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REVIEW ARTICLE

A Review of Phytochemicals and Pharmacological Potential of Curry Leaf

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Abstract

Murraya koenigii (L.) Spreng., commonly known as curry leaf, is an aromatic shrub native to India and widely distributed throughout tropical and subtropical regions. The plant occupies an important place in traditional medicine systems such as Ayurveda and various folk medicines. The leaves, stem, bark, roots, fruits, and seeds have been traditionally employed to treat ailments such as dysentery, stomach disorders, renal pain, piles, inflammation, microbial infections, and morning sickness. This review synthesizes current knowledge on its pharmacognosy, phytochemistry, and pharmacological potential of curry leaf powder with different solvents and aqueous extract revealed rich profiles of carbazole alkaloids (e.g., koenigin, mahanimbine, murrayastine, and murrayanine), steroids, glycosides, tannins, saponins, phenols, flavonoids, quinones, terpenoids, amino acids, and proteins; alongside phenylpropanoids, alkanes, and sesquiterpenes contribute biochemical complexity. These compounds underpin a vast assortment of bioactivities such as antifungal, antidiabetic, antimicrobial, antioxidant, anticancer, anthelmintic, anti-inflammatory, antibacterial, antiulcer, hepatoprotective, wound healing, and neuroprotective effects; thereby *M. koenigii* (curry leaf) underscoring its potential as a promising source of functional and therapeutic agents; although several studies have reported the phytochemical composition and pharmacological properties of *M. koenigii*, these findings are often presented independently. This review aims to consolidate recent studies and integrate the relationship between major phytochemical classes and their corresponding pharmacological activities.

Key words: Carbazole alkaloids, curry leaves, phytochemistry

INTRODUCTION

India is often hailed as the "Botanical Garden of the World," which encompasses more than 50,000 plant species. Many of these plants are essential to traditional systems such as Ayurveda, Siddha, Unani, and local health practices, serving approximately 80% of the global population for primary healthcare.[1,2] Curry leaf is a fragrant evergreen shrub in the Rutaceae family – a diverse group that includes around 150 genera and 1600 species.[3] Regionally, it is known as Karuveppilai in Tamil, Mitha Neem or Kurry Patta in Hindi, Barsunga in Bengali, and Surabhinimba in Sanskrit, reflecting its cultural and ethnomedicinal importance.[2] Within the genus Murraya, *Murraya koenigii* is one of the two species predominantly distributed in India, alongside *M. paniculata* (L.). The leaves are extensively incorporated into Indian cuisine due to their characteristic aroma and flavor imparted by volatile compounds such as P-caryophyllene, O-phellandrene, P-gurjunene, and P-elemene. Compounds such as β-pinene, β-caryophyllene, β-phellandrene, and α-pinene contribute to antimicrobial and food preservative properties either individually or through synergistic interactions. Nutritionally, curry leaves are rich in vitamins A, B, C, E, iron, and folic acid; combat oxidative

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stress through antioxidants such as tocopherol, β-carotene and lutein supporting liver health, neuroprotection, and potential anti-cancer effects.[5] The plant's therapeutic power comes from bioactive secondary metabolites, including alkaloids (koenimbine, koenine, mahanimbine, and girinimbine), carbazoles (murrayacine, murrayazolidine, and murrayazoline), flavonoids, glycosides, and others such as mukoeic acid, bismahanine, murrayanine, and koenigine-quinones. In addition, essential oils extracted from plants offer skin moisturizing benefits, and its extracts neutralize reactive oxygen species, thereby enhancing its pharmaceutical relevance. Curry leaf is available in morphotypes such as dwarf and brown, which vary in aroma and growth. In traditional Indian medicine, *M. koenigii* described as a tonic and stomachic herb is commonly employed in treating ailments such as edema, bruises, inflammation, piles, diarrhea, and even for snake bites.[6-8] Various plant parts, including leaves, bark, roots, and seeds, contain abundant bioactive compounds that exhibit antioxidant, antimicrobial, and hepatoprotective properties. Due to its extensive culinary application and ethnopharmacological significance, scientific investigations on curry leaf have intensified in recent decades, particularly focusing on its phytochemical diversity and pharmacological potential. Current research on *M. koenigii* has generated substantial information regarding its phytochemical composition and pharmacological properties. However, the available evidence remains fragmented, with most studies focusing on individual phytochemicals or isolated pharmacological activities. In addition, methodological variations in extraction procedures, phytochemical profiling, and biological evaluation have contributed to inconsistencies in the reported findings, limiting direct comparison among studies. The state-wise area and production statistics of curry leaf cultivation during 2023–2025 are presented in Figure 1 source obtained from India Stat database (2025).

