeling phase, extending from weeks to over a year post-injury, involves the replacement of type III collagen with the stronger type I collagen and the progressive restoration of tensile strength — ultimately yielding a scar or fully regenerated tissue, depending on wound characteristics and treatment [42-44].

Cellular and Molecular Mediators: The cellular orchestra of wound healing involves intricate paracrine and autocrine signaling networks. Fibroblasts are the principal ECM-producing cells in the proliferative phase, secreting collagen, fibronectin, and hyaluronic acid to form the granulation tissue scaffold. Keratinocytes are responsible for re-epithelialization; their migration, proliferation, and differentiation are stimulated by Epidermal Growth Factor (EGF), Keratinocyte Growth Factor (KGF), and fibroblast-derived paracrine signals. Macrophages regulate angiogenesis through VEGF secretion, and their transition from the M1 to M2 phenotype marks the shift from inflammation to tissue repair [45,46]. At the molecular level, Matrix Metalloproteinases (MMPs) — particularly MMP-1, MMP-8, and MMP-9 — degrade damaged ECM components to create space for new tissue formation while their activity is counter-regulated by Tissue Inhibitors of Metalloproteinases (TIMPs). TGF- β 1 plays a central role in fibroblast differentiation, collagen synthesis, and scar formation. VEGF and PDGF-BB are essential for angiogenesis and fibroblast recruitment, respectively. At physiological levels, reactive oxygen species act as second messengers that promote cell proliferation, whereas excess ROS impairs healing [47].

Skin Barrier Function and Dermal Repair: The skin barrier is constituted primarily by the stratum corneum, a stratified structure of cornified keratinocytes embedded in a lipid-rich matrix comprising ceramides, cholesterol, and free fatty acids. Disruption of this barrier — as occurs in wounds, burns, dermatitis, and xerosis — leads to elevated Transepidermal Water Loss (TEWL), increased susceptibility to microbial invasion, and impaired dermal repair. Natural lipid-rich substances, including plant-derived oils containing MCFAs and antioxidants, can restore barrier function by replenishing the lipid matrix, reducing TEWL, and providing antimicrobial protection to healing skin [48,49]. The role of fatty acids in skin barrier integrity is well-established: saturated fatty acids form part of the structural ceramide backbone, while unsaturated fatty acids contribute to membrane fluidity. MCFAs in PKO — particularly lauric acid — possess unique amphiphilic

properties that confer simultaneous lipophilic and antimicrobial functionalities relevant to wound-site membrane repair. Squalene, a component of PKO's unsaponifiable fraction, exhibits emollient properties and reduces transepidermal water loss, further supporting barrier restoration during dermal repair [50,51].

Ethnopharmacology: Theoretical Foundations

Definition and Scope of Ethnopharmacology: Ethnopharmacology, as defined in the scientific literature, is the interdisciplinary study of the empirical knowledge possessed by ethnic groups regarding the medicinal properties of plants, animals, fungi, and minerals — with the overarching aim of scientifically validating and translating traditional therapeutic claims into evidence-based practice. Ethnopharmacological knowledge systems represent millennia of accumulated empirical observation and represent an invaluable resource for identifying novel therapeutic agents, particularly in under-researched bioactive spaces such as African medicinal plants. The systematic documentation and scientific validation of ethnopharmacological claims constitute an important pathway for drug discovery from natural sources [52,53].

Traditional Uses of PKO in African and Asian Cultures: In West Africa, *Elaeis guineensis* occupies a position of unparalleled cultural and medicinal significance. Traditional healers and community members across Nigeria, Ghana, Cameroon, and Côte d'Ivoire use PKO and BPKO as topical agents to treat infected wounds, burns, ulcers, boils, and skin abscesses. Ethnopharmacological surveys in Nigeria have documented that approximately 1,000 family units utilize PKO as a transdermal carrier and topical antimicrobial for febrile infections and wound management, often in combination with other plant-derived materials. In Southeast Nigeria's Southeast-South geopolitical zones, BPKO is traditionally applied directly to wounds and is valued for its purported ability to reduce infection and accelerate healing [21,22]. In Southeast Asia — particularly in Cameroon, Nigeria, and neighboring West African nations — PKO is employed empirically in neonatal skin care as a protective emollient to prevent TEWL and maintain skin integrity in newborns. A review confirmed that PKO is widely used in neonatal settings as an emollient with demonstrable moisturizing effects, although its roles in preventing fatty acid deficiency and supporting neurological development remain areas of ongoing investigation. This cross-cultural and multi-generational usage of PKO for dermal care provides a robust ethnopharmacological basis for scientific investigation [54].

Methods

Study Design: Qualitative Narrative Literature Review

This study employs a qualitative narrative literature review design, deliberately selected for its epistemological compatibility with the research questions' multidisciplinary, exploratory nature. A narrative review offers flexibility in integrating heterogeneous study types — encompassing *in vitro* phytochemical analyses, *in vivo* animal pharmacology studies, ethnopharmacological surveys, and formulation research — within a coherent thematic synthesis. This

approach is particularly appropriate for topics where the evidence base is still developing and where conceptual synthesis, hypothesis generation, and identification of research gaps are primary goals rather than meta-analytic quantification of effect sizes [55].

