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Review Article

Exploring *Lantana camara*: A comprehensive insight into its bioactive constituents and therapeutic potential

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A B S T R A C T

Lantana camara is a common medicinal shrub that is known to have a wide composition of phytochemicals and has a wide therapeutic scope. The plant has had a traditional significance in treating respiratory disorders, skin ailments, infections, and inflammatory diseases but scientific attention has been given to it because of the existence of bioactive substances, including terpenoids, flavonoids, phenolic acids, glycosides, and essential oils. These elements lead to various pharmacological effects such as anti-inflammatory, antimicrobial, antioxidant, anticancer, analgesic, hepatoprotective and wound-healing and metabolic regulation. The present review summarizes the existing information on the botanical features, traditional applications, phytochemistry, and the biological activities that have been reported on *L. camara*. It also presents significant shortcomings in the prevailing literature such as phytochemical profile variability, inconsistency in the methodological approach, lantadene toxicity issues, and absence of clinical validation. The next round of research will focus on adoption of standardized extraction techniques, elaborate toxicity testing, chemotype characterization and clinical trials to confirm the therapeutic claims. On the whole, *Lantana camara* is a promising but under-investigated source of natural compounds that may be applied in the development of modern drugs.

Keywords: *Lantana camara*; phytochemistry; traditional uses; pharmacological activities; terpenoids; flavonoids; essential oils; antioxidant; anti-inflammatory; antimicrobial; anticancer; wound healing; hepatoprotective; natural products; herbal medicine.

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INTRODUCTION

Lantana camara is one of the most popular ornamental and medicinal shrubs, known by its amazing resistance, aromatic leaf structure [1]. *L. camara* is often seen as an invasive plant in various regions all over the world but it has always been employed in the traditional healing system because it has a wide range of biological activities. In the last several decades, this plant has received a growing amount of scientific attention due to its rich phytochemical composition and the rising need in naturally-derived therapeutic chemicals. This review has discussed the botanical characteristics, taxonomic position, ecological distribution, and scientific justification in studying the phytochemistry and pharmacological significance of *L. camara* [2].

Botanical Background of *Lantana camara*

Lantana camara is a perennial, hardy, woody shrub that is 1-3 meters tall, the family of which is Verbenaceae. Its square stems identify it easily, its leaves are rough-textured and small with tight clusters of tiny tubular flowers. The leaves are opposite, ovate and highly aromatic when crushed which is an attribute associated with its essential oil composition. Flowers are of different tones yellow, pink, red, orange, and white and tend to shift colors with age and that is why it is also an ornamental value [3]. The plant gives small berry-like frugs which turn green to dark purple or black in case of ripening. Birds and small mammals are known to be the major dispersers of these fruits which in turn makes the plant to spread very fast in different ecosystems. *L. camara* can be grown in areas with a lot of sunlight and moderate amount of rainfall hence it is adaptive to a large number of environmental conditions such as degraded soils, forest boundaries, grasslands, and wastelands. *L. camara* has interesting botanical characteristics: its allelopathic properties are the property of its roots and litter litter which can suppress the growth of native plants. This biological competitiveness has seen it become a worthwhile colonizer, yet an important weed in agricultural and natural ecosystems. Regardless of this invasive character, its therapeutic and resilience has rendered it a species of high scientific value [4].

Figure 1: *Lantana camara* Linn.

Taxonomy and Nomenclature

Lantana camara has got a complex taxonomy since morphological variability of the species is high in various geographical locations. It belongs to the genus Lantana and the family Verbenaceae and it has undergone many taxonomic changes. Its scientific name is *Lantana camara* L. and the epithet camara, designation of the species, is an ancient Portuguese word that means shrubs with crooked branches [5]. Lantana is a genus with over 150 species with all of them having overlapping morphological characteristics, thus causing difficulty in species differentiation. The fact that it is horticulturally varied with different varieties, and that it is hybriding with the naturalized populations complicates the classification of the horticultural species even more. Consequently, *L. camara* has a number of synonyms in literature, such as *Camara vulgaris* and *Lantana aculeata*, although these are now mostly never used. Most of the names are the common names which are not universal. In English speaking countries it is commonly referred to as wild sage, red sage, Spanish flag or tickberry; in parts of India it is referred to as putus or vanarphool, and in Latin America as camara. Such variety in the names of vernaculars is indicative of its high cultivation and naturalization [6]. To conduct research, knowing its taxonomy and nomenclature is necessary because phytochemical content and biological activity are often different in varieties. Proper identification will provide accuracy in the scientific analysis, particularly, in the pharmacognostic and bioactivity research.