Traditional uses

Curry leaf, scientifically known as *M. koenigii,* traditionally serves as a fragrance enhancer in soaps, employing its dried leaf powder, fresh foliage, and essential oil. These essential oils are particularly popular in soaps and cosmetic industries, as well as in aromatherapy, and are often used to add flavor to soups, curries and other dishes.[9-11] Curry leaves are particularly advantageous for women experiencing osteoporosis, calcium deficiency and similar issues, as they serve as an excellent natural calcium supplement, boasting high nutritional content with significant levels of iron, calcium, and vitamins A, B, B2, and C.[12] The entire plant has been employed as an antidiarrheal, antidepressant, stimulant, hair tonic and for treating diabetes, kidney pain and vomiting, with its different parts offering unique benefits: the stem (datan for strengthening teeth and gums), bark (as a stomachic, hair tonic, and carminative), leaves (anti-ulcer, analgesic, anti-anemic, purgative, flavoring and seasoning, and memory enhancement), and fruits (astringent) and roots (cooling agents, reducing inflammation, and itching and addressing blood disorders).[13] Conventionally, fresh curry foliage gets heated with coconut fat till it blackens, producing a superior scalp serum that diminishes premature graying and promotes hair growth. In historical practices, it has been used as diarrhea control, bloodstream purification, inflammatory suppression, and antidepressant.[14-16] Recent pharmacognostic and ethnopharmacological investigations have also validated several traditional medicinal uses of *M. koenigii*.[4,17]

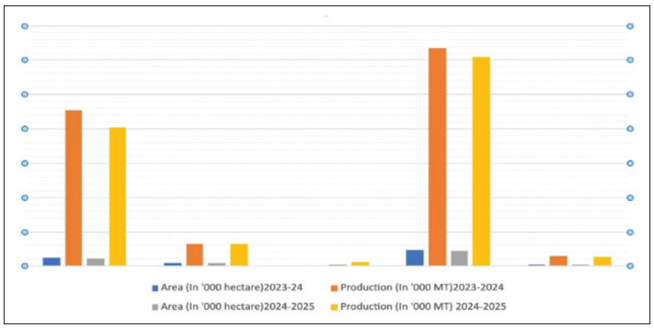


Figure 1: Graphical presentation of state-level data on curry leaf area and production (2023–2025)

PHYTOCHEMICAL

The mature curry leaves consist of 63.2% of moisture, 8.8% of protein, 39.4% of carbohydrates, 1.15% of nitrogen, 6.15% of fat, 18.92% of total sugars, 14.6% of starch, and 6.8% of crude fiber. Recent investigations have confirmed the presence of diverse secondary metabolites, particularly carbazole alkaloids, flavonoids, terpenoids, and phenolic compounds, which contribute significantly to the biological activities of *M. koenigii*.[18,19] Among these, carbazole alkaloids are the most extensively investigated due to their significant pharmacological potential. However, variations in phytochemical composition have been reported across studies due to differences in plant source, extraction methods, solvents, and analytical techniques. Furthermore, most studies emphasize qualitative identification, whereas comprehensive quantitative profiling and phytochemical-pharmacological correlations remain limited. Therefore, standardized extraction protocols and advanced analytical approaches are essential to improve the reproducibility and therapeutic interpretation of phytochemical findings. Nutritional and extractive composition is shown in Figure 2 as a heat map. The major phytochemical components reported in *M. koenigii* are outlined in Tables 1-3. Relationship between major phytochemical classes and pharmacological activities is shown in Table 4.

