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Exploring the scientific and technological potential of medicinal plants for anthelmintic therapiest

Explorando o potencial científico e tecnológico de plantas medicinais para terapias anti-helmínticas

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ABSTRACT

Parasitic infections are prevalent in tropical and underdeveloped regions, where poor sanitary conditions allow parasites to thrive. The common practice of administering anthelmintic drugs without prior diagnosis has led to increasing parasite resistance. An alternative approach involves the use of medicinal plants, traditionally employed in folk medicine for their anthelmintic properties. This article aims to explore the potential of medicinal plants for anthelmintic therapies, including an analysis of relevant scientific research and patents. Comprehensive searches were conducted in scientific databases (Science Direct, PubMed) and patent databases (WIPO, INPI, USPTO, EPO). A total of 32 scientific articles meeting our criteria were evaluated, focusing on plant species used, microorganisms tested, extraction methods, and outcomes. Results show that various plant parts are employed against parasites affecting both human and animal health, with many studies isolating bioactive compounds for testing. Additionally, 495 patents were reviewed, with 6 meeting the eligibility criteria—all filed by India. Despite the promising potential of medicinal plants in anthelmintic therapies, the number of patent filings remains low. However, scientific interest and advancements in the use of plant species for treating parasitic diseases are evident and show significant promise for future applications.

Keywords: Parasitic diseases. Treatment. Phytotherapy.

RESUMO

Infecções parasitárias são prevalentes em regiões tropicais e subdesenvolvidas, onde condições sanitárias precárias favorecem a proliferação de parasitas. A prática comum de administração de fármacos anti-helmínticos sem diagnóstico prévio tem contribuído para o aumento da resistência parasitária. Uma abordagem alternativa envolve o uso de plantas medicinais, tradicionalmente empregadas na medicina popular por suas propriedades anti-helmínticas. Este artigo tem como objetivo explorar o potencial das plantas medicinais em terapias anti-helmínticas, incluindo uma análise de pesquisas científicas e patentes relevantes. Foram realizadas buscas abrangentes em bases de dados científicas (Science Direct, PubMed) e de patentes (WIPO, INPI, USPTO, EPO). Um total de 32 artigos científicos que atenderam aos critérios de inclusão foi avaliado, com foco nas espécies vegetais utilizadas, nos microrganismos testados, nos métodos de extração e nos resultados obtidos. Os achados indicam que diversas partes de plantas são empregadas no combate a parasitas que afetam a saúde humana e animal, sendo que muitos estudos buscaram isolar compostos bioativos para testes específicos. Além disso, 495 patentes foram analisadas, das quais 6 atenderam aos critérios de elegibilidade—todas depositadas pela Índia. Apesar do potencial promissor das plantas medicinais em terapias anti-helmínticas, o número de depósitos de patentes permanece reduzido. Contudo, observa-se crescente interesse científico e avanços no uso de espécies vegetais para o tratamento de doenças parasitárias, evidenciando perspectivas significativas para aplicações futuras.

Palavras-chave: Doenças parasitárias. Tratamento. Fitoterapia.

1. INTRODUCTION

Helminthiases are prevalent in developing tropical regions, particularly in areas with precarious sanitation, affecting over one-third of the global population[1]. Transmission occurs via soil, with *Ascaris lumbricoides*, *Trichuris trichiura*, hookworms (*Ancylostoma duodenale*, *Necator americanus*), *Strongyloides stercoralis*, and *Enterobius vermicularis* being the most common[2]. These parasites infect the gastrointestinal tract through ingestion of eggs or larvae, with an estimated 300 million individuals severely affected—many of them schoolchildren[3]—who are also more susceptible to co-infections and higher mortality risk[4].

