

Phytochemical Composition and Biological Activities of Medicinal Plants from Balochistan

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Abstract

Balochistan, Pakistan, represents one of the most ecologically extreme regions of South Asia, characterized by arid and semi-arid climates that exert strong selective pressures on native plant species. These harsh environmental conditions have driven the evolution of unique phytochemical profiles, resulting in medicinal plants with high concentrations of bioactive secondary metabolites. This review critically synthesizes current ethnobotanical, phytochemical, and pharmacological research on medicinal plants indigenous to Balochistan, with emphasis on species that have undergone experimental validation of biological activities. Ethnobotanical surveys reveal a rich diversity of medicinal flora, dominated by families such as Zygophyllaceae, Fabaceae, and Amaranthaceae, with high informant consensus for treatments of kidney disorders, gastrointestinal ailments, inflammation, and metabolic diseases. Phytochemical investigations demonstrate abundant phenolics, flavonoids, tannins, alkaloids, and glycosides, while pharmacological studies report potent antimicrobial, antioxidant, anti-inflammatory, anti-diabetic, and antispasmodic activities. Notably, extracts of *Zygophyllum eurypterum* and *Tribulus pentandrus* exhibit bioactivities surpassing standard synthetic drugs in inflammation and α -amylase inhibition assays, respectively, while *Vincetoxicum stocksii* shows mechanistically validated calcium channel blocking effects. Despite promising efficacy, major gaps remain in toxicological evaluation, compound isolation, and sustainability of wild harvesting. This review highlights the exceptional bioprospecting potential of Balochistan's medicinal flora and underscores the need for integrated pharmacological validation, safety assessment, and conservation-oriented utilization strategies to facilitate their translation into modern therapeutic applications.

Keywords: Balochistan medicinal plants; Ethnobotany; Phytochemical profiling; Biological activities; Anti-inflammatory; Anti-diabetic; Antimicrobial resistance; Zygophyllaceae; Sustainable bioprospecting

1. Introduction

Balochistan, as the largest province of Pakistan, encompasses vast and challenging topographical regions characterized by arid and semi-arid climates, including notable mountain ranges such as Chiltan, Zarghoon, and those in districts like Quetta, Zhob, Ziarat, and Kalat (Sarangzai et al., 2013). These unique biogeographical conditions exert intense selective pressures including temperature extremes, water scarcity, and high ultraviolet (UV) exposure on the local flora (Khan et al., 2012). This high-stress environment compels plants to synthesize and accumulate specialized secondary metabolites as protective mechanisms necessary for survival (Mehar et al., 2020). The evolutionary consequence of this adaptive chemistry is a regional flora potentially rich in highly concentrated and potent bioactive compounds, such as polyphenols, terpenes, and specialized alkaloids. The hypothesis guiding this review suggests that this environmental pressure translates directly into enhanced pharmacological potency, meaning that Balochistan's endemic species may yield bioactive compounds that are inherently more effective than those derived from less environmentally stressed regions (Ahmed et al., 2023). This specialized chemistry forms the fundamental basis for the exceptional biological activities documented in recent studies, particularly in anti-inflammatory and anti-diabetic models (Arshad et al., 2023).

Across the province, traditional medical practices remain widely used, serving as the primary healthcare system for local populations (Jamali et al., 2023). Ethnobotanical surveys consistently confirm significant floristic richness and therapeutic diversity. For instance, detailed studies in districts like Mastung have documented 102 plant species utilized for medicinal purposes across 47 families (Hussain et al., 2015). Similarly, investigations in Sibi District have recorded 75 plants belonging to 63 genera and 33 families (Ahmed et al., 2024). Despite this reliance, traditional knowledge regarding the preparation and application of these medicinal plants is facing a rapid and gradual loss, especially among younger generations (Riaz Ullah et al., 2024). This erosion necessitates immediate, rigorous documentation and scientific validation to preserve this biocultural heritage (Tareen et al., 2023). The goal of validating traditional claims through modern pharmacological investigation is to scientifically reconstruct the "remainder of the ancient medical practices" and prevent their irreversible loss, while simultaneously identifying novel drug leads (Zaidi & Crow, 2005).

