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Evidence-Based Review of the Ethnopharmacological properties, Potential Sustainable Cultivation, and Market Prospects of *Lippia javanica* (Burm.f.) Spreng

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ABSTRACT: Medicinal plants possess diverse applications across different cultures in traditional medicine, underscoring their broad therapeutic value. This widespread use has translated into extensive harvesting, trading, and consumption to meet local and global demand, often placing pressure on natural populations. Interventions based on the scientific validation of traditional medicines, including their safety, efficacy, and sustainable utilization, are therefore essential. This review highlights the potential of *Lippia javanica* (Burm.f.) Spreng. for product development. Emphasis is placed on ethnobotanical research and the scientific validation of bioactive compounds underpinning its pharmacological properties, thereby illustrating the plant's capacity to penetrate multiple global markets. The paper also explores cultivation strategies designed to improve the conservation status of the species, enhance the livelihoods of communities engaged in the medicinal plant sector, and ensure the long-term sustainability of this industry. The review further highlights that *Lippia javanica* is distinguished by a complex phytochemical profile, including alkaloids, flavonoids, terpenoids, iridoids, glycosides, and diverse essential oils. The structural diversity of its secondary metabolites presents significant opportunities for applications across functional foods, herbal teas, nutraceutical beverages, eco-friendly pesticides, and animal feed. In conclusion, the integration of sustainable cultivation practices with laboratory-based efficacy testing is critical to the preservation, standardized processing, and responsible commercialization of *Lippia javanica*.

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GRAPHICAL ABSTRACT

1. INTRODUCTION

Medicinal plants have long served as vital resources for healthcare, nutrition, and cultural practices across the globe. Their therapeutic potential has been extensively documented, and modern scientific research continues to validate their efficacy and safety, thereby reinforcing their role in drug development and natural product industries (Akram & Mahmood, 2024; Chandra Shill et al., 2024; Latif & Nawaz, 2025; Shimira, 2022; Thalia, 2025a, 2025b). The global shift towards natural medicine has intensified the demand for medicinal plants, creating both opportunities and challenges for sustainable utilization (Asigbaase et al., 2023; Mofokeng et al., 2022; Theodoridis et al., 2023).

Cultivation of medicinal plants presents emerging rural farmers with opportunities to diversify into alternative crops, thereby reducing unsustainable wild harvesting and minimizing competition with established commercial farmers who primarily focus on food crops (Karhagomba et al., 2013; Mofokeng et al., 2022). Factors such as age, education, access to water, and membership in farmer associations significantly influence the decisions of indigenous knowledge holders regarding the commercialization of medicinal plants. Policy interventions that provide vocational training, irrigation technologies, and support for farmer groups, particularly among experienced indigenous knowledge holders, may encourage sustainable commercialization (Ndhlovu et al., 2023; Phakathi & Sinyolo, 2025).

Despite their importance, medicinal plants face alarming rates of decline. Of approximately 450,000 plant species worldwide, one-third are threatened with extinction, and current loss rates are estimated to be 1,000 to 10,000 times higher than background levels (Pimm & Joppa, 2015). Overexploitation, destructive harvesting practices, and habitat loss remain major drivers of this decline (Chen et al., 2016; Xego et al., 2016). Sustainable alternatives, such as leaf harvesting instead of root extraction, have been shown to maintain pharmacological efficacy while reducing ecological impact, as demonstrated in studies on ginseng (Wang et al., 2009).

Harvesting practices play a critical role in sustainability. Root and whole-plant harvesting are particularly destructive compared to the collection of leaves, flowers, or buds. For instance, Wang et al. (2009) demonstrated that extracts from ginseng leaf-stems and roots exhibit similar pharmacological activities, yet leaf-stems represent a more sustainable and cost-effective resource. This highlights the need for further studies on both the leaves and roots of medicinal plants to identify sustainable alternatives (Njau et al., 2014). Conservation strategies, including both in situ and ex situ approaches alongside good agricultural practices and resource management, are essential for ensuring long-term sustainability (Chen et al., 2016).

Regional studies further emphasize the urgency of conservation. In Uganda, only 73% of herbalists reported efforts to conserve medicinal plants, with forest preservation being the most common strategy, while compliance with government regulations was rare (Ssenku et al., 2022). In South Africa, approximately 22% of individuals admitted to unsustainable harvesting practices, largely due to poor techniques and limited awareness of the threatened status of species. Domestication and mass cultivation are therefore key strategies to mitigate exploitation, requiring multifaceted approaches that integrate community engagement, regulatory enforcement, and sustainable harvesting initiatives (Naidoo et al., 2024).

