

In Vitro Propagation and Pharmacological Potential of *Crateva adansonii* DC: Biotechnological Advances and Bioactive Profiles

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Abstract

Crateva adansonii DC. (Capparaceae) is a medicinal tree of significant ethnomedicinal value in West Africa and South Asia, widely utilised for the treatment of inflammation, renal disorders, and metabolic diseases. Despite its therapeutic importance, the species faces existential threats from habitat fragmentation and unsustainable harvesting, necessitating urgent conservation interventions. This review synthesises current knowledge regarding the botanical characteristics, phytochemical constituents, and pharmacological activities of *C. adansonii*, with a specific focus on *in vitro* propagation protocols as a tool for germplasm conservation. Analysis of existing literature reveals that while micropropagation has been achieved using nodal and shoot tip explants, reproducibility remains a challenge due to inconsistent reporting of hormonal requirements and acclimatisation protocols. Phytochemical investigations have identified diverse secondary metabolites, including triterpenes (e.g., lupeol), flavonoids, and glucosinolates; however, significant intraspecific variability in metabolite profiles complicates standardisation. We identify critical research gaps, particularly the lack of voucher specimen citations in experimental studies and the need for optimised elicitation strategies to enhance secondary metabolite production. This review advocates for the integration of biotechnological tools with rigorous phytochemical profiling to ensure the sustainable utilisation and conservation of this threatened medicinal species.

Keywords: *Crateva adansonii*; *In vitro* propagation; Secondary metabolites; Phytochemistry; Ethnomedicine; Conservation biology.

Introduction

Crateva adansonii DC. Is a significant medicinal plant species belonging to the Capparidaceae family, widely distributed throughout tropical and subtropical regions (Kumar *et al.*, 2020). This species, frequently referred to as the sacred garlic pear, is highly valued in traditional medicine systems across Africa and Asia for its diverse therapeutic applications, ranging from the treatment of hypertension and diabetes to the management of bacterial infections and rheumatism (Ahama-Esseh *et al.*, 2017; Igolia *et al.*, 2012; Mignanwandé *et al.*, 2020). The Capparaceae family, commonly known as the caper family, comprises a diverse group of flowering plants predominantly distributed in tropical and subtropical regions, including arid zones of Asia, Africa, and Saudi Arabia (Nazar *et al.*, 2018; Pal *et al.*, 2020). Members of this family are typically characterised by shrubs or small trees that exhibit remarkable adaptability to harsh environmental conditions, often serving as essential components of desert ecosystems by providing vegetative

cover, improving soil stability, and preventing erosion in dry, sandy habitats. Related taxa exemplify these xerophytic adaptations. One of them is *Capparis decidua*, a much-branched shrub that serves as a vital resource for food, fodder, fuel, and medicine in the rural economies of arid regions. Taxonomically, the family is distinguished by specific morphological features, including hypogynous flowers with a distinct gynophore, tetradynamous or polyandrous stamens, and parietal placentation (Singh *et al.*, 2011; Zingue *et al.*, 2016).

Botanical Description and Phylogenetic Position

Crateva adansonii DC. Is typically characterised as a small to medium-sized deciduous tree that can reach heights of up to 15 meters, displaying a distinct crooked bole with greyish-brown, fissured bark. The crown is much-branched and bears trifoliate leaves with petioles supporting ovate, entire, and acute leaflets that are reticulately veined (Ahama-Esseh *et al.*, 2017; Kumar *et al.*, 2020). The inflorescence consists of terminal or axillary corymbs that develop into showy, white to

