INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

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Review Article

Therapeutic Potentials of *Matricaria Chamomilla*: A Review of Recent Pharmacological Studies

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ARTICLE INFO

Published: 23 Sept. 2025
Keywords:
Matricaria chamomilla; phytochemicals; apigenin; traditional medicine; pharmacological activity; herbal therapeutics
DOI:
10.5281/zenodo.17181484

ABSTRACT

Matricaria chamomilla L. (German chamomile) has been extensively utilized in traditional medicine and has recently gained significant attention for its broad pharmacological profile. This review consolidates contemporary findings regarding its therapeutic potential, focusing on its bioactive phytochemicals and associated pharmacological actions. The plant is rich in flavonoids (e.g., apigenin, luteolin, quercetin), sesquiterpenes (notably α-bisabolol and chamazulene), coumarins, polyphenols, and essential oils, which are primarily responsible for its medicinal efficacy. Modern investigations have demonstrated its notable anti-inflammatory, antioxidant, antimicrobial, hepatoprotective, neuroprotective, and anticancer properties. These effects are mediated through diverse mechanisms such as modulation of pro-inflammatory cytokines (e.g., TNF-α, IL-6), inhibition of oxidative stress markers (e.g., MDA, TOS), and interference with cellular pathways including NF-κB, COX-2, and Wnt/β-catenin signaling. The anxiolytic action of apigenin through positive modulation of GABA_A receptors highlights its neuropharmacological relevance. Additionally, synergistic interactions with conventional drugs and selective COX-2 inhibition suggest its potential in reducing adverse drug reactions. The variability in phytochemical content due to extraction methods and geographical factors underscores the need for standardization. Despite promising preclinical outcomes, clinical data remain limited. Therefore, rigorous translational research, including pharmacokinetic studies and well-designed clinical trials, is necessary to validate its safety and efficacy. Overall, M. chamomilla emerges as a potent candidate for integration into evidence-based phytotherapy. Future directions should focus on quality control, compound synergy elucidation, and clinical translation to optimize its role in complementary medicine.

INTRODUCTION

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

A vital natural resource for any nation, medicinal plants are essential to rural communities' access to basic healthcare. Beyond serving as key raw materials for traditional medicine production, these plants themselves act as healing agents [1]. In recent years, herbal medicine has experienced significant growth worldwide, gaining popularity in both developed and developing nations. This rise is largely due to its natural origins and the perception that it carries fewer side effects than conventional pharmaceuticals. Today, many traditional medicines are derived not only from medicinal plants but also from minerals and other organic substances [2]. The Royal Botanic Gardens, Kew, has recorded that around 28,187 plant species are used medicinally across the globe [3]. Meanwhile, estimates from the International Union for Conservation of Nature (IUCN) and the World Wildlife Fund (WWF) suggest that between 50,000 and 80,000 flowering plant species serve medicinal purposes worldwide [4]. Throughout history, medicinal plants have served as an integral part of almost every culture's healthcare system. According to estimates, 80–85% of individuals in both industrialized and developing nations get their primary medical care from conventional medicine. Much of this traditional healing is believed to come from plant extracts or the active compounds they contain [5-7]. Chamomile, or *M. chamomilla*, is a popular medicinal herb that is a member of the *Asteraceae* family. It thrives in a range of soil types, pH levels, and temperature conditions, demonstrating its remarkable adaptability. Native to northern and western Asia as well as southern and eastern Europe, German chamomile has earned a reputation as a valuable medicinal plant [8]. In fact, ancient Egyptians considered it a divine gift from the sun god and have used it medicinally for centuries [9]. Because of its many therapeutic properties and pleasant aroma, the plant is often called a “star” [10]. German chamomile exists in both diploid and tetraploid genetic forms, with the tetraploid varieties typically growing taller and larger than their diploid counterparts [11]. However, one challenge with cultivating chamomile is its staggered flowering, which makes mechanical harvesting difficult and increases the labor required to pick the flower heads. To support large-scale farming and industrial use, more research is needed in areas like advanced farming techniques, breeding improved varieties, genetic improvements, and more efficient methods of extracting its essential oils. Additionally, it’s important to carefully study the factors that affect how its active compounds are extracted. The flower heads of German chamomile have long been used in herbal teas and various extract-based preparations. These flower heads and their extracts find applications in a wide range of products, including herbal medicines, teas, culinary flavourings, cosmetics, dyes, and even insect repellents [12, 13]. Historically, *M. chamomilla* has been employed in many countries to address numerous health issues such as respiratory problems [14], liver disorders [15], digestive ailments [16], the common cold [17], and neuropsychiatric conditions. It’s also frequently used to treat skin, eye, and mouth ailments [18], as well as to ease pain and fight infections [19]. *M. chamomilla* has garnered a lot of attention from researchers in a variety of disciplines because of its wide spectrum of pharmacological effects. It’s most well-known and extensively researched application is still in medicine. Due to its high concentration of flavones, polysaccharides, and lipophilic compounds all of which support its therapeutic qualities. German chamomile essential oil is especially prized in the pharmaceutical industry. These essential oils are frequently utilized as the food, aromatherapy, as well as perfumery industries in addition to medical. Their anti-inflammatory, antiulcer, antimicrobial, antiseptic, antispasmodic, sedative, immune-