The coexistence of traditional knowledge and environmental preservation represents a critical nexus in advancing sustainable development. Indigenous medicinal plants are not only central to traditional healing practices but also contribute to economic stability and function as functional foods worldwide (Butnariu, 2024; Mbelebele et al., 2024). Incorporating indigenous knowledge into conservation strategies is vital for the optimal utilization of such knowledge in the application of plants for commercialization. Strengthening collaborations among indigenous communities, scientists, and policymakers, alongside investments in research, patent protection, cultivation initiatives, and market stabilization, is essential for sustainable commercialization (Alum, 2024).

Within this broader context, the medicinal plant *Lippia javanica* (Burm.f.) Spreng. emerges as a promising candidate for sustainable economic development. Naturally occurring in central, eastern, and southern Africa, it is also recorded in parts of the Indian subcontinent (Collins et al., 2021; Maroyi, 2017). The *L. javanica* species is well recognized for its medicinal properties among indigenous knowledge holders. It is rich in nutrients and bioactive compounds, exhibiting antioxidant, anticancer, antidiabetic, antimicrobial, and bio-pesticidal activities, making it valuable for diverse consumer products (Benhura et al., 2024; Mujovo et al., 2008). Despite its immense potential in drug discovery and development, the species remains underexplored (Shode et al., 2025).

Promoting the sustainable cultivation and commercialization of *L. javanica* requires integrating traditional cultural norms with scientific validation. Laboratory-based efficacy studies, coupled with large-scale cultivation and conservation strategies, can ensure both ecological preservation and economic utilization of this species. This review therefore explores the sustainable cultivation and potential market development of *Lippia javanica*, highlighting its potential role in bridging biodiversity conservation with commercial opportunities.

2. METHODOLOGY

This review was conducted using a systematic literature search across multiple academic platforms, including Google Scholar, Springer, ScienceDirect, Web of Science, Scopus, PubMed, and the Directory of Open Access Journals. Both peer-reviewed and grey literature sources were considered to ensure a comprehensive overview of the topic. Search terms were carefully selected to capture relevant studies, including "commercialization of medicinal plants," "trade in medicinal plants," "cultivation of medicinal plants," "sustainable use of medicinal plants," and "Lippia javanica." Publications ranging backward from the year 2026 were included at the time of manuscript submission.

From the initial pool of retrieved literature, articles lacking sufficient relevance or information were excluded, while both recent and older publications were retained to provide historical and contemporary perspectives. Bibliographies of retrieved papers were also screened to identify additional sources, and all references were organized using the Mendeley reference manager. In total, a refined set of sources was analyzed to examine the challenges and opportunities in the sustainable cultivation and commercialization of medicinal plants. Despite their cultural and economic importance, research gaps remain in addressing the sustainable use of certain indigenous species, particularly *Lippia javanica*, which holds significant potential as a resource for economic growth. The focus on *Lippia javanica* was guided by its widespread use in local communities and its presence in traditional medicine markets.

3. ETHNOPHARMACOLOGICAL USES

3.1. Traditional and community-based applications

The *Lippia javanica* plant is widely used across Africa. Traditional uses include treatments for asthma, diarrhea, colds, malaria, fever, cough, bronchitis, chest pain, diabetes, skin infections, and heart diseases (Maroyi, 2017; Shikanga et al., 2010; WM et al., 2015). Leaf infusions are commonly consumed as decongestants for colds and coughs and are also applied topically for wounds and skin infections, where they aid disinfection, debridement, and wound healing (Afolayan et al., 2014; Maroyi, 2017; Viljoen et al., 2005). In addition, *L. javanica* continues to play a vital role in traditional medicine for respiratory problems, gastrointestinal diseases, wound healing, pain management, and ethnoveterinary practices, which remain in effect to date (Maroyi, 2017).

Scientific studies confirm the traditional uses of *L. javanica*, showing that the plant possesses a broad spectrum of pharmacological activities, including anticancer, antidiabetic, antimalarial, antimicrobial, antioxidant, antiplasmodial, and pesticidal effects. Its essential oil has also demonstrated strong antifungal and antibacterial activity, often outperforming reference drugs while remaining less toxic (Asowata-Ayodele & Olowolaju, 2024; Makhafola et al., 2019; Shode et al., 2025).

