
Phytochemical Diversity and Therapeutic Potential of Indigenous Medicinal Plants of South Africa

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ABSTRACT

South Africa contains exceptional indigenous plant diversity embedded in long-standing ethnomedical systems. Medicinal plants used by traditional health practitioners represent a chemically heterogeneous reservoir of phenolics, flavonoids, terpenoids, alkaloids, tannins, saponins, quinones and other specialized metabolites. This review integrates ethnobotanical, phytochemical, pharmacological and safety-oriented literature to evaluate representative species and their reported antioxidant, antimicrobial, anti-inflammatory, wound-healing and anticancer potential. Evidence indicates that therapeutic potential depends strongly on species identity, plant organ, geography, harvest stage, extraction solvent and chemical standardization. Recent Limpopo research demonstrates measurable antimicrobial, antioxidant and antiproliferative activity and shows how GC-TOF-MS can reveal complex chemical signatures. However, translation of crude-extract activity into reproducible medicines is constrained by chemotypic variation, incomplete pharmacokinetic characterization, toxicity uncertainty, inconsistent authentication and limited clinical validation. An integrated pathway combining voucher authentication, chromatographic fingerprinting, quantitative markers, bioassay-guided fractionation, mechanism-oriented assays, toxicology and sustainable sourcing is therefore proposed.

KEYWORDS: *South Africa, Indigenous medicinal plants, Phytochemicals, Ethnopharmacology, Natural products, Antioxidant activity, Antimicrobial activity, Anti-inflammatory activity, Drug discovery, Sustainable utilization*

INTRODUCTION

South Africa is a globally important centre of plant diversity and a major setting for traditional medicine research. Medicinal-plant use is not simply a historical practice; it remains connected to community health, cultural identity, household remedies and commercial herbal products. The contemporary scientific challenge is to determine which traditionally selected species contain reproducible bioactive chemical profiles, which molecular targets are affected, and under what preparation and dose conditions the observed effects can be translated into safe therapeutic products. Recent inventories have documented thousands of medicinal and ritual plant species across southern Africa, illustrating the scale of the chemical and ethnobotanical resource available for investigation [1].

The pharmacological value of a plant cannot be inferred solely from its traditional indication. Plant extracts are multicomponent systems whose composition changes with genotype, soil, climate, season, plant part, maturity and extraction conditions. Consequently, two extracts bearing the same vernacular plant name may not be chemically or pharmacologically equivalent. This issue is particularly important in South Africa, where geographically separated populations may experience contrasting ecological pressures and where indigenous knowledge is distributed across diverse cultural groups. Modern phytochemical research must therefore connect botanical identity and provenance with analytical chemistry and biological testing rather than treating medicinal plants as chemically uniform raw materials [2,3].

South African species already illustrate several routes by which indigenous plants can contribute to natural-product science. *Aloe ferox* has attracted attention for its specialized metabolites and commercial use; *Artemisia afra* is widely investigated for traditional respiratory applications; *Pelargonium sidoides* has become a prominent example of a South African plant associated with standardized herbal preparations; *Aspalathus linearis* provides a distinctive example of a polyphenol-rich indigenous resource; and *Harpagophytum procumbens* has been studied extensively for anti-inflammatory and pain-related applications [2,4]. Additional species, including *Sutherlandia frutescens*, *Warburgia salutaris*, *Lippia javanica* and *Hypoxis hemerocallidea*, broaden the pharmacological landscape.

The problem addressed in this review is the fragmentation of evidence. Ethnobotanical studies often document uses without comprehensive chemical profiling; phytochemical investigations

may identify compounds without establishing their contribution to activity; and in vitro pharmacology frequently advances faster than pharmacokinetic, toxicological and clinical evaluation. This creates a translational bottleneck in which promising indigenous plants remain either under-characterized or marketed without adequate chemical standardization. A rigorous synthesis is therefore needed to identify recurring phytochemical patterns, evaluate therapeutic evidence and define research priorities that are scientifically defensible and culturally responsible.