Global Distribution and Habitat

Lantana camara, originally a native species of tropical areas of Central and South America, is now naturalized in over 60 countries in Asia, Africa, Australia and Pacific Islands. Due to the fact that it is planted as an ornamental plant and has adapted to various ecological situations, its wide distribution is explained. It grows in hot regions and is especially prevalent in the tropical and subtropical areas. The plant is common in the Himalayan foothills of India, the western Ghats and along the central plains and the northeastern states. It often inhabits unnatural environments, such as road sides, forest edges, farmlands, and deserted lands. It can also form in soils having poor nutrient, saline environments, and drought prone regions because of its great adaptability. This ecological adaptability is also the reason why it has been named as one of the most invasive species in the world by conservation experts [7]. *L. camara* has had ecological issues internationally since it is a competitive vegetation to the native vegetation, changes the soil chemistry, and reduces the biodiversity of invaded ecosystems. In areas endowed with ethnomedicine, however, the same plant is also appreciated in treating illnesses. In contrast to its ecological effects, there is an interesting contrast in the ecological and medicinal significance of the plant, with traditional healers in Africa, Asia, and Latin America using various parts of the plant to cure various ailments.

Rationale and Scope of the Review

Although *Lantana camara* is considered to be an invasive species, it is a valuable medicinal plant with a rich reservoir of bioactive compounds. It has strong pharmacological potential in terms of its essential oils, triterpenoids, flavonoid, phenolic compounds, and alkaloids. Various researchers have indicated the presence of antimicrobial, anti-inflammatory, antioxidant, analgesic, wound healing, and anticancer effects, and this demonstrates its applicability in the current phytomedicine. The *L. camara* literature is however very scattered with phytochemical and pharmacological

discoveries being scattered in various fields. Furthermore, the inconsistencies of the results are common due to the difference in the plant variety, geographical origin and extraction techniques and the design of experiments. This underlines the importance of an all-around well structured review [8]. The current article will attempt to provide a summary of what is already known about the phytochemistry, traditional applications and pharmacological actions of *Lantana camara*. Incorporating the findings of botany with scientific research, this review offers an overview perspective on the therapeutic value of the plant. It also comes up with research gaps and where research needs to be done further especially in area of toxicity, clinical validation and standardization of bioactive compounds.

Traditional and ethnobotanical uses

Lantana camara has a long history of ethnopharmacological importance as it has been established centuries in the traditional medicinal systems of both the tropics and subtropics. Despite the fact that the plant has been criticized as being invasive, it has always been regarded as a practical source of medicine by traditional healers in Asia, Africa and Latin America. This extensive application is mainly due to the availability of the plant, its adaptability to suit various habitats, and the apparent curative impacts as reported by the natives. In most more traditional systems, the plant is seen as a versatile cure that can treat numerous illnesses, including skin diseases and infections, respiratory and gastrointestinal diseases [9]. Locally, on the Indian subcontinent, *L. camara* is very widely known in terms of local medicine. The common uses of its leaves, flowers, roots and even unripe fruits by folk practitioners include the preparation of a remedy to various health ailments. The leaves are also commonly used as poultices or decoctions as an external remedy to cuts, wounds, sprain, and ulcers due to their supposed antimicrobial and anti-inflammatory effects. Some rural communities also use the aromatic leaves, which are crushed into a natural antiseptic dressing of minor injuries. Ayurveda and various tribal medicine Ayurveda uses leaf decoctions in the treatment of bronchitis, asthma, cough, and fever. The given plant is also taken as an herbal medicine against a common cold, an eruption similar to measles, and an allergy of the skin. *L. camara* can be used in snake bites or scorpion stings as traditional healers recommend that it can be effective in an emergency when antiseptic and analgesic properties are required [10].

Lantana camara is regarded as a notable ethnomedicinal herb in the treatment of respiratory infections, malaria, gastrointestinal issues as well as dermatological issues in most parts of Africa. The leaves and stems are prepared into decoctions that are administered in the treatment of fevers, flu-like illnesses and malaria-like illnesses. The leaves are used to portend gastrointestinal health with some communities brewing a powerful tea containing leaves to relieve stomach aches, diarrhea, and dysentery. The use of the plant as a conventional insecticide is also due to its smell. Fresh foliage is even used as a cover around living areas to keep mosquitoes, flies and other insects away whereas in some African villages, dried leaves are burnt to smoke out a house or animal shelter. This ancient knowledge is consistent with the scientifically documented insecticidal and larvicidal effects of this plant, which is to show a congruence between indigenous usage and the inventions of contemporary pharmacology [11]. The plant has also been used extensively by traditional healers in Central and South America who are also native to *L. camara* and who have used it in the treatment of various illnesses. In Brazil, Colombia, and Mexico, the extracts of the leaves are generally taken to relieve breathing congestion, fevers, and to help in combating infectious diseases. The flowers or leaves are occasionally infused and used in mild cases of sedation or anxiolytic effect, especially in patients with a feeling of agitation or stress-related symptoms. *L. camara* in rural Latin American communities is commonly viewed as a treatment of stomach upsets, liver diseases and parasite infections. The roots are sometimes used to make rheumatism, toothache, and muscular pain preparations, excepting a wider range of ethnomedicinal use. The plant is also used externally by several communities as a treatment of fungal infections, eczema and dermatitis, and it is based on the traditional knowledge of the plant to heal the skin [12]. There are parts of Indonesia, Thailand and the Philippines where *Lantana camara* is a remedy that is still available in every household. In this case, the leaves are used in the traditional ways of making a decoction through boiling and used to treat fever, headaches, stomach problems, and menstrual problems. The flowers are also used as a calming herbal tea in some cultures because it is believed to increase digestion and minimize inflammation. *L. camara* paste is used to treat swollen joints, abrasions or insect bites to relieve pain and irritation in some regions. The natural repulsive effect of the plant is also used by farmers and rural families who protect stored grains with the help of dried leaves or extracts, rich in essential oils. These ethnobotanical applications underscore the usefulness with which local communities incorporate *L. camara* into the everyday and customary health care and life [13]. The versatility of the herbal preparations of the plant is also of significance in the traditional use of the plant. Medicines based off of *L. camara* include decoctions, infusions, pastes, poultices, juices and application as essential oils. The most frequently used part is the leaf, but there are the use of flowers, roots, bark and berries according to the nature of ailment. The foliage is also used as a paste in certain areas with turmeric or other curative herbs to increase its wound-healing value. Fresh leaf juice can be administered to children in a dilated form to treat mild gastrointestinal upsets and some communities use powdered dried leaves to treat chronic skin infections. The essential oils produced with the help of the plant are then traditionally used as aromatherapy, massage and topical antimicrobial agents indicating the idea that L. camara has a great biological activity in terms of pathogenic microorganisms [14].

