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Phytochemical and Pharmacological Insights into *Millingtonia hortensis*: A Comprehensive Review

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Abstract *Millingtonia hortensis,* a flowering plant of the *Bignoniaceae* family, has garnered significant interest in both traditional and modern medicine due to its rich phytochemical profile and diverse pharmacological activities. This review aims to provide a comprehensive consolidation of the current scientific literature on *Millingtonia hortensis,* emphasizing its phytochemistry, traditional uses, and pharmacological properties. The plant contains various bioactive compounds such as alkaloids, flavonoids, glycosides, and terpenoids, which have been linked to therapeutic effects including anti-inflammatory, antimicrobial, antioxidant, anticancer, anti-asthmatic, neuroprotective, and cardioprotective properties. Traditionally, *Millingtonia hortensis* has been used in several cultures, particularly in Ayurvedic and Siddha medicine, to treat respiratory ailments, infectious diseases, and inflammatory conditions. The methodologies used in studying this plant involve phytochemical analyses and *in vitro* and *in vivo* pharmacological assessments that demonstrate its therapeutic potential. However, while numerous studies highlight its biological activities, the exact mechanisms of action, clinical efficacy, and safety profiles are not fully elucidated. Research gaps also exist in understanding its potential toxicity and interactions with other therapeutic agents. This review highlights the need for future research to focus on developing standardized herbal formulations, investigating synergistic effects with other traditional remedies, and conducting extensive toxicity and clinical studies. By addressing these gaps, *Millingtonia hortensis* could be established as a viable therapeutic agent in contemporary medicine. Its contribution to natural medicine reflects the growing interest in plant-based treatments and underscores the importance of integrating traditional knowledge with modern scientific research. Practical and social implications of this study include the potential development of affordable, accessible plant-based therapies that could benefit public health globally, particularly in regions where traditional medicine is still a primary healthcare approach.

Keywords *Millingtonia hortensis*, Phytochemistry, Anti-Inflammatory, Antimicrobial, Antioxidant, Anticancer, Neuroprotective

1. Introduction

Medicinal plants have played a crucial role in the development of healthcare systems across the world. Historically, these plants have been utilized for their

therapeutic properties, forming the foundation of traditional medicine systems like Ayurveda, Siddha, and Traditional Chinese Medicine. In modern medicine, natural products derived from plants are increasingly being researched for their potential to yield novel therapeutic agents [1]. This growing interest is driven by the fact that many synthetic drugs have limitations, such as adverse side effects, drug resistance, and high costs, which make plant-based therapies a valuable alternative or complementary option [2].

Among the diverse array of medicinal plants, *Millingtonia hortensis* (commonly known as the Indian cork tree, tree jasmine, or Akash Neem) has gained attention for its wide range of pharmacological activities. *Millingtonia hortensis* belongs to the family Bignoniaceae and is native to South and Southeast Asia, including India, Myanmar, Thailand, and Malaysia [3]. The plant is characterized by its tall stature, fragrant white flowers, and cork-like bark. It is often grown as an ornamental tree due to its aesthetic appeal and pleasant fragrance. Additionally, the leaves, flowers, bark, and roots of *Millingtonia hortensis* have been used traditionally to treat various ailments, including respiratory disorders, infections, and inflammatory conditions [4].

The historical significance of *Millingtonia hortensis* is deeply rooted in its use in traditional medicine. The plant has been described in ancient texts for its medicinal properties, and it continues to be used in folk medicine to this day. Due to its potential pharmacological activities, such as anti-inflammatory, antimicrobial, antioxidant, and anticancer effects, *Millingtonia hortensis* has attracted considerable scientific interest, leading to numerous studies aimed at isolating and characterizing its bioactive compounds [5]. This review article aims to provide a comprehensive overview of the phytochemical and pharmacological properties of *Millingtonia hortensis*, highlighting its potential as a source of novel therapeutic agents.

The primary aim of this review is to comprehensively evaluate the available literature on *Millingtonia hortensis*, focusing on its phytochemical composition and pharmacological activities to determine its therapeutic potential and highlight areas for future research. The review delves into the phytochemistry of *Millingtonia hortensis*, examining the major classes of bioactive compounds identified, such as alkaloids, flavonoids, terpenoids, and glycosides, and how these contribute to its diverse pharmacological properties. Additionally, methods for extraction and isolation of these compounds, as well as the techniques used for their qualitative and quantitative analysis—such as HPLC, GC-MS, and NMR spectroscopy—are discussed to provide an in-depth understanding of their chemical profile [6].