In high-prevalence regions, mass drug administration is recommended, mainly for school-age children[5], using albendazole or mebendazole without prior diagnosis[6]. However, frequent and improper use has promoted resistance and the selection of genes linked to autoimmunity, reinforcing the need to identify new anthelmintic substances[7,8]. Medicinal plants emerge as a viable alternative, given their traditional antiparasitic use and potential for isolating active compounds such as tannins, flavonoids, terpenes, and alkaloids[9]. Metabolites including cinnamic acid, carvacrol, thymol, and gallic acid have demonstrated proven anthelmintic activity[10]. Species such as *Punica granatum*, *Ginkgo biloba*, *Thymus vulgaris*, and *Carica papaya*—tested via extracts, essential oils, and latex—exhibited defined mechanisms of action[10]. Brazil's biodiversity offers a rich source for such studies, as many native species with traditional anthelmintic use are distributed across its six biomes[9]. Nevertheless, research remains limited, justifying this study's aim to survey scientific and technological developments on plant species with anthelmintic potential.

2. MATERIALS AND METHODS

This quantitative, descriptive study employed scientific and technological prospecting on medicinal plant-based anthelmintic therapies, following Silva et al.[11]. Literature searches in Science Direct and PubMed applied the PRISMA protocol[12], using the MeSH terms "Medicinal Plants" AND "Anthelmintics" in titles, abstracts, and keywords. Publications (2014–2024) in English were included; reviews, conference papers, theses, editorials, nonoriginal reports, and duplicates were excluded. Titles, abstracts, and full texts were screened for data extraction. Data were managed in StArt software (LaPES/UFSCar).

Patent searches were conducted in INPI, WIPO (Patentscope), EPO, and USPTO databases, using "Medicinal Plants" AND "Anthelmintics" (Portuguese for INPI, English for others). Inclusion criteria: classification under A61K, publication within the last 10 years, and relevance to anthelmintic activity against human parasites or experimental models. Screening involved titles, abstracts, and full-text eligibility confirmation. Extracted data included title, author, year, plant species, form tested, concentration, target parasite, and country of origin.

3. RESULTS

A review of the studies in Table 1 confirms the therapeutic potential of medicinal plants for helminth control. Various species and their phytochemicals have shown efficacy against *Haemonchus placei*, *Haemonchus contortus*, and *Gyrodactylus kobayashii*. Standardized extraction methods and diverse *in vitro* and *in vivo* assays enabled the identification of bioactive molecules with significant anthelmintic activity. Prominent results were observed for *Sarcocephalus latifolius*, *Kyllinga odorata*, *Chenopodium album*, and *Jasminum grandiflorum* L. subsp. *floribundum*, with compounds such as plumbagin, flavonoids, essential oils, and rutin emerging as promising candidates. These findings reinforce the value of ethnopharmacological approaches and the need for continued bioprospecting of botanical resources.

Table 1 - Exploring the Potential of Medicinal Plants: An Anti-helminthic Approach.

REF.	PART OF THE PLANT	OBJECTIVE	MICROORG.	METHOD	BIOLOGICAL TESTS	OUTCOME
13	*Lavandula angustifolia* e *Quercus infectoria* (essential oils)	Investigating anthelmintic activity against the parasite *Marshallagia marshalli*	Parasite *Marshallagia marshalli*	Egg hatching tests, inhibition of adult and larval motility, DNA damage, evaluation of oxidative/nitrosative stress biomarkers	Egg hatching tests, inhibition of adult and larval motility, assessment of DNA damage and oxidative/nitrosative stress biomarkers	Essential oils showed significant activity against the parasite, with effects on egg hatching, motility and DNA damage
14	*Sarcocephalus latifolius* (leaves)	Identify and characterize anthelmintic compounds.	*Haemonchus placei* (verme adulto)	Leaf extraction and chromatographic separations.	Anthelmintic activity and cytotoxicity against mammalian cells	Bioactive compounds with anthelmintic activity identified