LITERATURE REVIEW

Ethnopharmacological selection is an efficient starting point for natural-product discovery because repeated traditional use can provide a biologically informed filter over large botanical inventories. Reviews of South African medicinal plants have shown extensive use for pain, inflammation, wounds, infections and other chronic or acute conditions [3,5]. A recent systematic review of wound-treatment practices further demonstrates that medicinal plants occupy an important position in documented empirical wound-healing traditions and that microbial contamination is a major consideration in the development of wound therapies [6]. Such observations do not establish clinical efficacy, but they provide hypotheses that can be tested through standardized laboratory methods.

Phytochemical diversity is particularly relevant because several metabolite classes can act through overlapping mechanisms. Phenolic acids and flavonoids may contribute to radical-scavenging, metal-chelation and modulation of inflammatory signaling. Terpenoids and essential-oil constituents can alter microbial membranes, interact with inflammatory mediators or affect cellular signaling. Tannins may influence microbial adhesion and protein interactions, while saponins can affect membrane permeability. Quinones and related aromatic metabolites can participate in redox processes and may contribute to antimicrobial or cytotoxic effects. The biological outcome of a crude extract is therefore often an emergent property of multiple compounds rather than the activity of a single dominant constituent [2,4].

Evidence for anti-inflammatory activity is particularly developed for South African medicinal plants. In a study of eleven plants traditionally used against inflammation, extracts prepared with several solvents were evaluated using 15-lipoxygenase inhibition, nitric-oxide inhibition in LPS-stimulated macrophages, total phenolic and flavonoid measurements, and DPPH and

ABTS antioxidant assays [7]. The study design is important because it demonstrates that solvent polarity can expose different chemical fractions and that antioxidant activity should not automatically be equated with anti-inflammatory efficacy. Mechanistic assays that directly interrogate inflammatory mediators provide stronger evidence than a single chemical antioxidant assay.

Antimicrobial research also provides a useful bridge between traditional indications and modern public-health needs. A 2023 investigation of *Senna petersiana*, *Gardenia volkensii*, *Acacia senegal* and *Clerodendrum glabrum* evaluated antibacterial, antioxidant, anti-inflammatory and cytotoxic properties using microbroth dilution, protein-denaturation, radical-scavenging and cell-viability approaches [8]. The convergence of several endpoints is valuable because an extract intended for respiratory or wound applications may need antimicrobial activity while also controlling oxidative and inflammatory responses. Nevertheless, *in vitro* inhibition must be interpreted cautiously: crude extracts may act at concentrations that are not achievable systemically, and activity in a test system does not establish clinical benefit.

Recent evidence from Senwabarwana, Limpopo, illustrates the increasing analytical sophistication of the field. Mongalo and colleagues examined selected medicinal plants using microdilution assays, MTT-based antiproliferative testing, DPPH, ABTS and iron-chelation assays, and GC-TOF-MS profiling [9]. *Talinum caffrum* showed a reported MIC of 0.05 mg/mL against *Salmonella arizonae*, while *Peltophorum africanum* showed an IC₅₀ of approximately 1.80 µg/mL against MCF-7 cells in that experimental system [9]. These values are useful as screening signals rather than clinical dose equivalents. The same study identified 127 compounds in the organic extract of *T. caffrum*, emphasizing the complexity of the chemical matrix and the need to distinguish tentative library identifications from purified, structurally confirmed compounds.

Anticancer research is another area where South African flora has generated substantial hypotheses. A review of traditionally used South African plants reported that several species and their secondary metabolites have shown *in vitro* activity against cancer-cell models, while emphasizing the limited documentation of traditional cancer indications and the need for pharmacokinetic and toxicity studies [10]. This distinction is critical. Cytotoxicity against a cancer cell line can indicate chemical potential, but therapeutic development requires

selectivity, mechanism, exposure data, formulation, animal safety and ultimately controlled clinical evidence.