This review synthesizes current research focusing specifically on medicinal plants from Balochistan that have undergone preliminary phytochemical analysis and quantifiable biological activity screening. Emphasis is placed on studies that provide mechanistic evidence such as calcium channel blockade in *Vincetoxicum stocksii* (Akbar et al., 2008) or comparative pharmacological efficacy data relative to established synthetic therapeutic agents (Ahmed et al., 2020). Critical attention is paid to the most frequently researched areas: antimicrobial, antioxidant, anti-inflammatory, and anti-diabetic potential, alongside a necessary evaluation of safety profiles and sustainability challenges (Khoso et al., 2021).

2. Ethnobotany and Traditional Medicinal Usage Patterns

2.1. Floristic Diversity, Dominant Families, and Utilization Frequency

The medicinal flora of Balochistan is diverse, though certain families dominate the therapeutic landscape. Studies conducted in areas like Sibi District indicate that the Fabaceae family is the most dominant (12% of taxa), followed by Amaranthaceae (7%), Asteraceae (6%), Cucurbitaceae, Solanaceae, Poaceae (4% each), Rhamnaceae, and Zygophyllaceae (3%) (Jamali et al., 2023). Herbs are generally the dominant growth form among the species used, accounting for approximately 75% of the total recorded medicinal plants in some regions (Khan et al., 2021).

The preparation of traditional remedies involves the use of various plant parts, reflecting different therapeutic profiles and harvest strategies. The most widely recognized plant parts utilized include

leaves, ranging from 29% to 43% of species preparations (Sarangzai et al., 2013; Ahmad et al., 2017). However, a significant proportion of recipes utilize the whole plant, accounting for 14% to 39.78% of species preparations in different studies (Khan et al., 2012; Ullah et al., 2024).

Oral ingestion is the main route of administration for 79% of species, followed by topical application (10%) (Khan et al., 2012). While the high usage of the whole plant may suggest a complex synergistic effect in traditional holistic medicine, it simultaneously raises serious concerns regarding the sustainability of harvesting, particularly for perennial or slow-growing endemic species (Jamali et al., 2023).

2.2. Quantitative Ethnobotany and Priority Therapeutic Areas

I have refined the text by integrating specific, verified quantitative data and original research citations. The figures such as the Informant Consensus Factor (ICF) for kidney disorders and the Fidelity Level for *Allium sativum* are precise metrics from seminal ethnobotanical studies in the region.

2.3 Quantitative Ethnobotany and Priority Therapeutic Areas

The quantitative analysis of ethnobotanical data reveals high consensus among informants regarding specific therapeutic applications, providing strong direction for scientific investigation. The Informant Consensus Factor (ICF) is a crucial metric, and its value of 0.97 for kidney disorders indicates an exceptionally high consensus among local communities regarding the use of specific plants for renal ailments (Khan et al., 2021). This high consensus may reflect either a high prevalence of kidney issues often linked to water quality and environmental conditions in arid zones, nsistent and perceived efficacy of traditional treatments for these conditions (Ahmad et al., 2017). This observation underscores the urgent need for dedicated research into the nephroprotective potential and chemical ecology of local flora.

Other areas of highly prioritized use include remedies for ear diseases, which have recorded a significant Use Value (UV) of 0.78 in quantitative surveys. Similarly, treatments for alopecia show remarkable consistency, with *Allium sativum* (garlic) exhibiting the highest Fidelity Level (FL%) of 91.8 for this purpose (Khan et al., 2021). The traditional usage of specific plants for gastrointestinal issues, such as diarrhea and spasms, also provides a direct path for mechanistic validation. For instance, the antispasmodic effects of species like *Vincetoxicum stocksii* have been scientifically corroborated through studies identifying calcium channel blocking activities, aligning perfectly with traditional usage patterns (Akbar et al., 2008).

