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Comparative Evidence on the Topical Wound-Healing Potential of Sap, Stem Bark, and Leaves of *Pterocarpus indicus*: A Narrative Review

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Abstract

Skin wounds require coordinated control of inflammation, oxidative stress, microbial contamination, and tissue regeneration. *Pterocarpus indicus* has traditionally been used for inflammatory, infectious, and skin-related conditions, but the relative suitability of its sap, stem bark, and leaves for topical wound-healing development remains unclear. This narrative review comparatively evaluated the phytochemical characteristics, pharmacological activities, direct wound-healing evidence, processing considerations, safety, and sustainability of these three plant parts. Relevant literature was identified through Scopus, PubMed, Web of Science, ScienceDirect, and Google Scholar, with priority given to phytochemical, in vitro, and in vivo studies. The reviewed evidence indicates that sap, stem bark, and leaves are pharmacologically distinct and should not be considered interchangeable materials. Stem bark currently provides the most direct wound-specific evidence through preclinical evaluation of re-epithelialization, although the findings remain preliminary and do not demonstrate superiority over the reference treatment. Leaves are supported mainly by antioxidant and antibacterial activities associated with flavonoids, terpenoids, and other secondary metabolites, whereas direct evidence for wound contraction and histopathological recovery remains insufficient. Sap contains flavonoids and has plausible astringent and antibacterial potential, but its chemical standardization, effective topical dose, dermal safety, formulation stability, and direct effects on tissue regeneration have not been adequately established. Consequently, none of the three plant parts can currently be considered definitively superior. Standardized head-to-head studies using equivalent doses, identical topical vehicles, relevant wound models, and integrated macroscopic, histopathological, microbiological, and safety outcomes are required to determine their comparative therapeutic value and translational feasibility.

Keywords : *Pterocarpus Indicus; Sap; Stem Bark; Leaves; Topical Wound Healing*

INTRODUCTION

Skin wounds disrupt the anatomical integrity and physiological barrier function of the skin, exposing underlying tissues to microbial contamination, fluid loss, and further tissue damage. The severity of these consequences is influenced by the depth, extent, cause, and condition of the wound. Once the skin barrier is damaged, resident microorganisms and opportunistic pathogens may colonize the wound surface and interfere with tissue restoration. An imbalanced wound microbiota can promote infection, persistent inflammation, and additional tissue destruction, ultimately delaying recovery. Therefore, wound management requires interventions that protect the injured area while supporting restoration of the skin structure and function (Armato & Freddi, 2021; Uberoi et al., 2024).

Wound healing is a coordinated biological process involving hemostasis, inflammation, proliferation, and tissue remodeling. During these overlapping phases, inflammatory cells remove damaged tissue and microorganisms, fibroblasts produce extracellular matrix components, new blood vessels develop, and keratinocytes restore the epithelial layer. Collagen deposition and subsequent matrix remodeling gradually increase the structural strength of the repaired tissue. These processes are regulated by cytokines and growth factors that control cellular migration, proliferation, angiogenesis, re-epithelialization, and extracellular-matrix formation. Disruption of this coordinated response may result in delayed wound closure, chronic wounds, or incomplete tissue regeneration (Peña & Martin, 2024).

Microbial infection, excessive oxidative stress, and prolonged inflammation are major factors that impair normal wound healing. Pathogenic microorganisms may form biofilms and release enzymes that damage tissue and reduce the effectiveness of antimicrobial treatment. Excessive production of reactive oxygen species can injure cells, degrade extracellular-matrix components, and disturb signaling pathways required for tissue repair. Persistent inflammation can also inhibit fibroblast activity, collagen formation, angiogenesis, and re-epithelialization. These factors are closely interconnected because microbial persistence can increase inflammatory and oxidative responses, while damaged tissue may create conditions that support further microbial growth. Topical agents with antimicrobial, antioxidant, anti-inflammatory, and tissue-repair activities may therefore provide broader benefits in wound management (Martins-Green et al., 2025; Ukaegbu et al., 2025).