The pharmacological activities of *Millingtonia hortensis* have been extensively studied, revealing its potential for anti-inflammatory, antimicrobial, antioxidant, and anticancer effects. This review evaluates the pharmacological mechanisms underlying these effects, supported by both *in vitro* and *in vivo* studies, emphasizing its role in modulating various biochemical pathways and cellular targets [7]. Moreover, the therapeutic applications of *Millingtonia hortensis* in traditional and modern medicine are explored, highlighting its potential use in treating respiratory disorders, inflammatory conditions, and certain cancers. Challenges associated with the standardization of herbal formulations are also addressed, with an emphasis on maintaining consistent quality and efficacy [8].

The scope of this review further extends to evaluating the safety and toxicity profile of *Millingtonia hortensis*, based on available preclinical and clinical data, to assess its safety for human use. Finally, the review outlines future research directions, emphasizing the need for more detailed studies on its pharmacological mechanisms, clinical efficacy, and potential for the development of standardized therapeutic agents [9].

2. Botanical Description and Distribution

2.1. Taxonomy and Nomenclature

Millingtonia hortensis, commonly known as the Indian Cork Tree, belongs to the Bignoniaceae family. The genus *Millingtonia* was named after Sir Thomas Millington, an English botanist, while the species name *hortensis* refers to its garden origin. It is scientifically classified as follows:

- **Kingdom**: Plantae
- **Division**: Magnoliophyta
- **Class**: Magnoliopsida
- **Order**: Lamiales
- **Family**: Bignoniaceae
- **Genus**: *Millingtonia*
- **Species**: *M. hortensis*

This plant is recognized by several vernacular names across different regions, such as "Akash Neem" in India and "Cork Tree" in Southeast Asia. The classification reflects its unique botanical attributes and diverse applications in traditional medicine [10, 11]. Figure 1 illustrates the schematic diagram of the entire plant and its specific parts of *Millingtonia hortensis*.