15	*M. inermis* (Henna) (leaves)	Identify anthelmintic substances	*Haemonchus contortus*	Phytochemical screening, UPLC-QToF-ESI-MS analysis	In vitro tests on *H. contortus,* toxicity test on Artemia salina larvae	Extracts of the leaves showed anthelmintic activity in vitro, with no significant toxicity
16	*Morinda lucida Benth* (Rubiaceae)	Identify anthelmintic compounds	*H. contortus and C. elegans*	Extract fractionation, HPLC-HRMS/MS analysis, cytotoxicity test	Anthelmintic activity tests on young adults of C. elegans, cytotoxicity test on WI38 cells	Active fractions identified, potential compounds suggested, need for further studies to confirm
17	*Euphorbia forskalii* (whole plants)	Evaluate in vitro anthelmintic activity against eggs, infesting larvae (L3) and adult worms of *Haemonchus contortus*.	*Haemonchus contortus*	Preparation of aqueous extracts from dried and grounded plants.	Tests for adult worm mortality, inhibition of egg hatching, inhibition of larval migration	Extracts of *E. forskalii* showed anthelmintic activity in vitro against adult worms of *H. contortus,* and significant inhibition of egg hatching and larval migration
18	*Ceiba pentandra (stem bark)*	Evaluate anthelmintic activity against *Haemonchus contortus*	Eggs, infective larvae (L3) and adult worms of *Haemonchus contortus*	In vitro tests (egg hatching test, inhibition of larval migration, inhibition of adult worm motility)	In vitro tests for different stages of parasites	*Ceiba pentandra* stem bark showed anthelmintic activity against *Haemonchus contortus*
19	*P. umbellata* (root extracts) and compound 4-nerolidylcatechol (4-NC)	Investigate anti-schistosomal effects against *Schistosoma mansoni*	Adult worms of *Schistosoma mansoni*	*Ex vivo* and *in vivo* tests and biochemical analysis	Tests on *Schistosoma mansoni* adults, murine models of schistosomiasis	Extracts and 4-NC showed significant anti-schistosomal activity, need for further studies
20	*Rumex crispus L*. (leaves)	Evaluate anthelmintic potency and identify bioactive compounds	*Caenorhabditis elegans*	Testing of solvent extracts for up to 72 hours; chemical analysis of compounds	Lethality tests and microscopic analysis	Confirmed anthelmintic potential; presence of various bioactive compounds
21	*Blumea lacera* (aerial parts)	Evaluate medicinal properties, including analgesic, anti-inflammatory, antidiarrheal, diuretic activity and acute toxicity.	*Paramphistomum cervi*	Extraction with 96% ethanol, pharmacological tests in mice.	Analgesic, anti-inflammatory, antidiarrheal, diuretic, acute toxicity, antioxidant, phytochemical, anthelmintic, cytotoxic tests	*B. lacera* has shown potential for treating various diseases, but has also shown toxicity in tests, suggesting the need to purify bioactive compounds
22	*Piper aduncum* (ethanolic extract)	Evaluate monogenetic control in *Colossoma macropomum*	*Colossoma macropomum* monogenetics	In vitro and in vivo tests; determination of CL50-24h	Physiological tests on treated fish	Efficacy of up to 99.2%; identification of dilapiol as the active component