Distinction from Systematic Literature Review

A Systematic Literature Review (SLR) employs a rigorously pre-specified protocol, standardized inclusion/exclusion criteria, risk-of-bias assessment tools, and — where feasible — quantitative meta-analysis to answer a focused clinical or empirical question. While SLRs offer high reproducibility and minimize selection bias, they are constrained in their ability to synthesize interdisciplinary bodies of literature involving methodologically diverse study designs. The present topic — PKO in wound healing and dermal repair — involves a heterogeneous literature spanning preclinical animal studies, *in vitro* cell assays, ethnopharmacological surveys, and phytochemical characterization studies that are not amenable to the uniform quality assessment and meta-analytic synthesis required by SLR methodology [56].

The narrative approach adopted here follows the IMRAD (Introduction, Methods, Results, and Discussion) structure advocated for narrative reviews as the preferred format ensuring scholarly rigor while retaining analytical flexibility. This mirrors the qualitative research methodology recommended in narrative review guidelines, in which thematic analysis of the synthesized literature drives the generation of insights that go beyond the simple aggregation of findings [57,58].

Search Strategy and Database Selection

Literature searches were conducted across multiple academic databases, including PubMed/MEDLINE, Scopus, Web of Science, Google Scholar, PubMed Central (PMC), ScienceDirect, Frontiers (multiple disciplinary journals), and the Journal of Ethnopharmacology. Additional sources included the Malaysian Palm Oil Board's Journal of Oil Palm Research (JOPR) and regional pharmacology journals from West Africa. Searches covered the period from January 2020 to April 2026, with the exception of foundational studies pre-dating 2020 that were included when they constituted primary, irreplaceable evidence for established claims.

Key search terms included, individually and in combination: "palm kernel oil," "*Elaeis guineensis*," "wound healing," "dermal repair," "skin barrier," "lauric acid," "ethnopharmacology," "antimicrobial," "anti-inflammatory," "antioxidant," "tocotrienol," "phytosterol," "TEWL," "collagen," "fibroblast," "keratinocyte," "VEGF," "TGF- β ," "NF- κ B," "Nrf2," "preclinical," "*in vivo*," "*in vitro*," "rat model," "burn wound," "excision wound," "neonatal skin care," "Black Palm Kernel Oil," "palm TRF," and "palm oil traditional medicine." Boolean operators AND/OR were employed to optimize search precision.

Thematic Analysis Framework

Following iterative searches and full-text screening of relevant articles, thematic analysis was conducted using an interpretive framework informed by Braun and Clarke's reflexive thematic

analysis methodology. Articles were analyzed for the following extraction domains: (1) bioactive composition and phytochemical characterization of PKO; (2) mechanisms of action relevant to wound healing; (3) preclinical outcomes in wound models (wound closure rate, microbial load, histopathological parameters); (4) dermal repair and skin barrier properties; (5) ethnopharmacological uses and their alignment with scientific evidence; and (6) formulation and delivery considerations. Four primary themes emerged from this analysis, forming the structure of the Results section [59].

Results: Thematic Findings

Theme 1: Bioactive Composition of PKO Relevant to Wound Healing

Medium-Chain Fatty Acids: Lauric and Myristic Acids as Primary Bioactive Drivers: Lauric acid (C12:0), constituting approximately 44.5% of PKO's total fatty acid content, emerges consistently across the literature as the principal bioactive driver of PKO's antimicrobial, emollient, and barrier-supportive properties relevant to wound healing. As a MCFA with a 12-carbon chain, lauric acid occupies a pharmacologically privileged position: it is sufficiently lipophilic to penetrate microbial cell membranes but also soluble enough at physiological temperatures to exert systemic antimicrobial effects. Mechanistically, lauric acid disrupts bacterial cell membranes by intercalating into lipid bilayers, increasing membrane permeability, inhibiting membrane-bound enzyme systems, including glucosyltransferase, and ultimately causing lysis of both gram-positive and gram-negative bacterial cells [60-62]. Studies on lauric acid's antimicrobial activity against *Staphylococcus aureus* — one of the most clinically significant wound pathogens globally — demonstrate a Minimum Inhibitory Concentration (MIC) of 156 µg/mL, with scanning electron microscopy confirming structural disruption of bacterial cell morphology following LA treatment. The antimicrobial potency of lauric acid against *S. aureus*, *Streptococcus* species, *Candida albicans*, and common gram-negative organisms provides PKO with a broad-spectrum antimicrobial profile that directly addresses the challenge of wound infection. Furthermore, lauric acid incorporated into innovative delivery vehicles such as biomimetic pectin-based hydrogels has demonstrated wound contraction acceleration, neovascularization promotion, collagen production enhancement, and macrophage recruitment facilitation in diabetic wound models — demonstrating that PKO's primary fatty acid constituent possesses multi-modal wound healing activities even when isolated from the oil matrix [6,63-65]. Myristic acid (C14:0), comprising approximately 16.9% of PKO, reinforces the antimicrobial and emollient properties through its own MCFA-mediated membrane-disruptive mechanism and contributes to the crystalline structure of PKO's lipid phase that is relevant to sustained-release formulation applications. Palmitic acid (C16:0, ~9.4%) adds emollient, occlusive, and skin-sealing properties, preventing TEWL and supporting barrier function during the dermal repair process [66,67,68].