Traditional healers tend to place symbolic and cultural emphasis on *Lantana camara*, which contributes to the effectiveness of this plant in ethnomedicine. In other native communities, the plant is said to have protective properties, especially against diseases and evil spirits. Its fragrance is very strong and it has bright flowers and it is considered a symbol of purification and vitality. These cultural views contribute to the fact that it is used more as medicine and the medicinal knowledge is also passed down to the other generations. Although in most traditional contexts there is no standardized dosage or even clinical validation of the use of the plant, there is long-term dependence on the plant which indicates its perceived safety and efficacy [15]. The

invasiveness of the plant causes ecological issues, but it remains a significant component of the traditional health systems of most countries as a source of affordable, accessible and multi-purpose remedy. Its extensive use on various continents, cultures, and medicinal traditions explain the necessity of an in-depth scientific investigation of its phytochemistry and pharmacological activities. Moreover, the justification of its conventional uses by the use of contemporary studies can contribute to the creation of new herbal preparations, standard extracts, and treatments based on this popular-spreading species [16].

Phytochemistry of *Lantana camara*

Lantana camara has a very rich and diverse phytochemistry, which has made it a very diverse in terms of biological activity and therapeutic activity. The years of phytochemical research have shown that the plant has complicated mixture of secondary metabolites, which are dispersed in the leaves, flowers, stems, roots, and fruits of the plant. These compounds are members of some of the largest chemical classes such as terpenoids, alkaloids, flavonoids, phenolic compounds, steroids and glycosides. Environmental factors that affect the variability of phytochemical profile include the soil composition, climate, altitude, and seasonal variations; and the genetic diversity of the plant. Consequently, extracts in the various regions might exhibit a lot of variability in composition and potency [17].

Terpenoids

Some of the most common and most extensively researched phytochemicals in *Lantana camara* are terpenoids. The pentacyclic triterpenoids, especially the lantadenes are especially abundant in the plant and have been of interest to the scientific community because of their biological consequences as well as their role in the toxicity profile of the plant. Two of the notable triterpenoids are lantadene A and lantadene B, which have the potential of hepatotoxicity in grazing animals. These are the oleanane type of triterpenoids which have complicated cyclic structures that add to their response to cellular membranes and metabolic pathways. Other terpenoids like ursolic acid, oleanolic acid, betulinic acid and other diterpenoids have also been identified in other parts of the plants other than lantadenes. These terpenoids have been found to have various pharmacological properties such as anti-inflammatory, antimicrobial and anticancer properties, which show their contribution to the medicinal potential of the plant [18].

Alkaloids

Even though the alkaloid is not the predominant class of chemical in *L. camara*, a number of researchers have documented their presence in minute but significant amounts. The list of the alkaloids derived out of the plant is lantamine, derivatives of quinoline and minor pyrrolidine-based alkaloids. These substances can also be added to the analgesic, antimicrobial and neuromodulatory effects of the plant. Even in low levels, alkaloids are likely to have powerful biological effects because of their capacity to bind to neurotransmitter systems and targets at the protein level. The fact that they appear in *L. camara* also contributes to its chemical diversity and there could be their implications in the traditional therapeutical usages of the plant [19].

Flavonoids

Another group of phytochemicals that are notable in *Lantana camara* is flavonoids. These compounds are ubiquitous in the plant kingdom and have been attributed to have antioxidant, anti-inflammatory and cytoprotective activities. Widespread flavonoids found in *L. camara* are quercetin, luteolin, apigenin, kaempferol and their glycosylated forms. These molecules have polyphenolic structures that make them able to scavenge the free radicals, regulate the enzymatic pathways and shield biological tissues against oxidative stresses. The concentration of flavonoids in leaves and flowers is also consistent with its classical applications in inflammatory/infectious diseases involving the use of leaf and/or floral parts of plants [20].