23	*Spondias mombin L.* (leaves)	Isolate and characterize anthelmintic compounds, establish bioactivity and safety profile.	*Fasciola hepatica*	Chromatographic fractionation, characterization by spectroscopy and LC-ESI-MS.	Screening assays in F. hepatica, cytotoxicity in MDBK cells	Compound MC010 showed moderate anthelmintic activity against adult Fasciola hepatica worms, but with moderate toxicity in MDBK cells
24	*Cassia sieberiana* (root bark)	Validate traditional application as a vermifuge, analyze metabolic composition.	*Haemonchus contortus*	Extraction with 70% ethanol, chemical analysis, larval migration inhibition tests.	Larval migration inhibition tests	The ethyl acetate extract proved to be the most active, with a possible synergy between flavonoids and proanthocyanidins
25	Plumbagina, Timoquinona, Osthole, Psoraleno	Investigating the anthelmintic efficacy of phytochemical compounds.	*Gyrodactylus kobayashii* (monogenetic parasite)	Exposure of fish to different compounds and in vitro and in vivo tests.	Efficacy of the compounds against the monogenean parasite	Plumbagin was the most effective compound against *G. kobayashii*
26	Thymoquinone (TQ) of *Nigella sativa* seeds	Investigate the anthelmintic effect of TQ on adult worms of *Gigantocotyle explanatum*	Gigantocotyle explanatum adult worms	Treatment with different concentrations of TQ; analysis of ultrastructure, motility, antioxidant/detoxifying enzymes and DNA profiles	Electron microscopy, enzyme activity tests, DNA analysis	TQ inhibited glutathione metabolism, imbalanced the redox system and inhibited enzymes, reflecting anthelmintic potential, but further studies are needed
27	*Jasminum grandiflorum L.* subsp. *Floribundum* (aerial parts)	Fractionation and identification of anthelmintic compounds.	Various microorganisms (larvae, adults and cysts)	Extraction of the aerial parts and testing for anthelmintic activity.	Evaluation of the compounds on different microorganisms.	Flavonoids and secoiridoid glycosides have shown anthelmintic activity.
28	*Spondias mombin L.* (Anacardiaceae)	Isolating and characterizing anthelmintic compounds	*Haemonchus placei*	Bioassay-guided chromatographic fractionation, spectroscopy, LC-ESI-MS analysis	Cytotoxicity screening in mammalian cells	Pheophorbide-a isolate showed anthelmintic activity and low toxicity to mammalian cells.
29	*Cinnamomum bejolghota* (leaves)	Investigate anthelminthic and antihypertensive activity in vitro	*Caenorhabditis elegans* (Adult nematodes)	Column chromatography, compound isolation	Activity tests against adult nematodes, egg hatching, larval development	Geranial compound showed the greatest activity against adult nematodes and egg hatching
30	*Bombax ceiba, Diospyros rhodocalyx, Vitex glabrata, Terminalia*	Examine the anthelmintic efficacy of crude plant extracts and rutin against	Gastrothylax crumenifer	Obtaining crude plant extracts, fractionation bioassay and	Tests of anthelmintic activity of	N-butanol extract of Terminalia catappa leaves and rutin

	catappa and Cassia alata	*Gastrothylax* crumenifer		identification of rutin	extracts and rutin	showed greater anthelmintic activity against Gastrothylax crumenifer
31	*Cuscuta reflexa* (extracts)	Evaluate anti-diarrheal activity in pigeons	Causes of diarrhea in pigeons	Intramuscular administration of extracts; induction of diarrhea in pigeons	Tests to assess frequency and onset of diarrhea	Significant anti-diarrheal activity observed
32	*Tetrapleura tetraptera (stem bark and fruits)*	Investigation of the antitrypanosomal activity and anthelmintic activity	Blood form of *Trypanosoma brucei brucei; earthworms Pheretima posthuma*	In vitro antitrypanosomal and anthelmintic tests	In vitro antitrypanosomal and anthelmintic tests	Extracts showed antitrypanosomal and anthelmintic activity
33	*Ptaeroxylon obliquum (leaves)*	Determine anthelmintic, antifungal and antimycobacterial activities	Eggs and larvae of *Haemonchus contortus*; fungal and bacterial microorganisms	In vitro tests for different activities and structural analysis	In vitro tests for different activities	Extract and obliquumol showed anthelmintic and antifungal activity
34	*Ziziphus mucronata (unspecified part)*	Provide an overview of pharmacological properties and biological activity	Various pathogens, including *Mycobacterium tuberculosis*, *Staphylococcus aureus*, etc.	Literature review	In vitro tests for various biological activities	*Ziziphus mucronata* has shown potential antimicrobial, antioxidant, anti-inflammatory and anthelmintic activity, among others.
35	*Acacia farnesiana (pods)*	Identify anthelmintic compounds against *H. contortus*	Eggs and larvae of *H. contortus*	Bioguided chemical fractionation of the pods; testing for anthelmintic activity	Tests on eggs and larvae and analysis of compounds	EtOAc-F fraction showed significant ovicidal and larvicidal activity
36	*Curcuma zedoaria*	To investigate anti-helminthic activities against Gyrodactylus kobayashii	*Gyrodactylus kobayashii*	Testing methanolic extracts and in vitro and in vivo studies	In vitro and in vivo tests; microscopic analysis	Extract and curdione compound showed anthelmintic activity
37	*Salvadora persica* L. (Root extracts)	Investigate the anthelmintic, anticoccidial and antioxidant activity of the extracts	*Allolobophora caliginosa (anti-helminthic and Eimeria papillata (anticoccidial)*	In vivo and in vitro tests of the extracts; biochemical analysis	Paralysis tests, oocyst count, biochemical analysis	Extracts have shown anthelmintic, anticoccidial and antioxidant activity, further studies needed
38	*Allium sativum (garlic)*	Determine in vivo efficacy in horses infected with strongyloides	Intestinal strongyles in horses	Field trial on mares and fecal egg reduction test	Fecal egg count reduction tests	Garlic has not shown significant efficacy
39	*Andrographis paniculata (leaves)*	Evaluate ovicidal and larvicidal effects against *Ancylostoma duodenale*	*Ancylostoma duodenale*	Tests of extracts against eggs and larvae and identification of diterpenoid compounds	Ovicidal and larvicidal activity tests	Extracts showed significant ovicidal and larvicidal activity
40	*Kniphofia foliosa Hochst.*	Describe activity against various microorganisms	*Plasmodium falciparum*, *C. elegans*, *A.*	Cytotoxicity and anti-parasitic activity tests	Cytotoxicity and anti-parasitic activity tests	Knipholone has shown activity against