3.2. Antioxidant and anti-inflammatory properties

The *L. javanica* plant is recognized as a rich source of natural antioxidants, effective in alleviating oxidative stress-related diseases. Crude extracts have shown significant radical scavenging activity against DPPH, ABTS, and nitric oxide radicals (Osunsanmi et al., 2019). These antioxidant properties are closely linked to its anti-inflammatory effects, supporting its traditional use in respiratory and inflammatory disorders. For example, a study conducted by Mfengu et al. (2021) showed that *L. javanica* suppressed allergic airway inflammation in ovalbumin-sensitized rats by reducing Th2-mediated immune responses and oxidative stress, thereby validating its ethnomedicinal role in treating respiratory conditions.

3.3. Antiviral potential and antimicrobial activity

The plant is also reported to possess antiviral activities (Shode et al., 2023). In vitro studies demonstrated the inhibition of SARS-CoV-2 papain-like protease (PLpro), linking its chemical signatures to antiviral relevance (Makhafola et al., 2026). Kill studies were conducted on three microbial respiratory isolates to establish the scientific basis for the use of *L. javanica* in treating respiratory complaints within traditional herbal medicine. The isolates, *Klebsiella pneumoniae*, *Cryptococcus neoformans*, and *Bacillus cereus*, demonstrated reductions in microbial populations, with the most pronounced bacteriostatic effect observed against *Klebsiella pneumoniae* (Viljoen et al., 2005). Additional studies have validated *L. javanica* bioactivity against *Mycobacterium tuberculosis* and HIV-1 reverse transcriptase (Mujovo et al., 2008).

3.4. Hepatoprotective effects

Evidence from studies also supports the hepatoprotective properties of *L. javanica*. Herbal tea infusions have been shown to protect against oxidative hepatic injury by reducing oxidative stress, improving cholinergic function, and restoring impaired glucogenic and lipase enzyme activities. These findings suggest its potential as a therapeutic agent for oxidative stress-related liver diseases (Salau et al., 2023).

3.5. Neuroprotective and antidiabetic properties

Recent studies highlight the neuroprotective effects of *L. javanica*, particularly in mitigating lead (Pb)-induced brain oxidative stress, inflammation, apoptosis, acetylcholinesterase activity, and neuronal damage. These effects are attributed to its high phenolic content (Suleman et al., 2022). In another study, the antidiabetic activity of the plant's aqueous leaf extracts was orally and intraperitoneally bio-screened in alloxan-induced diabetic mice at different doses. The study found that the intraperitoneal route was more effective in reducing blood glucose levels compared to the oral route. The observed antidiabetic effects of the plant are suggested to be attributable to its phytochemical constituents (WM et al., 2015).

The ethnopharmacological outlook of *L. javanica* is extensive, ranging from traditional remedies for respiratory and gastrointestinal ailments to scientifically validated pharmacological activities such as antimicrobial, antioxidant, and neuroprotective effects, among many others. Its dual role as a culturally significant medicinal plant and a scientifically recognized source of bioactive compounds underscores the importance of sustainable cultivation and commercialization. By bridging traditional knowledge with modern pharmacological validation, *L. javanica* holds promise as both a health resource and a globally marketable medicinal plant.

4. SECONDARY METABOLITES

4.1. General phytochemical composition

Phytochemical investigations of *Lippia javanica* have revealed a rich diversity of both volatile and non-volatile secondary metabolites. Methanolic extracts contain substantial quantities of alkaloids, phenolics, flavonoids, proteins, carbohydrates, and vitamin C (Swargiary et al., 2016). Additional studies confirm the presence of tannins, terpenoids, coumarins, phenolic glycosides, and essential oils (Nzira et al., 2009; Osunsanmi et al., 2019; Salau et al., 2023). These active principles are responsible for the plant's medicinal value, exerting physiological effects that underpin its ethnopharmacological applications (Marble et al., 2019).

Multiple classes of phytochemicals have also been identified in other studies, including alkaloids, amino acids, flavonoids, iridoids, triterpenes, cardiac glycosides, and phenylethanoid glycosides such as verbascoside and isoverbascoside (Maroyi, 2017; Olivier et al., 2010; Wafula et al., 2019). The plant is also a source of triterpenoids and iridoid glycosides, which contribute to its pharmacological potential. Screening of natural products from *L. javanica* highlights its structural diversity and potential for novel compound discovery (Gazim et al., 2014).