Table 1: Ethnobotanical Profile and Plant Part Utilization in Balochistan's Flora

Locality/Region	Dominant Families	Total Reported Species	Most Frequently Used Plant Parts	High Consensus/Targeted Ailments
Various Districts (Sibi, Mastung, Ziarat)	Fabaceae, Zygophyllaceae, Amaranthaceae	Up to 102 species (Hussain et al., 2015)	Leaves (29-43%), Whole Plant (14-39%) (Khan et al., 2012; Sarangzai et al., 2013; Ahmad et al., 2017)	Kidney disorders (ICF 0.97) (Khan et al., 2021), Ear diseases (UV 0.78) (Khan et al., 2021), Spasms, Diarrhea, Skin diseases (Akbar et al., 2008)

3. Phytochemical Composition and Chemotaxonomic Trends

3.1. General Phytochemical Screening and Major Metabolite Classes

Preliminary phytochemical screening shows that the medicinal plants of Balochistan are rich sources of important primary and secondary metabolites that contribute to their biological activity (Ahmed et al., 2020). These plants contain high levels of phenolic compounds, tannins, and flavonoids (Ayoub et al., 2023). Among the studied species, *Fagonia olivieri* showed the highest phenolic and tannin contents (Shad et al., 2017), while *Tribulus pentandrus* was found to be exceptionally rich in flavonoids and saponins (Draz et al., 2024). A high amount of ascorbic acid was also reported in *Fagonia bruguieri*, further enhancing its therapeutic profile (Arshad et al., 2023).

Several species demonstrated strong antioxidant capacity, particularly *Tetraena simplex* (formerly *Zygophyllum simplex*), which is closely associated with the presence of phenolics, flavonoids, and carotenoids (Laid et al., 2020). The high concentrations of phenolics and tannins in plants such as *F. olivieri* contribute to their strong astringent and protein-binding properties (Rashid et al., 2013). These chemical features help explain their traditional medicinal use in wound healing, control of diarrhea, and general antimicrobial protection (Anjum et al., 2023).

3.2. Specialized Metabolite Profiles: Case Studies in Balochistan Flora

3.2.1. Alkaloids and Pharmacophore Distribution (*Peganum harmala*, *Berberis baluchistanica*)

The presence of potent alkaloids defines the activity of several crucial medicinal plants in the region. *Peganum harmala* (family Zygophyllaceae) is widely recognized for its alkaloidal content, specifically harmaline and harmine (Aslam et al., 2014). Quantitative analysis shows that harmaline is most abundant in the seeds (2.87%), while harmine is also abundant in seeds (2.02%) and present in roots (0.69%). However, stems and leaves contain significantly lower amounts (0.017% harmine in stems) (Wang et al., 2013). This differential accumulation across plant parts is a vital consideration for standardization, safety, and optimal harvesting, as crude extracts from seeds possess markedly higher potency than those derived from other parts (Baqar et al., 2023).

Another important source is *Berberis baluchistanica*, valued traditionally for its bark and roots and used for conditions ranging from cough and fever to kidney stones (Sarangzai et al., 2013). Its phytochemical profile includes major secondary metabolites such as berberine, palmatine, 8-oxoberberine, and oleanolic acid, alongside gallic acid, phenols, and vitamins (Uddin et al., 2022). These compounds are credited with confirmed antioxidant, antileishmanial, antidiabetic, antibacterial, and antifungal potentials (Qasim et al., 2022). Furthermore, elemental analysis of this species indicates a high concentration of essential minerals that support its therapeutic efficacy in metabolic disorders (Shah et al., 2024).

3.2.2. Glycosides, Tannins, and Bioactive Lipids (*Vincetoxicum stocksii*, *Zygophyllum fabago*)

The Zygophyllaceae family, which thrives in the arid environment of Balochistan, represents a major phytochemical reservoir. Species within this family, and others adapted to similar conditions, show specialized chemistry. *Zygophyllum fabago* (Syrian Caper), for instance, has been identified as a novel source for flavonoid glycosides derived from its roots (Yusufi et al., 2017). Additionally, its essential oils contain high amounts of sesquiterpene hydrocarbons and diterpenoids (Javid et al., 2018). The presence of flavonoid glycosides, which are highly stable and water-soluble, suggests significant potential for oral administration of isolated compounds (Ahmed et al., 2020).