greenish-white flowers, which are polyandrous with numerous long stamens and a distinct gynophore supporting the superior ovary (Atchou *et al.*, 2020; Mignanwandé *et al.*, 2020). The fruit is a large, globose berry that turns yellowish-orange when ripe, containing numerous seeds embedded in a pulpy aril (Mignanwandé *et al.*, 2020). This species exhibits a broad natural range across tropical and subtropical regions, with significant populations documented throughout the Indian subcontinent, Southeast Asia, and extending into parts of Africa (Nazar *et al.*, 2018). In India, the species is commonly found in deciduous forests and along riverbanks, while its presence in Southeast Asia includes countries such as Thailand, Malaysia, and Indonesia, where it thrives in warm, humid climates. The species' adaptability allows it to persist in diverse ecological niches, ranging from lowland tropical forests to riparian zones, demonstrating a tolerance for varying soil types and moisture levels that facilitates its widespread cultivation and naturalisation (Ewas, 2023). Molecular systematic studies have been instrumental in clarifying the evolutionary lineages within the family, often resolving historical debates regarding the circumscription of genera and their placement relative to the Brassicaceae. Phylogenetic analyses utilising chloroplast DNA sequences have consistently supported the monophyly of Capparaeae as a distinct lineage separate from Brassicaceae, despite the presence of shared morphological traits such as tetradynamous stamens and parietal placentation (Fici, 2014). These genetic investigations further reveal that the family exhibits a complex evolutionary history characterised by distinct clades that often correlate with biogeographical distribution patterns rather than solely with morphological similarities (Chedraoui *et al.*, 2017; Chishty, 2016).

Ethnomedicinal Significance

Throughout its native range, *Crateva adansonii* holds a prominent position in various indigenous pharmacopoeias, where different plant parts, including the bark, leaves, roots, and fruits, are utilised to treat a wide spectrum of ailments. Phytochemical investigations have identified a diverse array of bioactive constituents within the plant, such as alkaloids, coumarins, anthracene derivatives, flavonoids, essential oils, lignans, anthocyanin pigments, tannins, and triterpenes, which underpin its therapeutic potential (Mignanwandé *et al.*, 2023). These phytochemical constituents are associated with a broad spectrum of pharmacological activities, including anti-radical, anti-microbial, and cytotoxic effects, which have been the subject of increasing scientific scrutiny to validate traditional therapeutic claims (Nounagnon *et al.*, 2018). Contemporary research methodologies, such as semi-structured interviews with traditional healers and spectrophotometric assays, have been employed to document indigenous usage patterns and quantify the antioxidant capacity of extracts through standard assays like FRAP and DPPH. The qualitative and quantitative composition of these secondary metabolites is largely influenced by environmental conditions, suggesting that the plant's antioxidant capacity may synergistically enhance its antibacterial properties (Mignanwandé *et al.*, 2020). This interplay between environmental factors and secondary metabolism underscores the importance of standardising extraction protocols to ensure consistent therapeutic efficacy in pharmaceutical applications. Future research directions should prioritise the isolation and structural elucidation of specific bioactive molecules responsible for the observed pharmacological effects, alongside rigorous *in vivo* and clinical trials to establish safety profiles and dosage regimens for human use (Begum *et al.*, 2024; Nahar *et al.*, 2025).

The present review was conducted using a structured and systematic literature survey to critically evaluate the *in vitro* propagation strategies and pharmacological potential of *Crateva adansonii* DC., with particular emphasis on conservation needs and emerging therapeutic relevance. Peer-reviewed articles were retrieved from major scientific databases, including Scopus, Web of Science, PubMed, and Science Direct, using targeted keywords such as “micropropagation,” “plant tissue culture,” “secondary metabolites,” “phytochemical profiling,” and “pharmacological activity” combined with the species name. Only English-language research articles reporting validated experimental protocols, phytochemical analyses (GC–MS, HPLC, LC–MS), biological activity assays, or conservation-related assessments were included, while non-indexed sources and methodologically ambiguous reports were excluded. Extracted data were thematically synthesised to assess propagation efficiency, bioactive compound characterisation, documented pharmacological activities, and evidence of ecological pressure on natural populations. A comparative analytical approach was applied to identify methodological inconsistencies, underexplored bioactive mechanisms, and gaps in large-scale conservation and clinical validation studies, thereby establishing a scientific rationale for integrating biotechnological interventions with sustainable utilisation and pharmacological advancement.

In Vitro Propagation Strategies of *Crateva adansonii* DC

In recent decades, the field of plant science has witnessed several breakthrough discoveries, particularly through the application of *in vitro* technology (Kulus & Tymoszuk, 2024). The term “micropropagation” refers to the process of producing numerous plants from small fragments of plant tissue (Kulus & Tymoszuk, 2024). This technique has become helpful in addressing various challenges faced by traditional propagation methods, such as slow growth rates, plant sterility, susceptibility to diseases, and limited availability of planting material (Kulus & Tymoszuk, 2024).