Plant-derived preparations are increasingly investigated as potential topical wound-healing agents because they contain bioactive compounds with multiple pharmacological activities. Flavonoids, tannins, phenolic compounds, terpenoids, and alkaloids may contribute to microbial inhibition, oxidative-stress reduction, inflammatory regulation, and tissue regeneration. However, most evidence supporting medicinal plants for wound healing is derived from phytochemical studies, laboratory assays, and animal experiments. Variations in plant materials, extraction procedures, concentrations, formulations, and wound models frequently complicate comparison between studies. Clinical evidence also remains limited for many plant-derived preparations, emphasizing the need for critical evaluation before their therapeutic use can be recommended (Moses et al., 2023).

Pterocarpus indicus, commonly known as angsana or narra, is a medicinal plant traditionally used for inflammatory, infectious, and skin-related conditions. Different parts of

P. indicus, including sap, stem bark, and leaves, have been investigated for their phytochemical and pharmacological properties. Flavonoids have been identified in the sap, while terpenoids and other bioactive constituents have been isolated from the leaves. Extracts prepared from the stem bark, leaves, and other plant parts have also demonstrated varying antibacterial and antioxidant activities (Arbain et al., 2021; Nurmila et al., 2019; Ragasa et al., 2005). Stem-bark preparations have additionally been evaluated in an experimental wound model using re-epithelialization as an outcome, whereas evidence for sap and leaves remains more strongly associated with phytochemical and indirect pharmacological findings (Naeluvar & Eryani, 2023).

Despite the reported medicinal properties of *Pterocarpus indicus*, evidence regarding the relative suitability of its sap, stem bark, and leaves for topical wound-healing development remains fragmented. Existing studies have generally examined individual plant parts using different extraction procedures, concentrations, formulations, biological assays, wound models, and outcome parameters, thereby limiting direct comparison of their therapeutic potential. A plant-part-based evaluation is therefore needed to distinguish indirect pharmacological evidence, such as antibacterial and antioxidant activities, from direct wound-healing outcomes, including wound closure, re-epithelialization, collagen deposition, and histopathological improvement. Accordingly, this narrative review comparatively evaluates the phytochemical characteristics, pharmacological activities, wound-healing evidence, processing considerations, safety, and sustainability of P. indicus sap, stem bark, and leaves to clarify their respective strengths, limitations, and potential for development as topical wound-healing agents.

METHODS

This article employed a narrative literature review approach to compare the wound-healing potential of the sap, stem bark, and leaves of *Pterocarpus indicus* as topical agents. Relevant literature was identified through Scopus, PubMed, Web of Science, ScienceDirect, and Google Scholar using combinations of the keywords "*Pterocarpus indicus*," "sap," "latex," "stem bark," "leaves," "topical," "wound healing," "re-epithelialization," "histopathology," "antibacterial," "antioxidant," and "anti-inflammatory." Original phytochemical, in vitro, and in vivo studies were prioritized, while relevant review and ethnopharmacological articles were used to support the scientific background. Studies were selected based on their relevance to the phytochemical composition, pharmacological activities, wound-healing effects, or topical application of the three plant parts. The selected evidence was synthesized descriptively to compare the strengths, limitations, and research gaps of P. indicus sap, stem bark, and leaves as topical wound-healing candidates.

DISCUSSION

Wound healing is a dynamic biological process consisting of overlapping hemostatic, inflammatory, proliferative, and remodeling phases. Following injury, hemostasis limits blood loss and establishes a provisional matrix, while inflammatory cells remove microorganisms and damaged tissue. The proliferative phase is characterized by fibroblast migration and proliferation, angiogenesis, extracellular-matrix formation, collagen deposition, and

keratinocyte-mediated re-epithelialization. During remodeling, collagen fibers are reorganized and matured to restore tissue integrity and mechanical strength. Effective healing therefore depends on the coordinated regulation of cellular migration, proliferation, vascular formation, matrix deposition, and epithelial restoration (Peña & Martin, 2024).