PHARMACOLOGICAL ACTIVITY

Several recent studies have summarized the broad spectrum of pharmacological activities exhibited by *M. koenigii*,

including antioxidant, antimicrobial, antidiabetic, anti-inflammatory and hepatoprotective effects.[4,20] The diverse pharmacological activities reported for *M. koenigii,* including antioxidant, antibacterial, antifungal, antidiabetic, anthelmintic, anti-inflammatory, and hepatoprotective effects, are summarized in Figure 3.

Antifungal activity

Mahanimbine, murrayanine, and girinimbine obtained from stem bark showed anti-fungal activity toward human pathogenic fungi.[53] *M. koenigii* (curry leaves) exhibits strong antifungal activity, mainly from its essential oils and phytochemicals such as terpenoids, alkaloids, flavonoids, tannins, saponins, and phenolics. Leaf extracts – alcoholic, methanolic and ethanolic prove effective *in vitro*, supporting traditional folk medicine uses for treating diarrhea, dysentery, and skin eruptions.[54] These compounds inhibit mycelial growth and target fungi such *Candida tropicalis*, *Aspergillus niger*, *Candida albicans*, *Microsporum gypseum*, *Aspergillus fumigatus*, *Rhizoctonia solani*, *Colletotrichum falcatum,* and *Fusarium oxysporum*.[55,56] Quantitative analyses from multiple studies revealed inhibition zones ranging from 12 to 28 mm depending on extract concentration and fungal strain susceptibility. Acetone extract from fresh leaves of *M. koenigii* yields three key carbazole alkaloids – murrayanol, mahanine, and mahanimbine – which deliver strong antifungal effect exceeding 70% under *in vitro* conditions along with antimicrobial, topoisomerase □ and □ inhibition, and mosquito-killing activity.[1] Meta-synthesis of available reports suggested that ethanolic and methanolic extracts consistently exhibited stronger antifungal activity than aqueous extracts, likely due to improved extraction efficiency of terpenoids and carbazole alkaloids.