			fischeri, *M. tuberculosis*, HIV-1			*Plasmodium falciparum*
41	*Baccharis conferta (aerial parts)*	Isolar ovicidal composts against Haemonchus contortus	*Haemonchus contortus* eggs	Extraction and fractionation; ovicidal activity tests	Ovicidal activity tests	Fractions and isolated compounds inhibited egg hatching

Source: Prepared by the authors.

From the technological innovation perspective, database searches retrieved 495 patents, of which 14 met the relevance criteria. After excluding patents without methodological clarity, outdated documents, and those for exclusively veterinary use, six remained (Table 2). All originated from India and were filed between 2010 and 2022, reflecting the country's significant helminthiasis burden—particularly *Ancylostoma duodenale*—and strategic investment in phytotherapeutic innovation. In the face of rising global drug resistance and the impact of helminthiases on child health and quality of life, these patents represent critical steps toward accessible and effective alternatives to conventional treatments.

Table 2 - Survey of patent information obtained from the different databases used in this study.

REF.	TITLE	FORMULATION	PARASITE	INNOVATION	COUNTRY
42	Plant protection preparation useful for the treatment of filaria, especially as a macrofilaricidal agent	Ethanolic and methanolic extracts of Calotropis sp. and isolated compounds were tested at concentrations of 125 µg/ml and 62.5 µg/m	*Brugia malayi*	At a concentration of 125 µg/ml, this ethanolic extract showed 100% microfilaricidal activity. At this concentration, the extract had an IC50 value of no more than 52.6 µg/ml. The selectivity index (SI) in relation to adult motility was not less than 64.8.	India
43	Microencapsulated herbal product with ovicidal and larvicidal properties against *Ancylostoma duodenale* (hookworm)	Microencapsulated Andrographis paniculata extract, concentrations tested against *Ancylostoma duodenale* were 0.25 to 5mg	*Ancylostoma duodenale*	The microencapsulated product was able to reduce the parasite count, with a rate of 100% at a concentration of 5 mg, a value similar to and even higher than the positive control.	India
44	A new formulation of Chenopodium album for antelmintic activity	*Chenopodium album* plant extracts prepared with petroleum ether, ethyl acetate, methanol, hydroalcoholic and aqueous solvents tested at concentrations of 2-10mg/ml	*Eisenia foetida* (experimental model)	All extracts lead to paralysis of Eisenia foetida except the hydroalcoholic extract, the ethyl acetate extract was effective at all concentrations tested.	India
45	A new formulation of *Operculina*	Extract of the roots/rhizomes of	*Eisenia foetida*	All extracts (except the aqueous extract) lead to	India

