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Review Article

Phytochemical and Pharmacological Investigation of *Anthocephalus chinensis's* Fruit

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ABSTRACT

Anthocephalus Chinensis represents an evergreen medicinal tree found in the Rubiaceae family with noted therapeutic effects against fever alongside anemia diabetes and leprosy and additional diseases. Although many studies confirm the medicinal properties of the Anthocephalus Chinensis root, bark and leaves scientists have yet to conduct extensive research on its fruit properties. The purpose of this review is to provide updated extensive data about the phytochemical and pharmacological work on Anthocephalus Chinensis fruits which confirms its notable therapeutic benefits through its rich range of secondary metabolites. Evidence reveals that the fruit extract holds substantial phytochemicals including alkaloids, flavonoids, phenols, and saponins which enable high antimicrobial and antioxidant actions through minimum inhibitory concentrations of 1.875 mg/ml against particular bacterial strains. The traditional medicinal properties of this plant stem from its ability to demonstrate multiple therapeutic effects such as wound healing together with anti-inflammatory response and anti-diabetic process. The identification of compounds like cadambagenic acid and β-sitosterol further reinforces its promise as a natural alternative to synthetic medications.

Introduction

Medicinal plants remain the primary source of healthcare for most of the global population, with a diverse range of species used in traditional systems worldwide. In India and neighboring regions, Ayurveda has a rich heritage of utilizing these plants for therapeutic purposes. Recognized as the "Botanical Paradise," India is the world's largest producer of medicinal plants used in the treatment of various diseases, including diabetes, heart disease, cancer, and liver disorders (Sharma et al., 2022; Mishra, 2013).

Anthocephalus cadamba (Roxb.) Miq. [Syn. *A. chinensis* (Lamk) A. Rich., family Rubiaceae], commonly known as 'Kadamba', is among the most valuable medicinal evergreen tropical trees in Ayurveda. It thrives in humid regions across India—such as Bihar, Orissa, Andhra Pradesh, Andaman and Nicobar Islands, Karnataka, Kerala, and Madhya Pradesh—and extends to Thailand, Indochina, Malaysia, and Papua New Guinea (Mishra, 2013; Mondal et al., 2020). Traditionally, *A. cadamba* has been employed to treat fever, anemia, uterine disorders, skin diseases, leprosy, dysentery, and blood-related conditions, as well as to enhance reproductive health.

Tribal communities use hot water extracts of the leaves as an astringent, for stomatitis, and for wound cleansing. Dried leaf powder acts as an anthelmintic, while flowers serve as both a vegetable and a gargle for oral hygiene. The cooling fruit is believed to purify the blood and remove mucus; its juice is used to alleviate fever and stomach disorders. The bark exhibits astringent, antibacterial, fibriferous, and diuretic properties, with its juice traditionally administered to treat fever, cough, and eye inflammation.

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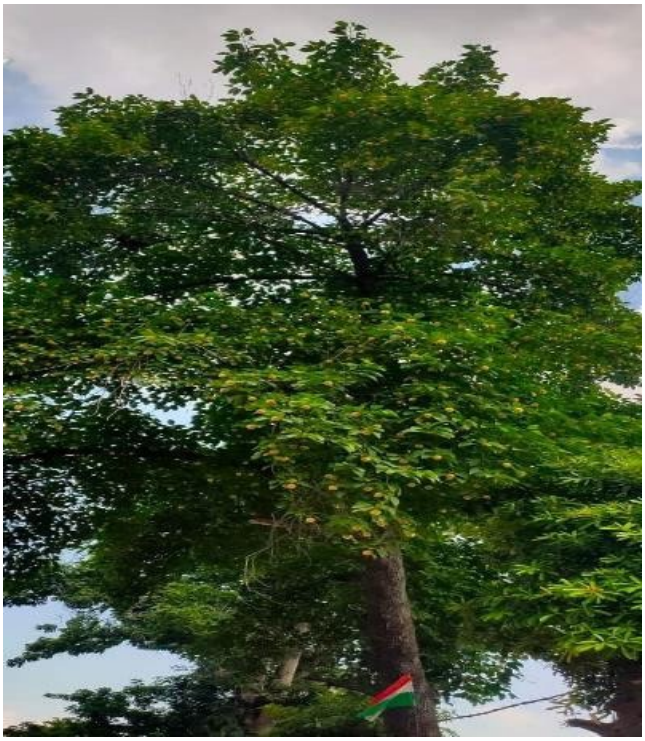