modulating, and wound-healing effects make German chamomile oil a vital ingredient in many pharmaceutical products [20].

2.1. Taxonomical Description

The *Asteraceae* family includes the well-known medicinal plant *M. chamomilla* L., which Linnaeus initially categorized in 1753. Often referred to as German chamomile, this species is thought to be the original chamomile. The English name "chamomile" comes from the Greek words *chamos*, meaning "on the ground," and *melos*, meaning "apple," which likely refers both to its low-growing habit and the apple-like fragrance of its flowers [22]. The distinctive apple scent of the blossoms is what the name most probably highlights. Below is a detailed, hierarchical scientific classification of German chamomile [23].

Table 1. Taxonomical classification of *Matricaria chamomilla*

Kingdom	Plantae
Subkingdom	Tracheobionta
Super division	Spermatophyta
Division	Magnoliophyta
Class	Magnoliopsida
Order	Asterales
Family	Asteraceae
Genus	Matricaria
Species	Chamomilla
Synonyms	*Matricaria recutita* L.
	Chamomilla vulgaris
	Chamaemelu M. chamomilla L.
	Chrysanthemu M. chamomilla L.

1.2. Geographic Description

The genus *Matricaria* consists of five species, primarily distributed across Europe, northern Africa, Macaronesia, western, southwestern, and central Asia, as well as western North America [24]. This genus shows a wide geographical spread and diverse adaptations, commonly growing in grasslands, disturbed areas, along highways and railways, and in vacant or waste spaces [25, 26]. Among these five species, two *Matricaria aurea* and *Matricaria chamomilla* are located in India. A detailed overview of the species distribution within the *Matricaria* genus is provided below [27, 28].