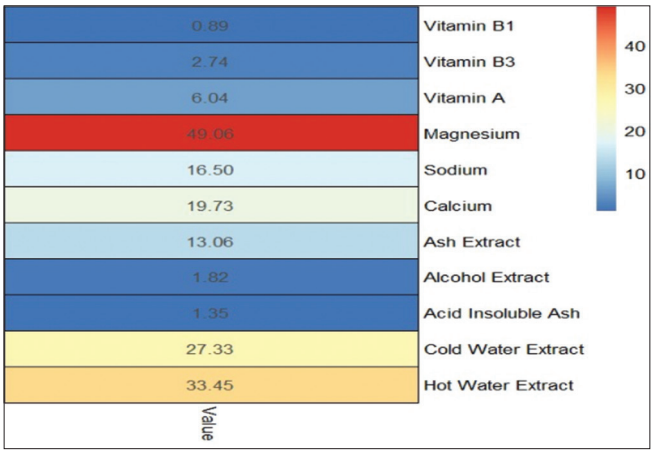


Figure 2: Heat map of nutritional and extractive composition

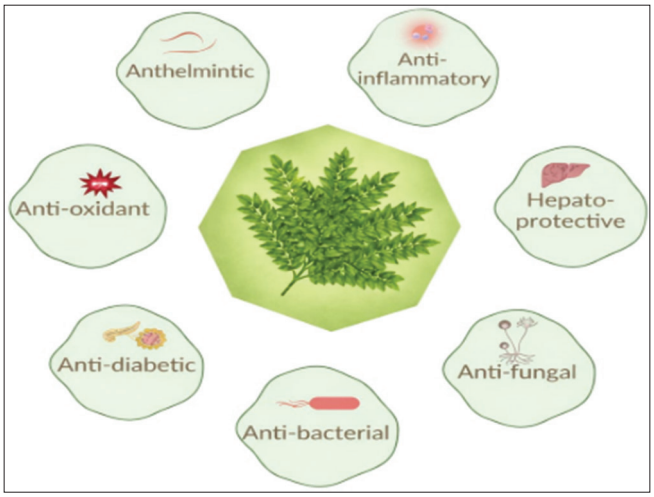


Figure 3: Pharmacological activity of curry leaves

Antibacterial activity

Antibiotic resistance has driven the evaluation of plant-driven antimicrobial agents. The leaf extract has a wide range of antibacterial activity in both Gram-positive and Gram-negative bacteria such *Escherichia coli*, *Staphylococcus aureus*, *Streptococcus* spp., *Proteus* spp., and *Klebsiella pneumoniae*. The antibacterial activity of acetone, methanol, and ethanol extracts is mainly due to the presence of carbazole alkaloids such as mahanine, mahanimbine, and murrayanol. The synthesized results obtained quantitative data showed that the inhibition zones were 10–25 mm when the extract concentration was 50–500 µg/mL.[57,58] Methanol and ethanol leaf extracts exhibit strong activity, while isolated pyranocarbazoles further enhance their efficacy. These natural compounds offer a safer way to fight infections, perfect for adding to everyday meals as a preventive remedy.[59]

Rising antibiotic resistance has sparked interest in natural alternatives like curry leaves (*M. koenigii*), which offer potent antibacterial effects with minimal side effects.[60] Isolated pyranocarbazoles exhibited enhanced antibacterial activity, particularly against *K. pneumoniae* and *S. aureus*.[15] Green synthesized silver nanoparticles (AgNPs) from *M. koenigii* were found to be active against multidrug resistant (MDR) bacterial strains.[61] Furthermore, the essential oil was able to reduce the biofilm formation by about 80% in *Pseudomonas aeruginosa*, which is attributed to the components cinnamaldehyde, linalool, and spathulenol.[62] Similarly, ethanol leaf extracts were also found to be antimycobacterial against *Mycobacterium smegmatis* (IC_{50} 400 µg/mL) and synergistic against *Mycobacterium bovis* Bacillus Calmette-Guérin and *M. smegmatis* in combination with rifampicin.[63,64] Comparative studies also showed ethanol extracts exhibit similar antibacterial activity to amikacin and gentamicin against *S. aureus*, *E. coli*, *Streptococcus* spp., and *Proteus* spp., but lesser activity against *K. pneumoniae* and *P. aeruginosa*.[65]

Overall, it is concluded that ethanol and methanol extracts consistently show higher antibacterial activity as compared to other solvent extracts and that carbazole alkaloids, essential oils and AgNPs synthesized by the plants contribute to improving the antibacterial activity against susceptible and MDR bacterial pathogens. The results suggest that