The progression of wound healing can be impaired by microbial contamination, excessive oxidative stress, and persistent inflammation. Pathogenic microorganisms may invade damaged tissue, form biofilms, evade host defenses, and reduce susceptibility to antimicrobial treatment, thereby prolonging inflammation and delaying tissue repair (Uberoi et al., 2024). Reactive oxygen species have physiological roles in antimicrobial defense and cellular signaling; however, excessive accumulation causes oxidative damage, disrupts the healing cascade, and contributes to chronic wound development (Ukaegbu et al., 2025). Antibacterial, antioxidant, and anti-inflammatory activities may consequently support wound healing by controlling microbial burden, maintaining oxidative balance, and facilitating the transition from inflammation to tissue proliferation. Plant-derived secondary metabolites may exert these complementary effects at different stages of wound repair, although such pharmacological activities should be regarded as supportive rather than direct evidence of wound-healing effectiveness (Cedillo-Cortezano et al., 2024).

Wound-healing effectiveness should be evaluated using complementary macroscopic and histopathological parameters. Changes in wound area and wound-closure percentage provide information about the rate of visible repair but do not fully represent the quality of regenerated tissue. Histopathological evaluation can provide additional evidence through measurements of re-epithelialization, inflammatory-cell infiltration, fibroblast proliferation, angiogenesis, granulation-tissue formation, and collagen deposition or organization. These parameters should be interpreted collectively because rapid wound contraction does not necessarily indicate complete structural recovery. Accordingly, the wound-healing potential of *Pterocarpus indicus* sap, stem bark, and leaves should be assessed by distinguishing indirect antibacterial, antioxidant, and anti-inflammatory evidence from direct wound-closure and tissue-regeneration outcomes (Masson-Meyers et al., 2020).

The reddish sap released following incision of *Pterocarpus indicus* bark has traditionally been associated with medicinal and astringent applications. Phytochemical examination has confirmed the presence of flavonoids in P. indicus sap, indicating that this material contains bioactive constituents with potential relevance to wound management (Nurmila et al., 2019). Although the sap has also been described as a powerful astringent, its tannin composition has not been sufficiently characterized using standardized quantitative and chromatographic methods (Rojas-Sandoval, 2022). Astringency may theoretically promote local protein precipitation, tissue tightening, and surface desiccation; however, these effects should be regarded as mechanistic possibilities rather than direct evidence of accelerated wound repair. Evidence from plant exudates more generally suggests that astringent and adhesive properties may contribute to wound contraction, granulation-tissue formation, and collagen synthesis, but these findings cannot be directly generalized to P. indicus sap without species-specific investigation (Zaheri-Abdevand & Badr, 2023).

Direct pharmacological evidence for P. indicus sap remains limited primarily to antibacterial evaluation. An in vitro comparative study reported that sap—referred to as latex

in that investigation—along with leaf and stem-bark preparations inhibited the growth of Streptococcus mutans at several tested concentrations (Armedita et al., 2018). This antibacterial activity may be relevant to wound management because controlling microbial growth can reduce infection-related interference with tissue repair. Nevertheless, activity against a cariogenic bacterium does not establish effectiveness against common wound pathogens or demonstrate improved wound closure. Compounds associated with P. indicus, including pterostilbene, have been reported to possess antioxidant, antimicrobial, and anti-inflammatory activities; however, the available evidence does not confirm that pterostilbene is present at an effective concentration in the sap or that these activities occur after its topical application (Surien et al., 2023). Therefore, antioxidant and anti-inflammatory effects should currently be presented as plausible but unverified properties of P. indicus sap.

The development of P. indicus sap as a topical wound-healing agent is further limited by the absence of standardized chemical markers, validated topical doses, dermal-irritation data, formulation-stability studies, and direct histopathological evaluation. Existing animal research demonstrating re-epithelialization after P. indicus treatment has used stem-bark extract rather than sap and therefore cannot be interpreted as direct evidence for sap-mediated tissue regeneration (Naeluvar & Eryani, 2023). Accordingly, future studies should determine whether topical application of P. indicus sap promotes wound contraction, reduces inflammatory-cell infiltration, enhances fibroblast proliferation and angiogenesis, increases collagen deposition, and accelerates re-epithelialization. Based on the current evidence, P. indicus sap should be regarded as a promising topical candidate supported by preliminary phytochemical and antibacterial findings and a plausible astringent mechanism, rather than as an established wound-healing agent.