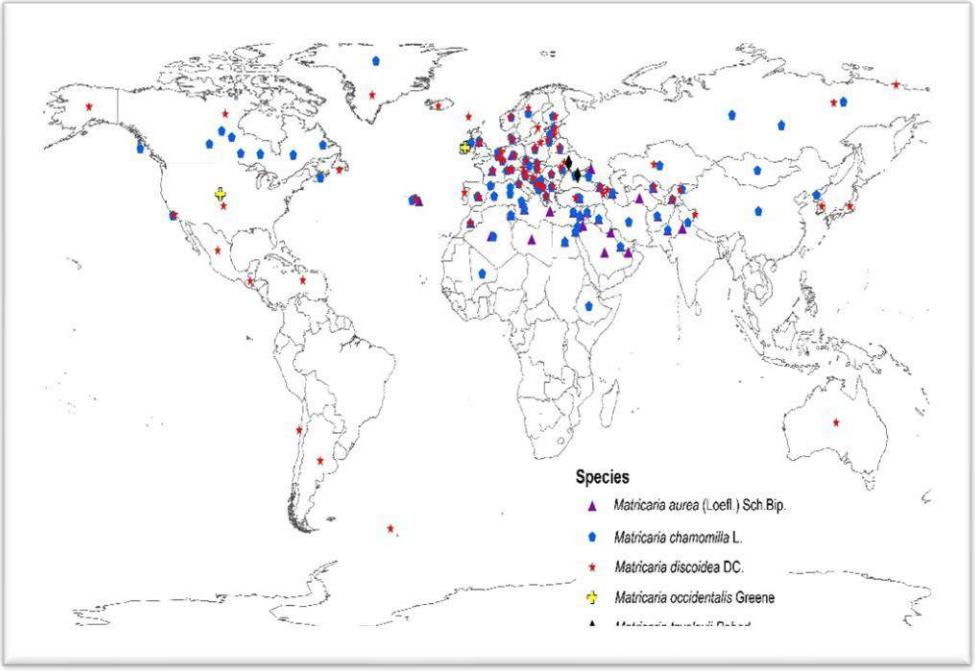

Figure 1. Geographical Distribution of *Matricaria chamomilla*

1.3. Botanical and Ecology Description

German chamomile is a fragrant herb that typically grows between 10 and 60 cm tall each year, though it can sometimes reach up to 80 cm. The plant has tall, branching stems and slender, spindle-shaped taproots [29]. Its leaves are compound and arranged alternately. A distinctive trait of the *Asteraceae* family is how the flowers are grouped into a head, or capitulum, made up of central disc florets surrounded by a ring of outer ray florets. These flower heads are heterogamous, radiate outward, develop singly at the tips of branches, and measure about 1 to 3 cm in diameter [30]. The flower stalks, or peduncles, range from 3 to 6 cm in length, with cup-shaped involucres at their base surrounding the heads [30]. The plant yields achenes that are, tiny, cylindrical fruits that measure around 0.8 to 1 mm in length and 0.5 mm in width. These achenes have three prominent ribs on the outer (abaxial) surface and two finer ribs along the edges.

Figure 2. *M. chamomilla* Flower and Plant

1.4.Bioactive Compounds in *M. chamomilla* [31, 32]

Chamomile (*M. chamomilla* L.) boasts a diverse and rich phytochemical makeup, which underpins its wide range of pharmacological effects. One of its main components is the essential oil, making up about 0.4 to 1.5% of the plant's content. This oil is particularly notable for its high chamazulene content (ranging from 1 to 15%), a compound that gives the oil its distinctive blue hue and is well-known for its anti-inflammatory benefits. Other significant components include sesquiterpenes like farnesene and β-caryophyllene, as well as α-bisabolol and its oxide forms, particularly α-bisabolol oxide A and B. These substances work together to give the oil its anti-inflammatory, antibacterial, and muscle-relaxing properties. Flavonoids form another key group of bioactive substances in chamomile, with compounds such as apigenin, luteolin, and quercetin derivatives receiving extensive attention for their antioxidant, anti-inflammatory, and cell-protective actions. These flavonoids are particularly valued for their ability to influence important cellular signalling pathways and enzyme activities. Chamomile also contains a lot of polyphenols, which increase its potent antioxidant properties by scavenging dangerous free radicals and lowering oxidative stress. The inclusion of coumarins, with their

anticoagulant and anti-inflammatory qualities, further enhances the medicinal benefits of chamomile. Triterpenes as well as plant sterols further support its antibacterial and anti-inflammatory properties. Polysaccharides extracted from chamomile have shown strong antioxidant capabilities, mainly by neutralizing reactive oxygen species and supporting the body's cellular defenses. Other important compounds include amino acids, sugars, proteins, and mucins, which may help protect mucous membranes and modulate the immune system. Phenolic acids like caffeic acid, along with polyacetylenes and various minerals, have also been identified in the plant, adding to its overall medicinal value. The many therapeutic applications of chamomile in both conventional and contemporary herbal medicine are based on the combination, synergistic actions of these many compounds.

1.5. Ethnomedicinal use of *M. chamomilla*. [21]

Traditionally, different portions of *M. chamomilla* have been utilized in a variety of ways, including compresses, inhalations, decoctions, and infusions. The plant parts used, preparation methods, and related traditional medicinal purposes are compiled in this table.

Table 2. Traditional uses of *Matricaria chamomilla* based on plant parts and preparation methods

Part Used	Mode of Preparation	Traditional Use
Flower	Infusion Decoction	Diabetes
Leaves	Decoction	Antispasmodic
Whole plant	Infusion	Nervous disorders
Flower	Infusion	Diabetes mellitus
Flower	Infusion Decoction	Depression, fever, cancer sore, infections, abscess, painful menstruation, nervousness, colic, diarrhoea, angina
Flower head	Infusion	Colic spasm, cold, sedative
Flowery plant	Infusion	Eye infection, dysmenorrhea, gases, insomnia, cold, conjunctivitis, kidney stones, digestive disorder, cough, headache, female genital infection, gastralgia
Not specified	Decoction Infusion	Nausea, gastric and intestinal anti-inflammatory, conjunctivitis, antiemetic, digestive, stomach ache, ocular antiseptic, antiseptic
Flowering top	Infusion Decoction	Asthma, digestive, insomnia, throat and ear infection, gases, cellulitis, stress, intestinal colic, neuralgia, stomach ache, depression, sciatic pain, nervousness, mouth infection
Whole plant Stem Inflorescence	Infusion Decoction In the bath	Muscular pain, tired eyes, menstrual pain, cold, irritability, conjunctivitis, gastrointestinal pain, broken bones, sprain, abdominal colic, cough
Aerial parts	Infusion	dye yellow, Sedative, bleach hair
Flower	Infusion	Digestive, Sedative
Flower head	Decoction Inhalation Compress	Cold, Genitalia, cleansing face, swollen eyes, throat pain.
Flowering tops	Tea	Cough, diarrhoea, Intestinal discomfort.
Flower	Infusion	Stomach disorder
Flower	Infusion	Sedative, conjunctivitis, cold, anti-inflammatory, immune system strengthening

