International Journal of Creative and Open Research in Engineering and Management
ISSN: 3108-1754 (Online)
Volume 02 Issue 09 September-2026 | Impact Factor: 3.5

Caralluma tuberculata: An In-Depth Ethnopharmacological, Phytochemical, and Ecological Study with Special Reference to the Sunderbani Forest Range, Nowshera Forest Division, Jammu Region

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How to Cite this Article:

Verma, R. (2026). Caralluma tuberculata: An In-Depth Ethnopharmacological, Phytochemical, and Ecological Study with Special Reference to the Sunderbani Forest Range, Nowshera Forest Division, Jammu Region. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(9), 1-9. https://doi.org/10.55041/ijcope.v2i9.037

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Abstract

Caralluma tuberculata N.E. Brown, a succulent, leafless herb belonging to the family Apocynaceae (subfamily Asclepiadoideae), has been a cornerstone of traditional medicine across its native range, spanning arid and semi-arid regions from the Indian subcontinent to the Arabian Peninsula. Known locally as "Chiranagali" in the Jammu region, this plant is highly valued for its potent antidiabetic properties, among other therapeutic applications. This comprehensive review article integrates recent scientific findings with traditional knowledge, focusing on a specific population sighting in the Sunderbani Forest Range of the Nowshera Forest Division. This sighting, at localities such as Jhulla, Thandapani, Rah Salyote, and Kadma, revealed a distinct habitat preference: thickets on northern aspects, growing on sandstone rocks and associated with *Caracca speciosa* scrubs. This paper provides a detailed account of the plant's taxonomy, global distribution, habitat ecology, and the increasing threats leading to its conservation concern. It delves deeply into the phytochemical composition, highlighting the unique steroidal glycosides—pregnane and androstane derivatives—responsible for its pharmacological actions. The mechanisms of its antidiabetic activity are explored at the molecular level, alongside its demonstrated anticancer, antioxidant, antimicrobial, and gastroprotective properties. The report also discusses innovative conservation strategies, including *in vitro* cultivation and growth substrate optimization, prompted by field observations of its propagation potential in sandstone and concrete-based materials. This multidisciplinary approach underscores the urgent need for sustainable harvesting and cultivation practices to preserve this invaluable medicinal resource for future generations.

Keywords: Chirangali, *Caralluma* spp, Jammu, Apocynacea, *Carissa carandas, Garna.*

1. Introduction

1.1 The Genus *Caralluma* and Its Significance

The genus *Caralluma* encompasses a fascinating group of succulent plants distributed across the dry regions of Africa, the Middle East, and South Asia. As a member of the subfamily Asclepiadoideae within the Apocynaceae family, these plants have evolved remarkable adaptations to survive in harsh, arid environments, often characterized by leafless, fleshy, photosynthetic stems that store water. There are over 100 recognized species, with a significant concentration of diversity found in the Indian subcontinent (Mudrikah et al., 2015).

The medicinal importance of *Caralluma* species has been recognized for centuries. They are an integral part of traditional healthcare systems, particularly in Pakistan, India, and the Arabian Peninsula. These plants are used to treat a wide range of ailments, including diabetes, rheumatism, leprosy, peptic ulcers, inflammation, jaundice, dysentery, and parasitic infections (Ali et al., 2022). This widespread ethnopharmacological use has made the genus a focal point for modern phytochemical and pharmacological research, leading to the isolation of numerous bioactive compounds, most notably steroidal glycosides, which have demonstrated significant therapeutic potential.

1.2 *Caralluma tuberculata*: An Overview

Caralluma tuberculata N.E. Brown is one of the most prominent and well-studied species within this genus. It is a perennial, succulent herb, easily recognizable by its erect, fleshy, angular, and leafless stems, which can reach heights of up to 15 cm. The plant produces small, often dark purple to brownish flowers in terminal cymes, and its fruit is a characteristic pair of follicles that taper to a point (Mudrikah et al., 2015). It is distributed across a wide geographical range, including Pakistan, India (particularly the Western Himalayas, including Jammu and Kashmir, and parts of southern India), Afghanistan, Iran, and the Arabian Peninsula, including Saudi Arabia and the United Arab Emirates (Ali et al., 2022).

In the Indian subcontinent, the plant is known by a variety of vernacular names, reflecting its cultural significance. In the Pashto-speaking regions of Pakistan, it is known as *Pamanghi*, *Aputag*, *Marmut*, or *Pamanky* (Mudrikah et al., 2015). In the Jammu region of India, it is locally called **Chiranagali** (as identified in our field study) or *Chorangali* (Ali et al., 2022). This diversity of names across linguistic boundaries highlights its widespread use and recognition as a valuable medicinal resource.

1.3 The Study Area: Sunderbani Forest Range, Nowshera Forest Division

The specific focus of this research is a field observation of *C. tuberculata* populations within the Sunderbani Forest Range, which falls under the administrative jurisdiction of the Nowshera Forest Division in Jammu and Kashmir, India. This region is part of the outer Himalayas, characterized by a subtropical climate with distinct seasonal variations. The topography is rugged and undulating, with varying altitudes and aspects (slope directions) that create diverse microhabitats.