Figure 1: Picture of Anthocephalus cadamba Tree

Taxonomically, *A. cadamba* has undergone extensive nomenclatural revisions, with several synonyms reported: *Anthocephalus chinensis* (Lamk.) A. Rich. ex Walp., *Sarcocephalus cadamba* (Roxb.) Kurz., *Anthocephalus macrophyllus* (Roxb.) Havil., *Anthocephalus indicus* A. Rich., *Nauclea cadamba* (Roxb.), *Anthocephalus morindaefolius* Korth., and *Neolamarckia cadamba* (Roxb.) Bosser. Among these, *Anthocephalus cadamba* (Roxb.) Miq. is the most widely accepted nomenclature.

Commonly referred to as wild cinchona or bur-flower (Figure 1), the plant is also known locally as Kadambah, Kadamb, Jabon, Kalem-payan, and Thkoow, varying by region across Australia, China, India, Indonesia, Malaysia, Nepal, Thailand, Papua New Guinea, the Philippines, Singapore, and Vietnam (Singh, 2023; Yadav et al., 2022).

Botanical Characteristics of Anthocephalus chinensis (Syn. Neolamarckia cadamba)

Tree Morphology

Anthocephalus chinensis is a medium to large deciduous tree reaching 20–40 m in height, characterized by a clean cylindrical trunk, rounded crown, and smooth branches (Chatterjee et al., 2021; Sharma et al., 2022). The tree's girth ranges from 2–2.5 m and is commonly found up to 500 m elevation in the slopes of evergreen forests across India. Young trees possess smooth, greyish-green bark, which darkens and develops longitudinal fissures with age.

Leaf Characteristics

Leaves are large, glossy, and opposite, measuring 15–50 cm in length and 8–25 cm in width. They are broadly ovate to elliptic-oblong with pinnate venation, mucronate apex, and a pulvinus base. The leaves are arranged in a decussate pattern, contributing to the tree's aesthetic and ecological value. Kadamba leaves are beneficial for reforestation projects as their abundant litter enriches the soil's chemical and physical properties (Sakthivel et al., 2022). Medicinally, they are bitter, astringent, and nutritious; a decoction is used as a gargle for stomatitis and pharyngitis.

Fruit Structure

The fruit is a fleshy, globose syncarp, 5–8 cm in diameter, which turns from green to orange-red upon ripening. It has a spongy texture and a mildly sweet taste. Each infructescence contains thousands of small, tightly packed capsules, releasing seeds when mature (Sakthivel et al., 2022; Pal et al., 2014). Phytochemical screening of methanolic fruit extracts revealed alkaloids, anthraquinone glycosides, flavonoids, phenols, tannins, terpenoids, and sterols. The fruit also contains anthocyanins, proanthocyanidins, triterpenes, secoiridoids, and indole alkaloids, along with quinovic acid, cadambine, cadamine, β-sitosterol, and cadambagenic acid (Chatterjee et al., 2021).

Biological and Therapeutic Importance of *Neolamarckia cadamba*

Phytochemical and Pharmacological Relevance

Neolamarckia cadamba (syn. Anthocephalus chinensis) is an important member of the Rubiaceae family, valued for its rich phytochemical profile comprising quinovic acid, cadambagenic acid, sitosterol, cadamine, and cadambine (Singh, 2023). These bioactive compounds exhibit diverse pharmacological properties, enabling the plant to serve as a natural alternative to synthetic drugs in preventing and treating multiple diseases.