Flower Leaves	Infusion	Aroma for shampoos, eye care, vaginal disorder, skin care, digestive disorder
Herb	Infusion	Cough, anxiety, mouthwash, digestive disorder, eyewash skin and mucus inflammation
Herb	Infusion	Stomach disorder & Cold
Herb	Infusion	Liver disorder, mouthwash, insomnia, burns, anxiety, digestive disorder, cough, eyewash, skin inflammation
Inflorescences	Infusion Compress Vapour inhalation	Stress, sore throat, colic, gingivitis, ulcer, allergy, catarrh, aphthae, eye infection, constipation, insomnia, migraine, skin issues (inflammation, dermatitis, acne, burn, eczema, itching, wound antiseptic), ulcer, and stomach disorders

2. Phytochemical Interest

After extensive research, the phytochemical makeup of *M. chamomilla* essential oil and its extracts was determined to consist of over 120 distinct components. Typically, these compositions are rich in terpenoids, phenolic acids, flavonoids, and coumarins. **[21]**

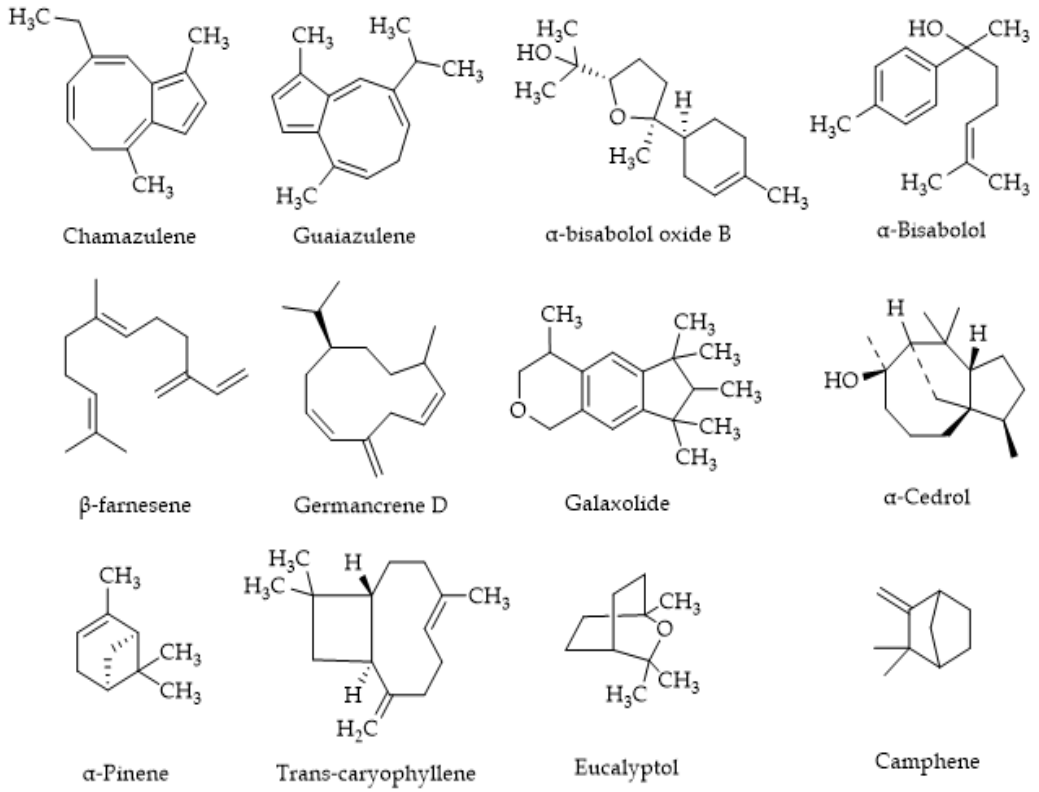

Figure 3. Structures of terpenoids in *M. chamomilla*.

