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ANTHELMINTIC POTENTIAL OF LANTANA CAMARA LINN LEAVES

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Abstract:

Helminth infections remain a major health concern, particularly in tropical and subtropical regions, affecting both humans and livestock. The increasing resistance to conventional anthelmintic drugs and their associated side effects have propelled the exploration of plant-based alternatives. *Lantana camara* Linn, a widely distributed ornamental shrub belonging to the Verbenaceae family, has gained significant attention in ethnopharmacology due to its diverse medicinal properties. Among its various applications, the anthelmintic potential of its leaves has been increasingly studied in recent years.

This review aims to provide an in-depth analysis of the anthelmintic activity of *Lantana camara* leaves, focusing on its phytochemical constituents, mechanisms of action, and experimental models used to evaluate efficacy. The leaves are known to contain bioactive compounds such as flavonoids, alkaloids, saponins, tannins, and essential oils—each of which may contribute to helminthicidal activity through mechanisms like neuromuscular blockade, inhibition of energy metabolism, and damage to the parasite's cuticle.

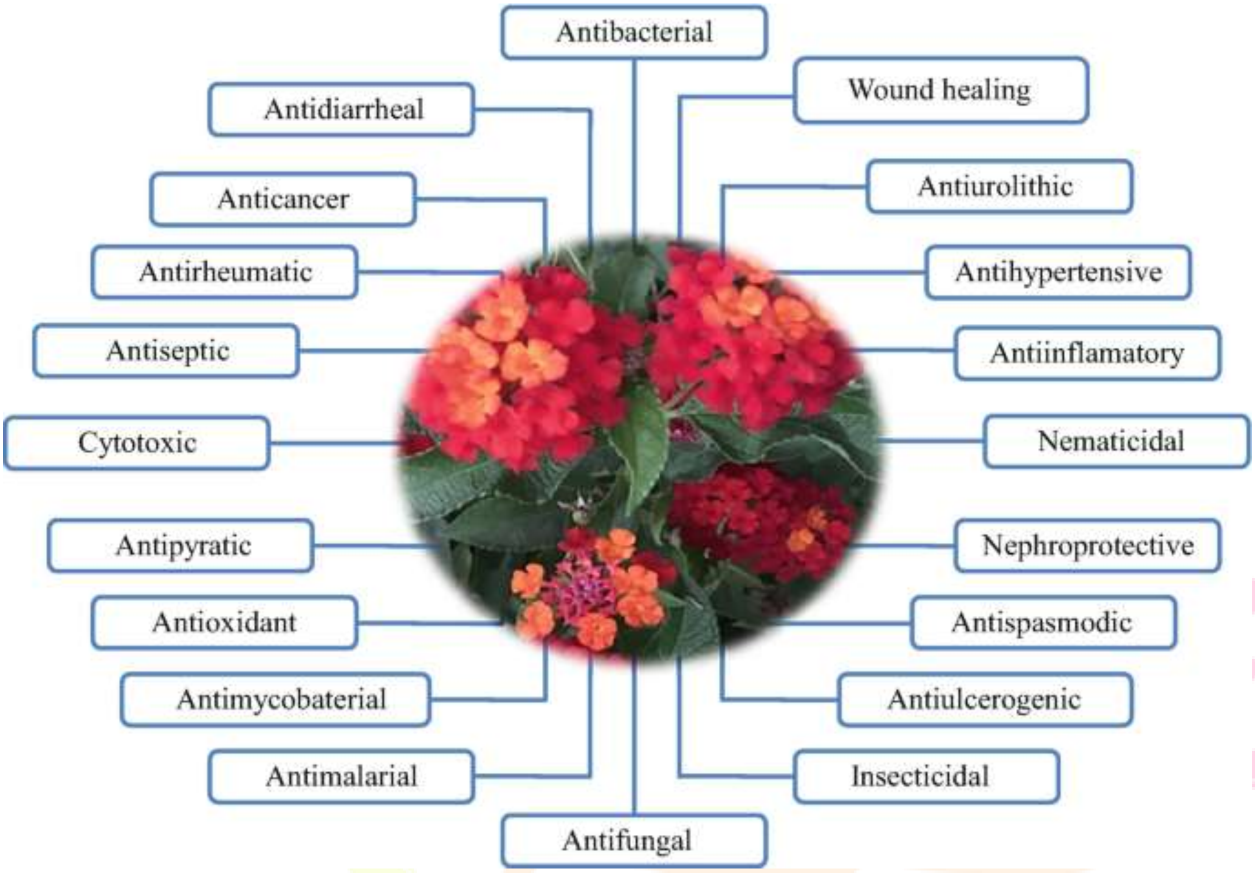
In vitro and in vivo studies conducted using earthworm (*Pheretimaposthuma*) and roundworm (*Ascaridia galli*) models have shown significant paralytic and lethal effects of *Lantana camara* leaf extracts, often in a dose-dependent manner. Methanolic and ethanolic extracts have demonstrated higher potency compared to aqueous preparations, likely due to better solubility of active constituents. Comparative studies with standard anthelmintics like albendazole and piperazine citrate have revealed promising activity of *Lantana camara* extracts, suggesting its potential as a complementary or alternative treatment.