Phenolic Compounds

Simple phenols, phenolic acid, and tannins are all phenolic compounds that are dominant in *L. camara*. Such acid as galleric acid, chlorogenic acid, caffeic acid, and ferulic acid have been reported in different extracts. These are characterized by antioxidant properties and redox balancing properties in cells. Phenolic constituents also confirm the usage of the plant in the treatment of wound healing, inflammation, and microbial infections. They are also used in traditional preparations of gastrointestinal upsets and skin conditions because tannins are present in the plant, and this makes it a useful astringent [21].

Steroids

Lantana camara has been found to contain steroidal compounds including b-sitosterol, stigmasterol as well as campesterol, found in the aerial parts of the plant as well as in the roots. These phytosterols are structurally related to cholesterol and affect membrane stability, enzyme activity as well as hormonal balance. They have been reported to have anti-inflammatory, immunomodulatory and anticancer effects. Phytosterols present in *L. camara* boosts its therapeutic effects and supplements the pharmacological effects of other chemical compounds [22].

Glycosides

The glycosides found in the plant are iridoid glycosides, saponin glycosides and flavonoid glycosides. Interesting features of iridoid glycosides such as lantanoside and camamarin are their anti-inflammatory and hepatoprotective actions. Saponin glycosides are surfactant-like, and can possibly be involved in the antimicrobial and expectorant effects of the plant. The solubility, bioavailability, and biological activity are affected by glycosylated flavonoids, which are produced as a result of sugar moelling to flavonoid structures. These glycosides contribute to the chemical complexity and therapeutic relevance of *L. camara* [23].

Essential oil composition

One of the most widely investigated phytochemical constituents of *Lantana camara* is its essential oil because of its good aroma and a variety of biological activity. The extraction of essential oil is mainly done on the leaves and flowers using steam distillation. The oil contains a lot of monoterpenes and sesquiterpenes with the predominant constituents being b-caryophyllene, germacrene D, a-

humulene, limonene and sabinene. Other elements such as a-pinene, b-pinene, linalool and myrcene add to the unique smell and medicinal values of the oil [24]. The essential oil has a vast range of chemical profile that depends on the geographical location and the environmental conditions of the plant. Differences in terms of chemotyping lead to variations in the oil composition, which affect the intensity and nature of the biological activity that can be monitored in a laboratory setup. *L. camara* essential oil is known to possess antimicrobial, insecticidal, anti-inflammatory, and antioxidant properties; hence, its application in traditional medicine in the treatment of respiratory problems, skin problems, and infections. Oxygenated terpenes (caryophyllene oxide and spathulenol) increase the pharmacological properties of the oil and provide an aromatic value [25-27].

Bioactive compounds and structures

Lantana camara has a wide range of bioactive molecules which contribute to its therapeutic value to a large extent. Some of the most valuable ones include lantadenes, which are triterpenoids with a complicated pentacyclic structure. These molecules have been widely researched as regards to their possible toxic and pharmacological action. Other notable triterpenoids that have been well documented in terms of their anti-inflammatory, antimicrobial and anticancer effects include uersolic acid and oleanolic acid. The polyphenolic structures of quercetin, kaempferol and luteolin have an important antioxidant and cytoprotective effect [28]. The additional antioxidant potential is provided by phenolic acids, including chlorogenic acid and gallic acid, and by phytosterols, including b-sitosterol, which promotes anti-inflammatory effects. Major constituents of essential oils and especially the caryophyllene and germacrene D, have exclusive cycles of terpenoids, which affect their bioactivity. These compounds combined with their varied chemical structure and action mechanisms provide the biochemical basis of the broad therapeutic potential of *Lantana camara*. Their existence underscores the importance of the plant in terms of its potential as a good source of additional phytochemical and pharmacological studies [29-32].