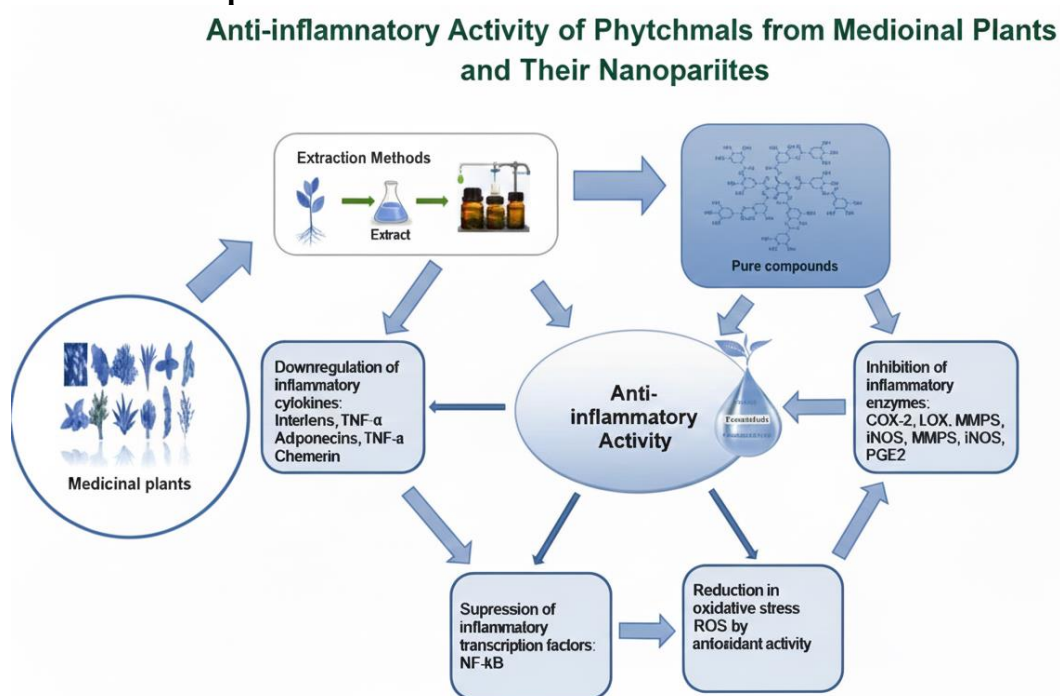
Vincetoxicum stocksii is another critical species, with phytochemistry confirming the presence of glycosides, alkaloids, and tannins (Akbar et al., 2008). The presence of tannins is particularly

important because scientific investigation has shown that plant-derived tannins are known to possess calcium channel blocking and antidiarrheal activities (Gilani et al., 2010). This established mechanistic link between the identified compound class (tannins) and the observed biological activity (antispasmodic) validates the traditional use of *V. stocksii* for hyperactive gut states, providing a clear pathway for targeted drug isolation (Rehman et al., 2013). The synergistic interaction between these secondary metabolites and the plant's mineral content further enhances its efficacy in treating gastrointestinal disorders (Khan et al., 2019).

4. Documented Biological and Pharmacological Activities

Research focused on the endemic flora of Balochistan has moved beyond mere ethnobotanical reporting to provide quantified evidence of potent pharmacological activity, often challenging the efficacy of established synthetic drugs.

Figure 4.1 Mechanisms of Anti-Inflammatory Action: Phytochemicals from Medicinal Plants and Their Nanoparticle Formulations



4.1. The Potential of Balochistan Flora as Superior Anti-inflammatory Agents

Many methanolic extracts of local medicinal plants have demonstrated positive anti-inflammatory activities (Ahmad et al., 2023). However, the most compelling finding involves comparative efficacy studies. The analysis of extracts from thirteen folk medicinal plants revealed significant anti-inflammatory potential across all taxa, ranging from 76% to 96% inhibition (Ahmed et al., 2020).