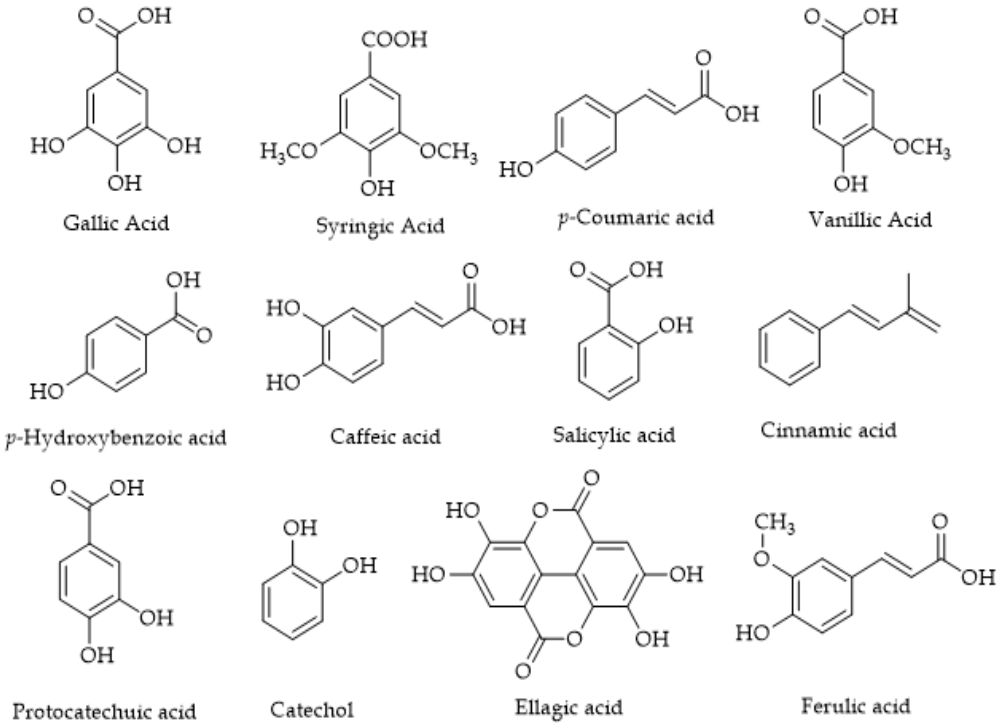

Figure 4. Structures of phenolic compounds in *M. chamomilla*.

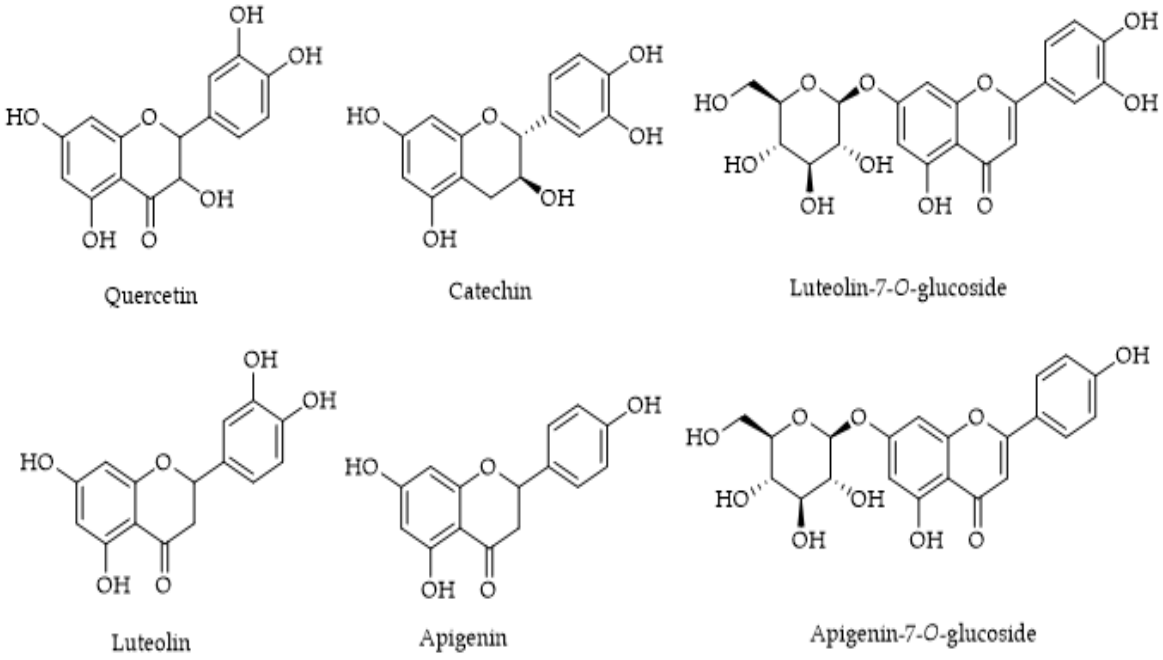

Figure 5. Structures of flavonoids in *M. chamomilla*.