Tocotrienols and Tocopherols: Antioxidant and Anti-Inflammatory Potency: Palm oil is uniquely characterized by its

high tocotrienol content, which accounts for approximately 65–70% of its total vitamin E fraction — a proportion unmatched by most other vegetable oils. PKO, as a kernel-derived product sharing the biochemical heritage of the oil palm, contains tocotrienols (predominantly α -tocotrienol, γ -tocotrienol, and δ -tocotrienol) alongside tocopherols. Tocotrienols exhibit greater antioxidant potency than tocopherols — with increases in radical-scavenging efficiency of approximately 40–60% in comparative assays — owing to their unsaturated side chain that allows superior penetration into lipid membrane layers [69,70,71]. In the context of wound healing, tocotrienols exert anti-inflammatory effects primarily by directly inhibiting NF- κ B activation, thereby downregulating cyclooxygenase-2 (COX-2) expression and reducing the production of pro-inflammatory cytokines, including TNF- α and IL-6. *In vitro* studies using macrophage and keratinocyte cell lines have demonstrated that palm oil extracts suppress NF- κ B activation in a dose-dependent manner, with 50–100 µg/mL reducing TNF- α secretion by approximately 40%. This cytokine-modulatory capacity is highly relevant to wound healing because excessive and prolonged inflammation — driven by TNF- α , IL-6, and IL-1 β — is a primary mechanism underlying chronic wound chronification and impaired healing [72-74]. Tocotrienols also enhance endogenous antioxidant enzyme activity — including Superoxide Dismutase (SOD), Catalase (CAT), and Glutathione Peroxidase (GPx) — strengthening the wound microenvironment's capacity to manage ROS-mediated cellular damage. This antioxidant support is particularly critical in diabetic wounds, where elevated glucose-driven ROS production severely impairs fibroblast and keratinocyte function. The collective anti-inflammatory and antioxidant activities of palm tocotrienols, present in PKO, thus address two of the most fundamental pathological drivers of impaired wound healing [75].

Phytosterols, Squalene, and Other Bioactive Minor Constituents: Phytosterols (β -sitosterol, campesterol, stigmasterol) in PKO contribute to restoring skin lipid barrier integrity by integrating into the lipid bilayer of the stratum corneum, modulating membrane fluidity, and supporting immune-regulatory functions through steroid hormone receptor signaling pathways. Squalene, a triterpene present in PKO's unsaponifiable fraction, functions as a natural emollient with strong affinity for skin lipids; it is rapidly and efficiently absorbed into the dermal layers, restoring skin suppleness without leaving an occlusive residue, and has been shown to reverse elevated TEWL in sodium lauryl sulfate-challenged skin models. In the context of wound healing, squalene provides antioxidant protection by scavenging singlet oxygen, reducing lipid peroxidation, and supporting barrier repair [76-78]. The phytochemical profile of PKO further includes saponins, phenolics, tannins, and alkaloids, which collectively contribute to antimicrobial, astringent, and tissue-protective activities reported in ethnopharmacological applications. A 2025 GC-MS analysis of PKO extracts identified twelve bioactive compounds in hot-pressed PKO, with 9,12-octadecadienoic acid methyl ester as the highest-percentage compound (48.19%), alongside compounds with alcohol, carboxylic acid, amine, and aromatic functional groups with

pharmacological relevance. This compositional richness positions PKO as a multi-constituent pharmacological agent whose wound healing effects likely arise from synergistic interactions among its numerous bioactive components [34,79,80].

Theme 2: Preclinical Evidence of PKO in Wound Healing

In Vivo Animal Models: Burn and Excision Wound Studies:

The most direct preclinical evidence for PKO's wound healing activity comes from animal model studies employing standardized excision and burn wound models. A study published in the *World Journal of Pharmacy and Pharmaceutical Sciences (WJPPS)* in 2022 systematically evaluated the wound-healing effects of Black Palm Kernel Oil (BPKO) combined with cicatrin antibiotic powder in a Wistar rat model infected with *S. aureus* and *E. coli*. A total of 55 Wistar albino rats (both sexes, 80–100 g) were divided into 11 treatment groups of 5 animals each [29]. The results demonstrated significant reductions in microbial bioload accompanied by measurable wound contraction across all treatment groups from day 3 to day 19, with Group 4 (BPKO + cicatrin) exhibiting the most potent inhibitory activity — evidenced by complete absence of visible bacterial colonies and superior wound contraction. This study is particularly significant because it employed infected wound models that simulate the clinical reality of contaminated wounds, thereby directly evaluating PKO's antimicrobial and wound-healing activities under bacteriologically challenging conditions [29]. Earlier, foundational preclinical research reported that topical PKO achieved full closure of burn wounds in albino Wistar rats by day 8 post-treatment, compared to day 14 for shea butter and to povidone-iodine, a standard topical antiseptic, which achieved comparably rapid closure. This significant acceleration of burn wound closure with PKO treatment underscores the oil's potential as an affordable, readily available alternative to conventional wound care agents in resource-limited settings where povidone iodine may be inaccessible or cost-prohibitive [81].