Explant Selection and Surface Sterilisation: The selection of appropriate explants is a critical determinant of success in establishing sterile *in vitro* cultures, as the choice of plant tissue directly influences morphogenetic responses and contamination rates (Babbar *et al.*, 2009). Different explant types, such as nodal segments, shoot tips, or leaf discs, exhibit varying degrees of recalcitrance to sterilisation and distinct capacities for regeneration, necessitating a tailored approach to surface sterilisation protocols to balance microbial elimination with tissue viability (Mohammed *et al.*, 2025; Sookruksawong, 2024). Effective sterilisation typically involves sequential treatments with ethanol and sodium hypochlorite or mercuric chloride, where the concentration and duration of exposure must be optimised to prevent phytotoxicity while ensuring aseptic conditions (Sathuphan *et al.*, 2025; Sharma *et al.*, 2023). Establishing an effective micropropagation protocol requires the optimisation of media composition, including the selection of basal salts and carbon sources, alongside the precise application of plant growth regulators to induce organogenesis (Kaushik *et al.*, 2024; Kulus & Tymoszuk, 2024).

Culture Media Optimisation for *C. adansonii*: The formulation of an optimal culture medium is fundamental to maximising regeneration efficiency, requiring a strategic balance between basal salts, carbon sources, and plant growth regulators to trigger specific morphogenetic pathways in *Crateva adansonii* (Kulus & Tymoszuk, 2024; Pithiya *et al.*,

2022). Basal salts such as Murashige and Skoog provide essential macro- and micronutrients that support cellular metabolism, while sucrose serves as the primary carbon source to sustain growth in the absence of photosynthesis (Pithiya *et al.*, 2022). The precise manipulation of plant growth regulators, particularly auxins and cytokinins, is subsequently required to direct cellular differentiation toward either shoot or root formation, thereby establishing a complete regeneration pathway (Jena *et al.*, 2025; Kulus & Tymoszuk, 2024). Murashige and Skoog (MS) medium modifications often involve adjusting the concentrations of nitrogen, potassium, and calcium to better suit the specific nutritional requirements of woody medicinal plants like *Crateva adansonii* (Malabadi *et al.*, 2023). Research indicates that the addition of cytokinins like benzylaminopurine and auxins such as naphthalene acetic acid significantly promotes micropropagation in related species, suggesting that similar hormonal combinations may be effective for *C. adansonii* (Ali *et al.*, 2022). Incorporating organic growth additives into the culture media can further stimulate tissue growth and accelerate the development of vigorous plantlets (Hamdeni *et al.*, 2022).

The precise manipulation of plant growth regulators, particularly auxins and cytokinins, is subsequently required to direct cellular differentiation toward either shoot or root formation, thereby establishing a complete regeneration pathway (Sidik *et al.*, 2024). A higher cytokinin-to-auxin ratio is generally employed to favour shoot proliferation, whereas increased auxin concentrations are necessary to induce robust root formation (Sathuphan *et al.*, 2025). Consequently, the transition from the multiplication phase to the rooting stage necessitates a reduction or elimination of cytokinins to prevent the inhibition of root initiation, while auxins such as indole-3-butyric acid or naphthalene acetic acid are introduced to stimulate rhizogenesis (Sidik *et al.*, 2024; Sudheer *et al.*, 2022). The efficacy of these rooting treatments is typically evaluated by quantifying parameters such as root number, length, and the overall rooting frequency of the regenerated plantlets (Abdella *et al.*, 2023). Furthermore, the physical properties of the culture medium, including gelling agent concentration and pH stability, play a significant role in determining nutrient availability and uptake efficiency during the rooting phase (Hamdeni *et al.*, 2022; Sudheer *et al.*, 2022). This interaction between endogenous hormones and exogenously applied regulators is complex, often requiring species-specific adjustments to the growth regulator composition and concentration to achieve optimal organogenesis (Suge, 1984).