	turpethum for antelmintic activity	*Operculina turpethum* prepared with petroleum ether, ethyl acetate, methanol, hydroalcoholic and aqueous solvents	(experimental model)	paralysis and earthworm fatality. The OTPE extract exhibits potential anthelmintic activity at a dose of 10 mg/ml, causing paralysis and earthworm fatality and is more potent than the PCT suspension. At a dose of 10 mg/ml, the PT and DT times for OTPE were recorded as (9.38 ± 1.82) and (54.93 ± 1.78).	
46	*Cocos nucifera* (coconut) shell ash as an anthelmintic drug substance	*Cocos nucifera* ash was tested at concentrations of 2, 4, 8, 10 and 20 mg/ml	*Pheretima posthuma* and *Haemonchus contortus*	The ashes proved to be effective when comparing the time to death of the concentrations tested with that obtained with the standard, at the same concentration of 4mg/ml they showed a time to death of 20±0.38 and 17±0.36o for the control and test respectively.	India
47	Comparative in vitro anthelmintic activity of *Adhatoda vasica bark* and *Momordica charantia* against *Pheretima posthuma*	Ethanolic extract of the bark of *Adhatoda vasica* and *Momordica Charantia* against *Pheretima Posthuma* at concentrations of 10, 20, 25 and 50 mg/ml in the in vitro test and 100, 150 and 200mg/ml in the in vivo test.	*Pheretima Posthuma* (experimental model)	The death time of Pheretima Posthuma was evaluated, and the percentage of diarrhea inhibition was 55.27%, 66.33% and 63.81% at body doses of 100, 150 and 200mg/Kg, respectively.	India

Source: Prepared by the authors.

4. DISCUSSION

The analyzed results confirm that medicinal plants harbor diverse bioactive compounds with potential efficacy against multiple parasites. However, variability in effects, coupled with the need for further studies on safety and dosage, underscores the complexity of their therapeutic use. The following discussion addresses anthelmintic effects, extraction methods, and safety–efficacy evaluation.

4.1 Infectious and Parasitic Diseases

Infectious parasitic diseases (IPDs), caused by helminths with varied transmission cycles, present significant clinical and epidemiological complexity and affect populations in socially and environmentally vulnerable areas[48]. Although mortality from IPDs has declined in Brazil in recent decades, rates remain high compared to other countries[48]. These diseases affect both humans and animals; in humans, examples include malaria, Chagas disease, and ascariasis[48].

4.2 Medicinal Plants in the Treatment of Parasitic Diseases

Medicinal plants have been investigated for parasite control in human and veterinary contexts. They offer a wide range of chemical compounds that may provide therapeutic benefits but can also pose risks. Proper identification, conservation, preparation, and knowledge of adverse effects are essential[49]. Some species, such as *Chenopodium ambrosioides* and *Mentha suaveolens*, are effective against enteroparasitoses[50], while green tea and mint have shown activity against *Entamoeba histolytica* and *Giardia*, partly by altering intestinal pH and inhibiting parasite proliferation[51].

4.3 Bioactive Compounds in Medicinal Plants: Examples and Sources

The bioactive profile of medicinal plants varies with species, plant part, and dosage[52-53]. Multiple plant parts—leaves, roots, rhizomes, aerial structures, stem bark, and fruits—have been studied for anthelmintic activity[10,54-56]. Leaves, due to high metabolic activity and sunlight exposure, often accumulate secondary metabolites[54], while roots and rhizomes may contain compounds that protect against soil pathogens. Aerial parts also harbor diverse metabolites due to environmental exposure[10,54-56].

The choice of plant part is influenced by traditional medicinal practices[10,54]. Analysis of Table 1 shows leaves as the most investigated structures, with numerous studies confirming their efficacy against varied parasites[14,15,19,20,23,29,33,37,39]. Roots and rhizomes are also recurrently tested[24,57], as are aerial parts[27,41,58,59]. Less commonly, stem bark and fruits[32] have been evaluated, still contributing valuable insights into plant-based anthelmintic development.

4.4 Negative Effects of Parasitic Diseases in Animals

The diversity of plant parts studied for anthelmintic activity reflects variations in bioactive compounds and the influence of local medicinal traditions[54,55], reinforcing the need for a holistic approach in evaluating medicinal plants. Animal parasitic diseases impact the economy, society, and public health[60]. The reviewed studies address a wide spectrum of parasites—including helminths, protozoa, and others—affecting both humans and animals, with some species transmissible between them, such as *Ancylostoma duodenale*[63] Livestock parasites, including *Haemonchus contortus* in small ruminants[61] and

Paramphistomum cervi in cattle[62], cause direct economic losses, highlighting the urgency of developing new treatments.