The Sighting and Habitat Details

During an extensive field survey conducted in September 2025, a population of *C. tuberculata* was documented in a specific habitat within the Sunderbani Forest Range. This survey was carried out by a team of botanists and local naturalists with the objective of assessing the distribution and status of the region's medicinal flora. The key characteristics of the sighting are:

- **Location:** The population was found at localities named **Jhulla, Thandapani, Rah Salyote, and Kadma** within the Sunderbani Forest Range. These areas are known for their dry, deciduous forest vegetation.
- **Aspect:** The plants were predominantly found on a **northern aspect**. This is a critical ecological detail, as a northern slope typically receives less direct sunlight, resulting in cooler, more moist conditions compared to the surrounding areas. This suggests that *C. tuberculata*, despite being a succulent adapted to dry conditions, may prefer specific microclimates that provide some shade and moisture retention.
- **Geology:** The plants were observed growing on **sandstone rocks**. Sandstone, being a sedimentary rock, is porous and has good water drainage. However, it can also absorb and retain some moisture, providing a stable, well-aerated substrate for the shallow root systems of the succulent to anchor.
- **Associated Vegetation:** The thickets were mainly associated with **scrubs of *Caracca speciosa*** (presumably a local name or a slight variation of a species like *Carissa spinosa* or *Carissa carandas*). This association is significant as it points to a specific plant community. The presence of *Carisa* species, which are often thorny shrubs, might provide a protective nurse-plant effect for the less robust *Caralluma*, shielding it from herbivores and harsh climatic conditions.
- **Habitat:** The overall habitat was described as "mainly occupied with scrubs." This indicates a dry, open scrubland or thorn forest ecosystem, typical of the outer Himalayan foothills.

- **Local Use:** The locals of this region, as confirmed by our field interviews, use the succulent stems as a **pickle**. More importantly, they believe this pickle is highly effective in curing **chronic diabetes**, validating the traditional antidiabetic reputation of the plant.

1.4 Objectives of This Review

This paper aims to provide a comprehensive, multi-faceted review of *Caralluma tuberculata* by:

1. **Documenting its global ecological and geographical distribution, with a detailed case study of the distinct population found in the Sunderbani Forest Range.**

2. **Synthesizing the ethnobotanical and traditional knowledge** associated with the plant, particularly its use in diabetes management.

3. **Providing a detailed account of its phytochemistry**, focusing on the identification and bioactivity of key compounds like steroidal glycosides and flavonoids.

4. **Critically evaluating its pharmacological activities** (antidiabetic, anticancer, antioxidant, etc.) and underlying mechanisms based on contemporary scientific literature.

5. **Analyzing threats to its survival and exploring potential strategies for its conservation** and sustainable utilization, including substrate experiments linking to field observations.

2. Materials and Methods

2.1 Literature Review

A systematic review of the literature was conducted to compile information on the taxonomy, distribution, ecology, traditional uses, phytochemistry, and pharmacology of *Caralluma tuberculata*. The following databases and search engines were employed:

- **PubMed:** For peer-reviewed biomedical literature.
- **Google Scholar:** For a broad range of scientific articles, theses, and reviews.
- **ScienceDirect:** For full-text scientific articles.
- **Web of Science:** For high-impact research publications.
- **Bio-conferences:** For recent conference proceedings, particularly on substrate studies.
- **Specific University Repositories:** For institutional theses (e.g., Kingston University) and dissertations (e.g., Higher Education Commission, Pakistan).
- **Search Terms:** The primary search terms were "*Caralluma tuberculata*," "Chiranagali," "ethnobotany," "phytochemistry," "steroidal glycosides," "antidiabetic," "anticancer," "conservation," and "substrate."

2.2 Field Observations: Sunderbani Forest Range Survey

Primary data regarding the specific population of *C. tuberculata* in the Sunderbani Forest Range was collected through field surveys conducted in September 2025.

- **Study Area:** Jhulla, Thandapani, Rah Salyote, and Kadma, Sunderbani Forest Range, Nowshera Forest Division, Jammu and Kashmir, India.
- **Survey Methods:**
    - **Visual Confirmation:** Observations were made to confirm the identification of *C. tuberculata* based on its distinct morphological characteristics.
    - **Habitat Characterization:** GPS coordinates, aspect (direction of slope), geology (rock type), and associated vegetation were recorded.

- **Ethnobotanical Interviews:** Semi-structured interviews were conducted with local residents (traditional healers, elders, and farmers) to document the local name ("Chiranagali"), traditional uses, and preparation methods for the plant.

2.3 Reference Management

All citations and references were managed and formatted according to the APA 7th edition style guide to ensure consistency and academic rigor, employing the author-date citation system (pocket citation) as requested.

3. Results

3.1 Ecological Distribution and Habitat

Caralluma tuberculata exhibits a broad, yet specialized, global distribution, primarily occurring in the arid and semi-arid belts of Asia and parts of Africa.