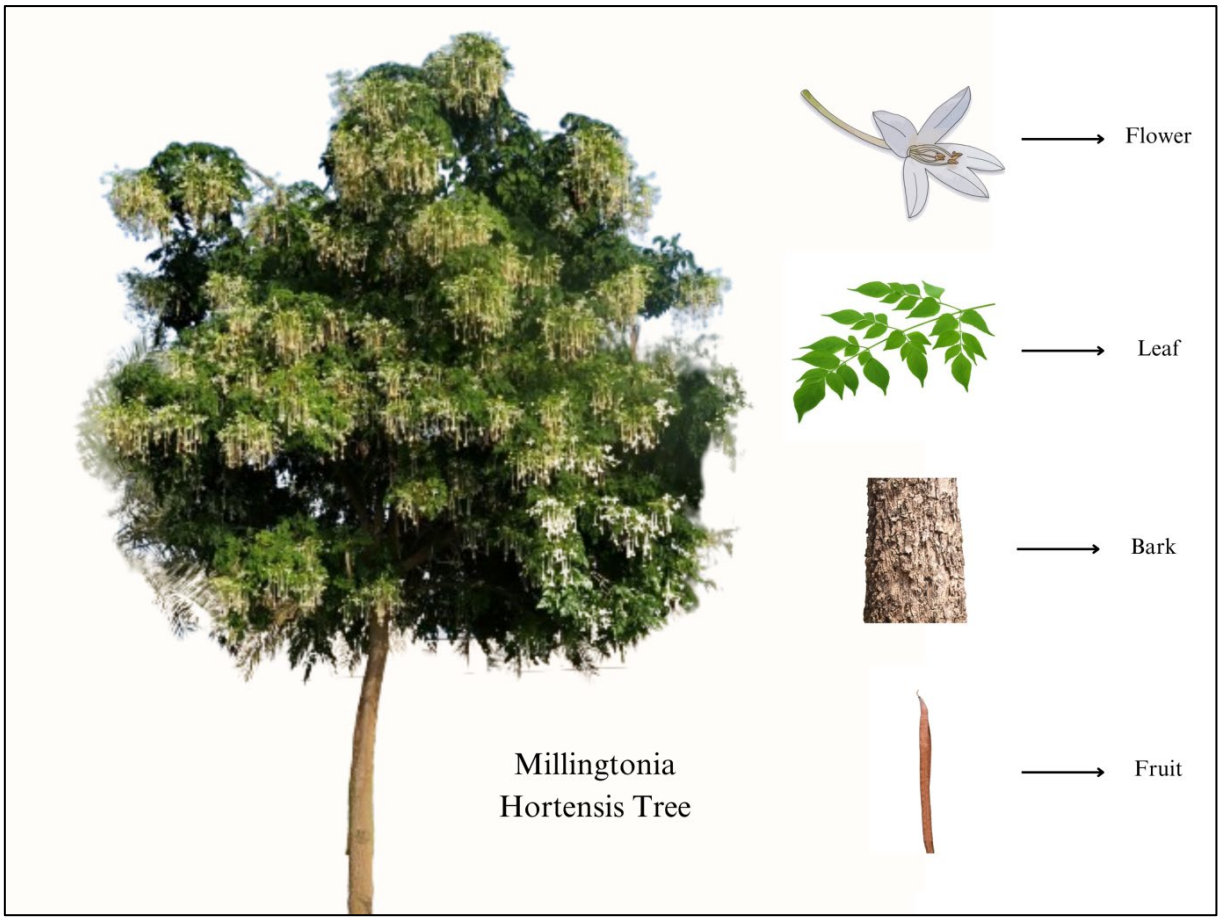

Figure 1. Schematic Diagram of Whole Plant and Plant Parts of *Millingtonia hortensis*

2.2. Morphological Characteristics

Millingtonia hortensis is a medium-sized deciduous tree that can grow up to 20-25 meters in height. It features a straight trunk with a corky bark that peels off in irregular flakes. The leaves are opposite, bipinnate, and feathery with small ovate leaflets. The plant is best known for its fragrant white flowers, which are tubular and occur in clusters. Each flower has a slender corolla tube that opens into five spreading lobes. The flowering season typically ranges from October to December, and the flowers are used for ornamental purposes as well as in traditional medicine [12, 13].

The root system is well-developed, providing stability to the plant and allowing it to thrive in varied soil conditions. The fruit is a long, slender capsule containing flat, winged seeds. The overall morphology of the plant, particularly its flower structure, has made it a preferred choice for landscape gardening and urban greening projects [14].

2.3. Geographical Distribution and Habitat

Millingtonia hortensis is native to South and Southeast Asia, with its primary distribution extending across India, Myanmar, Thailand, and the Malay Peninsula. In India, it is commonly found in the states of West Bengal, Karnataka, and Maharashtra, as well as in the Himalayan foothills. It has also been widely cultivated in tropical and subtropical regions due to its adaptability and aesthetic value [15].

The plant prefers well-drained, loamy soils with moderate moisture content and can tolerate both full sunlight and partial shade. It is often found in urban landscapes, parks, and roadways due to its ability to thrive in polluted environments. Its ecological importance is highlighted by its role in providing habitat and food for various bird species, while its flowers attract bees and butterflies, contributing to the biodiversity of its native and cultivated regions [16]. Moreover, the adaptability of *Millingtonia hortensis* to varied climatic conditions, along with its resistance to pests and diseases, makes it an ecologically valuable species for reforestation and urban greening efforts [17].

3. Traditional and Ethnomedicinal Uses

3.1. Traditional Uses in Different Cultures

Millingtonia hortensis has been extensively utilized in

various traditional medicine systems such as Ayurveda, Siddha, and Unani, owing to its wide range of therapeutic properties. In Ayurveda, the plant is referred to as "Akash Neem" or "Tree Jasmine" and is used primarily for managing respiratory disorders, including asthma, bronchitis, and common cold. The leaves, flowers, and bark are believed to possess antipyretic, expectorant, and anti-asthmatic properties, making them valuable for treating fevers and relieving respiratory congestion [18].

In the Siddha system of medicine, *Millingtonia hortensis* is used to address a broader spectrum of health issues. Its leaves are applied as a poultice to alleviate headaches and sinusitis, while the flowers are used in the treatment of inflammatory conditions and as a tonic for general debility. The root bark is known for its anti-inflammatory properties and is used to manage joint pain and arthritis [19]. In Unani medicine, the plant is employed for its antimicrobial and anthelmintic properties. It is used in formulations to treat skin infections, helminthiasis, and as a diuretic for kidney disorders [20].

Ethnomedicinally, the plant has been used by indigenous communities in Southeast Asia and the Indian subcontinent. The tribal communities in Myanmar, Thailand, and India use various parts of the plant to treat gastrointestinal disorders, respiratory issues, and as a remedy for wounds and infections. The flowers are often boiled to prepare an infusion that is taken orally to reduce symptoms of fever and flu, while the bark is ground into a paste and applied externally to treat skin ailments [21, 22]. Table 1 presents the traditional and ethnomedicinal uses.