Biological Importance

Ecological Role

The Kadamba tree contributes significantly to tropical ecosystems by supporting pollinators and wildlife through its dense canopy and fruiting bodies. Its extensive root system aids in soil conservation and land reclamation, while its leaf litter enhances nutrient cycling and organic matter content in the soil.

Ethnobotanical Uses

Traditionally, various plant parts are utilized in medicine—bark for fever, anemia, uterine disorders, skin diseases, wounds, and diarrhea; leaves as poultices; and flowers for managing diabetes, liver disorders, and as general tonics. Floral extracts are also incorporated into traditional cosmetic formulations (Yadav, 2022).

Table 1: Pharmacological properties of N. Cadamba with its benefits

Activity	*Phytochemicals Involved*	*Effects*
Antimicrobial	Cadambine, Quinovic acid derivatives	Inhibits growth of bacteria and fungi (Kumar A et al.,2021)
Antidiabetic	Cadambagenic acid,β-sitosterol	Reduces blood sugar levels (Pandey A et al., 2017).
Anti-inflammatory	Tetradecanoic acid, Oleic acid	Alleviates inflammation (Kumar A et al., 2021).
Anticancer	3α-dihydrocadambine	Inhibits tumor growth reverses drug Resistance (Nie M et al., 2022).
Antioxidant	Gamma-sitosterol, 5-Hydroxymethyl furfural	Protects cells from oxidative stress (Kumar A et al., 2021).
Anti-hepatotoxic	Cadambine and its derivatives	Protects liver function (Pandey A et al., 2017).
Anti-parasitic	Various alkaloids	Effective against parasitic infections (Kumar A et al., 2021).

Therapeutic Importance

The therapeutic potential of *N. cadamba* has been well documented in both traditional and modern systems of medicine (Kumar et al., 2021; Pandey et al., 2016). Its bark, leaves, and fruit exhibit a broad spectrum of pharmacological activities, including antimalarial, antiproliferative, antioxidant, anticancer, and anti-inflammatory properties (Singh et al., 2023; Zhao et al., 2021). The plant is also reported to possess antihepatotoxic, analgesic, antipyretic, diuretic, and laxative effects (Pandey et al., 2017).

Recent studies have identified chloroform extracts of *N. cadamba* leaves as active against liver cancer cell lines and *Escherichia coli* (Mishra et al., 2023). Moreover, fruit peel—often discarded as waste—contains potent anti-inflammatory, antioxidant, antimicrobial, and antitumor metabolites (Selvakumar et al., 2022). These findings highlight the plant's broad medicinal relevance and potential in developing preventive and therapeutic strategies globally (Kumar et al., 2021). The pharmacological activities of the Cadamba tree are summarized in Table 1, illustrating its diverse therapeutic applications in ethnomedicine.

Despite its broad pharmacological potential, the Cadamba tree faces challenges in commercialization, primarily due to limitations in phytochemical solubility and the lack of standardized model systems. Nevertheless, continuous advancements in phytochemistry and pharmacological research are expected to overcome these barriers and further expand its therapeutic applications (Dwevedi et al., 2015; Swati et al., 2023).

Phytochemical Analysis Techniques of *Anthocephalus Chinensis* Fruit

Extraction and Fractionation

The initial step in phytochemical evaluation involves extracting bioactive compounds from *A. Chinensis* fruit using solvents such as methanol, ethanol, or water. Fractionation of these crude extracts is typically performed through liquid–liquid extraction and column chromatography, allowing separation based on polarity and other physicochemical properties. This process enhances the identification of individual phytoconstituents for further qualitative and quantitative studies.

Chromatographic Analysis

High-Performance Liquid Chromatography (HPLC) and Gas Chromatography (GC) are widely employed to analyze the chemical profile of *A. chinensis* fruit extracts. These techniques enable the separation and quantification of phytochemicals, revealing the distribution and abundance of diverse organic compounds within different extract fractions.