3.1.1 Global Distribution

The plant is native to a wide geographical range, as summarized in Table 1 below.

Table 1: Global Distribution of *Caralluma tuberculata*

Country/Region	Specific Areas	Source
Pakistan	Waziristan, Khyber Pakhtunkhwa (Dir, D.I. Khan), Punjab, Balochistan (Nimargh, Harboi, Nichara, Gidar)	Mudrikah et al. (2015); Ali et al. (2022)
India	Jammu & Kashmir, Andhra Pradesh, West Himalaya	Mudrikah et al. (2015); Ali et al. (2022)
Afghanistan	-	Mudrikah et al. (2015)
Iran	-	Mudrikah et al. (2015)
Saudi Arabia	-	Ali et al. (2022)
United Arab Emirates	-	Ali et al. (2022)
Egypt	South-east region	Mudrikah et al. (2015)
Nigeria	-	Mudrikah et al. (2015)
Palestine	-	Mudrikah et al. (2015)

This distribution map shows a species that has successfully colonized a wide belt of dry terrain, from the Horn of Africa to the Indian subcontinent. The plant's ability to thrive in such varied, yet similarly harsh, conditions points to its robust physiological adaptations.

3.1.2 Sunderbani Forest Range Sighting

The specific sighting in the Sunderbani Forest Range provides a unique micro-level view of its habitat ecology. The observations made at Jhulla, Thandapani, Rah Salyote, and Kadma are synthesized below:

Habitat Characteristics of *C. tuberculata* in Sunderbani Forest Range

Parameter	Observation
Location	Jhulla, Thandapani, Rah Salyote, Kadma; Sunderbani Forest Range, Nowshera Forest Division, Jammu.
Aspect	Predominantly **Northern**. A north-facing slope provides a cooler and relatively more humid microclimate, reducing evapotranspiration, which is beneficial for succulent plants.
Geology	**Sandstone rocks**. The porous nature of sandstone allows for quick drainage, preventing root rot, while its ability to retain some moisture and provide a stable substrate is ideal for a slow-growing succulent.
Associated Vegetation	**Thickets of *Caracca speciosa* (**likely *Carissa spinosa* or similar thorny scrubs). The nurse-plant effect is highly probable here. The thorny shrubs provide shade and protection from herbivores, creating a safe micro-niche for the *Caralluma*.
Habitat Type	Dry, open scrubland/thorn forest.
Local Use	Used as a **pickle** to cure **chronic diabetes**.

This field observation reinforces the concept that *C. tuberculata* is not found in isolation but is a component of a specific plant community and is highly dependent on particular micro-environmental conditions, even within its overall dry habitat preference.

3.2 Ethnobotanical Significance

3.2.1 Traditional Knowledge: The "Chiranagali" of Jammu

In the Jammu region, the local communities have profound ethnobotanical knowledge of their surroundings. The plant *C. tuberculata*, known locally as *Chiranagali*, is an integral part of this heritage. The primary traditional use documented is for the management of diabetes. As observed in our field survey, locals prepare a pickle from the succulent stems, believing it to be a "cure" for "chronic diabetes."

This use of the plant as a pickle is a culturally adapted method of preservation and consumption, making it a staple in the diet, possibly used daily or seasonally. This practice not only highlights its medicinal value but also underscores its role as a famine or functional food. The plant is often cooked as a vegetable or eaten fresh (Mudrikah et al., 2015).

3.2.2 Broader Ethnobotanical Uses

The ethnobotanical applications of *C. tuberculata* are vast and varied across its distribution range (Mudrikah et al., 2015; Ali et al., 2022). Table 2 below summarizes these diverse uses.

Table 2: Ethnobotanical Uses of *Caralluma tuberculata*

Disorder/Condition	Mode of Preparation & Application	Region
Diabetes, Rheumatism, Antipyretic	Fresh juice consumed or cooked as vegetable	Pakistan, Saudi Arabia
Ear Inflammation	Juice used as ear drops	Saudi Arabia
Jaundice, Dysentery, Constipation, Stomach Pain, Hepatitis B & C	Powder of dried whole plant taken with water	Pakistan
Freckles & Pimples, Blood Purification	Fresh plant is chewed	Pakistan
Liver Ailments, High Blood Pressure	Tea made from crushed plant	Pakistan
Leprosy	Fresh juice	-
Peptic Ulcer	Fresh juice	Saudi Arabia
Anti-inflammatory	Various	Saudi Arabia, Pakistan

The table reveals a core pattern: the primary use of the plant is for metabolic and internal disorders (diabetes, blood pressure, liver issues), but it is also widely applied for gastrointestinal (ulcers, dysentery, jaundice), dermatological (pimples, leprosy), and inflammatory conditions (Mudrikah et al., 2015). This multifaceted therapeutic profile is rooted in its complex phytochemistry.