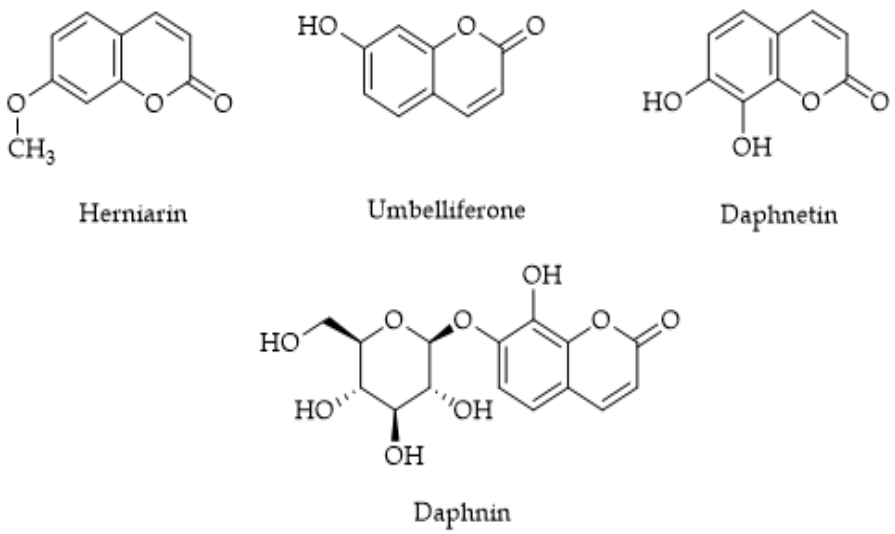

Figure 6. Structures of coumarins compounds in *M. chamomilla*.

3.1. Chemical composition of *M. chamomilla* and extracts [21]

Table 3 presents a comparative overview of the phytochemical constituents identified in *M. chamomilla* across various countries, plant parts, and extraction methods. It highlights the diversity of major bioactive groups such as flavonoids, phenolic acids, coumarins, and amino acids. This summary reflects the influence of geographic origin and solvent type on the phytochemical profile.

Table 3. Phytochemicals in *Matricaria chamomilla* from various sources

Source/ Country	Part	Component's group	Main Components
Egypt	Flower and roots Powder	Flavonoids Phenolic acids	Catechol), Quercetin, Luteolin O-acylhexoside, Chlorogenic acid, Ellagic acid
	Flower Aqueous	Flavonoids Phenolic acids	Rosmarinic acid, Myricetin, Quercetin, Naringenin, Benzoic acid
Slovakia	Leaf rosettes Methanol	Phenolic acids	Chlorogenic acid, p-coumaric acid, Vanillic acid, Caffeic acid, Ferulic acid
	Flower or leaves Methanol	Coumarin	Z-GMCA, Herniarin, E-GMCA, Daphnin, Skimmin, Daphnetin, Umbelliferone
	Leaves Methanol	Coumarin Phenolic acids	Caffeic acid, Z-GMCA, E-GMCA, Vanillic acid
Iran	Flower Methanol	Flavonoids	Apigenin, Luteolin

	Not specified Ethanol	Alkane	1, 2-benzenedicarboxylic acid , 3-fluorophenethylamine, 1, 2, 2-trimethylcyclopropylamine, Hex-5-enylamine, 7-methoxy-2, 3, 4, 5, 6, 7-hexahydro, Phenol, 4-(2-aminoethyl), n-Heptacosane , 2,6,10,14,18,22-tetracosahexaene
Pakistan	Not specified Aqueous	Amino acids	L-glutamic acid, L-alanine, L-proline, L-asparagine, Aminobutyric acid, L-aspartic acid
China	Roots, stems, Leaves 70% aqueous methanol	Caffeoylquinic acids	Isochlorogenic acid B, Isochlorogenic acid A, Cryptochlorogenic acid, Neochlorogenic acid, Chlorogenic acid, Isochlorogenic acid C
	Flower Aqueous	Amino acids	Isoleucine + leucine, Proline, Alanine, Arginine + threonine