Commercially important species demonstrate the importance of moving from traditional use to standardization. A broad review by van Wyk highlighted the interconnected roles of ethnobotany, taxonomy, genetics, biochemistry, chemical variation, reproductive biology and horticulture in the sustainable development of southern African medicinal plants [2]. Chemical variation is not merely an analytical nuisance; it can directly affect efficacy, toxicity, shelf stability and regulatory consistency. Marker-based quality control, chromatographic fingerprints and authenticated voucher specimens are therefore essential components of future phytopharmaceutical development.

Recent regional inventories reinforce the scale of the opportunity. An updated inventory reported 3,784 medicinally used plant species in southern Africa and approximately 1,200 additional records compared with a 2002 survey, with Asteraceae and Fabaceae among the dominant families [1]. At the same time, the disappearance of indigenous knowledge and habitat pressure can reduce the opportunity to document plant-use traditions before they are lost [3]. The research agenda must consequently balance discovery with conservation and ethical engagement. The WHO has explicitly linked traditional-medicine research with biodiversity, indigenous knowledge, equity and sustainable use [11].

RESEARCH GAP

Despite extensive ethnobotanical documentation, the evidence base remains uneven across species and therapeutic indications. First, many plants have qualitative phytochemical screening data but lack quantitative, batch-to-batch chemical fingerprints. Second, compound annotations obtained from GC-MS or LC-MS libraries are not always followed by isolation and spectroscopic confirmation, limiting confidence in structure–activity relationships. Third, most pharmacological evidence remains preclinical, with relatively few standardized preparations supported by pharmacokinetic, toxicological and clinical datasets. Fourth, ecological and geographical variation is insufficiently integrated into phytochemical datasets. Finally, sustainable harvesting, benefit sharing and intellectual-property considerations are often discussed separately from laboratory discovery rather than being embedded in the research design [1,3,11].

OBJECTIVES

- To synthesize evidence on the phytochemical diversity of selected indigenous South African medicinal plants.
- To map major phytochemical classes against reported antioxidant, antimicrobial, anti-inflammatory, wound-healing and anticancer activities.
- To identify methodological factors that influence extract composition and reproducibility.
- To evaluate translational barriers involving authentication, standardization, toxicity, pharmacokinetics and clinical validation.
- To propose a research framework for sustainable and evidence-based development of indigenous medicinal plants.

METHODOLOGY

This study was designed as a structured analytical review rather than a new wet-laboratory experiment. Literature was identified from peer-reviewed scientific sources indexed through PubMed, Web of Science, Scopus, ScienceDirect and Google Scholar, supplemented by authoritative biodiversity and traditional-medicine resources. Search concepts combined plant identity terms with South Africa or southern Africa and keywords including ethnobotany, phytochemistry, LC-MS, GC-MS, metabolomics, antioxidant, antimicrobial, anti-inflammatory, wound healing, cytotoxicity, cancer, toxicity and pharmacokinetics. Priority was given to studies that connected a documented indigenous use with a defined plant species, plant part, extraction procedure and biological assay [3,7–10].

Data were organized into five analytical domains: botanical provenance, phytochemical composition, biological endpoint, experimental strength and translational readiness. Botanical provenance included scientific name, plant part and geographic context. Phytochemical data were grouped into broad classes and, where available, named marker compounds or metabolite families. Biological endpoints were separated into chemical antioxidant assays, antimicrobial assays, cell-based anti-inflammatory assays, cytotoxicity and antiproliferative models, and wound-healing evidence. This separation was used to avoid treating chemically different assays as interchangeable measures of therapeutic efficacy.

Reported numerical findings were extracted only when the source provided a clearly defined assay endpoint. For antimicrobial studies, minimum inhibitory concentration (MIC) was

treated as an assay-specific screening measure. For cell-based studies, IC₅₀ or related viability metrics were interpreted as concentration-response indicators rather than therapeutic doses. Antioxidant results from DPPH and ABTS were treated as chemical radical-scavenging measurements and not as direct evidence of *in vivo* antioxidant effects. The review also considered methodological details such as solvent selection, extraction ratio, temperature, assay controls and replication because these variables can substantially influence apparent activity.