Callus Induction and Organogenesis: The induction of callus and subsequent organogenesis in *Crateva adansonii* relies heavily on the synergistic interaction between exogenously applied auxins and cytokinins within the culture medium. Specifically, the ratio of these two hormone classes determines the developmental fate of the cells, where a high auxin-to-cytokinin ratio typically promotes root formation and a high cytokinin-to-auxin ratio favors shoot regeneration (Jagiello-Kubiec *et al.*, 2021; Zhi & Hu, 2023). This hormonal balance is critical for de novo shoot organogenesis, as the signalling pathways of cytokinins and auxins act as master regulators of cellular differentiation and tissue patterning (Raspor *et al.*, 2021). Intermediate levels of both hormones are known to induce the formation of an amorphous cell mass referred to as a callus, which serves as a vital intermediate for indirect organogenesis (Ibáñez *et al.*, 2020). The process of differentiation into shoots, known as

caulogenesis, is typically favored by a higher rate of cytokinins to auxins, whereas the opposite ratio promotes rhizogenesis or root formation (Petti, 2020). Somatic embryogenesis represents an alternative regenerative pathway where stress treatments or high auxin concentrations can induce the formation of embryos from somatic cells, demonstrating the totipotency of plant cells (Ibáñez *et al.*, 2020; Nimavat & Parikh, 2024). De novo root regeneration can be initiated through direct organogenesis from explants or indirectly via callus formation, with the latter pathway often requiring specific hormonal cues to trigger the developmental switch from undifferentiated tissue to root primordia (Murthy *et al.*, 2023; Yu *et al.*, 2017). The successful execution of these regenerative pathways is contingent upon the presence of competent cells capable of epigenetic reprogramming and the precise spatial and temporal regulation of endogenous hormone synthesis (Pasternak & Steinmacher, 2024).

Rooting and Acclimatisation: The successful establishment of a complete micropropagation protocol for *Crateva adansonii* necessitates the transfer of well-developed shoots to a rooting medium containing auxins such as indole-3-butyric acid or naphthalene acetic acid, which are critical for stimulating rhizogenesis and ensuring the development of a functional root system (Robert *et al.*, 2023). Rhizogenesis is a complex developmental process heavily dependent on growth regulators, particularly auxins, which promote root initiation by stimulating meristem formation in cells at wound sites (Islam *et al.*, 2024). The efficacy of these rooting treatments is typically evaluated by quantifying parameters such as root number, length, and the overall rooting frequency of the regenerated plantlets (Kundu *et al.*, 2023). Following the in vitro rooting phase, plantlets must undergo a carefully managed acclimatisation process to survive the transition from a high-humidity, heterotrophic culture environment to ex vitro conditions where they are exposed to lower humidity and autotrophic growth requirements (Murthy *et al.*, 2023). This critical transition requires a gradual reduction in humidity to prevent desiccation while simultaneously encouraging the development of a robust cuticle and functional stomata that can regulate water loss effectively (Murthy *et al.*, 2023).

Biotechnological Applications: The establishment of efficient in vitro regeneration systems for *Crateva adansonii* facilitates advanced biotechnological interventions, including the conservation of elite germplasm and the implementation of genetic improvement programs. Somatic embryogenesis and organogenesis protocols provide the cellular basis for genetic transformation, enabling the introduction of desirable traits such as pest resistance or enhanced secondary metabolite production through Agrobacterium-mediated or biolistic methods (Girijashankar *et al.*, 2005; Long *et al.*, 2022). Furthermore, the application of specific morphogenic factors can reprogram somatic cells to induce shoot or somatic embryogenesis, offering a potential breakthrough for genotype-flexible transformation in this species (Wan *et al.*, 2023). These advanced techniques also support the production of pathogen-free clones and the large-scale multiplication of genetically superior lines, which is essential for meeting the demands of horticulture and pharmaceutical industries (Chandra *et al.*, 2010; Grzelak *et al.*, 2024). The synthesis of these biotechnological approaches underscores the critical importance of optimising in vitro protocols to ensure the sustainable utilisation and preservation of this valuable medicinal plant species (Khezri *et al.*, 2024).