Formulation and Wound Healing Evaluation of *E. guineensis* Extracts: A pivotal study published in the *Journal of Ethnopharmacology* evaluated the wound-healing activity of *E. guineensis* leaf extract (10% w/w ointment) in a *Staphylococcus aureus*-infected wound model in Sprague-Dawley rats [82]. The study assessed wound-healing activity using wound Closure Rate, Colony-Forming Unit (CFU) reduction, histological analysis of granulation tissue, and MMP expression. Results showed potent wound-healing activity, with significantly improved wound closure, a progressive reduction in microbial counts during the proliferative phase, and MMP expression profiles that were strongly correlated with the progression of tissue remodeling. While this study used leaf extract rather than kernel oil specifically, it corroborates the pleiotropic wound-healing pharmacology of *E. guineensis* as a species, including the anti-inflammatory, antibacterial, and tissue-regenerative properties shared among extracts from different plant parts [83-85].

Palm Tocotrienol-Rich Fraction (TRF) Studies: Several well-designed preclinical studies focusing on Palm Tocotrienol-Rich

Fraction (TRF) — a component-enriched derivative obtainable from palm oil, including PKO — provide compelling mechanistic and efficacy evidence. A study published in *Food Research* evaluated the wound-healing potential of palm TRF in streptozotocin-induced Type 2 Diabetes (T2D) Wistar rats [47]. The TRF treatment group demonstrated 100% wound contraction by Day 10, compared to significantly slower closure in the untreated control and metformin-treated groups. TRF treatment elevated PDGF-BB levels (a critical growth factor for fibroblast recruitment and wound contraction initiation), reduced malondialdehyde (MDA — a marker of lipid peroxidation) levels, and stabilized blood glucose. This multimodal activity of palm TRF directly addresses the three principal wound-healing impairments in diabetes: oxidative stress, insufficient growth factor signaling, and hyperglycemia-related cellular dysfunction [47]. Complementing these findings, a study published in the *Journal of Oil Palm Research (JOPR)*, reported a comprehensive evaluation of topical palm TRF on cutaneous wound healing in type 2 diabetic mice. Full-thickness wounds were created on the mouse dorsa, and the TRF formulation was applied topically. The TRF-treated group showed enhanced wound Closure, Elevated Catalase (CAT) and Glutathione Peroxidase (GPx) activity, increased hydroxyproline (a collagen synthesis marker), elevated TGF- β 1 levels, and reduced MMP-9 production. Multiplex immunoassay revealed modulation of pro-inflammatory cytokines and chemokines, with increased IL-4 (anti-inflammatory) and VEGF production, and reduced GM-CSF, indicating a shift toward an anti-inflammatory, pro-angiogenic wound microenvironment favorable for healing. Histological analyses confirmed enhanced CD31-positive vessel formation (angiogenesis) and increased Masson's trichrome-positive collagen deposition in TRF-treated wounds [75]. Further evidence for the tocotrienol-wound healing axis in palm-derived oil comes from a comprehensive review in *Pharmaceutics*, which synthesized multiple studies demonstrating that palm-derived tocotrienols reduce scar formation, enhance wound closure, stimulate VEGF-mediated angiogenesis, and modulate the immune response toward a healing-permissive phenotype [16,86]. Notably, a pronosomal gel delivery system for palm TRF demonstrated promising topical delivery characteristics, including controlled release and enhanced stability — indicating the translational potential of PKO bioactives in pharmaceutical formulations [87,88].

In Vitro Cellular Studies: At the cellular level, lauric acid — as the primary bioactive constituent of PKO — demonstrates direct stimulatory effects on wound healing cell biology. A 2025 study in *Lasers in Medical Science* investigated lauric acid-loaded solid lipid nanoparticles (LT-SLNs) combined with photobiomodulation in an *in vitro* diabetic wound fibroblast model [89]. Results demonstrated that LT-SLNs combined with 830 nm photobiomodulation exhibited no cytotoxicity at 12.5 mg/mL, significantly enhanced wound closure dynamics, improved ATP production, and increased migratory activity in diabetic WS1 fibroblasts at both 24- and 48-hour time points. This study establishes that lauric acid, at concentrations achievable through PKO application, directly promotes fibroblast function critical for wound repair [89]. The

influence of vegetable oils on keratinocyte and fibroblast biology has been comprehensively examined [90,91]. While their primary focus was on oils rich in linoleic acid for keratinocyte proliferation, the study established that the biological activity of vegetable oils in wound healing depends primarily on their fatty acid composition, with different fatty acid types offering complementary cellular activities — a finding relevant to PKO's MCFA-rich profile and its cellular mechanism of action. Unsaponifiable compounds, including phytosterols and squalene, were found to promote keratinocyte migration through different pathways than fatty acids — suggesting that PKO's minor constituents contribute independently to dermal repair processes [92-94].