Furthermore, the review discusses the need for standardized extract preparation, toxicity profiling, and clinical trials to confirm safety and efficacy. With the growing threat of drug resistance and the need for eco-friendly, low-cost therapeutics, *Lantana camara* emerges as a promising candidate for developing novel anthelmintic agents.

Keywords:

Lantana camara, anthelmintic activity, medicinal plants, phytochemicals, helminthiasis, ethnomedicine, herbal therapy, parasitic worms, plant-based anthelmintics, pharmacological review

Introduction



Helminth infections, also known as worm infestations, are a major health problem in many parts of the world, especially in areas with poor hygiene and sanitation. These infections are caused by parasitic worms such as roundworms, tapeworms, and flukes. They can lead to serious health issues like malnutrition, weakness, anemia, poor growth in children, and in severe cases, even death. Animals, especially livestock, are also affected, which causes economic losses in the agriculture and dairy industries.

To treat these infections, synthetic anthelmintic drugs like albendazole and mebendazole are commonly used. However, over time, many parasites have become resistant to these drugs. In addition, the repeated use of synthetic medicines can lead to side effects, and in rural or underdeveloped areas, access to modern medicines can be limited or expensive. Because of these problems, scientists are now looking for natural and safer alternatives—especially from plants.

Medicinal plants have been used in traditional medicine for thousands of years. Many cultures have used plant leaves, roots, seeds, and extracts to treat various diseases, including worm infections. One such plant is *Lantana camara* Linn, a common flowering shrub found in tropical and subtropical regions. Though it is often considered a weed, it is well known in traditional medicine for its healing properties. The leaves of *Lantana camara* have been used by tribal and rural communities to treat skin infections, respiratory problems, wounds, and intestinal worms.

Studies have shown that the leaves of *Lantana camara* contain many active compounds like flavonoids, tannins, alkaloids, and essential oils, which may help kill or paralyze parasitic worms. Researchers have tested these extracts in laboratory animals and found promising results, especially against earthworms and other common helminths.

2. Botanical Description of *Lantana camara*

2.1 Taxonomy and Classification

Lantana camara Linn is a flowering plant belonging to the **Verbenaceae** family. It is widely recognized for its colorful flowers and strong aromatic properties. Botanically, it is classified as follows:

- **Kingdom:** Plantae
- **Clade:** Angiosperms
- **Clade:** Eudicots
- **Clade:**Asterids
- **Order:**Lamiales
- **Family:** Verbenaceae
- **Genus:***Lantana*
- **Species:***Lantana camara* Linn

This plant is often referred to by other common names depending on the region, such as **wild sage**, **red sage**, **tickberry**, and **lantana weed**. Due to its invasive nature, it is often classified as a weed in agricultural regions, but it has important traditional medicinal uses in many cultures.

2.2 Morphology of the Plant

Lantana camara is a **rough-textured, multi-branched shrub** that typically grows to a height of 1–2.5 meters, but under favorable conditions, it can reach up to 4 meters. The plant has the following features:

- **Leaves:** Opposite, simple, ovate leaves with a rough surface and serrated (toothed) edges. They emit a strong aroma when crushed due to the presence of volatile oils. Leaf size ranges from 2 to 10 cm in length.
- **Stems:** Square-shaped and woody with age. Young stems are green and hairy, while mature stems become hard and woody.
- **Flowers:** Small, tubular flowers that bloom in dense clusters known as umbels. Flower colors range from yellow, orange, red, pink, purple, and white. The flowers often change color as they age, a trait that attracts pollinators like butterflies and bees.
- **Fruits:** Small, green berries that turn deep purple or black when ripe. The fruit contains seeds that are easily dispersed by birds and animals.