Spectroscopic Identification

Advanced spectroscopic methods such as Nuclear Magnetic Resonance (NMR) spectroscopy and Mass Spectrometry (MS) are used for structural elucidation of isolated compounds. These tools provide critical information regarding molecular weight, elemental composition, and the structural characteristics of the bioactive constituents present in *A. Chinensis* fruit (Mishra et al., 2023; Pandey et al., 2017).

Phytochemical Constituents of *Anthocephalus chinensis* Fruit

The fruits of *Neolamarckia cadamba* (syn. *A. chinensis*) [Figure. 2 and Figure. 3] are rich in secondary metabolites

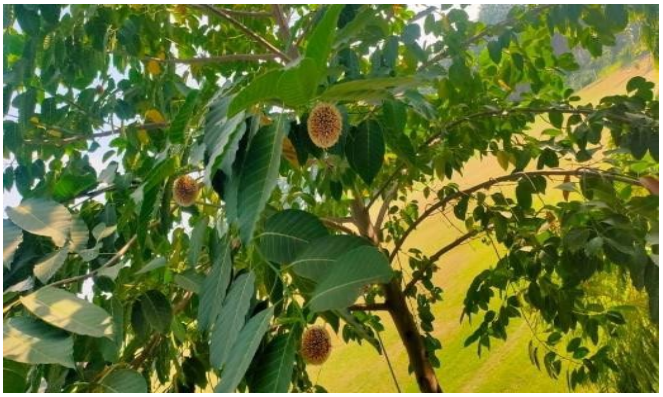

Figure 2: KadambFruit

Figure 3: Full bloomed Kadamb fruit

exhibiting diverse bioactivities. Major phytochemical classes include phenolic acids, flavonoids, terpenoids, and alkaloids. According to mass spectrometric analysis, approximately 36.97% of the fruit extract comprises phenolic acids, 28.10% flavonoids, and 22.18% terpenoids and alkaloids combined. Notable compounds identified include caffeic acid, tannic acid, syringic acid, and quercetin (Pandey et al., 2017).

An 80% methanolic extract of unripe fruits (MACF) demonstrated high concentrations of catechin, gallic acid, and kaempferol (Bala et al., 2017). Catechin derivatives such as procyanidins and tannins were particularly abundant in aqueous extracts. Phytochemical content varies considerably with fruit maturity and extraction technique; phenolic content has been reported to reach 3.14 mm GAE/g during ripening (Pandey et al., 2017). Ripe fruits display higher phenolic concentrations and antioxidant potential, whereas unripe fruits exhibit superior antibacterial activity (Pandey et al., 2017).

Furthermore, *A. Chinensis* fruits contain essential nutrients, including proteins, fats, and minerals, contributing to their nutritional and pharmacological value (Pandey et al., 2017). Comparative studies on other medicinal plants, such as Perilla frutescens, have shown solvent-dependent variations in phytochemical yield, with ethanol extracts containing higher levels of alkaloids, flavonoids, terpenoids, phenols, and saponins than aqueous extracts (Yang et al., 2024; Sharma & Khandelwal, 2023).

The fruits of Anthocephalus cadamba are a rich source of diverse bioactive compounds, including indole alkaloids, phenolics, flavonoids, saponins, and terpenes, which contribute to their notable antioxidant, antimutagenic, anticancer, and antimicrobial properties (Qureshi et al., 2021; Tairin et al., 2015). These findings suggest that A. cadamba fruits may serve as valuable functional foods and natural preservatives for nutraceutical and pharmaceutical applications (Pandey et al., 2017; Bala et al., 2017). Variations in bioactive composition across different maturity stages highlight the importance of optimizing extraction techniques tailored for specific pharmacological or food industry applications.