1.6. Relevance of specific compounds to pharmacological activity

The specific bioactive compounds of *M. chamomilla* play critical roles in its pharmacological activities. Below is an overview of key compounds and their relevance to therapeutic effects **[31-33]**:

Table 4. Major bioactive compounds in *M. chamomilla* and their pharmacological activities

Flavonoids	**Apigenin**	Anti-inflammatory, antioxidant, anticancer and anxiolytic properties
	Luteolin	Neuroprotective, anti-inflammatory, and antioxidant effects
	Quercetin	Antioxidant and anti-inflammatory properties
Sesquiterpenes	**Chamazulene**	Anti-inflammatory and antioxidant effects
	α-Bisabolol	Antimicrobial, anti-inflammatory, anticancer and wound-healing properties
Coumarins		Anticoagulant and anti-inflammatory effects
Polyphenols		Antioxidant activity, reducing oxidative stress and protecting against age-related diseases
Bisabolol oxide A and Tonghaosu		Antiproliferative effects, antiangiogenic potential
Essential oils		Antimicrobial, antispasmodic, and antiulcerogenic effects
Saponins and Tannins		Antimicrobial and protective effects against gastrointestinal disorders
Phenyl Carboxylic acids		Antioxidants, supporting cellular protection
Other Compounds	**Alkaloids, amino acids, sugars, proteins, mucins, and mineral substances**	Wound healing, memory enhancement, and metabolic regulation

Recent Pharmacological Findings

Recent pharmacological findings on *M. chamomilla* (German chamomile) highlight its wide range of therapeutic activities supported by its bioactive compounds such as flavonoids (e.g., apigenin), terpenoids (e.g., bisabolol), and coumarins.

4.1. Anti-inflammatory activity

The potent anti-inflammatory properties of *M. chamomilla* (MC) and its diverse extracts have been demonstrated in several investigations using a variety of experimental paradigms. For example, one study used the carrageenan-induced paw edema model in mice to explore how an ethanolic extract of *M. chamomilla* (MCE) interacted with two commonly used non-steroidal anti-inflammatory drugs (NSAIDs), diclofenac and indomethacin [34]. The findings revealed that when MCE was given alongside these NSAIDs, the anti-inflammatory effect was significantly enhanced compared to NSAIDs alone, suggesting a synergistic interaction at the systemic level [35]. A hydroalcoholic extract of *M. chamomilla* was administered to rats in a different investigation to investigate its impact on inflammatory biomarkers. Blood samples taken before and after treatment showed that the extract, at a dose of 110 mg/kg, notably reduced systemic inflammation by inhibiting the increase of pro-inflammatory markers such as fibrinogen, C-reactive protein (CRP), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF-α) [36]. German chamomile essential oil's anti-inflammatory properties have also been studied. According to enzyme inhibition tests, the essential oil spares COX-1 while specifically inhibiting cyclooxygenase-2 (COX-2), a crucial enzyme implicated in inflammation. This selective inhibition is important because COX-2 targeting is often associated with fewer gastrointestinal side effects compared to non-selective COX inhibitors [37]. Furthermore, immunological cells from BALB/c mice were used to examine the immunomodulatory effects of *M. chamomilla* aqueous and ethanolic extracts. When lipopolysaccharide (LPS) was present, the ethanolic extract decreased macrophage viability whereas the aqueous extract boosted it. Measurements of cytokines like interleukin-10 (IL-10) and interferon-gamma (IFN-γ) further revealed distinct immunoregulatory actions depending on the extract type [38]. All of these results offer compelling evidence for *M. chamomilla*'s immunomodulatory and anti-inflammatory qualities, which are probably due to its complex phytochemical makeup and capacity to affect both pro- and anti-inflammatory pathways.

1.7. Antioxidant activity

Numerous *in-vitro* and *in-vivo* investigations have investigated *M. chamomilla*'s antioxidant qualities, indicating its promise as a natural remedy for oxidative stress reduction. In one thorough investigation, a mix of lab and animal models were used to assess the antioxidant potential of chamomile extract. The 2, 2-diphenyl-1-picrylhydrazyl (DPPH) assay was used to examine the extract's capacity to neutralize free radicals *in-vitro*. For the *in-vivo* part, researchers induced oxidative stress in rats through radiation exposure and then measured the total oxidant status (TOS) and total antioxidant capacity (TAC) using Erel's method [39]. Results showed that chamomile extract significantly protected against radiation-induced oxidative damage by lowering the oxidative burden (TOS) and boosting the antioxidant defense (TAC) [40]. Another study focused solely on the in vitro antioxidant effects of *M. chamomilla* extract, confirming its strong free radical scavenging ability with a DPPH scavenging activity value of 3.08 ± 0.25 mg/mL