This hardy shrub grows rapidly and can adapt to a wide range of soil and environmental conditions, which contributes to its invasive behavior in many countries.

2.3 Geographic Distribution

Lantana camara is **native to Central and South America**, but it has now spread globally due to its ornamental value and adaptability. It thrives in:

- **Tropical and subtropical climates**
- **Dry and moist forest regions**

- **Grasslands and agricultural lands**
- **Roadsides and waste lands**

It is commonly found in **India, Africa, Southeast Asia, Australia, and Pacific islands**, where it grows wild and often dominates native plant species. In India, it is widespread in rural and forest regions and is considered both a weed and a medicinal resource.

2.4 Traditional Uses in Folk Medicine

Despite being labeled invasive in some areas, *Lantana camara* holds **important value in traditional and folk medicine**. For generations, rural communities and tribal populations have used different parts of the plant to treat a wide variety of ailments. Traditional uses include:

- **Leaves:** Used to treat wounds, skin infections, leprosy, and intestinal worms. Decoctions and pastes made from leaves are applied externally or taken orally.
- **Flowers:** Used to relieve fevers and as a remedy for cold and cough.
- **Roots:** Used in traditional medicine as a tonic, and for treating malaria and rheumatism.
- **Fruits:** Occasionally used for herbal remedies, although some parts are considered toxic if consumed in large quantities.

The **leaf extract**, in particular, has shown promising **anthelmintic, antibacterial, anti-inflammatory, and wound-healing** properties in traditional and scientific studies. This makes *Lantana camara* a plant of interest for developing herbal formulations, especially in areas where access to modern healthcare is limited.

3. Phytochemical Constituents of *Lantana camara* Leaves

3.1 Active Compounds Found in *Lantana camara* Leaves

Lantana camara leaves are rich in a wide range of **bioactive phytochemicals**. These naturally occurring compounds are responsible for the plant's pharmacological activities, including its **anthelmintic, antimicrobial, antioxidant, anti-inflammatory, and wound healing** effects.

The major classes of phytochemicals identified in *Lantana camara* leaves include:

- **Flavonoids:** These are polyphenolic compounds known for their **antioxidant** and **anti-inflammatory** properties. In the context of anthelmintic activity, flavonoids may interfere with energy metabolism or act as enzyme inhibitors in helminths.
- **Alkaloids:** These nitrogen-containing compounds are often toxic to parasites. Alkaloids can **disrupt nerve transmission** in helminths, leading to paralysis or death.
- **Tannins:** Tannins are astringent polyphenols that can **bind to proteins in the parasite's cuticle** and digestive tract, causing damage or reducing nutrient absorption.
- **Saponins:** These compounds form soap-like foams and have **membrane-disrupting** properties. Saponins may kill helminths by damaging their outer surface or interfering with their cell membranes.
- **Terpenoids and essential oils:** These are volatile compounds that may exhibit **neurotoxic** or **cytotoxic effects** on worms.

- **Phenolic compounds:** Known for their **free radical scavenging activity**, these compounds may contribute to the plant's overall anti-infective potential.

The combination of these compounds in *Lantana camara* makes the plant a powerful candidate for pharmacological applications.

3.2 Methods of Extraction and Phytochemical Screening

To study the bioactive components of *Lantana camara* leaves, researchers use various **extraction techniques**. The method of extraction plays a crucial role in determining which compounds are isolated and their concentration.

Common extraction methods include:

- **Soxhlet extraction** using solvents like ethanol, methanol, chloroform, and petroleum ether.
- **Cold maceration** and **hot infusion**, particularly for aqueous or hydroalcoholic extracts.
- **Steam distillation** for isolating essential oils.