The fruit demonstrates a favorable nutritional and mineral profile, characterized by high calcium content (123.7 mg/100 g), along with essential minerals such as zinc (11.05 mg), iron (28.30 mg), copper (4.19 mg), magnesium (71.04 mg), potassium (36.7 mg), sodium (10.7 mg), and manganese (13.7 mg) per 100 g of edible portion. In addition, it contains approximately 75% moisture, 18% carbohydrates, 3% protein, and 2% fat. This nutrient composition, combined with its dietary fiber content, supports its potential role in improving gastrointestinal and metabolic health.

Moreover, various phytochemical classes—including steroids, terpenoids, diterpenoids, triterpenoids, coumarins, reducing sugars, and amide derivatives—have been isolated from A. cadamba fruit, offering a broad spectrum of biological activities and therapeutic potential (Tairin et al., 2015). Collectively, these properties position Anthocephalus cadamba as a promising candidate for developing functional food ingredients, herbal formulations, and novel natural therapeutics.

Major Phytochemical Constituents

The major phytochemical constituents of *Neolamarckia cadamba* (cadamba) fruit include:

Alkaloids

A.Chinensis fruit contains several indole alkaloids, including cadambine, 3alpha-dihydrocadambine, and iso-dihydrocadambine. These compounds are known for their potential antimicrobial, and anti- inflammatory properties. The unique structural features of these alkaloids contribute to their biological activities and potential therapeutic applications.

Terpenoids

Various terpenoids such as beta – sitosterol, stigmasterol, and lupeol, have been identified in the fruit extract. These compounds exhibit diverse pharmacological activities, including antioxidants, anti- inflammatory, and anticancer properties. The presence of these terpenoids contributes to the overall therapeutic potential of *A. chinensis* fruit.

Phenolic Compounds

The fruit is rich in phenolic compounds, including flavonoids (e.g., quecertin, kaempferol) and phenol acids (e.g., gallicacid, chlorogenicacid). These compounds are known for their potent antioxidant activities and play a crucial role in the fruit's ability to scavenge free radicals and protect against oxidative stress (Qureshi et al., 2021; Ganjewala et al., 2013). The chemical constituents of the cadamba fruit *(Neolamarckia cadamba)* reveal a rich profile of phytochemicals and nutrients that contribute to its medicinal and nutritional value [Table 2].

The cadamba fruit's diverse chemical constituents not only contribute to its nutritional profile but also enhance its potential as a functional food. However, while the fruit

Table 2: Key Constituents of N. Cadamba with its content and type

Constituent	*Type*	*Content/Properties*
Alkaloids	Secondary Metabolite	52.00mg/g (equivalent to atropine) (Sharma T et al., 2023).
Flavonoids	Secondary Metabolite	110.33mg/g (equivalent to atropine) (Sharma T et al., 2023).
Phenols	Secondary Metabolite	50.33mg/g (equivalent to gallic acid) (Sharma T et al., 2023).
Saponins	Secondary Metabolite	22.33mg/g (equivalent to diosgenin) (Sharma T et al., 2023).
Triterpenes	Secondary Metabolite	Includes cadambine, cadamine, isocadambine (Pandey A et al., 2018).
Vitamins	Nutritional	Rich in Vitamin C, β-carotene, lycopene
Minerals	Nutritional	Contains Na, K, Mg, and Fe
Proteins	Nutritional	2.1% (Pandey A et al., 2018).
Fats	Nutritional	2.4% (Pandey A et al., 2018).
Calorific Value	Nutritional	103.7 kcal/100g (Pandey A et al., 2018).

shows promise in various applications, further research is necessary to fully understand its health benefits and commercial viability.

Pharmacological Activities of *Neolamarckia cadamba* (Anthocephalus cadamba) Fruits

The diverse chemical constituents of *Neolamarckia cadamba* (syn. *Anthocephalus cadamba*) fruit contribute not only to its nutritional significance but also to its wide range of pharmacological activities. Although the fruit demonstrates immense potential as a functional food, further research is required to fully elucidate its therapeutic mechanisms and establish commercial viability.