A qualitative evidence matrix was then developed. Plants with multiple independent evidence domains—ethnobotanical use, phytochemical characterization, biological activity and some indication of safety or standardization—were classified as higher-readiness candidates. Plants supported mainly by traditional use or preliminary screening were considered discovery-stage candidates. This framework is intentionally non-clinical: it ranks evidence breadth, not medical effectiveness. Figure 1 summarizes the proposed integrated discovery workflow, while Figure 2 presents a conceptual map of the major phytochemical classes encountered in South African medicinal-plant research.

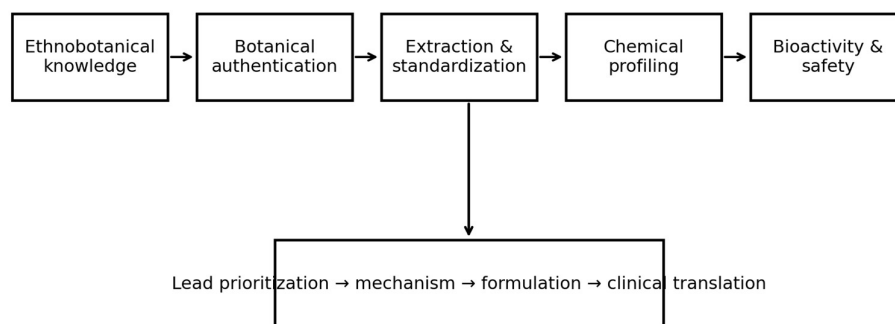


Figure 1: Integrated research workflow for converting indigenous medicinal-plant knowledge into standardized natural-product leads

RESULTS AND FINDINGS

The evidence synthesis indicates that South African indigenous medicinal plants constitute a chemically heterogeneous resource rather than a single pharmacological category. Phenolics and flavonoids recur in studies focused on antioxidant and anti-inflammatory activity, while terpenoids, essential-oil constituents, tannins, saponins, alkaloids and quinone-type metabolites

broaden the potential mechanisms. The diversity is amplified by differences among plant organs: leaves may be relatively enriched in volatile or phenolic constituents, roots and rhizomes can accumulate specialized terpenoids or other storage-associated metabolites, and bark may contain distinctive tannins and aromatic compounds. Consequently, extraction and plant-part selection should be considered part of the experimental hypothesis rather than routine sample preparation.

Table 1 summarizes representative species and evidence domains. *Aloe ferox*, *Artemisia afra*, *Pelargonium sidoides*, *Aspalathus linearis* and *Harpagophytum procumbens* are comparatively well represented in the literature and illustrate the spectrum from commercial herbal development to ethnopharmacological discovery. *Sutherlandia frutescens*, *Warburgia salutaris* and *Hypoxis hemerocallidea* remain important research subjects but require continued work on standardized chemistry and safety. The recent Limpopo study adds *Talinum caffrum* and *Peltophorum africanum* to the group of species with experimentally demonstrated in vitro antimicrobial, antioxidant and antiproliferative signals [9].

The strongest recent quantitative evidence comes from the 2026 Senwabarwana study. Across its selected extracts, antimicrobial activity varied by species and pathogen. *T. caffrum* reached an MIC of 0.05 mg/mL against *S. arizonae*, and *P. africanum* showed a reported MCF-7 IC₅₀ of 1.80 ± 0.001 µg/mL under the stated experimental conditions [9]. *T. caffrum* also produced low reported IC₅₀ values in ABTS and iron-chelation assays. These results illustrate two principles: biological activity can be highly selective for a plant–assay combination, and the chemical profile of the most active extract may contain many constituents whose individual contributions remain unresolved.

Evidence for inflammatory modulation is similarly multi-dimensional. Studies using nitric-oxide inhibition, 15-lipoxygenase inhibition and protein-denaturation models indicate that several South African plants contain constituents capable of affecting inflammatory-associated endpoints [7,8]. However, the relationship between phenolic content and anti-inflammatory activity is not necessarily linear. Extract complexity, synergistic interactions and differential cellular uptake can produce activity that is poorly predicted by total phenolic or flavonoid content alone. Future studies should therefore combine global metabolomics with targeted quantification and mechanistic validation.