After extraction, **phytochemical screening** is done using standard qualitative tests such as:

- **Mayer's and Wagner's test** for alkaloids
- **Ferric chloride test** for phenolics and tannins
- **Shinoda test** for flavonoids
- **Foam test** for saponins
- **Salkowski's test** for terpenoids

More advanced techniques like **Thin Layer Chromatography (TLC)**, **High-Performance Liquid Chromatography (HPLC)**, and **Gas Chromatography–Mass Spectrometry (GC-MS)** are used to identify and quantify specific compounds.

3.3 Role of These Compounds in Pharmacological Activity

Each of the phytochemicals in *Lantana camara* contributes uniquely to its medicinal properties:

- **Alkaloids and terpenoids** are often responsible for **neurotoxic effects** on worms, leading to **paralysis and expulsion**.
- **Tannins** bind to proteins on the worm's surface and digestive tract, which can **disrupt normal function and lead to death**.
- **Saponins** disrupt **cell membranes**, causing leakage of cellular content and worm lysis.
- **Flavonoids and phenols** provide **antioxidant support**, protecting host tissues and possibly weakening the parasite's defense systems.

The **synergistic action** of these compounds may enhance the overall anthelmintic efficacy of *Lantana camara* leaf extracts. Importantly, the effectiveness depends on the **concentration, type of extract**, and the **species of helminth** being targeted.

4. Overview of Anthelmintic Activity

4.1 Definition and Types of Anthelmintic Effects

Anthelmintic activity refers to the ability of a substance to kill or expel parasitic worms (helminths) from the body of humans or animals. These parasites can reside in the intestines or other parts of the body, leading to diseases such as **ascariasis, hookworm infection, schistosomiasis, and tapeworm infestations**.

Anthelmintic effects are generally classified into two major types based on how the parasite is affected:

1. Vermifuge (Paralytic) Effect:

- These agents **paralyze the worm** without killing it.
- The paralyzed worms are then expelled from the body through normal bowel movements.
- Example: **Piperazine citrate** causes flaccid paralysis of nematodes like *Ascaris*.

2. Vermicidal (Lethal) Effect:

- These agents **kill the worm directly** by disrupting vital systems.
- The dead worms may be digested or excreted.
- Example: **Albendazole** and **mebendazole** inhibit glucose uptake in worms, leading to energy depletion and death.

4.2 General Mechanisms of Action in Plant-Based Anthelmintics

Plants with anthelmintic properties work through a variety of **mechanisms**, depending on the phytochemicals present. These mechanisms can act alone or in combination to produce the desired effects:

Neuromuscular Disruption:

- Compounds like **alkaloids** and **terpenoids** may interfere with neurotransmitters in the worm's nervous system.
- This leads to **paralysis**, making it easier for the host to eliminate the worm.

Energy Metabolism Inhibition:

- Some plant compounds block glucose absorption or damage mitochondria in worms.
- Without energy, the worm becomes weak and eventually **dies from starvation**.

Disruption of Cell Membranes:

- **Saponins** and **essential oils** may disrupt the **integrity of the parasite's outer membrane**, causing **leakage of cellular content** and leading to death.

Cuticle Damage:

- **Tannins** can bind to the structural proteins on the worm's surface (cuticle), **damaging the protective layer**.
- This weakens the parasite and increases its vulnerability to the host's immune system.

Enzyme Inhibition:

- Flavonoids and other polyphenols may **inhibit vital enzymes** needed for the worm's survival, reproduction, or digestion.

Oxidative Stress:

- Antioxidants from plant extracts may induce **oxidative damage** in worm cells by producing free radicals, contributing to cell death.

In the case of *Lantana camara*, its rich phytochemical profile (including flavonoids, tannins, alkaloids, and saponins) suggests that it may work through multiple mechanisms at once, making it more effective against a range of parasitic worms.

5. Experimental Studies on *Lantana camara*

5.1 In Vitro Studies (e.g., using *Pheretimaposthuma*)

In vitro studies are conducted outside the body, typically in laboratory setups using test organisms such as earthworms (*Pheretimaposthuma*), which serve as a good model for studying anthelmintic activity due to their physiological similarities to intestinal worms.

Several studies have shown that **ethanolic, methanolic, and aqueous extracts** of *Lantana camara* leaves exhibit strong **anthelmintic activity** against *Pheretimaposthuma*. In these studies:

- The worms were exposed to various concentrations of the plant extract (e.g., 10, 25, 50, and 100 mg/mL).
- Researchers measured the **time taken for paralysis** (no movement even when shaken) and **time taken for death** (no response to external stimuli).