The stem bark of *Pterocarpus indicus* contains several secondary metabolites that may contribute to its pharmacological potential. Methanolic bark extract has been reported to contain terpenoids and steroids, along with compounds associated with antibacterial and antioxidant activities (Senthilkumar et al., 2020). Flavonoids, phenolic acids, and other bioactive constituents have also been documented across the genus Pterocarpus; however, their occurrence and concentrations cannot be assumed to be identical in every species or plant part (Arbain et al., 2021). Evidence specifically confirming tannins and their quantitative contribution in P. indicus stem bark remains insufficient. Therefore, the potential involvement of these phytochemicals in wound healing should be interpreted cautiously until the bark is characterized using validated analytical and standardization methods.

Antibacterial activity provides indirect support for the use of P. indicus stem bark in wound management. Extracts and solvent fractions prepared from the stem bark inhibited several bacterial species, with butanol and methanol fractions generally exhibiting stronger activity than less-polar fractions (Khan & Omoloso, 2003). Methanolic bark extract has also demonstrated activity against Bacillus subtilis, Staphylococcus aureus, and Escherichia coli, although the reported results varied according to the extraction solvent (Senthilkumar et al., 2020). These findings indicate that the stem bark contains antibacterial constituents that may help reduce microbial interference with tissue repair. Nevertheless, most available studies were not conducted using infected-wound models, and antibacterial activity alone does not

demonstrate improved wound closure, collagen formation, or restoration of normal tissue architecture.

Direct wound-healing evidence for P. indicus stem bark remains limited. In a rat incision-wound model, histological measurements of re-epithelialization after treatment with angsana bark extract did not differ significantly from those observed after povidone-iodine treatment (Naeluvar & Eryani, 2023). This finding suggests preliminary comparability with the reference treatment but does not establish superiority, particularly because the study evaluated a limited number of animals and focused primarily on re-epithelialization. Further studies should assess wound closure, inflammatory-cell infiltration, fibroblast proliferation, angiogenesis, collagen deposition, tensile strength, and dermal safety using standardized bark preparations. Extract development must also consider solvent selection, chemical consistency, and sustainable harvesting because repeated bark removal may damage the source tree. Accordingly, P. indicus stem bark should be regarded as a promising candidate supported by antibacterial and preliminary histopathological evidence rather than an established topical wound-healing agent.

The leaves of *Pterocarpus indicus* contain several classes of secondary metabolites that may provide a pharmacological basis for wound-healing applications. Phytochemical investigations have identified flavonoids, sterols, terpenoids, and other phenolic constituents in the leaves. Hartati et al. (2016) isolated stigmasterol and a flavonol glycoside from an ethyl acetate fraction of P. indicus leaf extract, with the flavonol glycoside demonstrating DPPH radical-scavenging activity at an IC_{50} of 18.53 µmol. Ragasa et al. (2005) also isolated a mixture predominantly composed of loliolide and a smaller proportion of paniculatadiol from the leaf extract. Tannins, saponins, alkaloids, glycosides, triterpenoids, and steroids have additionally been reported in ethanolic leaf preparations (Djamain et al., 2020). These constituents may be relevant to wound repair because antioxidant compounds can limit excessive oxidative damage during the inflammatory and proliferative phases. Nevertheless, antioxidant activity measured using a chemical radical-scavenging assay remains indirect evidence and does not confirm that the leaf extract can regulate oxidative stress within wounded tissue.

Antibacterial studies provide additional support for the topical potential of P. indicus leaves. Rahayu and Latifah (2026) demonstrated concentration-dependent activity of the leaf extract against Staphylococcus aureus and Salmonella typhimurium. At a concentration of 80%, the extract produced inhibition zones of 19.69 and 19.24 mm, respectively, although its activity remained lower than that of chloramphenicol. Ethanolic leaf extract also retained antibacterial activity after incorporation into a gel, producing an inhibition zone against S. aureus, although the magnitude of inhibition was influenced by the quantity of extract incorporated into the formulation (Djamain et al., 2020). Meanwhile, isolated loliolide–paniculatadiol from the leaves showed moderate activity against Candida albicans and weaker activity against several other microorganisms, but was inactive against S. aureus in that particular assay (Ragasa et al., 2005). These variable findings indicate that antimicrobial performance depends on the extract composition, concentration, test organism, and formulation. More importantly, in vitro microbial inhibition cannot by itself demonstrate prevention of wound infection or improvement of tissue regeneration.