Antioxidant Activity

Several studies have demonstrated that *N. cadamba* fruit extracts exhibit strong antioxidant potential. The ripe fruit extracts showed the highest total phenolic content (3.14 mM GAE/g extract) and the lowest IC_{50} value (231.33 µg/mL) in the DPPH radical scavenging assay, indicating potent free radical-scavenging capacity (Pandey et al., 2017). Similarly, the extracts exhibited significant ABTS radical scavenging activity (111.18 µM TEAC/g). Recent investigations also reported antioxidant efficacy within an IC_{50} range of 1.3 mg/mL, supporting its promising antioxidant profile (Sharma et al., 2023).

Antibacterial Activity

Extracts prepared from immature fruits have been found to possess strong antibacterial properties, reflected by their lower minimum inhibitory concentration (MIC) values. The antibacterial mechanism appears to involve disruption of bacterial membrane integrity, leakage of intracellular contents, and inhibition of sugar and amino acid uptake (Pandey et al., 2017). Aqueous extracts at 5–10 mg/disc exhibited notable inhibition against both Gram-positive and Gram-negative bacterial strains, confirming broad-spectrum antibacterial potential (Sharma et al., 2023).

Anthelmintic Activity

Hydroethanolic extracts of *N. cadamba* fruits showed greater anthelmintic efficacy compared to ethyl acetate extracts, particularly against *Ascaridia galli*, *Raillietina spiralis*, and *Pheretima posthuma*. The ethanolic extract induced paralysis and death of worms more rapidly than the standard drug albendazole, suggesting a promising natural anthelmintic alternative (Kaur et al., 2021).

Antifungal Activity

Both ethanolic and aqueous extracts of the fruit demonstrated inhibitory effects against pathogenic fungi including *Trichophyton rubrum*, *Candida albicans*, *Microsporum* spp., and *Aspergillus niger*. The maximum zones of inhibition recorded were 12.0 mm (hot water extract) and 15.0 mm (ethanolic extract) against *T. rubrum*, indicating substantial antifungal potential (Sharma et al., 2023).

Anticancer Activity

Preliminary studies indicate that *A. chinensis* fruit extracts exert anticancer effects by inhibiting cancer cell proliferation and inducing apoptosis. The alkaloids and flavonoids present in the fruit appear to block cell cycle progression and suppress angiogenesis, making it a potential candidate for developing natural anticancer therapies (Pandey et al., 2018).

Table 3: Description of N. Cadamba

Activity	*Extract Type*	*Key Chemical Compounds*	*Details*
Antimicrobial	Methanolic, Ethanolic	Cadambine, Dihydrocadambine	Exhibits significant antimicrobial activity, particularly against pathogens
Anticancer	Methanolic	Indole alkaloids, Cadambine derivatives	Demonstrated efficacy against Hela cancer cell lines
Antidiabetic	Various extracts	Flavonoids, Polyphenols	Shown to lower blood glucose levels and improve insulin sensitivity
Antioxidant	Ethanolic	Phenolic compounds	Exhibits strong antioxidant properties, reducing oxidative stress
Anti-inflammatory	Aqueous, Ethanolic	Flavonoids, Saponins	Reduces inflammation markers in various models
Analgesic	Ethanolic	Alkaloids, Flavonoids	Provides pain relief in experimental models
Antipyretic	Aqueous	Unknown	Reduces fever in animal studies.

Antidiabetic Activity

Animal studies have demonstrated the ability of A. chinensis fruit extract to lower blood glucose levels and enhance insulin sensitivity. The antidiabetic effect is attributed mainly to its phenolic and flavonoid compounds, which increase cellular glucose uptake and protect pancreatic β-cells from oxidative stress-induced damage (Sharma et al., 2023).