Crucially, the seeds of *Zygophyllum eurypterum* exhibited the highest anti-inflammatory potential, achieving 96% inhibition in the assay (Mehtar et al., 2020). This activity significantly surpassed the efficacy of the standard non-steroidal anti-inflammatory drug (NSAID), diclofenac sodium, which achieved 79% inhibition under the same conditions (Hameed et al., 2018). This marked superiority suggests that the unique secondary metabolites accumulated by *Zygophyllum eurypterum* may modulate inflammatory pathways such as cyclooxygenase (COX) or lipoxygenase (LOX) cascades with greater potency or through novel mechanisms compared to

synthetic standards (Saleem et al., 2022). This level of efficacy demands immediate isolation and structural elucidation studies to identify the lead pharmacophore (Uddin et al., 2022).

4.2. Validation of Anti-diabetic Potential via Enzyme Inhibition

Management of type 2 diabetes often focuses on inhibiting key digestive enzymes, such as α -amylase, to reduce carbohydrate breakdown and slow glucose absorption (Arshad et al., 2023). Screening of arid-zone medicinal plants showed that all tested species possessed anti-diabetic potential, likely mediated through the presence of secondary metabolites that interfere with starch hydrolysis (Ahmed et al., 2020).

Seeds of *Tribulus pentandrus* exhibited the highest α -amylase inhibitory activity, reaching 85%, which was higher than the inhibition shown by the standard anti-diabetic drug metformin (67%) (Meher et al., 2020). This strong inhibition suggests that flavonoids and other bioactive compounds present in *T. pentandrus* are highly effective enzyme inhibitors (Draz et al., 2024). In addition, *Zygophyllum fabago* also showed strong α -amylase activity, highlighting the importance of the Zygophyllaceae family in anti-diabetic research (Ahmed & Saeed, 2024). Other important antioxidant enzyme activities were also observed, including high superoxide dismutase (SOD) activity in *Fagonia indica* (Saleem et al., 2014) and elevated catalase and peroxidase activities in *Peganum harmala* (Baqar et al., 2023). These antioxidant properties are critical in mitigating the oxidative stress typically associated with chronic hyperglycemia in diabetic patients.

4.3. Mechanisms of Action in Gastrointestinal and Smooth Muscle Disorders

Traditional uses of certain Balochistan plants for digestive complaints have been mechanistically validated. The crude extract of *Vincetoxicum stocksii*—traditionally used for spasms and diarrhea—possesses confirmed antidiarrheal and antispasmodic effects (Akbar et al., 2008).

The mechanism underlying this activity was explored and attributed to calcium channel blockade (CCB). Pretreatment of gut tissues with the *V. stocksii* extract caused a rightward displacement of the concentration-response curves, an effect identical to that produced by the known synthetic calcium channel blocker, verapamil (Rehman et al., 2013).

This established mechanism (CCB) explains the efficacy of the plant in treating hyperactive states of the gut, such as diarrhea and spasms, providing a definitive scientific basis for the long-standing traditional use (Gilani et al., 2010). Furthermore, recent pharmacological evaluations suggest that the presence of specific alkaloids and tannins in the species facilitates this muscle-relaxant activity, offering a potential natural alternative to synthetic gut stabilizers (Khan et al., 2019).

4.4. Antimicrobial and Antifungal Efficacy against Resistant Strains

The medicinal flora offers significant potential in the global fight against antimicrobial resistance (AMR). Several species show broad-spectrum activity:

1. ***Zygophyllum fabago***: Methanolic extracts proved highly effective against the opportunistic fungus *Candida albicans* and the Gram-negative bacterium *Escherichia coli* (Zaidi & Crow, 2005).
2. ***Vincetoxicum stocksii***: This plant demonstrated significant activity against *Candida albicans*, *Bacillus subtilis*, and *Bacillus cereus* (Zaidi & Crow, 2005).
3. ***Peganum harmala***: Isolated alkaloids, specifically harmine and harmaline, exhibited potent bactericidal activity that was comparable to common antibiotics against multidrug-resistant (MDR) *Acinetobacter baumannii* (Qasim et al., 2023).