Direct evidence for the wound-healing effects of P. indicus leaves remains insufficient. The available studies have predominantly examined phytochemical composition, antioxidant capacity, and antibacterial activity rather than wound contraction, re-epithelialization, fibroblast proliferation, angiogenesis, collagen deposition, or histopathological recovery. Animal studies involving other members of the genus provide preliminary biological plausibility. An ointment prepared from Pterocarpus santalinus wood accelerated healing and supported collagen formation in normal and diabetic wound models, while Pterocarpus marsupium heartwood extract improved wound-healing parameters in experimental animals (Biswas et al., 2004; Gupta et al., 2012). However, these results cannot be directly extrapolated to P. indicus leaves because plant species, plant parts, chemical compositions, preparations, and doses differ substantially. Therefore, P. indicus leaves should currently be regarded as a promising topical candidate supported by phytochemical, antioxidant, and antibacterial evidence rather than as an established wound-healing agent.

The sap, stem bark, and leaves of *Pterocarpus indicus* exhibit distinct phytochemical and pharmacological characteristics and therefore should not be considered interchangeable materials. Extracts from the leaves and stem bark have shown antibacterial activity, although their potency varies according to the extraction solvent, concentration, and tested microorganism. Polar fractions derived from these plant parts generally demonstrated stronger antibacterial effects than less-polar fractions, while methanolic stem-bark extract inhibited several bacterial species, including Staphylococcus aureus and Escherichia coli (Khan & Omoloso, 2003; Senthilkumar et al., 2020). Leaf-derived terpenoids, including loliolide and paniculatadiol, have also demonstrated antimicrobial activity, although their effects differed among microorganisms (Ragasa et al., 2005). A direct in vitro comparison further showed that leaf extract, stem-bark extract, and sap—described as latex in the study—were capable of inhibiting Streptococcus mutans, with the magnitude of inhibition varying among the tested preparations and concentrations (Armedita et al., 2018). These findings indicate plant-part-dependent biological activity but do not directly establish comparative wound-healing effectiveness. The comparative strength and directness of the available evidence for P. indicus sap, stem bark, and leaves are summarized in Table 1.

Table 1. Comparative Evidence on *Pterocarpus indicus* Plant Parts for Topical Wound-Healing Development

Evidence domain	Sap	Stem bark	Leaves
Phytochemical evidence	Flavonoids have been identified, but standardized quantitative profiles remain limited (Nurmila et al., 2019).	Terpenoids, steroids, and other secondary metabolites have been reported, although comprehensive standardization remains unavailable (Arbain et al., 2021;	Flavonol glycoside, stigmasterol, loliolide, and paniculatadiol have been characterized (Hartati et al., 2016; Ragasa et al., 2005).

		Senthilkumar et al., 2020).	
Pharmacological evidence	Preliminary antibacterial activity has been reported, whereas antioxidant and anti-inflammatory effects remain unverified for sap (Armedita et al., 2018; Surien et al., 2023).	Antibacterial activity has been demonstrated against several bacterial species (Khan & Omoloso, 2003; Senthilkumar et al., 2020).	Antioxidant and antibacterial activities have been demonstrated in vitro (Djamain et al., 2020; Hartati et al., 2016; Rahayu & Latifah, 2026).
Astringent relevance	Astringent potential has been reported, but its active constituents and topical effects remain insufficiently standardized (Rojas-Sandoval, 2022).	Not a primary evidence domain.	Not a primary evidence domain.
Direct wound-healing evidence	No direct wound-closure or histopathological study was identified.	Preliminary re-epithelialization evidence is available from a rat incision-wound model, without demonstrated superiority over povidone iodine (Naeluvar & Eryani, 2023).	No direct wound-healing or histopathological study was identified.
Topical-development evidence	Effective dose, dermal safety, and formulation stability remain unestablished.	Dermal-safety and formulation evidence remain insufficient.	Preliminary antibacterial gel-formulation evidence is available, but wound-specific efficacy remains unestablished (Djamain et al., 2020).