4.5 Extraction Methods and Biological Tests

Most studies employed solvent-based extraction of bioactive compounds from different plant parts, using techniques such as ultrasound-assisted (UAE), microwave-assisted (MAE), pressurized liquid (PLE), and supercritical fluid extraction (SFE)[64]. Anthelmintic activity was assessed *in vitro* and *in vivo*[19,22,25,37,38,100] targeting survival, reproduction, and motility of parasites. Tests addressed different life stages—adult worms, larvae, and eggs—including adult worm motility inhibition[57], egg hatch inhibition[17], and larval assays[24,29]. Cytotoxicity evaluations on mammalian cells (e.g., mammary cells[14], WI38 cells[16]) ensured safety. Some studies also examined activity against non-helminth microorganisms such as bacteria and fungi[27].

4.6 Safety and Efficacy of Medicinal Plants

Safety assessments included cell viability tests, while efficacy trials covered diverse organisms, such as *Haemonchus placei*[14], *H. contortus* and *Trichostrongylus colubriformis*[58], *Eisenia foetida*[59], *Gyrodactylus kobayashii*[25], and *Marshallagia marshalli*[13]. Several plants and compounds showed strong anthelmintic potential: root extracts active against adult worms[57], ethyl acetate extracts with high efficacy[59], plumbagin[25], flavonoids and secoiridoid glycosides[27], and essential oils active against *M. marshalli*[13]. Others demonstrated limited or moderate efficacy, such as garlic, ineffective against equine strongyles[38], and MC010, moderately active against *Fasciola hepatica* but cytotoxic[23]. These findings underscore both the promise and limitations of plant-derived anthelmintics.

4.7 Technological Prospecting: Patent Analysis

India, with a high prevalence of helminth infections such as *Ancylostoma duodenale*, faces increasing drug resistance, prompting the search for novel therapeutic agents[65,66] Approximately 300 helminth species can infect humans, particularly affecting children's health and quality of life. The patents analyzed investigated species including *Andrographis paniculata*, *Chenopodium album*, *Calotropis* sp., *Cocos nucifera*, *Operculina turpethum*, *Adhatoda vasica*, and *Momordica charantia*. While mostly of Asian origin, *C. nucifera* and *M. charantia* are also found in Brazil. *M. charantia* shows antimicrobial and anthelmintic activity against *Fasciola hepatica* and *Strongyloides* spp.[67,68], while *A. paniculata*, rich in andrographolide, exhibits anti-inflammatory, antiviral, and antimalarial properties[69]. *C. album* demonstrated efficacy against *Haemonchus contortus*, with molecular docking identifying isolariciresinol 4′-O-β-D-glucoside as a promising compound[70]. *O. turpethum* roots contain lupel, betulin, β-sitosterol, and cycloartenol, all with antibacterial and antitumor activity[71,72]. Two patents tested activity against *A. duodenale* and *Brugia malayi*.

Other studies employed experimental models. Hookworm, prevalent in areas lacking basic sanitation, is a significant cause of mortality, transmitted via the fecal–oral route or contact with contaminated soil, and may be asymptomatic or cause anemia depending on parasite load[73,75]. *Brugia malayi* filariae, transmitted by insect bites, infect the human lymphatic system in their adult form, leading to elephantiasis—a condition with severe social stigma affecting mainly impoverished populations[75].

Mass drug administration remains a control strategy in high-incidence areas; however, it fosters resistance and is not fully effective[76]. Four patents tested experimental parasite models (*Eisenia foetida*, *Pheretima posthuma*, and *Haemonchus contortus*), chosen due to challenges in cultivating pathogenic helminths, whose complex life cycles require costly logistics[77]. Free-living, non-pathogenic helminths such as *E. foetida* and *P. posthuma* are commonly used because of their similarity to human intestinal parasites[59].