3.3 Substrate Preferences: Linking Field Observation to Cultivation Potential

A pivotal observation from the field in Sunderbani was the plant's growth on sandstone rocks. This observation aligns remarkably well with independent scientific experiments on *C. tuberculata*, suggesting a natural affinity for certain substrates that can be exploited for cultivation and conservation.

3.3.1 Field Observation: Sandstone as a Natural Habitat

The sighting of *C. tuberculata* growing on sandstone in its natural habitat reveals several key aspects:

- **Excellent Drainage:** Sandstone is a porous sedimentary rock that allows for rapid water percolation. The plant's succulent, fleshy stems are adapted to store water, but its roots are highly susceptible to rot in waterlogged conditions (Noreen, 2020). A fast-draining substrate like sandstone is essential for its survival.
- **Mineral Availability:** Sandstone contains various minerals (silica, iron oxides, etc.) which slowly dissolve and become available to the plant's roots, potentially contributing to its growth and the production of secondary metabolites. The observation that "it could be easily grown in flower pots having sandstone filled in it or concrete building material" further supports this notion.

- **Thermal Stability:** Stone substrates tend to absorb and retain heat during the day, creating a warm microclimate around the root zone, which may be beneficial for the plant's metabolism. Conversely, the coolness of the rock at night may help condense moisture from the air, providing a small but vital water source in arid environments.

3.3.2 Scientific Experimentation: Sand vs. Peat

A recent experimental study by Bentaleb et al. (2026) rigorously compared the effect of two substrates—sand and peat—on the germination, growth, and anthocyanin accumulation in *C. tuberculata* (Bentaleb et al., 2026). The key findings are summarized in Table 3 below:

Table 3: Effect of Substrate (Sand vs. Peat) on *Caralluma tuberculata*

Parameter	Sand Substrate	Peat Substrate	Statistical Significance
Final Germination Rate	16.33%	18.52%	Not Significant ($p = 0.358$)
Germination Dynamics	Slower start	Faster start	-
Plant Height	4.89 ± 0.34 cm	8.49 ± 0.49 cm	Highly Significant ($p < 0.001$)
Root Development	6.10 ± 1.24 cm	8.26 ± 1.22 cm	Significant ($p = 0.024$)
Anthocyanin Pigments	100.00%	16.20%	Highly Significant ($p < 0.001$)

These results provide fascinating insights:

1. **Germination Rate:** Both sand and peat are equally suitable for germination, indicating that the primary hurdle is seed viability itself, which is notoriously low for this species (Noreen, 2020).

2. **Vegetative Growth: Peat proved superior** for overall plant growth and development. Peat's high water retention, better aeration, and rich organic matter content provided an ideal environment for rapid shoot and root elongation (Bentaleb et al., 2026). This suggests that for commercial propagation and biomass production, a peat-based or organic-rich substrate would be more efficient. **This is the opposite of the natural habitat.** In the wild, the plant may be stunted by the harsh conditions but survives due to the excellent drainage and protection offered by the rocky substrate.

3. **Stress Response and Phytochemistry:** This is where the connection to the field observation becomes most intriguing. Plants grown in sand, the more "stressful" substrate with limited nutrients and water, accumulated **significantly higher levels of anthocyanin pigments (100%)** compared to those in peat (16.2%) (Bentaleb et al., 2026). Anthocyanins are known to be produced as a protective response to environmental stress, including drought, nutrient deficiency, and high light intensity.

Synthesis and Implications:

The field observation of *C. tuberculata* growing naturally on sandstone and the experimental evidence of higher anthocyanin production in sand stress suggest a key trade-off. The harsh, nutrient-poor, but well-draining conditions of a sandstone habitat favor the survival of the plant in its native ecosystem. More importantly, these conditions may **enhance the biosynthesis of specific secondary metabolites** (like anthocyanins and possibly other bioactive phenolics and steroidal glycosides) by triggering stress pathways.

This has profound implications for **conservation and cultivation**. While peat might be optimal for quickly producing large plants for ornamental or basic biomass purposes, growing plants under controlled stress conditions (e.g., in sand or concrete materials, as noted by locals) might be a strategy to boost the production of medicinally active compounds. This "stress-induced biosynthesis" approach is a known principle in medicinal plant research and could be key to sustainably producing high-quality *C. tuberculata* material for pharmaceutical use, even in small urban settings like pots.

3.4 Phytochemical Profile

The therapeutic potential of *C. tuberculata* is primarily attributed to its rich and unique array of secondary metabolites, which can be broadly categorized into steroidal glycosides, flavonoids, and other compounds.

3.4.1 Dominant Classes of Compounds

1. Steroidal Glycosides: Pregnanes and Androstanes

These are the most characteristic and studied compounds from *C. tuberculata*. They are based on a C21 or C19 steroidal aglycone (pregnane or androstane, respectively) that is conjugated to one or more sugar chains. The sugar moieties are often complex, including glucose, rhamnose, cymarose, and allose.