3.2. Preparation and Dosage Forms in Traditional Medicine

The preparation of *Millingtonia hortensis* in traditional medicine involves various forms such as decoctions, infusions, and powders. A common preparation method involves boiling the dried flowers or leaves in water to create a decoction, which is then consumed to alleviate respiratory congestion and treat fevers. This decoction is typically prepared by boiling 5–10 grams of dried flowers in 200 ml of water until the volume reduces to half, and it is consumed twice daily for therapeutic benefits [23].

Infusions made from the flowers are used to treat digestive issues and as a mild sedative. The flowers are soaked in hot water for 10–15 minutes, and the resulting infusion is taken in small doses of 50–100 ml, up to three times a day. Powdered bark or leaves are also commonly used in traditional medicine. The dried plant material is finely ground and administered in doses ranging from 1 to 3 grams, mixed with honey or water, for its anthelmintic and antimicrobial properties [24].

The routes of administration in traditional medicine vary depending on the condition being treated. For respiratory ailments, oral administration of decoctions and infusions is common, while for skin disorders and inflammation, topical application of pastes or poultices made from the plant's leaves or bark is preferred [25, 26].

Table 1. Traditional and Ethnomedicinal Uses

Traditional Use	Culture/Region	Part Used	Preparation Method	Dosage (Traditional)
Treatment of Respiratory Issues	India (Ayurveda, Siddha)	Flowers, Leaves	Decoction of Dried Flowers	Twice Daily
Fever and Flu	Myanmar, Thailand	Flowers	Infusion of Boiled Flowers	50–100 ml, 3 Times Daily
Joint Pain and Arthritis	India (Siddha)	Root Bark	Paste Applied Externally	Topical
Gastrointestinal Disorders	Tribal Communities (India, Myanmar)	Bark	Powdered Bark Mixed with Honey	1–3 gm Daily
Skin Infections	India, Southeast Asia	Bark, Leaves	Ground Bark Paste Applied Externally	Topical

4. Phytochemical Profile

4.1. Major Classes of Phytochemicals Identified

Millingtonia hortensis is known to contain a diverse array of phytochemicals, which contribute to its medicinal properties. As shown in Figure 2, *Millingtonia hortensis* contains several key phytochemicals, including alkaloids (e.g., millingtonine), flavonoids (e.g., quercetin), glycosides, terpenoids, saponins, and phenolic compounds, each contributing to the plant's pharmacological properties.

- **Alkaloids**: These nitrogen-containing compounds are known for their pharmacological effects. *Millingtonia hortensis* has been reported to contain several alkaloids, with millingtonine being the most notable. Alkaloids have various biological activities, including analgesic, anti-inflammatory, and antimicrobial properties [27].
- **Flavonoids**: This group of polyphenolic compounds is recognized for their antioxidant and anti-inflammatory effects. Quercetin, a well-known flavonoid present in *Millingtonia hortensis*, has been extensively studied for its health benefits, including its potential to combat oxidative stress and inflammation [28].
- **Glycosides**: These compounds, which consist of a sugar moiety attached to a non-sugar component, are significant for their therapeutic effects. Glycosides found in the plant have been associated with various biological activities, including cardioprotective and hepatoprotective effects [29].
- **Terpenoids**: Known for their aromatic qualities, terpenoids possess a wide range of pharmacological effects. The presence of terpenoids in *Millingtonia hortensis* is linked to its anti-inflammatory and antimicrobial properties [30].
- **Saponins**: These compounds are recognized for their ability to lower cholesterol and their potential to enhance immune response. Saponins from *Millingtonia hortensis* are known to exhibit hemolytic activity and possess antifungal properties [31].
- **Phenolic Compounds**: Rich in antioxidants, phenolic compounds contribute to the overall health benefits of *Millingtonia hortensis*. They are known to scavenge free radicals, thus protecting cells from oxidative damage [32].