Extracts were the most common form tested (4 patents), followed by microencapsulation (1 patent) and ashes (1 patent). Concentrations ranged from 200 mg/mL (ethanolic extracts of *Adhatoda vasica* and *Momordica charantia*) to 62.5 µg/mL (ethanolic and metallic extracts of *Calotropis* sp. and isolated compounds). All patents showed potential, with notable results for microencapsulated *Andrographis paniculata*, which reduced *A. duodenale* load at 5 mg, and ethanolic *Calotropis* sp., achieving 100% microfilaricidal activity at 125 µg/mL. Patent filings spanned 2010–2022, peaking in 2020 with three registrations (Figure 1).

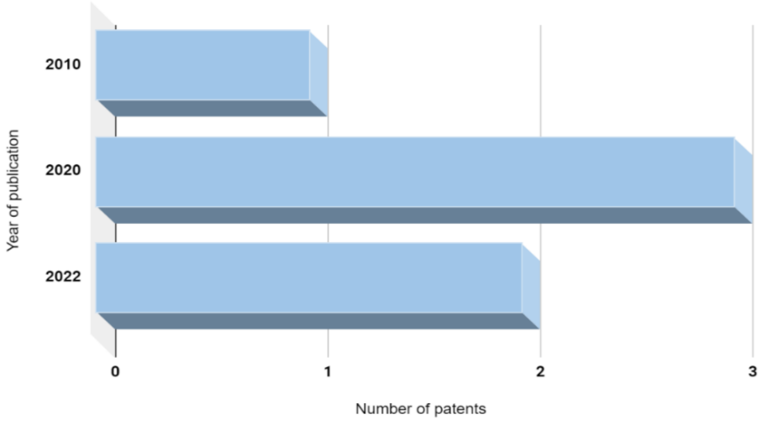

Figure 1 - Annual evolution of the number of patent registrations filed between 2010 and 2022.

The onset of the COVID-19 pandemic in 2020 stimulated global research and patenting activity, including innovations for emerging diseases[78]. India, home to major producers of Active Pharmaceutical Ingredients (APIs) and vaccines, experienced a surge in health-related patents[79]. The increase in patents for medicinal plant-based anthelmintic therapies in 2020 may reflect heightened global interest in natural medicines and alternative therapies during the pandemic, driven by greater health awareness[80]. Investments in research, institutional–corporate–government collaborations, and the country's rich plant diversity likely contributed to this growth[81,82].

Innovations in phytopharmaceuticals show notable advances over conventional treatments. An ethanolic extract exhibited microfilaricidal activity against *Brugia malayi* at low concentrations[42], while a microencapsulated product demonstrated ovicidal and larvicidal effects against *Ancylostoma duodenale*, matching or surpassing positive controlss[43]. Plant formulations of *Chenopodium album* and *Operculina turpethum* effectively paralyzed and killed worms[59]. Coconut shell ash proved active against *Pheretima posthuma* and *Haemonchus contortus*[46], and comparative assays of *Adhatoda vasica* and *Momordica charantia* yielded valuable insights for therapy development[47]. These alternatives offer potential improvements in efficacy, accessibility, and public health outcomes.

The number of scientific articles exceeded patents in this field, reflecting the natural progression from research to commercialization. Academic studies often precede patent filings, focusing on exploratory and pre-clinical evaluations of safety and efficacy. Patent registration, being complex, costly, and time-intensive, further explains the lower filing volume despite active research.

5. CONCLUSION

Research into the therapeutic potential of medicinal plants against helminths has made significant progress, highlighting compounds such as plumbagin, flavonoids and essential oils as promising anthelmintic agents. The analysis of plant parts reveals a diversity of bioactive compounds, emphasizing the importance of a holistic approach in herbal research. The studies address a wide range of parasites, highlighting the need for new therapies to combat these pathogens. In vitro and in vivo methods are used to assess the efficacy and safety of compounds, reflecting a commitment to evidence-based pharmaceutical research. The increase in the number of patent filings in India in 2020 highlights the growing global interest in anthelmintic therapies based on medicinal plants and the investments in research and development in this area. These innovations reveal significant advances in phytopharmaceutical therapies for the treatment of parasitic conditions, offering promising alternatives to conventional treatments and potentially benefiting public health on a global scale.

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