Findings from these experiments showed that:

- Higher concentrations of the extract resulted in **faster paralysis and death** of the worms.
- The ethanolic extract was often more effective than aqueous extract, likely due to better extraction of active compounds like alkaloids, flavonoids, and saponins.

These results suggest that *Lantana camara* leaf extract has a dose-dependent anthelmintic effect in vitro.

5.2 In Vivo Studies (e.g., in Animal Models like Mice or Goats)

In vivo studies involve testing in living animals, such as mice, rats, or livestock, to understand how the extract behaves inside a living system.

In studies involving infected mice or goats:

- Animals were orally administered with *Lantana camara* leaf extract at different doses (e.g., 100, 200, and 400 mg/kg body weight).
- Observations included **worm count in feces**, **weight gain**, **appetite**, **signs of infection**, and **histological analysis of intestines** after sacrifice.

Results showed:

- Significant **reduction in worm burden** in extract-treated animals compared to control.
- Improvement in general health and reduction in symptoms like diarrhea and weakness.
- The highest dose (400 mg/kg) often showed **comparable results to standard drugs** like albendazole.

These results confirmed the **therapeutic potential** of *Lantana camara* in treating helminth infections in animals.

5.3 Comparison with Standard Drugs

Standard anthelmintic drugs like **albendazole** and **piperazine citrate** are used as positive controls in both in vitro and in vivo experiments.

- In most studies, **albendazole (10 mg/mL)** caused paralysis and death of *Pheretimaposthuma* faster than lower concentrations of *Lantana camara* extract.
- However, **higher doses of the extract (50–100 mg/mL)** showed **comparable activity** to albendazole and piperazine citrate.
- This suggests that the extract may be nearly as effective as synthetic drugs at higher doses, with the added benefit of being plant-based and possibly safer.

5.4 Dose-Dependent Response and Efficacy

Almost all studies show a clear **dose-dependent response**—meaning, the **higher the concentration or dose of *Lantana camara* extract**, the **stronger and quicker its anthelmintic action**.

- Lower doses may cause paralysis without death.
- Moderate to high doses cause **rapid paralysis followed by worm death**.
- The **efficacy improves with solvent choice** (ethanol and methanol extracts being more potent than water extracts).

This indicates that both the **type of extract** and the **dosage** play a vital role in achieving effective results.

6. Proposed Mechanism of Action

The **anthelmintic effect** of *Lantana camara* leaf extracts is attributed to its **diverse phytochemical composition**, including flavonoids, alkaloids, tannins, saponins, and terpenoids. These bioactive compounds may act individually or synergistically to weaken, paralyze, or kill parasitic worms (helminths). While the exact mechanism is still under research, studies suggest multiple potential modes of action.

6.1 Neuromuscular Disruption

Many plant-derived compounds interfere with the **nervous system of helminths**, causing paralysis. This results in the **inability of the worms to maintain their grip** on the intestinal walls, leading to their expulsion.

- **Alkaloids** and **terpenoids** may **interfere with neurotransmitter activity**, such as acetylcholine, which controls muscle contraction in worms.
- This results in **flaccid or spastic paralysis**, after which the host can easily eliminate the worms through the digestive system.
- This mechanism is similar to how synthetic drugs like **piperazine** work.

6.2 Inhibition of Energy Metabolism

Worms rely on **glucose metabolism** for survival. If this pathway is blocked, the parasite becomes weak and eventually dies from energy deficiency.

- **Flavonoids** and **phenolic compounds** in *Lantana camara* may **inhibit key enzymes** involved in ATP production or glucose utilization.
- By disrupting mitochondrial activity, these compounds **reduce energy synthesis**, causing **gradual death** of the parasite.

This is a mechanism shared by drugs like **albendazole**, which inhibits glucose uptake in helminths.

6.3 Cuticle Disruption and Membrane Damage

The **cuticle** (outer covering) of helminths protects them from digestive enzymes and immune responses. Several phytochemicals can damage this protective barrier.