Theme 3: PKO in Dermal Repair and Skin Barrier Restoration

Emollient Properties and TEWL Reduction: PKO has been documented as an effective emollient that moisturizes skin, prevents Transepidermal Water Loss (TEWL), and maintains skin barrier function. A comprehensive review of neonatal skin care confirms PKO as one of the most commonly referenced natural oils in neonatal settings, valued for its emollient properties and its ability to prevent heat and water loss through immature epidermal barriers [95]. The empiric use of PKO in neonatal skin care across West Africa — particularly in Cameroon and Nigeria — reflects community-level validation of its barrier-supportive properties that have now been partially confirmed by scientific evaluation [95]. Benefits to natural oils on the epidermal permeability barrier have been demonstrated in the literature, with palm fruit oil pretreatment providing 22–62% reductions in TEWL compared to untreated controls in sodium lauryl sulfate-challenged skin. The emollient properties of lauric acid specifically contribute to PKO's skin barrier function: this MCFA acts as an antimicrobial lipid that protects against pathogenic colonization of compromised skin while also supporting the stratum corneum lipid matrix. The palmitic acid component (~9.4%) provides additional occlusive and sealing properties, further limiting TEWL at the wound site during the proliferative and remodeling phases [4-7].

Anti-Inflammatory Modulation in Skin Repair: The anti-inflammatory modulatory capacity of PKO's tocotrienol fraction is particularly relevant to dermal repair, where the controlled resolution of inflammation is prerequisite to the successful transition into the proliferative phase. *In vitro* studies using keratinocyte cell lines demonstrate that palm oil extracts protect keratinocytes from UV- and chemically induced oxidative stress, reducing intracellular oxidative radicals by 25–40% at concentrations of 50–100 µg/mL. This oxidative protection of keratinocytes is directly relevant to dermal repair, as keratinocyte survival and function are essential for epidermal reformation during wound healing [32,96,97]. Tocotrienols from palm oil suppress NF-κB activation and COX-2 expression in epidermal cells, thereby reducing pro-inflammatory cytokine levels (IL-6, TNF-α) that contribute to dermal inflammation and impair the skin's regenerative microenvironment. The 2022 study demonstrated that red palm oil (which shares key bioactive constituents with PKO,

particularly tocotrienols and tocopherols) modulates both NF-κB and Nrf2/GCL/HO-1 signaling pathways *in vivo*, thereby reducing inflammatory markers and enhancing antioxidant defense [98]. This dual-pathway modulation — simultaneously targeting both pro-inflammatory (NF-κB) and antioxidant defense (Nrf2) pathways — represents a pharmacologically sophisticated anti-inflammatory mechanism highly relevant to dermal repair and wound healing [98,99]. The *E. guineensis* leaf extract study by Uwamusi (2025, RPSP&PR) confirmed significant anti-inflammatory activity of the plant, with methanol extract showing dose-dependent inhibition of egg albumin-induced acute inflammation at 200 mg/kg, and hexane and ethyl acetate fractions demonstrating the highest specific anti-inflammatory activities. This pharmacological confirmation of *E. guineensis* anti-inflammatory properties across multiple plant fractions corroborates the relevance of PKO's tocotrienol and phytosterol components to inflammation modulation in skin repair contexts [100].

Antimicrobial Protection in Wound and Dermal Repair: Infection is among the most devastating complications of wound healing, capable of converting acute wounds into chronic non-healing conditions and contributing significantly to morbidity and mortality. PKO's antimicrobial properties — primarily mediated by its high lauric acid content — provide a critical layer of protection against this complication. A 2021 study in Scientific Reports demonstrated *in vitro* antagonistic inhibitory effects of crude palm seed oils and their main constituent, lauric acid, against *S. aureus*, including methicillin-resistant strains [101]. While an antagonistic interaction with oxacillin was observed in this study, the fundamental antimicrobial activity of crude palm seed oils and lauric acid against *S. aureus* was clearly established [102]. The 2024 study in SAJRM demonstrated the antimicrobial activity of PKO against uropathogens using agar well diffusion, providing direct evidence of PKO's activity against Gram-negative organisms relevant to wound infection [63]. Antimicrobial activity of *E. guineensis* ethanol extracts of leaves against *P. acnes*, *S. aureus*, *Malassezia furfur*, and *C. albicans* — all common skin pathogens implicated in wound infections and dermatological conditions — was demonstrated at concentrations of 10–50%, with the highest antibacterial activity against *P. acnes* (15.81 mm inhibition zone) and *S. aureus* (13.68 mm) at 50% extract concentration [103]. A 2025 study further confirmed significant antimicrobial activity (14.2 ± 0.2 mm inhibition) of *E. guineensis* peel ethanol extracts, with *in silico* molecular docking identifying compounds with higher binding scores than ciprofloxacin [79].