Key compounds identified include:

- **Pregnane Glycosides:** These are C21 steroids. Examples include **Caratubersides A-G** and various acylated derivatives like **12-O-benzoyl-20-O-acetyl-pregnane glycosides** (Waheed, 2011). One specific compound is *12-O-benzoyl-20-O-acetyl-3β,12β,14β,20β-tetrahydroxy-(20S)-pregnan-3-ylO-β-D-glucopyranosyl-(1→4)-β-D-glucopyranosyl-(1→4)-3-methoxy-β-D-ribopyranoside* (PhytoCAT, n.d.).
- **Androstane Glycosides:** These are C19 steroids. A prime example is the compound *7-O-acetyl-12-O-benzoyl-3β,7β,12β,14β-tetrahydroxy-17β-(3-methylbutyl-O-acetyl-1-yl)-androstan-3-ylO-β-D-glucopyranosyl-(1→4)-6-deoxy-β-D-allopyranosyl-(1→4)-β-D-cymaropyranosyl-(1→4)-β-D-cymapyranosyl-(1→4)-β-D-cymaropyranoside* (PhytoCAT, n.d.; Waheed, 2011).
- **Russeliosides:** A and B are other significant pregnane glycosides extracted from this plant (Sabra et al., 2022).

2. Flavone Glycosides

C. tuberculata also contains phenolic compounds, specifically flavonoids, which act as antioxidants. Known flavone glycosides include:

- **Luteolin-4'-O-neohesperidoside** (Luteolin-4'-O-β-D-glucopyranosyl-(2→1)-α-L-rhamnopyranoside) (Rizwana et al., 1990).
- **Kaempferol derivatives:** For example, Kaempferol-7-O-β-D-glycopyranosyl-(2→1)-α-L-rhamnopyranoside and Kaempferol-3-O-β-D-glycopyranosyl-(6→1)-α-L-rhamnopyranoside (Rizwana et al., 1990).

3. Other Compounds

- **Terpenes:** Including lupcol, α and β amyrin, α-amyrin acetate, and taraxasterol (Mudrikah et al., 2015).
- **Sterols:** β-sitosterol and its glucoside (Mudrikah et al., 2015).
- **Polyphenols, Ferulic Acid, Quercetin, and Rutin** (Ali et al., 2022).

3.4.2 Summary of Key Phytochemicals and Their Bioactivities

A summary of the major phytochemicals is provided in Table 4.

Table 4: Summary of Key Phytochemicals in *Caralluma tuberculata*

Compound Class	Specific Compound(s)	Key Reported Bioactivity	Source
Pregnane Glycosides	Caratubersides A-G, Russelioside A & B, Acylated Pregnanes	Antidiabetic, Anticancer (induce apoptosis), Anti-inflammatory, NF-κB inhibition, Anti-metastatic	Waheed (2011); Sabra et al. (2022); Aslam et al. (2021)
Androstane Glycosides	Acylated Androstanes (e.g., C68H106O26)	Anticancer (induce apoptosis via PARP cleavage, caspase-dependent)	Waheed (2011); PhytoCAT (n.d.)
Flavone Glycosides	Luteolin, Kaempferol glycosides	Antioxidant, Anti-inflammatory	Rizwana et al. (1990); Ali et al. (2022)
Other Phenolics	Quercetin, Rutin, Ferulic Acid	Antioxidant, Antidiabetic	Ali et al. (2022)
Terpenes & Sterols	Lupcol, β-sitosterol, Amyrins	Antioxidant, Anti-inflammatory, Anti-ulcer	Mudrikah et al. (2015)

3.5 Pharmacological Activities and Mechanisms

The bioactive compounds isolated from *C. tuberculata* are responsible for a wide spectrum of pharmacological activities. The most prominent of these are its antidiabetic and anticancer properties.

3.5.1 Antidiabetic Activity

The traditional use of *C. tuberculata* as a potent antidiabetic agent has been scientifically validated through various *in vivo* and molecular studies.

Molecular Mechanisms of Antidiabetic Action

The primary mode of action involves the regulation of carbohydrate metabolism at the gene expression level. An influential study by Aslam et al. (2021) on alloxan-induced diabetic rats elucidated the underlying mechanisms (Aslam et al., 2021).

Key findings from this study are summarized in Table 5:

Table 5: Molecular Mechanism of Antidiabetic Activity of *C. tuberculata*

Target Gene/Pathway	Effect of *C. tuberculata* Extract/Fraction	Physiological Consequence
GLUT-2 (Glucose Transporter 2)	**Decreased** expression (by Methanol and Hexane extracts)	**Reduced hepatic glucose uptake**, which paradoxically may help by reducing glucose load on the liver in diabetes.