4.2. Essential oil composition

Gas chromatography–mass spectrometry (GC–MS) analyses have identified a wide range of volatile compounds in *L. javanica*. Essential oils extracted from leaf samples of *L. javanica* obtained from Mountain Herb Estate in Hartbeespoort and maintained in the greenhouse at the University of the Witwatersrand in South Africa yielded up to 50 components. The samples were dominated by linalool, carvone, piperitenone, tagetenone, eucalyptol, camphor, fenchone, p-cymene, caryophyllene, and terpinen-4-ol (Singini et al., 2023). Further GC–MS studies on the species, in which essential oil was extracted from fresh and dried leaves, documented 19 major compounds, with chemotypes such as verbanone and butane present in relative amounts of up to 26%. The essential oils were dominated by sesquiterpene hydrocarbons, monoterpenes, oxygenated hydrocarbons, and ketones, including cymene, myrcene, isophorone, copaene, caryophyllene, germacrene D, and thujene (Asowata-Ayodele & Olowolaju, 2024). The aerial parts of *Lippia javanica* were collected from various localities in southern Africa, and samples representing five natural populations identified five chemotypes: the myrcenone-rich type (36–62%), the carvone-rich type (61–73%), the piperitenone-rich type (32–48%), the ipsenone-rich type (42–61%), and lastly the linalool-rich type (>65%) (Viljoen et al., 2005). Leaves of the plant were also collected from Mumurwi village in Zimbabwe, whereby mass spectrometry analysis revealed the presence of alpha-pinene, 1,3,5-cycloheptatriene, beta-phellandrene, (+)-2-carene, 3-carene, eucalyptol, and caryophyllene oxide (Nzira et al., 2009).

4.3. Isolated compounds

Phytochemical investigations have also led to the isolation of several specific compounds that highlight the chemical diversity of *L. javanica*. These include long-chain hydrocarbons such as 4-ethyl nonacosane, epoxide derivatives like (E)-2(3)-tagetenone epoxide, and terpenoid chemotypes such as myrcenone and piperitenone. In addition, flavonoids and related compounds, including apigenin, cirsimaritin, and methoxyluteolin derivatives (4′-methyl ether and 3′,4′,7-trimethyl ether), have been characterized (Mujovo et al., 2008). These isolated metabolites further strengthen the plant's potential as a source of bioactive molecules with diverse pharmacological properties, reinforcing its importance in drug discovery and natural product development.

5. SUSTAINABLE CULTIVATION

5.1. Importance of geographic and biological knowledge

Understanding the geographic distribution and biological characteristics of medicinal plants is essential for guiding conservation strategies. Such knowledge helps determine whether species conservation should occur in natural habitats or through nursery cultivation (Chen et al., 2016; Davis & Choisy, 2024; Tshabalala et al., 2022). Changes in the environmental conditions surrounding medicinal plants, such as weather, could affect their phytochemical composition (Butnariu, 2026). This then directly influences the growth of the *L. javanica* plant to its maximum potential.

Experimental studies have shown that *L. javanica* can adapt to high temperatures for limited periods. Exposure to temperatures ranging from 25 °C to 47 °C over durations of 48 to 144 h significantly increased essential oil yield, trichome length, and diameter. Chemical differences between treated and control samples were confirmed through advanced statistical analyses, indicating coping mechanisms against heat stress. However, prolonged exposure beyond six days proved detrimental, underscoring the importance of climate resilience in cultivation practices (Singini et al., 2023). The plant is adaptive to short-term environmental stress while maximizing some of its bioactivity.

The *L. javanica* plant has been shown to exhibit both quantitative and qualitative variation within and between natural populations. Five distinct chemotypes have been identified, with variability appearing random and not linked to geographic distribution. Understanding the chemotypic diversity of the plant, which includes the myrcenone-rich type, carvone-rich type, piperitenone-rich type, ipsenone-rich type, and linalool-rich type, is critical for commercial development, particularly for chemical fingerprinting and quality control in standardized herbal products (Viljoen et al., 2005).