Neuroprotective Activity

Neuroprotective effects of the fruit extract have been observed both in neuronal cell lines and in model systems exposed to oxidative stress. The phenolic constituents of *N. cadamba* are believed to scavenge reactive oxygen species and prevent neuronal degeneration, thereby showing promise in managing neurodegenerative disorders such as Alzheimer's and Parkinson's disease (Pandey et al., 2017).

Wound Healing Activity

Traditionally, *A. chinensis* fruit has been applied for wound healing, and contemporary research confirms this ethnomedicinal use. The tannins and phenolic compounds present in the fruit accelerate wound contraction, collagen deposition, and re-epithelialization while reducing microbial infection. These findings substantiate the therapeutic relevance of the fruit in promoting tissue repair and regeneration (Sharma et al., 2023).

The pharmacological activity of the Cadamba fruit (*Neolamarckia cadamba*) is remarkable for its diverse therapeutic potential. Rich in phytochemical constituents such as phenolics, flavonoids, alkaloids, saponins, and tannins, the fruit exhibits a broad spectrum of bioactivities including antioxidant, antibacterial, anthelmintic, and antifungal effects (Singh M et al., 2023). These compounds collectively contribute to its medicinal efficacy and justify its traditional use in ethnopharmacology.

As summarized in **Table 3,** the pharmacological activities of *N. cadamba* fruit are directly linked to its chemical composition, particularly the secondary metabolites responsible for oxidative stress reduction, antimicrobial defense, and metabolic regulation. Despite its promising pharmacological potential, current research on the fruit remains limited compared to other plant parts such as bark and leaves.

Therefore, further in-depth studies are warranted to explore its mechanisms of action, bioavailability, and possible clinical applications. Expanding research in this area could establish *N. cadamba* fruit as a viable source for developing functional foods, nutraceuticals, and novel therapeutic agents.

Potential Applications and Future Directions

Genetic improvement

The researchers suggest that these findings demonstrate potential for tree improvement programs through hybridization of *Neolamarckia cadamba* along with future work to develop high yielding genotypes from crossing superior plus trees in clusters V and VI (Rawat S et al., 2023).

Pharmaceutical applications

The phytoconstituents of N.cadamba have the potential of inhibitory effects against SARSCoV23CL protease. New investigations aiming to evaluate these compounds for potential COVID-19 prevention agents are necessary (Arora S et al., 2023).

Nutritional supplementation

It is inferred from its high mineral levels, in particular iron,calcium and magnesium in *N. cadamba* fruits, the potential utilization of fruits as nutritional supplement or a functional food ingredient (Pal I et al., 2014; Pandey A et al., 2018).

Natural preservatives

N. cadamba fruit extracts contain sufficient quantities of phenolic compounds and biological activity which represents their potential use as natural food preservatives

in industrial applications (Pandey A et al., 2018).

Medicinal applications

On going research into immunomodulatory, antimicrobial, anti-diabetic and anti-oxidant properties of *N. cadamba* provide new preventative therapies and disease curing strategies.

Large-scale cultivation

Large scale cultivation and genetic modifications in *N. cadamba* may be possible using their established regeneration protocol (Pal I et al., 2014).

CONCLUSION

Research about *Neolamarckia cadamba* (Roxb.) as a medical plant explored its phytochemical and pharmaceutical properties specifically regarding bioactive compound content in its fruits. Multiple studies previously documented that *Neolamarckia cadamba*'s fruit contains notable amounts of alkaloids together with flavonoids, phenols along with saponins that give the plant strong antimicrobial and antioxidant properties through minimum inhibitory concentrations which block different bacterial strains. Early medical practices make use of the plant to treat a wide range of health conditions that include diabetes together with inflammatory conditions and infections thus showing important therapeutic value for indigenous medicine. Future research should explore new ways to evaluate therapeutic applications of *Neolamarckia cadamba* and validate its traditional medical applications based on scientific evidence. Researchers should explore *Neolamarckia cadamba* as a solid prospect for pharmacological investigations that could lead toward medicinal applications and food manufacturing potential.

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