- **Tannins** bind to **cuticular proteins**, causing **shrinkage, wrinkling, or rupture** of the cuticle.
- **Saponins**, due to their surfactant-like nature, **interact with the lipid membranes**, causing **leakage of cellular contents**, leading to **cell lysis** and death.
- This physical damage exposes the parasite to the host's immune system and digestive enzymes, accelerating its elimination.

6.4 Oxidative Stress Induction

Some phytochemicals may cause **oxidative damage** within the worm's body.

- **Phenolic compounds** and **flavonoids** can generate **reactive oxygen species (ROS)** inside parasite cells.
- These ROS can damage vital cellular components such as **proteins, lipids, and DNA**, ultimately leading to **cell death**.

6.5 Synergistic and Multifactorial Effects

It is likely that the **combined action** of various phytochemicals in *Lantana camara* is more effective than individual compounds. This **synergistic effect** may increase efficacy and reduce the chances of resistance, which is an increasing concern in conventional anthelmintic therapy.

Summary of Targets:

Target	**Effect of Phytochemicals**
Neuromuscular system	Paralysis (alkaloids, terpenoids)
Energy metabolism	Starvation and death (flavonoids, phenolics)
Cuticle and membranes	Physical damage and leakage (tannins, saponins)
Intracellular components	Oxidative stress and cell damage (flavonoids, ROS)

7. Toxicity and Safety Profile

7.1 Acute and Chronic Toxicity Studies

While *Lantana camara* has shown promising **anthelmintic properties**, its **toxicity and safety** need careful evaluation, especially when considering its potential use as a medicinal agent. Some studies on toxicity have reported mixed results:

- **Acute toxicity studies** in rats and mice generally involve administering high doses of the plant extract (e.g., 500–2000 mg/kg body weight). These studies examine signs of toxicity, such as changes in **behavior, body weight, and internal organ damage**.
    - In some studies, doses up to 1000 mg/kg showed no **acute toxicity** (no severe signs of poisoning or organ failure).
    - However, at higher doses, symptoms like **lethargy, diarrhea, and vomiting** may occur, suggesting the plant could be **toxic at very high concentrations**.
- **Chronic toxicity studies** are often longer-term and assess **repeated exposure** to lower doses. Some animal studies have suggested that long-term exposure could potentially lead to **liver and kidney damage**, but these results are still inconclusive.

Despite this, no **major acute toxicity** has been observed at moderate doses, which indicates that *Lantana camara* can be relatively safe when used in appropriate amounts. However, more detailed **long-term toxicity studies** are needed.

7.2 Effects on Non-Target Organisms

As with many plant-based compounds, there is a risk that *Lantana camara* extracts could have unintended effects on **non-target organisms**. For example, while it is effective against helminths, there is concern about its **toxicity to beneficial soil organisms, insects**, and **wildlife**.

- Some studies have indicated that **saponins** and **flavonoids** may affect non-target species, particularly those with more sensitive **digestive systems**.
- However, data on the environmental impact of *Lantana camara* is limited, and it remains important to study its potential **ecotoxicity** before using it widely.

7.3 Traditional Knowledge on Safe Use

In traditional medicine, *Lantana camara* is used with great care, as local communities often know the **right dosages** and **preparations** based on centuries of experience. Some traditional uses include:

- **Topical application** of leaves for skin wounds and infections, with little reported adverse effects.
- **Aqueous decoctions** for internal use, with **low-to-moderate doses** believed to be safe.

Despite this, **safety margins** for long-term or high-dose use are not well established in the scientific literature, highlighting the importance of combining **traditional knowledge with scientific research**.

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8. Challenges and Limitations

8.1 Lack of Standardization in Extracts

One of the key challenges in researching and utilizing *Lantana camara* is the **lack of standardization** in its extracts. Different preparation methods, **solvent types**, and **plant parts** used (leaves, flowers, stems) can result in **variation in potency** and effectiveness.

- There is a need for consistent methods for **extract preparation** and **compound quantification** to ensure that the final product is reliable and effective.
- Without standardization, it is difficult to compare results across different studies and draw definitive conclusions.

8.2 Limited Clinical Data

While in vitro and animal studies suggest strong anthelmintic activity, **clinical data** (human trials) are scarce. Clinical studies would be crucial for:

- Understanding the **dosage forms** (e.g., capsule, powder, liquid) most suitable for humans.
- Evaluating the **long-term safety** and **efficacy** of *Lantana camara* in treating human helminth infections.
- Conducting **controlled trials** to confirm its effectiveness and any potential side effects in humans.