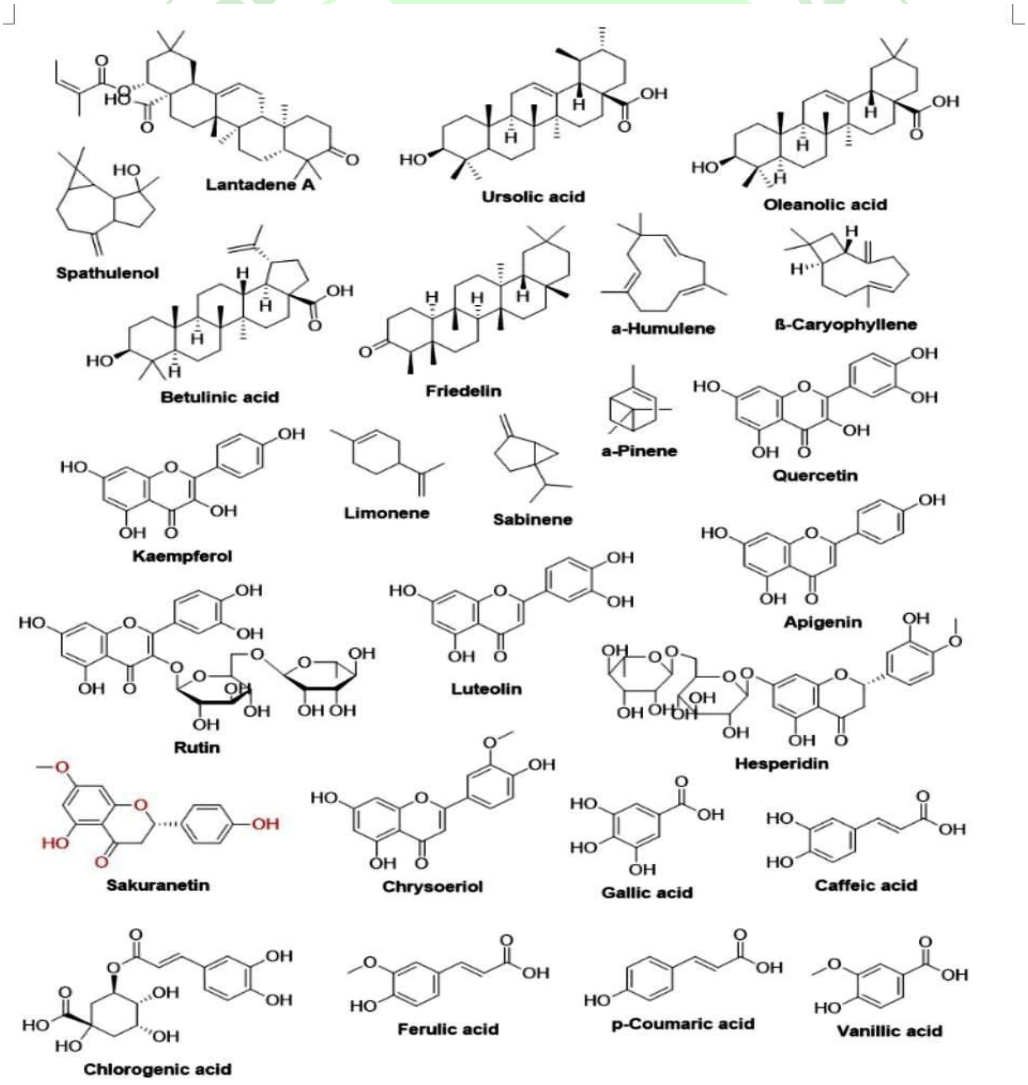

Figure 2: Phytoconstituents present in *Lantana camara* linn with their structures

Table 1: Major pharmaceuticals of *Lantana camara* and their reported pharmacological activities

Phytochemical Class	Compound Name	Plant Part	Reported Biological Activities
Triterpenoids	Ursolic acid	Leaves	Anti-inflammatory, anticancer, antioxidant, hepatoprotective
	Oleanolic acid	Leaves/Roots	Antidiabetic, hepatoprotective, anti-inflammatory
	Lantadene A & B	Leaves	Antimicrobial, cytotoxic, also associated with hepatotoxicity
	Betulinic acid	Leaves	Anticancer, antiviral, anti-inflammatory
Flavonoids	Quercetin	Leaves/Flowers	Antioxidant, anti-inflammatory, antimicrobial
	Kaempferol	Leaves	Anticancer, antioxidant, cardioprotective
	Luteolin	Leaves	Anti-inflammatory, neuroprotective
Phenolic Acids	Gallic acid	Leaves	Antioxidant, antimicrobial
	Chlorogenic acid	Leaves	Hepatoprotective, antioxidant
Alkaloids	Lantamine	Leaves	Analgesic, antimicrobial
Glycosides	Lantanoside	Leaves	Anti-inflammatory, hepatoprotective
	Iridoid glycosides	Various parts	Antimicrobial, wound healing
Sterols	β-Sitosterol	Leaves/Roots	Anti-inflammatory, cholesterol-lowering
	Stigmasterol	Leaves	Antioxidant, anti-arthritic
Essential Oils	β-Caryophyllene	Leaves	Anti-inflammatory, analgesic, antimicrobial
	Germacrene D	Leaves	Antimicrobial, insecticidal
	Linalool	Leaves/Flowers	Sedative, antibacterial

Pharmacological Activities of *Lantana camara*

Lantana camara has a very wide range of pharmacological actions, most of which are accredited to the multifarious phytochemical constructions. The plant has terpenoids, flavonoids, phenolic compounds, glycosides, steroids and essential oils which are synergistic in bringing therapeutic potential to the plant. Scientific proof of many of the traditional uses of this plant has been presented over the years by experimental studies; in vitro and in vivo. The next paragraph presents a detailed review of the key pharmacological processes *L. camara* is engaged in, with particular focus on the major mechanisms and the importance of bioactive compounds of *L. camara* [33].