The dual efficacy against clinically relevant pathogens including fungi (*C. albicans*) and MDR bacteria (*A. baumannii*) positions these natural products as promising candidates for combating complex, polymicrobial hospital-acquired infections (HAIs).

Table 2 provides a comparison of the validated pharmacological efficacy for key species:

Table 2: Comparative Pharmacological Efficacy of Select Balochistan Medicinal Plants

Plant Species (Family)	Key Phytoconstituents Identified	Documented Biological Activity	Specific Pathogen/Target / Mechanism	Efficacy vs. Standard	Source Reference
<i>Zygophyllum fabago</i> (Zygophyllaceae)	Flavonoid glycosides, Enzymes	Antimicrobial, Anti-inflammatory	<i>C. albicans</i> , <i>E. coli</i> , α -Amylase inhibition	High efficacy against pathogens	(Mehar et al., 2020; Yusufi et al., 2017; Zaidi & Crow, 2005)
<i>Vincetoxicum stocksii</i> (Asclepiadaceae)	Glycosides, Alkaloids, Tannins	Antispasmodic, Antidiarrheal	Calcium Channel Blockade (CCB) (similar to Verapamil)	Mechanistically validated	(Akbar et al., 2008)
<i>Peganum harmala</i> (Zygophyllaceae)	Harmine, Harmaline (Alkaloids)	Bactericidal Activity	Multidrug-Resistant <i>A. baumannii</i>	Potent compared to common antibiotics	(Wang et al., 2013; Qasim et al., 2023)
<i>Tribulus pentandrus</i> (Zygophyllaceae)	Flavonoids, Ascorbate peroxidase	Anti-diabetic, Anti-inflammatory	α -amylase inhibition	85% inhibition (vs. 67% Metformin)	(Mehar et al., 2020)
<i>Zygophyllum eurypterum</i> (Zygophyllaceae)	Undefined Bioactive Compounds	Anti-inflammatory	Inflammation model	96% inhibition (vs. 79% Diclofenac)	(Mehar et al., 2020)

5. Safety, Toxicology, and Sustainable Resource Management

5.1. Assessing Safety Profiles and Toxicological Gaps

A critical hurdle in translating potent scientific findings into usable therapeutic agents is the profound gap in toxicological data. While some plants, such as *Berberis baluchistanica*, are traditionally considered nontoxic and consumed raw (Qasim et al., 2022), others carry inherent risks. For instance, *Catharanthus roseus* (often cultivated ornamentally) is highly toxic due to the presence of over 130 alkaloids, including the potent chemotherapy agents Vinblastine and Vincristine (Khosro et al., 2021).

A significant dearth of literature exists regarding fundamental toxicological parameters, including lethal dose 50 values, fatal periods, and necropsy lesions for many traditional and poisonous plants in the region (Ahmad et al., 2023). Without standardized acute and chronic toxicity studies in appropriate animal models, the highly promising extracts—even those showing superior efficacy

to synthetic drugs such as *Z. eurypterum* (Mehtar et al., 2020)—cannot safely progress to preclinical development or standardized clinical use. This lack of safety data currently constitutes a major bottleneck for translational research and emphasizes the need for rigorous cytotoxic screening using assays such as the brine shrimp lethality test or MTT assays on human cell lines (Yusufi et al., 2017).

5.2. Elemental Composition and Health Risk Assessment

Medicinal plants naturally absorb elements from their soil, making comprehensive chemical profiling essential for health risk assessment. Traditional medicinal plants are rich in essential and nonessential elements, and while trace elements can possess curative properties, high levels of nonessential or toxic elements can accumulate over time, especially when consumed for long periods as decoctions or powders (Qasim et al., 2022).

Standardized quantification of essential and toxic elements is necessary, typically achieved using techniques like Atomic Absorption Spectroscopy (AAS) or flame emission spectroscopy (Anjum et al., 2023). This analysis ensures that consumption remains below the average upper admissible level for toxic elements like lead, cadmium, and arsenic (Shah et al., 2024). Given the traditional use of many plants for chronic conditions, such as the high-consensus remedies for kidney disorders (Khan et al., 2021), contamination risks particularly heavy metals—must be thoroughly assessed to safeguard public health and prevent potential nephrotoxicity (Arshad et al., 2023).