Without extensive clinical research, *Lantana camara* cannot be widely recommended for human use.

8.3 Need for Further Research and Trials

There is a significant **gap in research** regarding the **pharmacokinetics** (how the plant is absorbed, metabolized, and eliminated by the body) and **mechanism of action** in humans. More **controlled trials** in both animals and humans are needed to establish:

- Effective dosages and formulations.
- Safety profiles for long-term use.
- The precise **active compounds** responsible for anthelmintic activity.

9. Future Prospects

9.1 Potential for Herbal Formulation Development

Given its promising anthelmintic properties, *Lantana camara* has the potential to be developed into **herbal formulations** for the treatment of helminth infections, especially in regions where synthetic drugs are less accessible.

- **Powdered extracts, capsules, or syrups** made from *Lantana camara* could be used as **natural alternatives** or **complementary treatments** for helminthiasis.
- Formulations combining *Lantana camara* with other **herbal plants** could lead to **synergistic effects** that improve treatment outcomes.

9.2 Combination Therapy with Synthetic Drugs

Lantana camara could also be explored as part of **combination therapy** with conventional anthelmintic drugs like **albendazole** or **mebendazole**. This approach has the potential to:

- **Reduce drug resistance** by utilizing multiple mechanisms of action.
- **Enhance efficacy**, especially against resistant strains of worms.
- **Lower the required dosage** of synthetic drugs, reducing their side effects.

9.3 Scope in Veterinary Medicine

Beyond human medicine, *Lantana camara* shows great potential in **veterinary applications**, particularly in treating helminth infections in livestock (such as goats, sheep, and cattle). Its use could:

- **Reduce the reliance** on chemical dewormers in agriculture.
- Provide **a natural, cost-effective solution** for farmers, especially in developing countries.
- Help combat the growing problem of **anthelmintic resistance** in livestock.

These sections outline both the potential and challenges of using *Lantana camara* as an anthelmintic agent. The **future prospects** look promising, but more research is essential to translate these findings into practical applications.

Let me know if you'd like to add or expand on any of these points!

Here's a **detailed and concise conclusion** for your review paper:

10. Conclusion

10.1 Summary of Findings

Lantana camara has shown considerable potential as a **natural anthelmintic** agent, based on both **in vitro** and **in vivo studies**. The plant's leaf extracts, rich in phytochemicals such as **flavonoids, alkaloids, tannins, saponins, and terpenoids**, have demonstrated a significant ability to **paralyze, weaken, and kill parasitic worms**. The mechanisms of action are multifactorial, including effects on the **neuromuscular system**, **energy metabolism**, and **cuticle disruption** in helminths.

- **In vitro studies** with *Pheretimaposthuma* and **in vivo animal studies** (mice, goats) confirmed its dose-dependent anthelmintic activity.
- While the plant's extracts showed effectiveness comparable to **standard synthetic drugs** like albendazole and piperazine citrate, **clinical data** on human use remain limited.
- The plant also presents promising prospects for use in **veterinary medicine**, providing a natural alternative for livestock deworming.

10.2 Importance of Further Studies

Despite these promising findings, several important gaps remain:

- **Standardization of extracts** and methods is necessary to ensure consistency in the efficacy of *Lantana camara* preparations.

- **Clinical trials** involving human subjects are crucial to validate its safety, optimal dosage, and long-term use in treating helminth infections.
- Further research into the **mechanism of action** and **toxicity profiles** will be essential for determining its practical application.

10.3 Potential Role of *Lantana camara* in Future Anthelmintic Drug Development

The growing issue of **anthelmintic resistance** to conventional drugs emphasizes the need for alternative therapies. *Lantana camara* offers a **promising natural source** for the development of new anthelmintic treatments. The combination of its **anthelmintic efficacy**, **low toxicity at therapeutic doses**, and **availability** in many regions positions it as a valuable candidate for:

- The development of **herbal formulations** for both **human and veterinary medicine**.
- Potential **combination therapies** with synthetic drugs to **enhance efficacy** and **reduce resistance**.
- A **sustainable** and **cost-effective solution** for parasitic worm control, particularly in resource-limited areas.

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