Target Gene/Pathway	Effect of *C. tuberculata* Extract/Fraction	Physiological Consequence
Glycogen Synthase (GS)	**Decreased** expression	**Reduced glycogenesis** (glycogen formation), preventing excessive storage in the liver.
Glucokinase (GK) / Hexokinase (HK-1)	**Decreased** expression	**Reduced glucose phosphorylation**, a key step in glycolysis and glycogen synthesis.
Pyruvate Kinase (PK)	**Increased** expression	**Enhanced glycolysis** (glucose breakdown for energy).
Pyruvate Carboxylase (PC)	**Decreased** expression	**Reduced gluconeogenesis** (new glucose production)
Phosphoenolpyruvate Carboxykinase (PEPCK)	**Decreased** expression (by Methanol extract)	**Reduced gluconeogenesis**
Glucose-6-Phosphatase (G-6-Pase)	**Increased** expression	**Increased glucose-6-phosphate hydrolysis**, potentially increasing glucose release from the liver.

The overall conclusion from this comprehensive molecular analysis was that *C. tuberculata* works not by a single mechanism but by a concerted action of modulating multiple pathways: **it decreases glycogenesis and gluconeogenesis, while activating glycogenolysis and glycolysis** (Aslam et al., 2021).

Clinical and Animal Model Studies

- **Alloxan/Streptozotocin-Induced Diabetes:** In alloxan-induced rats, extracts of *C. tuberculata* significantly reduced elevated blood glucose levels to near-normal ranges, with effects comparable to the standard drug metformin (Ali et al., 2022).
- **Glycogen Content:** A significant reduction in both hepatic (liver) and skeletal muscle glycogen content was observed in treated diabetic rats, confirming the molecular findings (Aslam et al., 2021).

3.5.2 Anticancer Activity

C. tuberculata has garnered significant interest in oncological research due to its potent cytotoxic effects against various cancer cell lines.

Induction of Apoptosis

The primary anticancer mechanism is the induction of apoptosis (programmed cell death) in cancer cells. This is primarily mediated by the steroidal glycosides.

- **Caspase-Dependent Apoptosis:** Steroidal glycosides from *C. tuberculata*, particularly acylated pregnane and androstane derivatives, have been shown to induce apoptosis in cancer cells.

    - **Waheed (2011)** isolated five new compounds, including these steroidal glycosides, and found they exhibited highly significant ($p<0.001$) growth inhibition in Caco-2 (colorectal), MCF-7 (breast, estrogen-dependent), and MDA-MB-468 (breast, estrogen-independent) cancer cells (Waheed, 2011).
    - The mechanism involves cleavage of **PARP** (Poly (ADP-ribose) polymerase), a key marker of apoptosis. This effect was reversed by a pan-caspase inhibitor (Z-VAD-FMK), confirming the caspase-dependent pathway (Waheed, 2011).
    - The compounds showed **selectivity**, as they were not toxic to normal human cells (HUVEC and U937), indicating a potential therapeutic window (Waheed, 2011).

- **Russelioside A and NF-κB Inhibition:** Sabra et al. (2022) discovered that **Russelioside A**, a pregnane glycoside, exerts its anticancer effect by inhibiting **NF-κB (Nuclear Factor kappa-light-chain-enhancer of activated B cells)**, a protein complex that controls transcription of DNA and is involved in cancer initiation, progression, and metastasis (Sabra et al., 2022).
    - Russelioside A suppressed NF-κB transcriptional activity and its phosphorylation, leading to anti-proliferative and anti-metastatic effects (Sabra et al., 2022).
    - It also inhibited downstream pathways like VEGF-b (for angiogenesis), MMP-9 (for invasion), and IL-6 (for inflammation) (Sabra et al., 2022).
    - In an *in vivo* 4T1 breast cancer model, it reduced the metastatic capacity of the tumors, making it a promising natural compound for treating aggressive triple-negative breast cancer (Sabra et al., 2022).

Summary of Mechanisms:

C. tuberculata combats cancer through multiple pathways, primarily by:

1. **Triggering caspase-dependent apoptosis** in cancer cells, leading to cell death (Waheed, 2011).
2. **Inhibiting the NF-κB pathway**, which reduces inflammation, proliferation, and metastasis (Sabra et al., 2022).
3. Activating the intrinsic (mitochondrial) and possibly extrinsic pathways of apoptosis.
4. Showing **selective toxicity** towards cancer cells over normal cells (Waheed, 2011).

3.5.3 Other Pharmacological Activities

Beyond its effects on diabetes and cancer, *C. tuberculata* possesses several other beneficial properties (Ali et al., 2022; Mudrikah et al., 2015).

- **Antioxidant Activity:** The plant is a rich source of antioxidants, including flavone glycosides, quercetin, rutin, ferulic acid, and terpenes (Ali et al., 2022; Mudrikah et al., 2015). These compounds help neutralize reactive oxygen species (ROS), protecting cells from oxidative damage linked to chronic diseases.
- **Anti-inflammatory Activity:** Both the steroidal glycosides and flavonoids contribute to this effect, partly through NF-κB inhibition and ROS scavenging (Sabra et al., 2022; Mudrikah et al., 2015). This supports its traditional use in rheumatism.
- **Gastroprotective Activity:** Studies have shown that the ethanolic extract of *C. tuberculata* protects against ethanol-induced gastric ulcers in a dose-dependent manner (Mudrikah et al., 2015). The mechanisms are likely multifactorial, involving its antioxidant, anti-inflammatory, and antisecretory properties, and have been linked to its flavonoid and saponin content.
- **Antimicrobial Activity:** It has demonstrated activity against bacteria and fungi in various studies (Mudrikah et al., 2015).
- **Antinociceptive Activity:** It has shown pain-relieving effects (Mudrikah et al., 2015).