Theme 4: Ethnopharmacological Insights and Traditional Knowledge

Documented Traditional Uses of PKO: The ethnopharmacological literature consistently documents the central role of *E. guineensis* and PKO specifically in traditional wound care practices across West and Central Africa. A 2019 study on indigenous traditional knowledge documented the multifaceted medical applications of *E. guineensis* in sub-Saharan African communities, including the treatment of wounds, boils,

ulcers, fractures, and skin infections [104]. Ritual and medicinal uses of palms documented in 2014 confirmed that virtually all parts of the oil palm are employed in traditional medicine across sub-Saharan Africa, with the kernel oil used specifically for dermatological and wound-care applications [105]. An important ethnopharmacological study on the hypothesized biochemical modes of action of palm oils used in ethno-medicine proposed three principal mechanisms through which PKO exerts its traditional wound healing activities: (1) antimicrobial activity mediated by lauric acid and its monoglyceride (monolaurin) through membrane disruption of skin pathogens; (2) transdermal transport of bioactive antifebrile and anti-infective compounds through the skin barrier; and (3) formation of a protective lipid matrix at the wound surface that reduces microbial contamination while maintaining moisture. These hypothesized mechanisms are strongly supported by the preclinical and phytochemical literature reviewed in this article [106].

Neonatal Skin Care as a Case Study in Traditional-to-Clinical Translation: The empiric use of PKO in neonatal skin care in West Africa — particularly in Nigeria and Cameroon — represents perhaps the best-documented case of PKO's dermal applications moving from traditional practice into clinical awareness, with evidence supporting this practice. They concluded that PKO is a good emollient with demonstrable moisturizing effects and capacity to prevent transdermal heat and water loss in neonates — providing partial scientific justification for the widespread traditional practice [54]. A scoping review of neonatal and infant skin care reported the use of natural oils, including PKO, in neonatal settings and highlighted the need for evidence-based guidance on their use in vulnerable pediatric populations [95]. The translation of this traditional neonatal practice into clinical contexts illustrates the broader potential of PKO as a dermal care agent — demonstrating that, with appropriate scientific validation, ethnopharmacologically rooted practices can inform evidence-based dermatological interventions accessible to resource-limited communities [20].

African Oils in Dermatology: Bridging Traditional and Modern Knowledge: A landmark review in *Dermatologic Therapy* — the most comprehensive peer-reviewed synthesis of African oils in dermatological applications available to date — positioned PKO as one of the key traditional oils used in Nigeria for a spectrum of skin conditions, including dry skin, wounds, infections, and burns [107]. The review documented that PKO's constituents — free fatty acids, triglycerides, phytosterols, vitamins, and antioxidants — collectively support skin barrier function, wound healing, and antimicrobial and anti-inflammatory activities. This landmark synthesis provides significant clinical and scientific legitimacy to the traditional use of PKO in African dermatological practice, establishing a foundation for further research and potential clinical adoption [107]. The role of African medicinal plants in cutaneous wound repair was comprehensively examined in the *International Wound Journal*, which reviewed the phytochemical contributions of African-origin plants to wound healing and established that

antimicrobial, anti-inflammatory, antioxidant, and pro-angiogenic phytochemicals constitute the primary mechanistic basis for the activities of traditional African wound-healing plants. The overlap between PKO's documented phytochemical profile and these established wound-healing mechanisms strongly supports the scientific credibility of PKO's ethnopharmacological wound-care applications [108].

Discussion and Analysis

Synthesis of Bioactive Mechanisms: An Integrated Perspective on PKO's Wound Healing Activity

The thematic findings presented above collectively support a multimodal mechanistic model of PKO's wound-healing activities. PKO exerts its beneficial effects across all four phases of wound healing through complementary bioactive mechanisms: (1) in the hemostatic phase, the lipophilic constituents of PKO — particularly phytosterols and fatty acids — contribute to wound surface sealing and create conditions favorable for platelet aggregation and fibrin network formation; (2) in the inflammatory phase, tocotrienols suppress excessive NF- κ B activation and reduce TNF- α and IL-6, facilitating timely resolution of inflammation and progression to the proliferative phase; (3) in the proliferative phase, PDGF-BB stimulation by tocotrienols, VEGF induction, enhanced fibroblast migration, collagen synthesis support, and antimicrobial protection by lauric acid collectively accelerate granulation tissue formation and re-epithelialization; and (4) in the remodeling phase, antioxidant protection by tocotrienols and tocopherols reduces oxidative damage to newly formed collagen fibers, supporting optimal scar tissue quality and minimizing pathological scarring [75]. This integrated, multi-phase activity of PKO is particularly compelling when considered in the context of chronic wounds, which are characterized by pathological staling during the inflammatory phase, concurrent oxidative stress, bacterial contamination, and inadequate growth factor signaling. PKO's simultaneous anti-inflammatory, antioxidant, antimicrobial, and pro-proliferative capacities address multiple wound-healing impairments — a therapeutic profile that is difficult to replicate with single-agent conventional treatments [90,91,109,110].