Table 1: Alkaloid compounds in curry leaf

Compound	Molecular formula	Plant part	References
Mahanine	$C_{23}H_{25}NO_2$	Leaves, stem bark and seeds	[13,21-24]
Mahanimbine	$C_{23}H_{25}NO$	Leaves, roots, seeds and fruits	[13,23,24]
Murrayanol	$C_{25}H_{29}NO_2$	Leaves, roots and fruits	[13,23,24]
Murrayone (Coumarine)	$C_{15}H_{14}O_4$	Leaves	[21-24]
Murrayacinine	$C_{23}H_{23}NO_2$	Leaves, stems	[27,28]
Murrayanine	$C_{14}H_{11}NO_2$	Stem bark	[13,25]
Murrayamine B	$C_{24}H_{27}NO_2$	Leaves and stems	[29]
Murrayamine E	$C_{23}H_{25}NO_2$	Leaves and stems	[29]
Murrayakonine A	$C_{37}H_{36}N_2O_2$	Leaves and stems	[14]
Murrayakonine B	$C_{23}H_{23}NO_2$	Leaves and stems	[14]
Murrayakonine C	$C_{24}H_{25}NO_3$	Leaves and stems	[14]
Murrayakonine D	$C_{23}H_{25}NO_2$	Leaves and stems	[14]
Mahanimbinine	$C_{23}H_{27}NO_2$	Leaves and seeds	[30]
Murrayazoline	$C_{23}H_{25}NO$	Leaves, stem and stem	[13,26]
Murrayazolinol	$C_{23}H_{25}NO_2$	Stems bark	[13,25]
Murrayazolinine	$C_{23}H_{27}NO_2$	Leaves and seeds	[31]
Koenine	$C_{18}H_{17}NO_2$	Leaves	[32]
Koenoline	$C_{14}H_{13}NO_2$	Leaves, seeds	[33]
Koenigine	$C_{19}H_{19}NO_3$	Leaves	[13,23,24]
8,8” -Biskoenigine	$C_{38}H_{36}N_2O_6$	Leaves and stem	[33]
Koenimbine	$C_{19}H_{19}NO_2$	Leaves, fruits	[13,22-24]
Koenigicine	$C_{20}H_{21}NO_3$	Leaves, stems	[21-24]
Koenimbidine	$C_{20}H_{21}NO_3$	Leaves, roots	[21,22,24]
Iso-koenidine	$C_{20}H_{22}NO_3$	Leaves	[35]
Iso-koenigine	$C_{19}H_{20}NO_3$	Leaves	[35]
Mukonine	$C_{15}H_{13}NO_3$	Leaves, stems and roots	[36]
Mukonal	$C_{13}H_9NO_2$	Stems	[37]
Mukoeic acid	$C_{14}H_{11}NO_3$	Leaves, stems	[13,25]
Mukonicine	$C_{20}H_{21}NO_3$	Fruits, seeds and leaves	[38]
Mukoenine A	$C_{18}H_{19}NO$	Roots and stem bark	[13,25]
Mukoenine B	$C_{23}H_{25}NO_2$	Roots and stem bark	[13,25]
Mukoline	$C_{14}H_{13}NO_2$	Roots	[13,25]
Mukolidine	$C_{14}H_{11}NO_2$	Roots and stem bark	[13,25]
Girinimbine	$C_{18}H_{17}NO$	Stems bark, roots, and seeds	[13,26]
Glycozoline	$C_{14}H_{13}NO$	Stems	[39,40]
Girinimbilol	$C_{18}H_{19}NO$	Leaves	[21,22]
Bis-7-hydroxygirinimbine	$C_{36}H_{32}N_2O_4$	Leaves	[41]
O-Methylmurrayamine A	$C_{19}H_{20}NO_2$	Leaves	[21-24]
Mahanimbicine	$C_{23}H_{25}NO$	Leaves	[21-24]
Bicyclomahanimbicine	$C_{23}H_{25}NO$	Leaves	[21-24]
Cyclomahanimbine	$C_{23}H_{25}NO$	Leaves	[21,22]
Isomahanimbine	$C_{23}H_{25}NO$	Leaves and roots	[21-24]
Isomahanine	$C_{23}H_{25}NO_2$	Leaves, seeds and fruits	[13,21,22]
Mahanimboline	$C_{23}H_{25}NO_2$	Leaves	[13]

(Contd...)

Table 1: *(Continued)*

Compound	Molecular formula	Plant part	References
Phebalosin	$C_{15}H_{14}O_4$	Leaves	[21-24]
Pyrayafoline D	$C_{23}H_{25}NO_2$	Leaves and stem bark	[13,21,22]
Bispyrayafoline	$C_{48}H_{56}N_2O_4$	Fruits	[42]
Isolongifolene	$C_{15}H_{24}$	Leaves	[13]
Euchrestine B	$C_{24}H_{29}NO_2$	Leaves	[21,22]
Bismurrayafoline E	$C_{48}H_{56}N_2O_4$	Leaves	[21,22]
Osthol	$C_{15}H_{16}O_3$	Stem bark	[13,25]
Umbelliferone	$C_9H_6O_3$	Stem bark	[13,25]
(M)-murrastifoline-F	$C_{28}H_{24}N_2O_2$	Roots and stem bark	[13,25]
3-Methyl-9H-carbazole-9-carbaldehyde	$C_{14}H_{11}NO$	Roots	[13,25]
Bismahanine	$C_{46}H_{48}N_2O_4$	Roots and stem bark	[13,25]
Bikoeniquinone A	$C_{27}H_{20}N_2O_3$	Roots and stem bark	[13,25]
Bismurrayaquinone	$C_{26}H_{16}N_2O_4$	Roots and stem bark	[13,25]
3-Methylcarbazole	$C_{13}H_{11}N$	Roots	[13]
Murrayafoline A	$C_{14}H_{13}NO$	Roots	[13]
Kurryam	$C_{20}H_{21}NO_4$	Leaves	[43]
Karapinchamine A	$C_{23}H_{27}NO$	Leaves	[34]
Karapinchamine B	$C_{23}H_{25}NO_2$	Leaves	[29]
N-Benzyl carbazole A	$C_{27}H_{28}NO_5$	Leaves, stems	[35]
N-Benzyl carbazole B	$C_{26}H_{25}NO_4$	Leaves, stems	[35]