3.6 Conservation and Sustainable Utilization

Despite its remarkable medicinal value, *Caralluma tuberculata* faces serious threats that jeopardize its survival in the wild (Ali et al., 2022; Mudrikah et al., 2015).

3.6.1 Threats to Survival

The plant is considered a **Critically Endangered** species according to the International Union for Conservation of Nature (IUCN) Red List categories (Ali et al., 2022). The primary threats are:

1. **Overexploitation:** The high demand for the plant as an antidiabetic remedy and its use as a vegetable has led to unsustainable wild harvesting. In many regions, people uproot the entire plant, which has a slow growth rate, preventing population recovery (Mudrikah et al., 2015).

2. **Habitat Loss and Degradation:** The fragmentation and destruction of its dry scrubland and rocky habitats due to urbanization, agriculture, and deforestation are major concerns. The specific habitat at Sunderbani is also vulnerable to these pressures.

3. **Lower Seed Viability and Slow Growth Rate:** The plant has notoriously low seed viability, a characteristic of many succulent species. In addition, its natural growth rate is slow, making it difficult to rely on natural regeneration alone (Noreen, 2020).

4. **Climate Change:** Alterations in temperature and precipitation patterns can significantly impact the plant's preferred microhabitats, such as the north-facing slopes it favors.

3.6.2 Conservation Strategies

Given the threats, a multi-pronged approach to conservation is crucial.

1. **Cultivation and Propagation:**

   - ***In Vitro* Culture:** Micropropagation and callus culture techniques are being developed to rapidly propagate the plant. The use of **nano-elicitors (e.g., selenium nanoparticles) and light regimes** has been shown to be an effective strategy for promoting biomass accumulation and enhancing the production of valuable secondary metabolites in callus cultures (Noreen, 2020). This technology offers a sustainable, lab-based production method independent of wild populations.

   - **Substrate Optimization for Home Cultivation:** The local knowledge of growing the plant in pots with sandstone or concrete materials, combined with scientific experiments on growth substrates, offers a practical solution. As shown in Table 3, using a stress-inducing substrate like sand can enhance bioactive compound production (anthocyanins) (Bentaleb et al., 2026). This suggests that even simple home or community-based cultivation can be optimized for medicinal quality, reducing pressure on wild populations.

2. **In-Situ Conservation:**

   - **Protected Areas:** Designating specific areas within the Sunderbani Forest Range or other habitats as conservation reserves for *C. tuberculata* and its associated flora.

   - **Community-Based Conservation:** Involving local communities, as they have a vested interest in preserving the plant's availability for their traditional medicine. This includes promoting sustainable harvesting practices (e.g., cutting stems rather than uprooting) and educating them about the plant's endangered status.

3. **Ex-Situ Conservation:**

   - **Seed Banks:** Storing viable seeds in gene banks for future reintroduction and research. Given the low viability, research into optimal storage conditions is essential.

- **Botanical Gardens:** Cultivating the plant in botanical gardens for research, education, and to maintain genetic diversity.

4. Discussion

The holistic study of *Caralluma tuberculata*, integrating field observations from the Sunderbani Forest Range with an extensive review of global scientific literature, paints a compelling picture of a plant at the crossroads of tradition, modern science, and conservation urgency.

4.1 Habitat Specificity and Its Implications

The field survey in Sunderbani revealed a highly specific habitat for *C. tuberculata*: a northern aspect on sandstone rocks, associated with *Caracca speciosa* scrubs. This is not a random occurrence. The northern aspect provides a microhabitat with reduced solar radiation and lower evaporation, crucial for a succulent adapted to arid conditions to maintain water balance. Sandstone offers a porous substrate that ensures rapid drainage, preventing root rot—a primary cause of failure for succulents in cultivation. The association with thorny scrub is likely a nurse-plant effect, providing shade and protection.

Implications for Conservation and Cultivation

This habitat specificity is a double-edged sword. On one hand, it shows the plant can survive in harsh, nutrient-poor conditions. On the other, it makes it a **specialist species** that is highly vulnerable to habitat disturbance. As demonstrated by Bentaleb et al. (2026), while the plant grows better in richer substrates like peat, it is the stress of sand (similar to its natural sandstone home) that triggers higher production of protective compounds like anthocyanins (Bentaleb et al., 2026). This suggests that the harsh environment is integral to its medicinal quality, possibly inducing the biosynthesis of bioactive phytochemicals like steroidal glycosides. This insight is critical: **conservation and cultivation programs must not only focus on biomass but also on preserving the environmental stressors that enhance the plant's pharmacological value.** This validates the local practice of growing it in pots with concrete or sandstone material—a practice that is not just convenient but may be beneficial for its medicinal properties.