Table 1 indicates that the three plant parts differ in the type and directness of the available evidence. Stem bark currently provides the most direct wound-specific support because it has been evaluated in an experimental wound model using histological re-epithelialization as an outcome, although the evidence remains preliminary. Leaves are supported by a broader range of phytochemical, antioxidant, antibacterial, and formulation

studies, whereas sap remains comparatively underinvestigated despite its reported astringent and preliminary antibacterial potential. These findings do not establish the therapeutic superiority of any plant part.

Practical considerations may further influence the selection of a plant part for topical-product development. Sap is collected as a naturally occurring plant secretion and has been described as an astringent material, providing a plausible basis for its use on superficial wounds (Rojas-Sandoval, 2022). Its liquid form may offer formulation advantages; nevertheless, direct collection does not eliminate the need for purification, chemical standardization, microbial-quality control, stability testing, and safety evaluation. Leaves may represent a potentially renewable material because they can be collected without extensive removal of structural bark tissue, whereas repeated stem-bark harvesting may adversely affect plant health. However, comparative evidence regarding harvesting sustainability, extraction efficiency, production cost, and formulation stability remains limited. Consequently, no plant part can currently be regarded as definitively superior. Sap represents an underinvestigated candidate with potential astringent and formulation-related advantages, stem bark has the most direct preliminary wound-specific evidence, and leaves provide relevant antioxidant and antibacterial activities. Figure 1 summarizes the comparative evidence presented in Table 1 and the key steps required for topical wound-healing development.