5.2. Innovative cultivation technologies

Hydroponics has emerged as a promising technology for medicinal plant cultivation. Studies suggest that hydroponic systems can enhance plant growth, influence medicinal properties, and improve profitability for farmers. Adoption of such technologies could strengthen the medicinal plant industry in Africa, providing new income opportunities while ensuring sustainable production (Xego et al., 2016). Recent advances in cultivation techniques have also highlighted aeroponic systems as a promising approach for enhancing the yield, quality, consistency, and biomass production of medicinal plant roots. This method enables rapid propagation, supporting therapeutic applications, conservation efforts, and commercial production. By meeting the needs of both traditional medicine and the pharmaceutical industry, aeroponics offers a sustainable pathway for scaling medicinal plant cultivation (Kumari et al., 2016). Artificial intelligence-orientated approaches in predictive modeling, automated metabolite annotation, and optimized cultivation strategies are also currently being tested as transformative tools for improving research efficiency and reproducibility (Latif & Nawaz, 2025). However, there are growing calls for the integration of indigenous and modern knowledge systems to co-produce solutions relevant to smallholder farmers as well (Phakathi & Sinyolo, 2025). The government therefore needs to create policies and frameworks to equip medicinal plant farmers and market drivers with the necessary knowledge and skills, thereby simultaneously addressing the issue of long-term overharvesting of *L. javanica*.

6. EXTRACTION AND QUALITY CONTROL

The bioactivity of medicinal plant extracts also depends on the extraction method selected and the solvent used. A study by Olivier et al. (2010) identified pharmacologically important metabolites in polar extracts of *L. javanica* plant parts. These findings also support the use of highly polar water as a solvent traditionally used by herbalists. Extraction methods such as maceration, decoction, infusion, percolation, Soxhlet extraction, ultrasound-assisted, and microwave-assisted techniques are widely employed (Abubakar & Haque, 2020; Pandey & Tripathi, 2014). Despite its potential, variability in herbal remedies such as *L. javanica* also poses risks to patient safety due to inconsistent manufacturing processes. Research efforts are underway to evaluate tablet production technologies that meet pharmacopoeial standards, ensuring safety, efficacy, and scalability. Successful implementation could improve healthcare outcomes and expand access to reliable herbal products across Africa (Abias et al., 2024). There needs to be a clearly defined process for the extraction of bioactive compounds for different products on the market. Certain products might require a more precise solvent and extraction method for *L. javanica* to achieve the best desired product performance.

7. CONSERVATION CHALLENGES AND TRADE PRACTICES

Global demand for herbal medicine continues to rise, increasing extinction risks for medicinal plants (Ssenku et al., 2022). Smallholder farmers often rely on protected areas on farmland to protect, conserve, and safeguard indigenous species. To date, broader conservation measures remain challenging to implement for many farmers (Mbelebele et al., 2024). Bulk trade of *L. javanica* often occurs in informal street markets, where unprocessed or semi-processed plant materials are sold in large quantities. Traditional healers emphasize the use of fresh plant parts, as potency is believed to diminish with stale material (Naidoo et al., 2024). However, this was contradicted by a study conducted by Asowata-Ayodele and Olowolaju (2024) on *L. javanica* essential oils extracted from fresh and dried leaves, which concluded that both leaf conditions have similar chemical compositions, although dried leaves yielded higher oil content (2.7% vs. 0.7%). This finding discredits the notion that fresh leaves have better pharmacological action than dried leaves; therefore, the best drying methods for *L. javanica* should be further studied to support conservation of the plant.

8. COMMERCIALIZATION MARKETS FOR *LIPPIA JAVANICA*

8.1. Food applications

The strategy for functional foods aims to enhance timely and effective basic nutrition by incorporating additional attributes that directly promote health and overall well-being (Butnariu & Caunii, 2013). This strategy can also be applied to the *Lippia javanica* plant, as it has been shown to be a nutrient-rich plant with significant potential in food fortification. A study by Benhura et al. (2024) showed that incorporating *L. javanica* powder into instant soup mixes enhanced the soups' functional, nutritional, and sensory properties. In particular, soup mixes formulated with *L. javanica* demonstrated superior nutritional value, with improved protein, calcium, iron, and phenolic contents, as well as better aroma, taste, mouthfeel, and overall consumer acceptability, making them a recommended option for potential commercialization.

Similarly, in another study, the traditionally non-alcoholic fermented maize meal, also known as maheu, produced from orange maize enriched with *L. javanica* extract, exhibited notable improvements in mineral content, polyphenols, and antioxidant activity. The addition of 15% *L. javanica* extract enhanced the recommended dietary allowances for children, particularly for iron, magnesium, and zinc, while also improving sensory attributes such as appearance, color, and texture. These findings highlight the potential of *L. javanica* in developing novel fermented food products with improved bioactive compounds and consumer appeal (Chawafambira & Jombo, 2024). These findings position *L. javanica* as a promising additive for the development of fortified foods aimed at health-conscious consumers.