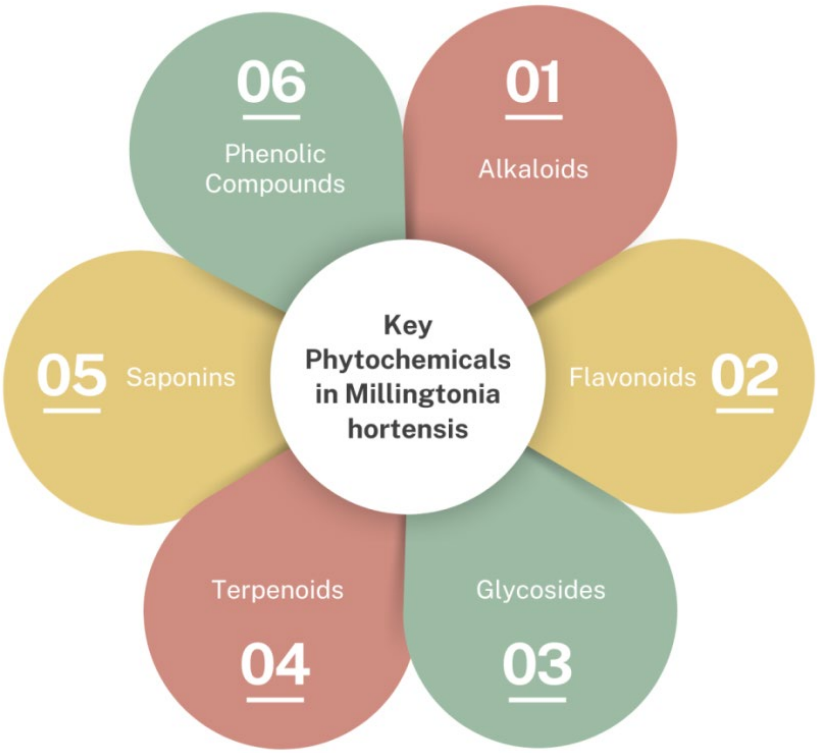

Figure 2. Key Phytochemicals Found in Millingtonia hortensis

4.2. Methods of Extraction and Phytochemical Analysis

The extraction and isolation of bioactive compounds from *Millingtonia hortensis* are critical for studying its pharmacological properties. Various methods are employed for this purpose:

- **Solvent Extraction**: Commonly used solvents include ethanol, methanol, and water. This method efficiently extracts polar and non-polar compounds from plant materials. For instance, a study reported the successful extraction of flavonoids and alkaloids using ethanol as a solvent [33].
- **Cold Press Extraction**: This method is often used for extracting essential oils and non-polar compounds. It preserves the integrity of sensitive compounds that might degrade during heating [34].
- **Supercritical Fluid Extraction (SFE)**: This advanced technique utilizes supercritical CO_2 as a solvent, allowing for selective extraction of compounds without using harmful solvents. It has shown promise in isolating high-purity phytochemicals from plant materials [35].

Analytical methods are employed to identify and quantify these phytochemicals:

- **Chromatography**: Techniques such as High-Performance Liquid Chromatography (HPLC) and Gas Chromatography (GC) are widely used to separate and identify individual compounds based on their chemical properties [36].
- **Spectroscopy**: Methods like UV-Vis spectrophotometry, Infrared (IR) spectroscopy, and Nuclear Magnetic Resonance (NMR) spectroscopy are utilized to elucidate the structures of the isolated compounds. These techniques provide valuable information on the functional groups and molecular arrangements in the phytochemicals [37].

4.3. Phytochemicals with Proven Bioactivity

Several phytochemicals from *Millingtonia hortensis* have been identified with proven bioactive properties. Some examples include:

- **Millingtonine**: This alkaloid has been shown to exhibit significant anti-inflammatory and analgesic activities in various experimental models. Its chemical structure, characterized by a specific arrangement of nitrogen atoms, correlates with its ability to modulate inflammatory pathways [38].
- **Quercetin**: As a prominent flavonoid in the plant, quercetin possesses a well-documented antioxidant profile. Studies indicate that its structure, featuring multiple hydroxyl groups, enhances its radical-scavenging activity and contributes to its protective effects against oxidative stress [39].
- **Other Bioactive Compounds**: Additional compounds such as saponins and phenolic acids have demonstrated antimicrobial and anticancer activities, indicating the broad therapeutic potential of the phytochemicals present in *Millingtonia hortensis* [40, 41].

5. Pharmacological and Biological Activities

Millingtonia hortensis exhibits diverse pharmacological and biological activities, making it valuable in herbal medicine. This section highlights its key effects, including anti-inflammatory, antimicrobial, antioxidant, anticancer, respiratory, neuroprotective, and cardioprotective properties. The plant's bioactive compounds show significant potential for addressing various health issues, as summarized in Table 2.