Wound-related applications are particularly promising because effective wound management can require antimicrobial, anti-inflammatory and antioxidant actions simultaneously. The systematic review of South African wound-treatment plants indicates a substantial ethnobotanical knowledge base [6]. From a formulation perspective, topical delivery may also reduce some systemic exposure constraints that complicate oral development, although dermal irritation, sensitization, microbial contamination, stability and active-compound release must still be rigorously assessed. Thus, a traditionally used wound plant should not be advanced simply because an extract inhibits a bacterial strain; the relevant product-development question is whether a standardized topical preparation can provide reproducible activity with an acceptable safety margin.

Figure 3 provides a qualitative evidence-breadth map for selected species. It should not be read as a clinical ranking. Instead, it visualizes how different plants occupy different stages of the evidence pipeline. Commercially established species may have stronger standardization and formulation knowledge but still require mechanistic refinement, whereas newly investigated species may display striking in vitro activity but lack pharmacokinetic and safety evidence.

Table 1: Representative indigenous South African medicinal plants and major evidence domains

Plant	Representative research focus	Major phytochemical themes	Evidence stage
Aloe ferox	Traditional skin, gastrointestinal and commercial herbal applications	Anthraquinone-related compounds, phenolics	Development/standardization
Artemisia afra	Respiratory and anti-inflammatory traditional use	Terpenoids, phenolics, volatile constituents	Preclinical/development
Pelargonium sidoides	Respiratory infections and standardized herbal preparations	Coumarin-like and phenolic constituents, tannins	Development/clinical interest

Aspalathus linearis	Antioxidant, metabolic and functional-food applications	Aspalathin and other polyphenols	Development
Harpagophytum procumbens	Pain and inflammation	Iridoid glycosides, including harpagoside	Preclinical/clinical interest
Sutherlandia frutescens	Traditional use for diverse inflammatory and chronic conditions	Flavonoids, triterpenoids, amino-acid derivatives	Discovery/preclinical
Talinum caffrum	Antimicrobial, antioxidant and antiproliferative screening	Complex GC-TOF-MS profile	Discovery/preclinical
Peltophorum africanum	Antimicrobial and antiproliferative screening	Polyphenolic and other specialized metabolites	Discovery/preclinical

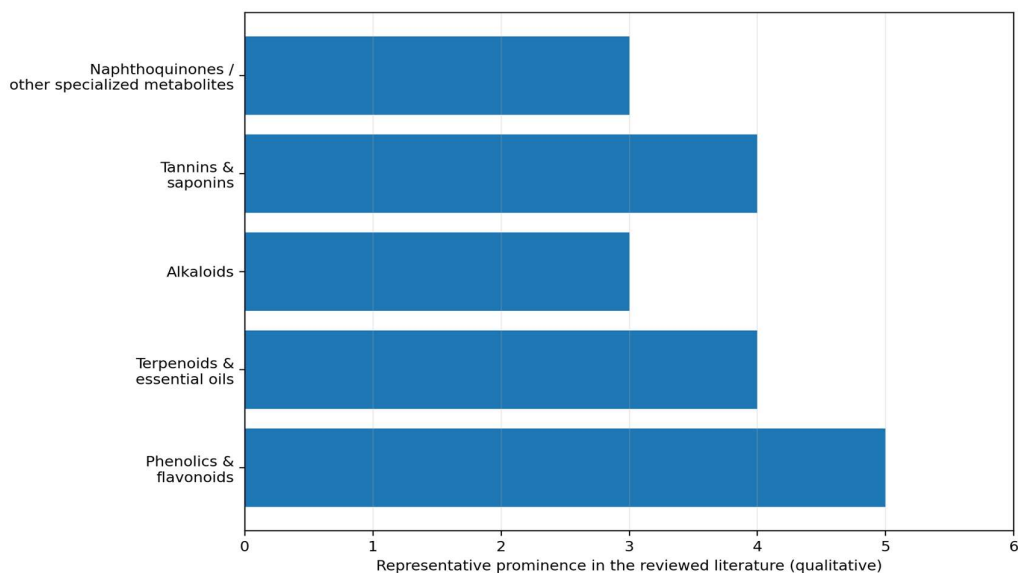


Figure 2: Conceptual distribution of major phytochemical classes reported across South African medicinal-plant research; bar lengths indicate qualitative prominence in the reviewed evidence, not measured concentrations