Table 2: Flavonoid compounds in leaves

Compound name	Molecular formula	References
Quercetin	$C_{15}H_{10}O_7$	[44]
Apigenin	$C_{15}H_{10}O_5$	[44]
Kaempferol	$C_{15}H_{10}O_6$	[44]
Rutin	$C_{27}H_{30}O_{16}$	[44]
Catechin	$C_{15}H_{14}O_6$	[44]
Myricetin	$C_{15}H_{10}O_8$	[44]
4-*O*-β-d-Rutinosyl-3 -methoxyphenyl-1-propanone	$C_{22}H_{32}O_{12}$	[35]
1-*O*-β-d-Rutinosyl-2(*R*)-ethyl-1-pentanol	$C_{19}H_{36}O_{10}$	[35]
8-Phenylethyl-*O*-β-d-rutinoside	$C_{20}H_{30}O_{10}$	[45]

M. koenigii could be a source of bioactive compounds for developing alternative antibacterials.

Antidiabetic activity

The antidiabetic activity of *M. koenigii* has been investigated using different extracts, isolated compounds, and experimental compounds, including animal studies and limited human investigations. Mahanimbine, isolated from the petroleum ether extract by column chromatography, inhibited α-amylase activity more effectively than acarbose and reduce blood glucose levels by 25–48% after 21 days.[66,78] It has also been reported to stimulate insulin secretion from pancreatic β-cells, thereby reducing blood glucose levels.[67] Dietary supplementation with *M. koenigii* leaves produced hypoglycemic and antihyperglycemic effects in rats.[68] Ethanolic leaf extracts reduced blood glucose through antioxidant and insulin–mimetic mechanisms,[69] while also decreasing malondialdehyde levels, increasing glutathione, and improving insulin resistance (homeostatic model assessment for insulin resistance).[70,71] Oral aqueous extracts lowered blood glucose in alloxan-induced diabetic rabbits and rats,[72-77] whereas chloroform extracts (250–500 mg/kg) were effective in alloxan-induced rats.[78] Fresh fruit juice also reduces blood glucose levels in diabetic rats.[79] In addition to koenidine, mahanimbine was associated with reduced postprandial blood glucose levels and improved insulin sensitivity in rats with type 2 diabetes.[80]

Studies showing that antidiabetic activity of *M. koenigii* consistently exhibits glucose-lowering activity in preclinical studies, whereas evidence from human studies remains limited.

Antioxidant activity

Adding *M. koenigii* leaf powder to high-fat diets significantly cuts lipid peroxidation (thiobarbituric acid reactive substances) levels.[10,81] Its carbazole alkaloids serve as potent natural antioxidants, key to preventing diseases tied