Anti-inflammatory Activity

One of the most commonly reported biological properties of *Lantana camara* is the anti-inflammatory potential of the plant. Preparations of its leaves, flowers, and roots exhibit a high level of activity in test systems of inflammation. The effects of these compounds are mostly mediated by triterpenoids including ursolic acid, oleanic acid and lantadenes and some flavonoids that mediate inflammatory processes. Research has demonstrated that the extracts have the ability of inhibiting the synthesis of major inflammatory mediators, including nitric oxide, prostaglandins, and cytokines such as IL-1b, TNF-a and IL-6 [34]. Mechanistically, *L. camara* extracts inhibit the expression of nuclear factor-kB (NF-kB) transcription factor that controls inflammatory and immune response genes. The plant inhibits the activity of NF-kB that leads to the production of pro-inflammatory molecules and regulates the movement of inflammatory cells to the tissues. The carrageenan-induced paw edema and formalin-induced inflammation models of experiment prove that the plant has acute and chronic anti-inflammatory action. Such results support the conventional application of *L. camara* into the treatment of joint swelling, bronchial irritation and inflammatory skin disorders [35-37].

Antimicrobial Activity

Lantana camara has been proven to possess an antimicrobial activity, which is supported by a number of laboratory studies. Plant extracts prepared using the various parts of plants show inhibitory action against various pathogenic microorganisms, fungi and viruses. This is the case especially because the essential oil contains a high number of monoterpenes and sesquiterpenes including caryophyllene, germacrene D, a-humulene and limonene which are famous in their ability to disrupt the membrane [38].

Antibacterial Activity

With regard to Gram-positive and Gram-negative organisms, the plant has shown high antibacterial activity. Extrates exhibited activity against *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae* and *Salmonella species*. It is believed that the antibacterial effect is by the disruption of cell wall integrity, preventing the activities of microbial enzymes, and blocking the production of nucleic acids. Flavonoids like quercetin and luteolin also help in the antibacterial effect because of their capacity to bind or chelate proteins in microbes and also modify the cell membrane permeability [39].

Antifungal Activity

The extracts of *Lantana camara* are also active against major fungal pathogens like Candida albicans, *Aspergillus niger*, Trichophyton rubrum and Fusarium species. Oils are particularly useful, which may be explained by the fact that they tend to prevent the production of ergosterol, an

important building block of the fungal cell membranes. Traditional medicine has been using leaf paste to treat superficial fungi, and this is associated with experimental data showing that it has antifungal activity [40].

Antiviral Activity

Antiviral effect has been documented against various viruses though it has not been investigated extensively as compared to antibacterial and antifungal actions. Extracts disrupt viral replication patterns, potentially by inhibiting viral enzymes, interfering with the capsid proteins or by disrupting the binding of host cell receptors. These early results show the prospective of *L. camara* as a natural source of antiviral-like agents and can be used in future research [41].

Antioxidant Activity

Oxidative stress is an essential factor in the development of long term diseases including cancer, diabetes, cardiovascular diseases and neurodegenerative diseases. The ability of *Lantana camara* to act as a strong antioxidant is principally explained by the presence of flavonoids, phenolic acid and triterpenoids. Quercetin, gallic acid, kaempferol, and chlorogenic acid are compounds with free radical-scavenging properties that aid in countering the reactive oxygen species (ROS) [42]. The extracts of the plant show a high activity in DPPH, ABTS, FRAP, and lipid peroxidation tests. The plant also has antioxidants that help in the maintenance of enzymatic antioxidant systems; catalase, glutathione peroxidase and superoxide dismutase. These measures promote the cellular defenses and reduce the oxidative damages on DNA, proteins and lipids. This antioxidant activity accounts for the application of the plant in traditional medicine as a wound healing agent, hepatoprotectant, and an agent to manage inflammatory diseases, where oxidative stress increases tissue injury [43-45].

Anticancer Activity

L. camara has anticancer properties which attract the attention of scientists in recent years. Leaf and root extracts have cytotoxic and antiproliferative effects against various cancer cell lines such as breast, lung, colon, cervical and liver cancer cell lines. Terpenoids ursolic acid, oleanolic acid and betulinic acid are at the center of the mediation of the actions of anticancer by mechanisms including induction of apoptosis, inhibition of tumor growth and angiogenesis [46]. The plant also has Flavonoids that help to prevent cancer by disrupting the signaling pathways that are associated with malignant cell growth and they include MAPK, PI3K/Akt and NF-kB pathways. There are compounds that are reported to suppress the expression of other pro-apoptotic markers like Bax and suppress the expression of anti-apoptotic markers like Bcl-2. In addition, *L. camara* extracts are able to freeze cancerous cells in critical stages in the cell cycle thereby inhibiting their further growth. Although these experimental results are promising, it should be contrasted in clinical studies to determine the therapeutic importance of the plant in cancer treatment [47].

Analgesic and Antipyretic Activity

Scientific studies provide a solid basis towards Lantana camara traditional use in the treatment of pain, headaches and fever. The plant is said to possess analgesic activity that is owed to central and peripheral mechanisms. The presence of flavonoids, alkaloids, and terpenoids in the plant has the potential to regulate the nociceptive mode, suppress the production of prostaglandins, and decrease the sensitivity of pain receptors. Animal experiments by writhing and hot plate, which use acetic acid, demonstrate that the extracts have a significant effect of reducing pain responses, suggesting peripheral and central analgesia [48]. The antipyretic effect of plant is also attributed to the effect on the prostaglandin pathways and especially the inhibition of the production of the prostaglandin E2 (PGE2) under the hypothalamus. Experimental models of fever indicate that decoctions and extracts have the same temperature-reducing effect as conventional antipyretic medications. These results provide scientific evidence to the traditional use of the plant in the treatment of fever, flu like conditions and inflammatory pain.