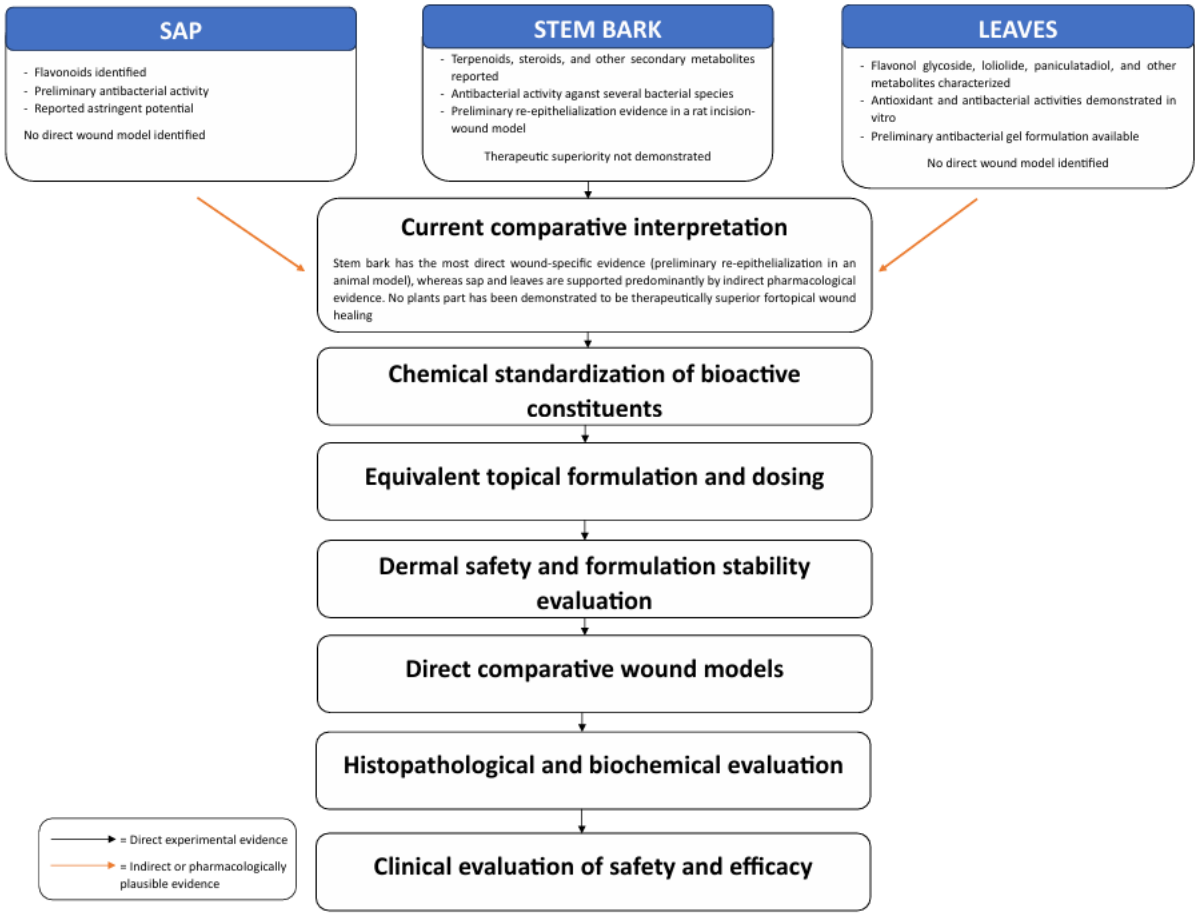

Figure 1. Comparative Evidence-to-Translation Framework for *Pterocarpus indicus* Plant Parts in Topical Wound-Healing Development

As illustrated in Figure 1, the three plant parts differ primarily in the directness of the available evidence. Stem bark provides the most direct wound-specific support, although the evidence remains preliminary, whereas leaves are supported mainly by phytochemical, antioxidant, antibacterial, and formulation studies. Sap remains comparatively underinvestigated despite its reported flavonoid content, antibacterial activity, and astringent potential. Nevertheless, no plant part can yet be considered therapeutically superior, and further standardization, safety testing, and direct comparative wound studies are required before clinical translation.

Current evidence on the wound-healing potential of *Pterocarpus indicus* remains limited and methodologically heterogeneous. Most studies have focused on phytochemical composition, antioxidant capacity, or antibacterial activity, whereas direct wound-healing outcomes have been investigated only to a limited extent. Evidence concerning sap and

leaves is predominantly indirect, while the available stem-bark study evaluated re-epithelialization without demonstrating superiority over the reference treatment (Naeluvar & Eryani, 2023). Comparisons among plant parts are further complicated by differences in extraction solvents, concentrations, formulations, test organisms, wound models, observation periods, and outcome parameters. Inconsistent terminology for sap, including sap, latex, exudate, and kino, may also complicate literature interpretation. Moreover, findings obtained from other Pterocarpus species or different plant organs cannot be directly extrapolated to P. indicus, because phytochemical composition and pharmacological activity may vary according to species and plant part.

Future studies should directly compare P. indicus sap, stem-bark extract, and leaf extract under standardized experimental conditions. Botanical authentication, harvesting procedures, preparation methods, chromatographic profiles, and quantitative chemical markers should be clearly reported before biological evaluation. Comparative experiments should use equivalent doses, identical topical vehicles, and appropriate untreated, vehicle, and standard-treatment controls. Evaluation should integrate wound-closure measurements with re-epithelialization, inflammatory-cell infiltration, fibroblast proliferation, angiogenesis, collagen deposition, tensile strength, and tissue organization to distinguish visible wound contraction from complete structural recovery (Masson-Meyers et al., 2020). Infected-wound models involving clinically relevant pathogens would help determine whether the reported antibacterial activities translate into meaningful infection control and improved tissue repair (Uberoi et al., 2024). Dermal irritation, sensitization, formulation stability, microbial quality, dose-response relationships, processing feasibility, and harvesting sustainability should also be examined. Controlled clinical studies should only be considered after standardized preparations demonstrate reproducible preclinical efficacy and acceptable topical safety, thereby preventing preliminary phytochemical or antimicrobial findings from being interpreted as established therapeutic effectiveness (Moses et al., 2023).

CONCLUSION

Pterocarpus indicus sap, stem bark, and leaves possess distinct phytochemical and pharmacological properties and should not be regarded as interchangeable topical materials. Stem bark has the strongest direct evidence for wound healing, although current findings are preliminary and do not demonstrate superiority over standard treatments. Leaves are mainly supported by antioxidant and antibacterial activities, while sap remains underexplored despite its potential astringent and formulation-related benefits. Consequently, no plant part can currently be considered superior for topical wound-healing applications. Future standardized comparative studies are needed to evaluate their efficacy, safety, and sustainability for clinical development.

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