Table 3: Terpenoid compounds in leaves

Compound	Molecular formula	References
β-Elemene	$C_{15}H_{24}$	[39]
β-Bisabolene	$C_{15}H_{24}$	[5]
β-Caryophyllene	$C_{15}H_{24}$	[5]
α-Capaene	$C_{15}H_{24}$	[46]
α-Humulene	$C_{15}H_{24}$	[46]
Dehydro aromadendrene	$C_{15}H_{22}$	[47]
Aromadendrene	$C_{15}H_{24}$	[48]
Junipene	$C_{15}H_{24}$	[49]
β-Selinene	$C_{15}H_{24}$	[50]
Cadinene	$C_{15}H_{26}$	[49]
Myrcene	$C_{10}H_{16}$	[51]
β-Pinene	$C_{10}H_{16}$	[51]
p-Cymene	$C_{10}H_{14}$	[51]
Limonene	$C_{10}H_{16}$	[51]
1,8-Cineole	$C_{10}H_{18}O$	[51]
[Z]-β-Ocimene	$C_{10}H_{16}$	[51]
[E]-β-Ocimene	$C_{10}H_{16}$	[51]
γ-Terpinene	$C_{10}H_{16}$	[51]
α-Terpinolene	$C_{10}H_{16}$	[51]
Linalool	$C_{10}H_{18}O$	[51]
1-Octen-3 yl acetate	$C_{10}H_{18}O_2$	[51]
3-Octanyl acetate	$C_{10}H_{20}O_2$	[51]
Allo-ocimene	$C_{10}H_{16}$	[51]
α-Terpineol	$C_{10}H_{18}O$	[51]
Nerol	$C_{10}H_{18}O$	[51]
Carvone	$C_{10}H_{14}O$	[51]
α-Gurjunene	$C_{15}H_{24}$	[51]
Germacrene D	$C_{15}H_{24}$	[51]
α-Amorphene	$C_{15}H_{24}$	[51]
Elemol	$C_{15}H_{26}O$	[51]
Viridiflorol	$C_{15}H_{26}O$	[51]
γ-Eudesmol	$C_{15}H_{26}O$	[51]
B-Eudesmol	$C_{15}H_{26}O$	[51]
A-Eudesmol	$C_{15}H_{26}O$	[51]
Blumenol A	$C_{13}H_{20}O_3$	[52]
Blumenol C	$C_{13}H_{22}O_2$	[52]
Icariside B1	$C_{19}H_{30}O_8$	[52]
Loliolide	$C_{11}H_{16}O_3$	[52]
(-)-Epiloliolide	$C_{11}H_{16}O_3$	[52]

to oxidative damage from lipid peroxidation. Leaf powder reduces malondialdehyde while modulating hydroperoxide levels, conjugated dienes, superoxide dismutase, and catalase in liver/heart. Oral feeding streptozotocin diabetic rats 15% leaf powder + 10% Brassica juncea seeds for 60 days (about 2 months) protects kidneys to improve body weight, creatinine, urine volume, urinary albumin, and serum glucose levels. Ideal as a food adjuvant for diabetics, easing oxidative stress, and beta-cell damage.[82]

Curry leaves compounds such as koenigine and mahanimbine from leaves exhibit strong antioxidant activity;[25] using the β-carotene-linoleic acid method, oleoresin extract led with 83.2% activity at 100 ppm, whereas water and methanol extracts followed at 16.7% and 11.3%. Butyl hydroxyanisole, a synthetic antioxidant, demonstrated 90.2% activity at the same concentration.[83] Ethanol leaf extract against free radical scavenging through 1,1-diphenyl-2-picrylhydrazyl (63.54% inhibition) and no methods show high antioxidant activity.[84,85]

Anthelmintic activity

Curry leaf extracts (ethanolic, aqueous, and methanolic) demonstrated significant anthelmintic activity against earthworms like *Pheretima posthuma* – comparable to the prescription medication Piperazine. Leaf tannins (polyphenols) having anthelmintic properties, bind to parasites proteins/glycoproteins in the gut or cuticle, paralyzing worms in 18 min (methanolic extract) and killing them by 45 min at higher doses.[86]

Alcohol-based extracts from curry leaves deliver stronger anthelmintic effects compared to petroleum ether extracts.[87] Water and ethanol-based extracts from *M. koenigii* roots exhibits strong vermifugal effects toward *Eudrilus eugeniae*.[88]

Anti-inflammatory activity

Several studies have evaluated anti-inflammatory activity of *M. koenigii* using different extraction solvents and doses. In carrageenan-induced paw edema in Wistar albino rats, the ethanolic leaf extract (250 mg/kg) showed higher activity than the aqueous extract, whereas hexane and petroleum ether and chloroform extracts.[89] Similarly, the methanolic leaf extract (400 mg/kg) showed higher activity than the aqueous extract, whereas hexane and petroleum ether extracts exhibited little or no anti-inflammatory effect.[90] The alcohol tincture of the stem bark (1 g/kg) and crude root extracts also demonstrated anti-inflammatory activity. In addition, the ethanolic extract (300–400 mg/kg) exhibited antihistaminic activity through mast cell stabilization.[13,91] Comparison of the available studies suggests that extraction solvent is a key factor influencing the anti-inflammatory activity of *M. koenigii*, with polar extracts generally exhibiting higher activity than non-polar solvents.