Table 2: Phytochemical classes, representative functions and therapeutic hypotheses

Phytochemical class	Representative role	Therapeutic hypothesis	Key analytical need
Phenolics/flavonoids	Radical scavenging; signaling modulation	Oxidative-stress and inflammatory modulation	HPLC/LC-MS quantification of validated markers
Terpenoids/essential oils	Membrane and receptor interactions	Antimicrobial and anti-inflammatory effects	GC-MS/GC-TOF-MS plus authentic standards
Tannins	Protein binding and microbial interactions	Topical antimicrobial/astringent effects	Targeted tannin/polyphenol profiling
Saponins	Membrane interaction and permeability	Antimicrobial and immunomodulatory hypotheses	LC-MS and hemolysis/cytotoxicity testing
Alkaloids	Diverse receptor/enzyme interactions	Analgesic, antimicrobial or cytotoxic hypotheses	LC-MS/MS and structure confirmation
Quinones/specialized aromatics	Redox and enzyme interactions	Antimicrobial/cytotoxic hypotheses	LC-MS/MS, NMR confirmation and stability studies

DISCUSSION

The central finding of this review is that phytochemical diversity is both the principal opportunity and the principal reproducibility problem in South African medicinal-plant research. Complex extracts can deliver multi-target biological effects, which may be valuable for conditions involving infection, inflammation and oxidative stress. At the same time, complexity makes it difficult to identify which constituents drive activity, whether they interact synergistically or antagonistically, and whether a standardized batch will reproduce the biological effect of the original research extract. This tension should shape experimental design from the earliest stage.

Extraction methodology deserves particular attention. Solvent polarity determines which metabolite classes enter an extract, while temperature and extraction time influence degradation and recovery. The 2026 Limpopo study used 70% ethanol and a defined solid-to-solvent ratio for extraction, demonstrating the value of reporting operational details that allow another laboratory to reproduce the preparation [9]. Future studies should report yield, moisture content, particle size, extraction cycles, solvent composition, storage conditions and chromatographic fingerprints. Without these data, comparisons between studies may be misleading even when the same species is investigated.

Analytical chemistry should also move beyond simple qualitative screening. Colorimetric total-phenolic and total-flavonoid assays are useful for rapid comparison but cannot establish individual chemical identity. High-resolution LC-MS/MS, GC-MS for volatile or derivatizable constituents, NMR spectroscopy and multivariate metabolomics can generate chemical fingerprints capable of distinguishing geography, harvest season and processing method. These fingerprints can then be correlated with bioactivity using chemometric methods. Bioactive features can be prioritized for isolation and structure confirmation, creating a traceable chain from plant material to chemical marker to biological endpoint.

Mechanistic pharmacology is the next critical step. Antioxidant assays such as DPPH and ABTS are valuable chemical screens, but they do not reproduce absorption, metabolism, tissue distribution or endogenous redox regulation. Likewise, bacterial MIC values provide evidence of growth inhibition but do not establish activity in infected tissue. For anti-inflammatory candidates, studies should progress from biochemical assays to relevant cell models and then to in vivo exposure-response experiments where justified. Cancer-related findings should include selectivity against non-malignant cells, apoptosis or cell-cycle mechanisms, molecular targets and pharmacokinetic feasibility before therapeutic claims are made [10].