Ethnopharmacological Validation and the Science-Tradition Interface

The convergence between ethnopharmacological claims and preclinical scientific evidence for PKO is striking and scientifically significant. Traditional uses of PKO for infected wounds, burns, boils, and skin ulcers across West Africa are supported by preclinical evidence of antimicrobial activity (lauric acid against *S. aureus*, *E. coli*, and *Candida*), accelerated burn wound closure in animal models, and anti-inflammatory modulation relevant to infected wound environments. This convergence validates the ethnopharmacological knowledge system as an empirically robust, if not formally validated, therapeutic framework — and strongly suggests that PKO's traditional wound care applications are biologically rational [81]. However, translating ethnopharmacological evidence into clinical recommendations

requires bridging significant knowledge gaps. Key among these are: (1) the absence of standardized preparations used in traditional practice — BPKO used traditionally is not equivalent to RBD-PKO used in commercial settings, and the pharmacological significance of this difference has not been systematically evaluated; (2) the lack of dose-response data for topical PKO application in human wound models; and (3) the relative scarcity of mechanistic studies that specifically attribute wound healing outcomes to PKO as a whole versus its individual constituent fractions. Addressing these gaps is essential for the responsible translation of PKO from traditional use to evidence-based clinical wound care. repository [1,96,111-113].

Comparative Positioning: PKO among Plant Oils for Wound Care

In the broader landscape of plant-derived oils investigated for wound healing and dermal repair, PKO occupies a distinctive position defined by its MCFA-rich profile. Compared to Virgin Coconut Oil (VCO) — the plant oil with the most extensive wound healing evidence base and a similarly high lauric acid content (46–54%) — PKO offers a comparable antimicrobial and emollient profile while differing in its tocotrienol richness, which provides additional anti-inflammatory and antioxidant benefits specific to palm-derived oils. A WHAM evidence summary reviewed evidence for topical coconut products. It confirmed VCO's efficacy for xerosis, psoriasis, and neonatal skin care, while noting a lack of evidence for clinical wound healing. This gap equally applies to PKO and underscores the urgent need for clinical trials across both oils [19,114].

Compared to shea butter — another widely used African traditional wound care agent — PKO demonstrated superior burn wound healing speed in at least one animal study (full closure by day 8 versus day 14 for shea butter), suggesting that the MCFA profile of PKO confers specific advantages over the predominantly unsaturated fatty acid profile of shea butter. In the context of the comprehensive review of vegetable butters and oils in skin wound healing in *Phytotherapy Research*, PKO is positioned among oils with strong antimicrobial and barrier-supporting properties relevant to wound care, sharing characteristics with coconut oil while offering unique tocotrienol-mediated anti-inflammatory benefits [90,91].

Against the backdrop of African oils in dermatology, PKO stands out for its accessibility, affordability, and broad traditional use, making it particularly promising for wound care applications in LMICs, where palm cultivation provides a domestic, sustainable supply of the oil [107]. The economic significance of the global palm oil industry — valued at USD 73.40 billion in 2024 and projected to reach USD 110.67 billion by 2033 — further supports the feasibility of scaling PKO-based wound care products should clinical evidence validate their efficacy [115].

Pharmaceutical Development Opportunities: Formulation and Delivery Innovations

The pharmacological potential of PKO is complemented by promising opportunities in pharmaceutical formulation. Palm

Kernel Oil Esters (PKOEs) have been extensively studied as vehicles for topical drug delivery, with nanoemulsions and Nanostructured Lipid Carriers (NLCs) based on PKOEs demonstrating favorable droplet sizes, zeta potentials, and *in vitro* release profiles for drugs including ibuprofen and sodium diclofenac. These delivery systems leverage PKO's favorable physicochemical properties — including its specific melting range, high stability, and skin permeation-enhancing fatty acids — to optimize topical drug delivery [116,117,118].

In the context of wound healing, NLC-based wound dressings containing active wound-healing agents have demonstrated faster wound closure, increased epithelial regeneration, enhanced angiogenesis, and improved collagen synthesis across multiple preclinical models. The integration of PKO's wound-healing bioactives (particularly tocotrienols and lauric acid) into NLC or nanoemulsion platforms represents a high-potential formulation strategy that could significantly enhance the therapeutic efficacy of PKO's native constituents. A proniosomal gel formulation for palm TRF delivery, recently evaluated by *Bunyamanop et al.*, (2025, *JAPS Online*), demonstrated promising TRF encapsulation efficiency and controlled topical release — illustrating the emerging pharmaceutical innovation landscape around palm-derived bioactives [67,119,120].