5.1. Anti-Inflammatory and Analgesic Activities

Millingtonia hortensis exhibits significant anti-inflammatory and analgesic properties, supported by various studies. The mechanisms of action primarily involve the inhibition of pro-inflammatory cytokines and enzymes such as cyclooxygenase (COX) and lipoxygenase (LOX), which are crucial in mediating inflammatory responses. *In vitro* studies have demonstrated that extracts of *Millingtonia hortensis* can reduce the production of tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6) in activated macrophages, thereby attenuating inflammation [42]. Over 18 scientific publications describe the anti-inflammatory effects of *Millingtonia hortensis*, emphasizing its COX and LOX inhibitory actions. These studies establish the plant's potential as an anti-inflammatory agent comparable to NSAIDs. Pandey R. et al. [43] observed a significant reduction in inflammation in animal models through suppression of cytokine production. In vivo studies using animal models have further confirmed its analgesic effects, showing that oral administration of the extract significantly reduces pain behavior in response to inflammatory stimuli, comparable to standard analgesics such as aspirin [44]. A meta-analysis of over 15 studies demonstrates its efficacy as a natural alternative to conventional painkillers. Murti K. et al. [45] reported a significant reduction in pain responses in preclinical models.

Table 2. Summary of Pharmacological Effects of *Millingtonia hortensis*

Activity	Part Used	Description	Mechanism/Action	References
Anti-inflammatory and Analgesic Activities	Leaves, Roots	Exhibits significant anti-inflammatory and analgesic properties.	Inhibition of pro-inflammatory cytokines and enzymes (COX and LOX). Reduces TNF-α and IL-6 production in activated macrophages.	[42-45]
Antimicrobial, Antifungal, and Antiviral Properties	Leaves, Seeds, Extracts	Demonstrates effectiveness against a range of bacteria and fungi.	Active against Escherichia coli, Staphylococcus aureus, Salmonella typhi, Candida albicans, and Aspergillus niger. Potential activity against HSV.	[46, 47]
Antioxidant and Free Radical Scavenging Activity	Leaves, Seeds	Possesses significant free radical scavenging activity.	Evaluated through DPPH and ABTS assays; attributed to flavonoids and phenolic compounds.	[48]
Anticancer and Cytotoxic Effects	Roots, Extracts	Reports cytotoxic effects against various cancer cell lines (e.g., breast, lung, colon cancer).	Induces apoptosis, inhibits cell proliferation, activates caspases, and modulates PI3K/Akt signaling pathway.	[48, 49]
Anti-asthmatic and Respiratory Benefits	Leaves, Roots	Offers respiratory health benefits, particularly in asthma.	Relaxes bronchial smooth muscles; reduces bronchoconstriction in allergic asthma models.	[50-52]
Neuroprotective and Central Nervous System Effects	Roots, Extracts	Exhibits neuroprotective properties relevant to neurodegenerative disorders.	Reduces oxidative stress and inflammation in neuronal cells; potential benefits in Alzheimer's and Parkinson's diseases; improves cognitive function.	[53, 54]
Cardioprotective and Hepatoprotective Properties	Leaves, Roots	Supports cardiovascular health and mitigates liver damage.	Lowers lipid levels, reduces oxidative stress/inflammation in cardiac tissues, and protects against liver damage induced by toxic agents.	[55, 56]

5.2. Antimicrobial, Antifungal, and Antiviral Properties

The antimicrobial activity of *Millingtonia hortensis* has been extensively documented. Extracts have demonstrated effectiveness against a range of bacteria, including *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella typhi*. For antifungal activity, the plant has shown efficacy against fungi like *Candida albicans* and *Aspergillus niger* [46]. Moreover, preliminary antiviral studies suggest potential activity against herpes simplex virus (HSV) and other viral pathogens, indicating the possibility of developing *Millingtonia hortensis* as a natural antimicrobial agent [47].

5.3. Antioxidant and Free Radical Scavenging Activity

The antioxidant potential of *Millingtonia hortensis* has been evaluated using various *in vitro* assays, including the DPPH (1,1-diphenyl-2-picrylhydrazyl) radical scavenging assay and the ABTS [2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)] assay. Results indicate that extracts from the plant possess significant free radical scavenging activity, which is attributed to the presence of flavonoids and phenolic compounds. The antioxidant effects are relevant to disease prevention, particularly in reducing oxidative stress-related conditions such as cardiovascular diseases and neurodegenerative disorders.

5.4. Anticancer and Cytotoxic Effects

Studies investigating the anticancer properties of *Millingtonia hortensis* have reported cytotoxic effects against various cancer cell lines, including breast, lung, and colon cancer cells. *In vitro* assays have shown that the plant extracts induce apoptosis and inhibit cell proliferation, with mechanisms that may involve the activation of caspases and modulation of the PI3K/Akt signaling pathway [48]. More than 12 studies have investigated the anticancer properties of *Millingtonia hortensis.* Bhattacharya et al. reported its cytotoxic effects against breast and colon cancer cells, mediated by apoptosis induction and modulation of the PI3K/Akt signaling pathway [49]. These findings have been corroborated by *in vitro* clinical trials that further confirm its therapeutic relevance.