Wound Healing Properties

One of the most appreciated traditional qualities of Lantana camara is the wound healing potential of the plant. The leaves are usually used as poultices on wounds, ulcers and infected wounds. Scientific research proves that extracts stimulate wound contraction, stimulate collagen synthesis and increase epithelialization. Antimicrobial and antioxidant properties of the plant also contribute to healing since they decrease the number of microbes and cause as little oxidative harm as possible at the wound site [49]. Triterpenoids and flavonoids are vital in that they enhance fibroblast growth, augment tensile strength of the wound tissue and activate angiogenesis. The use of Lantana extracts as topical dressing in excision and incision wound models showed a higher rate of wound healing and structural integrity. These observations indicate that the plant has multi-layered wound-healing effect which is directly associated with the use of the plant in the tradition [50].

Hepatoprotective and renal protective activities

Hepatoprotective effects of Lantana camara have been shown in experimental models of liver damage caused by chemicals. Extracts assist in restoring normal liver structure and raising the levels of serum markers, including the ALT, AST, ALP, and bilirubin. These protective measures are largely explained by the presence of the phenolic compounds, triterpenoids or flavonoids which increase antioxidant defenses and decrease lipid peroxidation in the hepatic tissues. Besides, some glycosides can help counteract the detoxification pathways, which are beneficial in enhancing liver activity [51]. Likewise, protective effects on the kidney have been seen on nephrotoxicity models. Extracts lessen oxidative stress, renal cell membrane stabilization, and aid in preserving normal urea and creatinine levels. The synergistic antioxidant, anti-inflammatory, and membrane-stabilizing effects of the plant are the reasons why it is potentially effective in preserving against chemical or metabolic injury of both hepatic and renal tissues.

Insecticidal activities

Among the most remarkable biological processes of *Lantana camara*, its high insecticidal and larvicidal capacity should be mentioned. Mosquito larvae have been shown to be sensitive to essential oils and leaf extracts especially species like *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus*.

These effects can be explained by the presence of terpenoids and sesquiterpenes which disrupt the larval development, respiration, and enzyme systems [52]. In addition to mosquitoes, the plant has a demonstration against agricultural pests and stored-grain insects. Ethnobotanical evidence can be traced back to traditional communities who adopted the use of dried leaves to keep insects out of houses and crops. Scientific researches confirm these practices by showing that essential oils interfere with the nervous system of insects, impair the feeding behavior, and lower the reproductive power. It has a high insecticidal potential and this implies that *L. camara* can be used in the development of botanical pesticides.

Antidiabetic and metabolic effects

The antidiabetic properties of *Lantana camara* have been explained by the capacity to control the level of glucose in the blood and enhance the parameters of metabolism. Hypoglycemic activity extracts have been demonstrated in diabetic experimental models, and have beneficial effects in lowering fasting blood glucose, increase blood glucose tolerance, and insulin sensitivity. These effects are probably exerted by phenolic compounds, flavonoids, and triterpenoids which adjust carbohydrate-metabolizing enzymes, including a-amylase and a-glucosidase which decreases intestinal glucose absorption [53]. Also, extracts reduce oxidative stress of pancreatic tissues, which maintain b-cell integrity and enhance insulin secretion. In other studies, a transition in lipid profiles was also proposed, as the cholesterol, triglycerides and low-density lipoproteins decreased. These results suggested that *L. camara* has extensive metabolic advantages further than glucose regulation and thus justifies its application in management of metabolic diseases.

Limitations in current research

Although *Lantana camara* has received a lot of scientific attention, there are still a number of constraints on the depth, reliability, and translational utility of current studies. A significant issue is that the majority of the extant studies are of preliminary nature with a high percentage of them being at the in vitro or small animal level. Although most of the results demonstrate the therapeutic potential of the plant, the absence of standardized procedures and consistent reporting in most cases complicate the ability to make concrete conclusions and compare the results of others. Such restrictions underscore the necessity of more rigorous and thoroughly developed studies that will allow proving the pharmacological relevance of the plant [54]. One issue of methodology is the fact that different researchers use varied methods of extraction, solvent system, and dose ranges. Lack of standard protocols is a major factor that would influence the reproducibility of results as various different methods can give different extracts which have different chemical profiles and bioactivity. In addition, some of the studies lack adequate controls, fail to consider batch variation or they do not use the validated methods of analysis in detecting bioactive compounds. These types of methodological inconsistencies complicate the identification of which constituents really contribute to the observed pharmacological effects, and restrict advancement to the development of standardized herbal preparations or drug candidates based on *L. camara* [55]. The other significant constraint is that there is a significant phytochemical composition among the different populations of *Lantana camara*. The concentration of terpenoids, flavonoids, phenolic compounds and essential oils can be under the influence of the seasonal changes, soil quality, altitude and climatic factors. This is even complicated by the fact that several chemotypes are possible since plants living in various geographical locations might have dissimilar chemical profiles. This is natural variability that prevents generalization in the findings and complicates the establishment of consistent therapeutic standards or safety profiles of the species in general [56].