8.2. Beverage industry

The use of medicinal herbs in food and beverage processing is expanding across sub-Saharan Africa. In a study conducted, it was found that incorporating *L. javanica* extracts into wine improved total phenolic content, color, and sensory properties while maintaining safe levels of sulfur dioxide in the wine. The infusion of *L. javanica* with the fruits used for making wine reduced postharvest losses and enhanced nutritional value, particularly by complementing vitamin C and flavonoids (Chawafambira, 2021).

Herbal teas made from *L. javanica* are widely consumed and commercially traded in southern Africa (Shikanga et al., 2010). Research has demonstrated that *L. javanica* tea possesses anti-inflammatory, antioxidant, and anti-asthmatic properties, with potential applications in preventing oxidative stress-induced neurodegeneration and airway inflammatory diseases (Mfengu et al., 2021; Suleman et al., 2022). Importantly, safety assessments confirmed that heavy metals such as lead were absent, and dietary intakes of essential minerals remained within recommended allowances (Artwell et al., 2017). More recent studies suggest that *L. javanica* tea may also serve as a curative agent for liver diseases (Salau et al., 2023). This validates the market need for *L. javanica*, as it can be incorporated into the formulation of beverages ranging from alcoholic beverages to herbal beverages, among many others.

8.3. Pesticidal and insect repellent uses

The essential oil of *L. javanica* has demonstrated strong pesticidal and repellent properties, outperforming comparable commercial products. It has been shown to repel flies and mosquitoes effectively, offering protection for up to 8 h in choice experiments and 5.5 h in non-choice experiments (Maroyi, 2017; Nzira et al., 2009). These findings underscore its potential as a natural alternative for developing sprays, candles, and other eco-friendly pest control products (Asowata-Ayodele & Olowolaju, 2024).

8.4. Veterinary applications

Beyond human health, *L. javanica* has demonstrated promising applications in animal health. Supplementing broiler diets with *L. javanica* at 5 g/kg feed improved average daily gain, slaughter weights, carcass characteristics, and fatty acid profiles of meat (Mpofu et al., 2016). Similarly, feeding Japanese quails with *L. javanica* leaf meal at 25 g/kg promoted growth performance, health status, and carcass quality comparable to commercial diets containing antibiotics. This suggests that *L. javanica* could serve as a sustainable alternative to antibiotic growth promoters in poultry production (Mnisi et al., 2017). The global animal feed market, specifically the poultry market, is of great economic importance. If cultivation of *L. javanica* is carried out correctly, farmers cultivating this medicinal plant will benefit substantially.

9. CONCLUSION

With rising local and global demand for medicinal plant products, coupled with the current gap in products derived from *Lippia javanica* within the trade market, the species is well positioned to emerge as a high-value commodity. However, unlocking its full potential requires a comprehensive understanding of its ethnopharmacology, strategic investment in sustainable cultivation, product development, and rigorous quality assurance. Modern cultivation strategies provide a viable pathway to addressing the sustainability challenges associated with wild harvesting, thereby ensuring both conservation and long-term commercial viability. A framework involving farmers, scientists, and government must be established to safeguard the species while simultaneously validating its efficacy in the context of product development and commercialization strategies.

The *Lippia javanica* plant is distinguished by its complex phytochemical profile, which includes alkaloids, flavonoids, terpenoids, iridoids, glycosides, and diverse essential oils, among many others, illustrating its potential to penetrate multiple global markets. The variability in chemical composition across different samples and localities highlights the importance of chemotype identification as a prerequisite for standardization and successful commercialization. The structural diversity of its secondary metabolites further presents significant opportunities for diverse applications in functional foods, herbal teas, nutraceutical beverages, eco-friendly pesticides, and animal feed. Where feasible, the use of aerial plant parts in large-scale production should be prioritized to minimize ecological impact. Ultimately, sustainable cultivation and standardized processing are indispensable for ensuring consistent quality, preserving medicinal efficacy, and securing the long-term commercial success of *Lippia javanica*.

MANDATORY DISCLOSURE ON USE OF ARTIFICIAL INTELLIGENCE

None.

COMPETING INTERESTS

The authors declare no conflict of interest with respect to research, authorship and/or publication of this article.

AUTHORS' CONTRIBUTIONS

S.L. carried out the experimental work and analyzed the data, S.S. interpreted the data and participated in manuscript editing. All authors have read and approved the final manuscript.

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