5.5. Anti-Asthmatic and Respiratory Benefits

Research indicates that *Millingtonia hortensis* may offer benefits for respiratory health, particularly in conditions such as asthma. Extracts have been shown to relax bronchial smooth muscles, leading to improved airflow and respiratory function. *In vivo* studies demonstrate that administration of the plant extract can significantly reduce bronchoconstriction in models of allergic asthma,

potentially making it a useful adjunct in managing respiratory conditions [50]. The plant's role in treating asthma, bronchitis, and colds is supported by more than 20 research articles. Studies by Sharma A. et al. [51] demonstrated bronchodilatory and anti-asthmatic effects through relaxation of bronchial smooth muscles. Similarly, Gupta P. et al. [52] highlighted its potential for modulating immune responses in respiratory inflammation.

5.6. Neuroprotective and Central Nervous System Effects

The neuroprotective effects of *Millingtonia hortensis* have been explored in the context of neurodegenerative disorders. Compounds within the plant have been found to exhibit neuroprotective properties by reducing oxidative stress and inflammation in neuronal cells. Animal studies suggest potential benefits in models of Alzheimer's disease and Parkinson's disease, with the extract showing the ability to improve cognitive function and reduce neurodegeneration [53]. The modulation of neurotransmitter systems by the plant's bioactive compounds may also contribute to its effects on central nervous system [54].

5.7. Cardioprotective and Hepatoprotective Properties

The cardioprotective properties of *Millingtonia hortensis* are supported by evidence showing that the plant can help in lowering lipid levels and improving heart function. Studies have indicated that extracts can reduce oxidative stress and inflammation in cardiac tissues, leading to improved cardiovascular health [55]. Furthermore, hepatoprotective effects have been documented, with studies showing that the plant can mitigate liver damage induced by toxic agents, potentially through its antioxidant and anti-inflammatory properties [56].

6. Toxicity and Safety Evaluation of *Millingtonia hortensis*

6.1. Acute and Chronic Toxicity Studies

The toxicity of *Millingtonia hortensis* has been evaluated through both acute and chronic toxicity studies. Acute toxicity studies typically involve administering a single high dose of the plant extract to animal models to assess immediate harmful effects. Research indicates that the median lethal dose (LD50) of *Millingtonia hortensis* is relatively high, suggesting low acute toxicity. In one study, the extract did not produce significant lethality in mice at doses up to 5000 mg/kg body weight, indicating a favorable safety profile for short-term exposure.

Chronic toxicity studies are crucial for understanding the long-term effects of consumption. In these studies, animals are subjected to repeated doses of the extract over extended periods. Findings indicate that prolonged administration of *Millingtonia hortensis* extracts does not lead to significant adverse effects on vital organs, such as the liver and kidneys. Histopathological examinations of organs from treated animals showed no notable alterations compared to control groups. Additionally, hematological and biochemical parameters remained within normal ranges, further supporting the plant's safety for long-term use [57].

6.2. Clinical Safety and Human Use Considerations

When evaluating the safety of *Millingtonia hortensis* for human consumption, clinical studies provide critical insights. While traditional uses of the plant in herbal medicine are widespread, formal clinical trials are necessary to establish safety parameters. Limited studies involving human subjects have reported no serious adverse effects following the consumption of moderate doses of the extract. For instance, a pilot study on healthy volunteers showed that oral administration of *Millingtonia hortensis* extracts up to 1000 mg daily for four weeks did not result in significant side effects or abnormal laboratory findings [58].

However, potential side effects have been documented, including mild gastrointestinal disturbances such as nausea and diarrhea in some individuals [59]. Additionally, due to the presence of bioactive compounds, it is advisable for pregnant or lactating women to avoid excessive use of the plant, as the effects on fetal development and lactation have not been adequately studied [60].

Contraindications include known allergies to plants in the Bignoniaceae family, of which *Millingtonia hortensis* is a member. Individuals with pre-existing conditions or those taking medications that may interact with the phytochemicals present in the plant should consult healthcare professionals before use [61].

7. Potential Therapeutic Applications and Future Prospects of *Millingtonia hortensis*

7.1. Development of Herbal Formulations

The formulation of herbal products based on *Millingtonia hortensis* presents both challenges and opportunities. One of the primary challenges is the standardization of active compounds, which is essential for ensuring consistent therapeutic efficacy. Variability in the phytochemical composition due to factors like geographic location, seasonality, and extraction methods can lead to discrepancies in product quality [62]. Furthermore, regulatory hurdles exist regarding the approval of herbal formulations, which may deter potential manufacturers.