Pharmacological Activities of *Crateva adansonii*

Antimicrobial Activity: *Crateva adansonii* has been traditionally utilised in folk medicine for its therapeutic potential against bacterial infections, prompting scientific investigation into its antimicrobial properties (Mignanwandé *et al.*, 2020). Phytochemical analyses have identified the presence of bioactive secondary metabolites, including flavonoids, tannins, saponins, cardiac glycosides, terpenes, and alkaloids, which may contribute to its observed biological effects (Ahama-Esseh *et al.*, 2017). Specifically, extracts of the plant have demonstrated antibacterial activity against pathogens commonly associated with skin and digestive disorders, such as *Escherichia coli*, *Staphylococcus aureus*, *Proteus mirabilis*, and *Pseudomonas aeruginosa* (Mignanwandé *et al.*, 2023; Nounagnon *et al.*, 2018).

Anti-inflammatory and Analgesic Effects: The bioactive constituents identified in *C. adansonii*, such as flavonoids, terpenoids, and phenolic compounds, are known to modulate intracellular signaling pathways including NF- κ B and MAPK, which are critical mediators of inflammatory responses (Ahama-Esseh *et al.*, 2017). For instance, experimental studies on keratinocytes infected with *Staphylococcus aureus* have demonstrated that specific extracts significantly reduce the expression and production of pro-inflammatory cytokines, including IL-6, IL-8, and TNF α , thereby validating the plant's ethnopharmacological use as an anti-inflammatory agent (Ahama-Esseh *et al.*, 2017). This modulation of the inflammatory cascade suggests that *C. adansonii* preparations may offer therapeutic benefits in managing infected skin lesions, either as standalone treatments or in combination with conventional antibacterial compounds (Ahama-Esseh *et al.*, 2017). Furthermore, the isolation of lupeol from *Crateva adansonii* has provided pharmacological evidence for its analgesic and anti-inflammatory potential, as this triterpenoid was shown to inhibit prostaglandins, the inflammatory enzyme myeloperoxidase, and the release of inflammatory cytokines associated with pain pathways (Rathinavel *et al.*, 2021). *In vivo* models using carrageenan-induced rat paw edema and cotton pellet-induced granuloma have further corroborated these findings, showing that lupeol-rich fractions elicit a higher percentage of inflammation inhibition compared to the reference standard indomethacin (Rathinavel *et al.*, 2021). The observed anti-inflammatory and analgesic effects are further supported by the presence of oleanolic acid and 4-epi-hederagenin, phytoconstituents isolated from the plant that exhibit significant bioactivity in cytotoxicity assays (Igolía *et al.*, 2012). These cytotoxic properties have been particularly noted in the context of cancer research, where *C. adansonii* extracts have demonstrated the capacity to inhibit the proliferation of mammary tumour cells in experimental models (Zingue *et al.*, 2016). Additionally, the plant's therapeutic potential extends to the management of cardiovascular complications, as the regulation of NF- κ B signalling pathways by its phytoconstituents may help mitigate the overexpression of osteoprotegerin, a factor implicated in inflammation-driven cardiovascular disease and mortality (Rathinavel *et al.*, 2021). The downregulation of NF- κ B signalling by these bioactive compounds also leads to decreased levels of nitric oxide synthase (iNOS) and cyclooxygenase-2, enzymes that are pivotal in the synthesis of pro-inflammatory mediators and tissue damage (Chen *et al.*, 2019; Rathinavel *et al.*, 2021).

Antioxidant Potential: The accumulation of free radicals such as superoxides, hydrogen peroxide, and hydroxyl ions creates an imbalance that leads to oxidative stress, resulting in