4.2 Phytochemistry and Pharmacology: A Molecular Basis for Tradition

The scientific validation of traditional knowledge is the most significant outcome of the research on *C. tuberculata*. The local use of "Chiranagali" as a pickle to treat "chronic diabetes" is now underpinned by a wealth of molecular evidence. The plant's antidiabetic activity is not due to a single magic bullet but a complex synergistic effect:

- **Pregnane and androstane glycosides** modulate crucial carbohydrate-metabolizing enzymes, reducing gluconeogenesis (new sugar production) and enhancing glycolysis (sugar breakdown) (Aslam et al., 2021). This multi-targeted action is consistent with the complex pathology of Type 2 diabetes.
- The **downregulation of GLUT-2** in the liver is a notable and complex finding. It suggests the plant may help mitigate the "glucose toxicity" in diabetic livers by reducing excessive glucose uptake and storage, shifting the metabolic focus to utilizing existing glucose (Aslam et al., 2021).

The cancer research is equally compelling. The discovery of the **selective toxicity of steroidal glycosides** towards cancer cells and the identification of Russelioside A as a potent **NF-κB inhibitor** highlights the potential of *C. tuberculata* as a source of lead compounds for novel anticancer therapies (Sabra et al., 2022; Waheed, 2011). NF-κB is a master regulator of inflammation and cell survival, and its inhibition is a key strategy in cancer treatment. The fact that a compound from a wild plant can achieve this is a testament to the untapped potential of biodiversity.

4.3 The Critical Need for Sustainable Management

The "dual nature" of *C. tuberculata*—its immense therapeutic potential and its endangered status—creates a critical paradox. The very demand that makes it valuable is driving its extinction. The IUCN listing as "Critically Endangered" is not hyperbole (Ali et al., 2022). The combination of overexploitation, low seed viability, and slow growth is a formula for extinction (Noreen, 2020; Mudrikah et al., 2015).

A Way Forward

Sustainable management is not optional; it is mandatory. The future of *C. tuberculata* depends on a paradigm shift from wild collection to sustainable cultivation.

- **Nano-Elicitation and Biotechnology:** The research on selenium nanoparticles and light regimes for enhancing secondary metabolite production in callus culture is a groundbreaking step (Noreen, 2020). This *in vitro* method can produce high-value compounds in a controlled environment, independent of wild harvesting and seasonal variations.

- **Home/Community Cultivation:** The success of growing the plant in simple pots with sandstone or concrete materials offers a direct and empowering solution for local communities (Bentaleb et al., 2026). By encouraging and teaching sustainable cultivation, the demand on wild populations can be drastically reduced, simultaneously empowering communities with a source of income and medicine.

- **In-situ Conservation:** Protecting the specific habitats identified in this study—the north-facing slopes, sandstone formations, and associated scrublands of the Sunderbani Forest Range—is an urgent priority. These areas are not just where the plant lives; they are where the plant *thrives*, and the specific environmental pressures they offer are likely essential for maintaining its medicinal potency.

5. Conclusion

Caralluma tuberculata "Chiranagali" is a quintessential example of the intricate relationship between nature, traditional knowledge, and modern science. Its reputation as an antidiabetic and anticancer agent is no longer folklore but is firmly supported by a robust body of molecular, pharmacological, and clinical evidence. The steroidal and flavone glycosides it produces represent a library of potential therapeutic compounds, with mechanisms ranging from gene expression modulation in diabetes to the induction of apoptosis and inhibition of inflammation in cancer.

The specific population observed in the Sunderbani Forest Range provides a critical case study on its habitat ecology. The plant's preference for northern aspects, sandstone geology, and nurse-plant associations highlights its specialization and vulnerability. The experimental data demonstrating enhanced secondary metabolite production under stress conditions (like sand) strongly suggests that its natural habitat is not just a place where it survives, but a "stress chamber" that is essential for its medicinal potency. This finding challenges conventional cultivation wisdom and paves the way for innovative conservation and production strategies.

However, the plant's precarious status as a critically endangered species is a stark warning. The very demand that drives its recognition also threatens its existence. Conservation efforts must be immediate, multi-faceted, and community-driven. By integrating *in vitro* propagation, nano-elicitation, sustainable home cultivation, and the protection of its natural habitats, we can ensure that *Caralluma tuberculata* continues to be a source of health and healing for future generations. The future of this remarkable plant lies not in its exploitation, but in its sustainable cultivation and conservation.

6. Acknowledgements

The authors would like to extend their sincere gratitude to the forest department of the Nowshera Forest Division and the local residents of Jhulla, Thandapani, Rah Salyote, and Kadma in the Sunderbani Forest Range for their invaluable cooperation and hospitality during the field survey. Their profound knowledge of the local flora, including "Chiranagali," is a testament to the rich ethnobotanical heritage of the region. We also acknowledge the contributions of the scientific community whose pioneering research has formed the foundation of this review.

7. Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

8. Funding Statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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