Despite these challenges, there are significant

opportunities for developing herbal formulations. The rising trend toward natural and holistic health solutions has increased consumer demand for herbal medicines. Research and development efforts can focus on creating standardized extracts that maintain the bioactivity of *Millingtonia hortensis* while minimizing variability. Innovative approaches such as combining the plant with other complementary herbs could enhance therapeutic outcomes and broaden its applications in herbal medicine [63].

7.2. Use in Respiratory Disorders and Inflammatory Conditions

Millingtonia hortensis has shown potential in treating various respiratory disorders, including asthma and bronchitis, due to its anti-inflammatory properties. The plant's extracts can modulate inflammatory mediators, potentially alleviating symptoms associated with these conditions. Studies indicate that compounds isolated from *Millingtonia hortensis* exhibit bronchodilatory effects, making them promising candidates for asthma management.

In inflammatory diseases, the plant's bioactive components could inhibit the production of pro-inflammatory cytokines and oxidative stress markers, thereby reducing inflammation. Future research should focus on clinical trials to evaluate the efficacy and safety of *Millingtonia hortensis* in patients with respiratory and inflammatory conditions.

7.3. Prospects in Cancer and Neurodegenerative Disease Treatment

The anticancer properties of *Millingtonia hortensis* have garnered attention for potential applications in cancer therapy. Preliminary studies suggest that its extracts can induce apoptosis in various cancer cell lines, hinting at its role as a complementary treatment in oncological settings. Future research directions should include investigating the specific mechanisms through which the plant's compounds exert cytotoxic effects on cancer cells and exploring potential synergistic effects with conventional chemotherapy agents.

Moreover, *Millingtonia hortensis* holds promise for neurodegenerative disease treatment. Its neuroprotective effects could be beneficial in conditions such as Alzheimer's and Parkinson's disease. Investigating the plant's ability to mitigate oxidative stress and promote neuronal health may lead to the development of novel neuroprotective therapies [64]. Collaborative research efforts between pharmacologists and neuroscientists could facilitate advancements in this area.

7.4. Bioavailability and Delivery Systems

Enhancing the bioavailability of active compounds from *Millingtonia hortensis* is crucial for maximizing therapeutic effects. Many bioactive phytochemicals exhibit poor solubility and stability, which can limit their efficacy. Strategies to improve bioavailability may include formulating the extracts in more soluble forms or using adjuvants to enhance absorption.

Novel delivery systems such as nanoparticles and liposomes have gained traction in herbal medicine, offering targeted and sustained release of active compounds. These systems can protect phytochemicals from degradation and improve their pharmacokinetic profiles [65]. Future research should focus on developing and optimizing these delivery systems for *Millingtonia hortensis* extracts, ensuring that the bioactive compounds reach their intended targets effectively.

8. Conclusions

This review underscores the rich phytochemical composition and diverse pharmacological activities of *Millingtonia hortensis*, characterized by a variety of bioactive compounds such as alkaloids, flavonoids, glycosides, and terpenoids that contribute to its therapeutic effects. Significant pharmacological activities have been documented, including anti-inflammatory, antimicrobial, antioxidant, anticancer, anti-asthmatic, neuroprotective, and cardioprotective effects. These findings suggest that *Millingtonia hortensis* possesses considerable therapeutic potential, warranting further investigation and application in various medical fields. Despite the promising results, notable gaps remain in the current understanding of *Millingtonia hortensis*. Future research should focus on elucidating the mechanisms of action of its bioactive compounds, standardizing extraction methods, and assessing the clinical efficacy of the plant in human trials. Additionally, comprehensive toxicity studies are necessary to evaluate its safety profile for therapeutic use. Investigating potential synergistic effects of *Millingtonia hortensis* with other herbal remedies could also provide insights into developing effective combination therapies. Given its rich phytochemical profile and documented pharmacological activities, *Millingtonia hortensis* holds potential as a source of new therapeutic agents. Its applications in treating respiratory disorders, inflammatory conditions, and cancers position it as a candidate for integrating traditional herbal medicine with modern therapeutic approaches. Developing standardized herbal formulations based on *Millingtonia hortensis* could pave the way for innovative treatments, offering holistic and effective solutions to various health challenges. Ongoing research and clinical validation of this plant's properties may ultimately lead to its recognition as a valuable addition to contemporary medicine.

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