cellular damage and the progression of chronic diseases (Nounagnon *et al.*, 2018, p. 62). In this context, the antioxidant capacity of *C. adansonii* serves as a crucial defence mechanism, as its phytoconstituents, including flavonoids, terpenoids, and phenolic compounds, can scavenge these reactive oxygen species and restore cellular redox homeostasis (Dogara, 2023; Dwivedi *et al.*, 2024). These compounds exert their protective effects through multiple mechanisms, such as inhibiting the expression or activities of free radical-generating enzymes, which enhances the activity of endogenous antioxidant enzymes, and directly neutralizing reactive oxygen species to terminate chain reactions (Effiong *et al.*, 2024, p. 3794). The therapeutic efficacy of these antioxidant phytochemicals is further evidenced by their ability to modulate critical signaling pathways, such as NF- κ B, which regulates the expression of pro-inflammatory cytokines like TNF- α , IL-6, and IL-1 β , thereby reducing the risk of chronic pathologies including diabetes, cardiovascular diseases, and cancer (Biswas *et al.*, 2022; Tarahi *et al.*, 2024, p. 782). The integration of these antioxidant properties with the plant's anti-inflammatory and cytotoxic activities highlights the multifaceted therapeutic potential of *C. adansonii* in addressing complex pathologies (Riaz *et al.*, 2023; Rodriguez-Yoldi, 2021).

Antidiabetic Potential: The phytochemical profile of *C. adansonii*, characterised by bioactive constituents such as flavonoids, terpenoids, and phenolic compounds, suggests a significant capacity for managing hyperglycemia and diabetes-related complications. These compounds exert their antidiabetic effects through mechanisms such as the inhibition of carbohydrate-digesting enzymes like α -amylase and α -glucosidase, which delay glucose absorption and mitigate postprandial blood sugar spikes (Aliyu *et al.*, 2019; Nwozo *et al.*, 2023). Additionally, these phytochemicals may enhance insulin sensitivity and protect pancreatic β -cells from oxidative damage, thereby addressing the underlying metabolic dysregulation associated with diabetes mellitus. Oxidative stress, resulting from an imbalance between reactive oxygen species production and the body's antioxidant defence, plays a critical role in the pathogenesis of diabetes and its associated complications (Aljerf *et al.*, 2025; Hassan *et al.*, 2017; Lawal *et al.*, 2016). By scavenging free radicals and upregulating endogenous antioxidant defences, the plant's constituent's help preserve pancreatic function and reduce the risk of microvascular and macrovascular damage often observed in diabetic patients (Nwozo *et al.*, 2023; Velmurugan, 2025). The therapeutic efficacy of these bioactive compounds is further supported by their ability to modulate inflammatory pathways, such as NF- κ B, which are frequently activated during hyperglycemia and contribute to insulin resistance and tissue injury (Anas *et al.*, 2025; Zhang *et al.*, 2015). Chronic inflammation is a key contributor to the development and progression of numerous chronic diseases, including type 2 diabetes, and plant-derived compounds have emerged as promising alternatives due to their potent anti-inflammatory properties and minimal adverse effects (Nakadate *et al.*, 2025). *In vivo* evaluations using murine models have provided empirical evidence for these antihyperglycemic effects, demonstrating that leaf extracts of *C. adansonii* significantly improve oral glucose tolerance and reduce basal blood glucose levels (Atchou *et al.*, 2020). Specifically, a dose of 500 mg/kg body weight was found to significantly lower blood glucose without inducing hypoglycemia, an effect attributed to the high concentration of phenolic compounds such as flavonoids and tannins that

may act alone or synergistically (Atchou *et al.*, 2020). These bioactive constituents, including saponins, polyphenols, and triterpenes, are known to restore pancreatic function, improve insulin secretion, and enhance insulin sensitivity in diabetic patients (Chinsembu, 2018; Mahmud *et al.*, 2025).

Conclusion

This review establishes *Crateva adansonii* DC. as a pharmacologically potent species with demonstrated efficacy in managing inflammation, diabetes, and microbial infections. However, its therapeutic utility is threatened by habitat fragmentation and unsustainable wild harvesting. The synthesis of current data indicates that while micropropagation offers a viable strategy for germplasm conservation, existing protocols require significant optimisation regarding reproducibility and acclimatisation efficiency.

There is a critical need to shift from wild-harvested material to controlled *in vitro* production systems to ensure the phytochemical uniformity required for clinical use. Ultimately, the sustainable utilisation of *C. adansonii* depends on a strategic integration of standardised biotechnological propagation with rigorous phytochemical profiling and mechanistic pharmacological validation.

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