The recent evidence from *T. caffrum* and *P. africanum* illustrates the importance of separating potency from translational readiness. Very low in vitro IC₅₀ values can be scientifically interesting, but a crude extract with high potency may contain compounds that are unstable, poorly absorbed or toxic to normal cells. Conversely, a moderately active extract may be valuable if it has excellent safety, topical applicability, favorable formulation characteristics and reproducible chemistry. Therefore, prioritization should use a multi-parameter decision

model incorporating activity, selectivity, chemical reproducibility, toxicity, sustainability and feasibility of supply.

Traditional knowledge introduces an additional dimension: scientific validation must not become a mechanism for extraction of community knowledge without recognition or benefit sharing. Indigenous knowledge should be documented with appropriate permissions, attribution and governance. Sustainable harvesting is equally important because demand for medicinal plants can increase pressure on wild populations. Cultivation, propagation protocols, controlled harvesting and tissue-culture approaches may help maintain supply while reducing ecological impact. WHO guidance emphasizes the importance of biodiversity, indigenous knowledge, equity and sustainable access in traditional-medicine development [11].

The commercial pathway is most realistic for standardized preparations rather than loosely defined crude materials. A development program should establish botanical identity using voucher specimens and taxonomic confirmation, define a chemical fingerprint, select quantitative marker compounds, set contaminant limits, validate extraction parameters, assess stability and determine biological specifications. Quality-control assays should be linked to a clinically relevant biological mechanism where possible. This approach is compatible with phytopharmaceutical, nutraceutical and topical-product development while allowing different levels of evidence depending on the intended claim.

South Africa is particularly well positioned to develop an integrated platform because its biodiversity, ethnobotanical knowledge, analytical laboratories and pharmaceutical research infrastructure can support the full discovery pipeline. Collaboration among botanists, ethnopharmacologists, analytical chemists, pharmacologists, formulation scientists, toxicologists, clinicians and community knowledge holders would reduce the fragmentation currently seen across the literature. The updated southern African inventory provides a large candidate pool, while focused mechanistic studies can narrow that pool to manageable development targets [1].

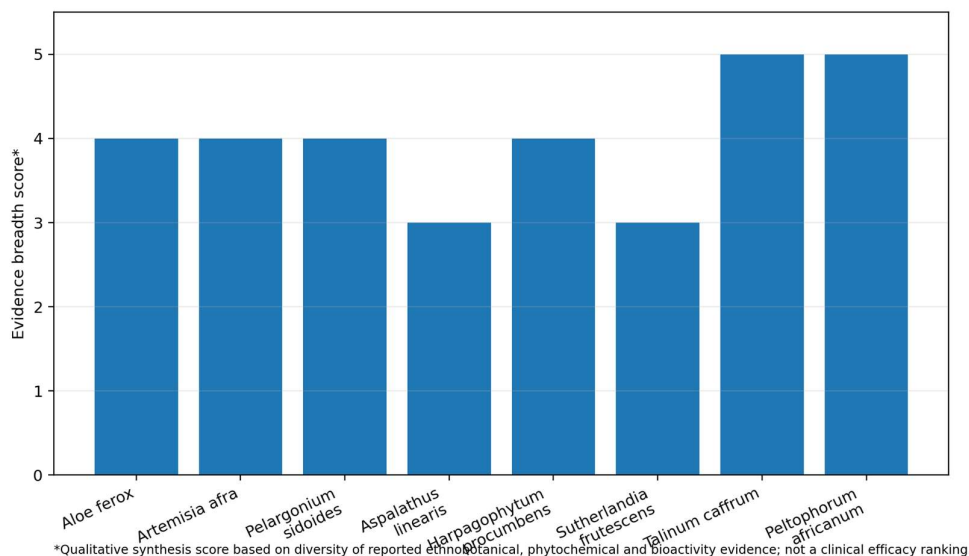


Figure 3: Qualitative evidence-breadth map for selected indigenous South African medicinal plants. Scores represent breadth of published evidence rather than clinical efficacy