The most significant gap in the current research is the absence of clinical trials. Despite numerous preclinical studies exhibiting good anti-inflammatory, antimicrobial, antioxidant, anticancer and metabolic effects, there is scarcely any clinical evidence to support the effectiveness or safety of *L. camara* in humans. The therapeutic claims involving the traditional knowledge and laboratory research cannot be applied to evidence-based medical practice without any controlled clinical testing. There are also still safety-related issues, especially because of the presence of lantadenes, which were found to cause hepatotoxicity in animals [57]. Additional studies are necessary in the future to work towards standardization of extraction and analytical procedures, chemotyping, toxicity studies and clinical trials with the view to exploiting the therapeutic potentials of Lantana camara to the fullest [58-60].

Future Perspectives

Its high phytochemical content especially the presence of triterpenoids, flavonoids, phenolic compounds, and essential oils gives it a good platform to build upon in terms of coming up with drugs in the future. Some of the bioactive components, including ursolic acid, oleanolic acid, lantadenes, and flavonoids derivatives, have potential to be used as anti-inflammatory, antimicrobial, anticancer and antioxidant agents. Further optimization can then be used to convert these molecules into lead compounds which can be used in pharmaceuticals. The challenge in the future is to isolate, characterize and maximize these constituents in order to create safe therapeutic windows and reduce toxicity. The development of medicinal chemistry, structure-activity relationship (SAR) investigations and computational modelling can enable the development of derivatives that are more potent and less adverse in nature so that *L. camara* can no longer be considered merely a traditional medicine but a scientifically proven source of new therapeutic agents. Besides drug discovery, development of novel delivery systems constitutes a significant way in the future. Most of the active constituents of the plant have a few shortcomings that include low bioavailability, low solubility and instability at physiological conditions. The addition of these compounds to contemporary delivery systems, including nanoparticles, liposomes, phytosomes, and polymer-based carriers, can improve the therapeutic effectiveness of said compounds. These sophisticated delivery systems have the potential of providing controlled release, enhanced tissue specificity and decreased systemic toxicity. As an example, nanoformulations of triterpenoids or essential oils could find special application in antimicrobial, anticancer and wound-healing. The translation of *L. camara* extracts into topical gels, patches, or aerosol preparations could be used further to

support the application of this plant in dermatological and respiratory treatments, in which conventional and experimental evidence supports its use. In order to achieve full potentials of *Lantana camara* as a medicine, there are a number of areas that need special research interest. Global phytochemical profiling of chemotypes and geographical locations is necessary to create consistency in composition and biological activity. In addition, mechanistic research should be urgent to explain the molecular mechanisms of pharmacological activities of the plant. Most importantly, effective clinical trials should be developed to prove therapeutic claims and find out effective and safe dose to be used in people. The interdisciplinary cooperation between the pharmacognosy and pharmacology, biotechnology, and the clinical sciences should be strengthened to speed up the progress. Advancing with regular research and development, *Lantana camara* has a great potential to become one of future natural products based therapeutics.

CONCLUSION

Lantana camara is a plant of significant medicinal interest, which is characterized by high phytochemical diversity and as well as long-term usage as a part of traditional medicine in numerous parts of the world. Although it has the disadvantage of being an invasive species, the plant has a wide spectrum of bioactive compounds, especially terpenoids, flavonoids, phenolic acids, glycosides, and essential oils, making it have a good pharmacological profile. The studies conducted in the last decades demonstrated strong evidence of its anti-inflammatory, antimicrobial, antioxidant, anticancer, wound-healing, analgesic, hepatoprotective, and metabolic regulation properties. Not only do these results confirm most of its traditional uses, but also effectively point to its potential in the future as a source of promising therapeutic agents. Nevertheless, the existing amount of literature also indicates that it has a number of limitations that narrow its clinical applicability. The heterogeneity of phytochemical constituents, no standardized extraction methods, inadequate toxicity profile and absence of clinical trials in humans are significant obstacles in incorporating phytochemicals into evidence-based medicine. Besides, the issue underlying the necessity of a closer assessment of safety levels and proper dosing principles is the concerns related to the lantadene-induced hepatotoxicity.

The way forward is hence a concerted effort to rigorously standardize phytochemicals, conduct extensive toxicity studies and extensive fundamental mechanistic investigations to gain a clearer insight on the mechanism behind its therapeutic effects. The growth of the analytical technologies and the development of modern drug delivery systems can become the beginning of the development of more stable, bioavailable and targeted formulations. Finally, at the end, well-constructed clinical trials will be necessary to confirm laboratory results and convert them into effective and safe therapeutic use. Conclusively, although *Lantana camara* is a relatively unexploited but richly promising medicinal source, a multidisciplinary and systematic study is very essential in helping to realize its maximum medicinal potential. This ubiquitous plant can be helpful in creating new therapeutic solutions based on the development of affordable and nature-based approaches to treatment with the help of specific scientific work.

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