Limitations of Current Evidence and Research Priorities

A balanced assessment of the evidence base for PKO's wound-healing activities requires a candid acknowledgment of its current limitations. First, the heterogeneity of preclinical study designs — varying in animal species (Wistar rats, Sprague-Dawley rats, mice), wound models (burn, excision, infected, diabetic), PKO preparation types (BPKO, TRF, CPKO, leaf extracts), treatment durations, and outcome measures — makes direct cross-study comparison difficult and limits the strength of conclusions. Second, the absence of standardized PKO preparations with defined and verified bioactive compositions is a significant methodological weakness that must be addressed in future research [121]. Third, a small number of *in vitro* studies have produced conflicting antimicrobial results — for example, one phytochemical study found no antimicrobial activity of PKO against MRSA and *E. coli* in a standard laboratory setting, in contrast to the broader body of positive antimicrobial evidence. These conflicting findings may reflect differences in PKO extraction methods, concentrations tested, testing methodologies, and specific PKO grades — underscoring the need for standardization. Fourth, and most critically, the absence of Phase I/II clinical trials in human wound patients remains the most significant gap separating PKO's promising preclinical profile from clinical applicability [19,20].

Conclusion

Substantive Conclusions

This narrative review has synthesized preclinical evidence and ethnopharmacological insights across the four thematic domains relevant to PKO's role in wound healing and dermal repair, and several substantive conclusions emerge from this

synthesis. First, the bioactive compositional profile of PKO — particularly its high lauric acid content (~44.5%), tocotrienol-rich vitamin E fraction, phytosterols, and squalene — provides a robust pharmacological basis for multimodal wound-healing activities spanning antimicrobial protection, anti-inflammatory modulation, antioxidant defense, proliferative cell support, and barrier restoration. The scientific plausibility of PKO's wound healing properties is firmly established at the phytochemical level. Second, preclinical evidence — while heterogeneous and not yet definitive — consistently supports the wound-healing and dermal-repair activities of PKO and its key constituents. BPKO demonstrates significant acceleration of wound closure and reduction of microbial bioburden in infected wound models; palm TRF enhances diabetic wound closure through PDGF-BB, VEGF, and antioxidant enzyme-mediated mechanisms; lauric acid directly promotes fibroblast proliferation and migration while exerting broad-spectrum antimicrobial activity against key wound pathogens; and *E. guineensis* extracts consistently demonstrate wound healing enhancement across multiple animal models and histopathological parameters. Third, ethnopharmacological evidence for PKO's wound-healing applications is extensive and multicultural, demonstrating strong convergence with scientific findings — providing cross-validation of PKO's therapeutic properties through independent knowledge systems. The traditional use of PKO for infected wounds, burns, and skin conditions across West Africa is directly supported by preclinical studies documenting antimicrobial, anti-inflammatory, and wound-healing activities — a convergence that powerfully validates both the ethnopharmacological knowledge system and the scientific evidence base.

Fourth, PKO occupies a distinctive and favorable position among plant-derived wound-healing oils: its MCFA-rich profile confers antimicrobial and emollient properties comparable to VCO. At the same time, its palm-specific tocotrienol content provides anti-inflammatory and antioxidant benefits that extend beyond those of most other plant oils. As a product of the globally significant oil palm industry, PKO offers exceptional scalability and affordability as a wound care agent in LMICs — a critical dimension given the economic burden of chronic wound management in these settings.

Research Recommendations

Based on the evidence synthesized in this review, the following research recommendations are proposed:

- a. Standardization of PKO Preparations for Pharmacological Research:** Future studies must employ precisely characterized PKO preparations — with full GC-MS fatty acid profiles, tocotrienol quantification, and phytosterol content — to enable meaningful cross-study comparisons and dose-response determinations.
- b. Development of Standardized Chronic Wound Preclinical Models:** Research should expand beyond acute burn and excision models to systematically evaluate PKO in

chronic wound models — including streptozotocin-induced diabetic wound models, venous insufficiency models, and pressure injury models — to build evidence relevant to the clinically most burdensome wound types.

c. Mechanistic Elucidation of PKO's Molecular Pharmacology: Dedicated mechanistic studies should systematically investigate PKO's effects on NF- κ B/Nrf2 signaling, MMP regulation, growth factor expression (VEGF, PDGF, TGF- β 1), macrophage polarization, and collagen maturation — ideally using standardized PKO fractions to attribute specific activities to defined constituents.

d. Clinical Translation Through Phase I/II Trials: The most critical research priority is the development and execution of well-designed clinical trials evaluating the safety, tolerability, and preliminary efficacy of standardized PKO formulations in defined wound populations — beginning with Phase I safety studies followed by Phase II efficacy assessments in burns, diabetic wounds, and xerotic conditions in resource-limited settings.

e. Formulation Innovation for Enhanced Bioavailability: Continued development of PKO-based nano-delivery platforms (NLCs, nanoemulsions, proniosomal gels, lauric acid-loaded hydrogels) should be pursued to optimize skin penetration, sustained release, and bioavailability of PKO's key wound healing constituents.

f. Systematic Ethnopharmacological Documentation: Comprehensive ethnobotanical surveys documenting PKO use for wound healing across diverse West African, Southeast Asian, and South American communities — with standardized ethnopharmacological protocols — should be prioritized to build a comprehensive, cross-culturally validated knowledge base for PKO's therapeutic applications.

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Conflict of Interest

None.

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