Hepatoprotective activity

M. koenigii leaf extract protects the liver through synergistic action of carbazole alkaloids (girinimbine, mahanimbine, isomahanimbine, mahanine, murrayazoline,

Table 4: Relationship between major phytochemical classes and pharmacological activities

Phytochemical class	Major compounds	Pharmacological activities	Proposed mechanism	References
Carbazole alkaloids	Mahanine, Mahanimbine, Girinimbine, Koenimbine	Anticancer, Antidiabetic, Antimicrobial	Apoptosis induction, enzyme inhibition, modulation of cellular signaling pathways	[19,22,46,80]
Flavonoids	Quercetin, Kaempferol, Rutin	Antioxidant, Anti-inflammatory	Free radical scavenging, inhibition of oxidative stress and inflammatory mediators	[4,44,84]
Phenolics	Phenolic acids, Polyphenols	Antioxidant, Hepatoprotective	Reactive oxygen species neutralization and protection against oxidative damage	[4,70,94]
Terpenoids	β-Caryophyllene, Limonene, α-Pinene	Antimicrobial, Anti-inflammatory	Disruption of microbial cell membranes and modulation of inflammatory responses	[19,49,51]
Tannins	Various tannins	Anthelmintic, Antimicrobial	Protein precipitation and interference with parasite metabolism	[18,86]
Saponins	Saponins	Antimicrobial, Antifungal	Membrane permeabilization and disruption of microbial cell integrity	[18,54,56]
Quinones	Carbazole quinones	Anticancer, Antioxidant	Induction of oxidative stress in target cells and modulation of redox pathways	[20,32,41]
Glycosides	Rutinosides, Icariside B1	Antioxidant, Hepatoprotective	Radical scavenging and cellular protective effects	[4,52,94]
Steroids	Phytosterols	Anti-inflammatory	Cytokine modulation and stabilization of inflammatory responses	[12,13,95]
Amino acids and proteins	Essential amino acids and proteins	Nutritional benefits	Protein synthesis, tissue maintenance and metabolic regulation	[11,17,21]

and murrayazolidine) and ascorbic acid, α-tocopherol and minerals (Zn, Cu, and Fe); these act as free radical quenchers, stabilizing hepatocyte membranes, and curbing fat metabolism. Aqueous extracts preserve healthy hepatocyte structure against ethanol damage, comparable to L-ornithine-L-aspartate, while acetone dried bark extract provide superior protection of liver cells from control groups and other solvents in $CC1_4$-induced liver damage. Crude water extract shields against ethanol-induced hepatotoxicity in animals, countering chronic alcohol harm while maintaining the enzyme oxidant level.[92] Water extract of carbazole alkaloids + tannins protects HepG2 cells from ethanol-induced hepatotoxicity, keeping enzymatic and non-enzymatic antioxidants normal and cells intact.[93] Hydro-ethanolic leaf extract blunt $CC1_4$ liver damage in rats, slashing hepatic markers and maintaining the enzymatic antioxidants level.[94] Overall, synthesis of hepatoprotective studies indicates that aqueous and hydroethanolic extracts provide superior liver protection through membrane stabilization, free radical scavenging, and modulation of oxidative stress pathways.

CONCLUSION

M. koenigii (curry leaf) is a valuable medicinal and culinary plant possessing a rich repertoire of bioactive phytochemicals, particularly carbazole alkaloids, flavonoids, terpenoids, and phenolic compounds. Evidence from traditional usage and contemporary scientific investigations demonstrates its diverse pharmacological properties, including antioxidant, antimicrobial, antidiabetic, anti-inflammatory, anthelmintic, and hepatoprotective activities. Recent studies have further strengthened the therapeutic relevance of curry leaves and highlighted their potential application in pharmaceutical, nutraceutical and functional food industries. Nevertheless, additional mechanistic investigations, toxicity evaluations, and clinical studies are required to fully establish the efficacy and safety of its bioactive constituents for future drug-development and health-promoting applications.

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