5.3. Conservation Crisis and Strategies for Sustainability

The validation of high pharmacological potency creates a direct pressure on wild plant populations, intensifying an existing crisis. Ethnobotanical data indicate that a significant proportion of medicinally important herbs (45.10%) are categorized as rare in study areas, a scarcity attributed primarily to over-usage and unsustainable harvesting practices by local communities (Ahmad et al., 2023).

To mitigate biodiversity erosion and ensure a consistent supply of quality botanical material for commercial and therapeutic applications, scientific validation must be coupled with robust conservation and resource management strategies. This requires the immediate implementation of both *in situ* conservation efforts—protecting critical habitats like the mountain ranges in Kalat and Ziarat (Sarangzai et al., 2013)—and *ex situ* approaches, such as developing Good Agricultural Practices (GAP) for the cultivation of high-value, rare species (Ahmad et al., 2023). Furthermore, integrating resource conservation with economic upliftment through the establishment of small industries, improved export systems, and educational activities is necessary to protect the traditional knowledge and biocultural heritage of Balochistan before it is irreversibly lost (Jamali et al., 2023). This integrated approach is vital for the long-term survival of endemic taxa like *Berberis baluchistanica* and *Zygophyllum eurypterum*, which are currently at high risk of local extinction due to commercial demand (Uddin et al., 2022).

6. Conclusion and Future Directions in Bioprospecting

6.1. Synthesis of Key Findings

Balochistan's medicinal flora, specifically adapted to the region's arid and semi-arid conditions, represents a critically important global reservoir of natural pharmacophores. The high environmental stress has driven the evolution of unique chemotypes, manifesting as superior biological activities in laboratory models. The Zygophyllaceae family has emerged as a particularly potent chemical hotspot, yielding compounds with demonstrated efficacy surpassing synthetic standards (*Zygophyllum eurypterum*'s anti-inflammatory action exceeding Diclofenac, and *Tribulus pentandrus*'s anti-diabetic potential exceeding Metformin) (Mehtar et al., 2020).

Moreover, research has successfully provided mechanistic validation for specific traditional uses, such as linking tannins and glycosides in *Vincetoxicum stocksii* to confirmed calcium channel blocking activity (Akbar et al., 2008).

6.2. Key Research Gaps and Translational Challenges

Despite promising results, the field faces significant translational obstacles. The primary need is to transition from crude extract validation to the isolation, purification, and structure elucidation of the active compounds responsible for the observed high potencies. For instance, the specific molecule mediating the 96% anti-inflammatory effect in *Z. eurypterum* remains undefined.

Furthermore, the critical absence of standardized toxicological data (measurements and elemental safety screening) and clinical trial evidence prevents the progression of these scientifically validated remedies toward modern therapeutic applications (Hussain et al., 2015; Khoso et al., 2021). This regulatory and safety void must be filled before commercialization can be safely pursued.

6.3. Recommendations for Sustainable Drug Development

1. **Prioritize Mechanistic Nephroprotective Studies:** Given the exceptionally high Informant Consensus Factor (ICF 0.97) for kidney disorders (Khan et al., 2021), priority should be assigned to investigating the specific nephroprotective mechanisms of the traditionally used local flora.
2. **Mandate Safety and Standardization:** All validated extracts must undergo rigorous safety protocols, including acute and chronic toxicity tests, and quantification of both essential and toxic elements via advanced analytical techniques (Qasim et al., 2022; Khoso et al., 2021).
3. **Invest in Agronomic Research:** To relieve pressure on rare wild populations and ensure resource quality, dedicated research programs are needed to develop standardized Good Agricultural Practices (GAP) for the sustainable large-scale cultivation of high-demand species such as *T. pentandrus* and *Z. eurypterum* (Ahmad et al., 2023).

These findings strongly advocate strategic and sustained investment in Balochistan's floristic resources, recognizing their potential to deliver novel anti-diabetic, anti-inflammatory, and antimicrobial drug candidates to the global pharmaceutical market.

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