Table 3: Translational priorities for indigenous medicinal-plant research

Research stage	Priority activity	Output	Main risk controlled
Authentication	Voucher specimen, taxonomy, DNA barcoding where needed	Traceable botanical identity	Misidentification/adulteration
Chemical standardization	LC-MS/GC-MS fingerprint and quantitative markers	Batch specification	Chemotypic variability
Bioassay confirmation	Orthogonal assays and positive controls	Reproducible activity profile	Assay-specific false positives
Mechanism	Target/pathway validation and selectivity testing	Mechanistic hypothesis	Non-specific toxicity

ADME/toxicology	Exposure, metabolism, organ and genotoxicity studies	Safety margin	Unfavorable systemic exposure
Formulation	Stable standardized dosage form	Reproducible product	Instability/poor delivery
Sustainability/ethics	Cultivation, access agreements, benefit sharing	Responsible supply chain	Resource depletion and inequity
Clinical translation	Well-controlled human studies where justified	Evidence-based therapeutic claim	Overstatement of efficacy

CONCLUSION

Indigenous medicinal plants of South Africa represent a scientifically important reservoir of chemical diversity with potential relevance to antimicrobial, antioxidant, anti-inflammatory, wound-healing and anticancer discovery. The literature shows that this potential is supported by a combination of ethnobotanical knowledge, phytochemical characterization and increasingly sophisticated in vitro assays. Recent work using GC-TOF-MS, microdilution, antioxidant assays and cancer-cell models demonstrates that under-investigated species can yield measurable and sometimes strong biological signals [9].

Nevertheless, therapeutic potential should not be equated with established clinical efficacy. The major scientific priorities are authentication, chemical standardization, mechanistic validation, selectivity, pharmacokinetics, toxicology and reproducible formulation. A coordinated research framework that integrates these elements with biodiversity conservation and ethical engagement can convert South Africa's indigenous medicinal-plant diversity into credible natural-product leads while respecting the communities and ecosystems that sustain this knowledge.

LIMITATIONS

- This review is evidence-synthesis based and does not generate new experimental data; numerical findings are therefore dependent on the methods and reporting quality of primary studies.
- Plant names, chemotypes, plant parts and extraction procedures are not uniform across the literature, which limits direct quantitative comparison.
- Many reported activities are based on in vitro assays and cannot be directly extrapolated to human therapeutic doses or clinical outcomes.
- Phytochemical annotations from mass-spectral libraries may remain tentative unless supported by authentic standards, isolation or NMR-based structural confirmation.
- Published evidence is uneven across species, provinces and therapeutic indications, creating potential publication and geographic bias.

FUTURE SCOPE

Future work should establish a South African medicinal-plant biobank linking authenticated voucher specimens to geographic coordinates, cultivation conditions, harvest dates, DNA identity, metabolomic fingerprints and archived extracts. Such a resource would enable longitudinal chemotype studies and make independent replication substantially easier. A national or regional reference library of LC-MS/MS and GC-MS signatures could also support authentication and detection of adulteration.

Priority species should then enter bioassay-guided and mechanism-guided pipelines. Untargeted metabolomics can identify chemical features associated with activity, while targeted quantitative assays can define reproducible marker ranges. Fractionation should be accompanied by activity tracking so that active fractions are connected to confirmed compounds rather than simply to broad phytochemical classes. Where synergy is suspected, mixture-design experiments can determine whether combinations outperform individual constituents without assuming synergy in advance.

Translational studies should include ADME characterization, physiologically relevant models, formulation development and standardized toxicology. For topical products, skin permeation, irritation, sensitization, microbial stability and wound-repair endpoints should be integrated. For oral candidates, plasma exposure, metabolite identification, CYP interactions and organ-

specific toxicity become more important. Clinical research should begin only when botanical identity, chemical quality and preclinical safety are sufficiently established.

Finally, sustainable commercialization should be designed with communities rather than added after discovery. Cultivation programs, traceable supply chains, conservation targets, fair compensation and transparent benefit-sharing agreements can align pharmaceutical innovation with biodiversity protection. This integrated approach would help South African medicinal-plant science progress from descriptive ethnobotany toward reproducible, mechanism-based and socially responsible natural-product development.

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