[41]. Similarly, a separate investigation used the DPPH method as described by Brand-Williams et al. [42] to assess the extract's capacity to donate protons, further supporting its role as a primary antioxidant. These findings reinforce chamomile's effectiveness in neutralizing free radicals, suggesting its usefulness in conditions related to oxidative stress [43]. Taken together, these studies provide compelling evidence of *M. chamomilla*'s robust antioxidant capabilities. The extract's ability to manage oxidative stress both *in-vitro* and in living organisms highlights its therapeutic potential, especially in situations where reactive oxygen species levels are elevated.

1.8. Antibacterial Activity

Numerous investigations have emphasized *M. chamomilla*'s antibacterial qualities, especially when it comes to clinically significant drug-resistant bacterial strains. In one study, methicillin-resistant Staphylococcus aureus (MRSA) and clinical isolates of multidrug-resistant (MDR) Pseudomonas aeruginosa were tested against ethanolic extracts from *M. chamomilla* leaves and flowers. The antibacterial effects were assessed using broth microdilution and agar well diffusion methods [44]. Results showed that the ethanolic leaf extract was effective against MDR *P. aeruginosa*, while the flower extract demonstrated stronger activity against MRSA, suggesting that different plant parts target different bacterial strains [45]. In another study, the ethanolic flower extract was specifically evaluated for its activity against MRSA strains using the same agar well diffusion and broth microdilution techniques. The strong antibacterial effect observed supports the potential use of chamomile flower extract as a natural antimicrobial agent in managing resistant infections [46]. Additionally, the agar disk diffusion technique was used to investigate the antibacterial activity from an extract made from ethyl acetate (EthOAc) of *M. chamomilla* against Enterococcus faecalis. The extract showed significant inhibition, especially when combined with chlorhexidine, indicating its possible role in endodontic treatments to combat *E. faecalis*, a common cause of persistent root canal infections [47]. Together, these studies emphasize the promising antibacterial potential of chamomile extracts, especially against resistant pathogens like MRSA, MDR P. aeruginosa, and *E. faecalis*. These findings suggest that compounds from *M. chamomilla* could be valuable in developing complementary or alternative antibacterial therapies.

1.9.Anticarcinogenic activity

Various experimental approaches have explored the anticancer potential of *M. chamomilla*, revealing promising effects against different cancer cell types. These studies emphasize the plant's bioactive compounds as potential alternatives for cancer prevention and therapy. The capacity of *M. chamomilla*'s secondary metabolites to inhibit cyclooxygenase-2 (COX-2), an enzyme implicated in inflammation and the development of cancer, was the subject of one thorough study. In order to evaluate these chemicals' lethal effects, the team also tested them on a panel of 60 human cancer cell lines. Interestingly, myricetin, a crucial flavonoid in chamomile tea with cytotoxic and anti-inflammatory effects, shown strong efficacy. Proteomic analysis further identified molecular signatures associated with sensitivity or resistance to myricetin in tumor cells, shedding light on its anticancer mechanisms and supporting its potential as a natural cancer-preventive or adjunct therapeutic agent [48]. A hydroalcoholic extract from *M. chamomilla*'s aerial parts was used in another investigation to examine the anticancer

effects on two human breast cancer cell lines, MCF-7 and MDA-MB-468. Using assays like MTT for cell viability, Hoechst/propidium iodide staining for apoptosis and necrosis, clonogenic assays for cell proliferation, and migration/invasion tests, researchers found that the extract significantly inhibited cancer cell invasion, migration, and growth while promoting apoptosis in a dose- and time-dependent manner. These findings highlight the extract's potential in both breast cancer treatment and prevention [49]. Additionally, research on aqueous extracts of chamomile seeds, chemically modified through sulfation and prepared under various pH conditions, evaluated their effects on Ehrlich ascites carcinoma cells using the trypan blue exclusion assay at doses ranging from 300 to 900 µg/mL. The modified extracts showed modest but statistically significant tumor cell inhibition, indicating some level of cytotoxic activity [50, 43]. Overall, these investigations offer compelling evidence for *M. chamomilla*'s anticancer qualities, which are primarily ascribed to its wide range of bioactive phytochemicals and secondary metabolites. Its ability to suppress cancer cell growth, migration, and survival suggests it could serve as a valuable natural agent, particularly as a complementary or supportive option in cancer therapy.

1.10. Hepatoprotective effects

The hepatoprotective activities of *M. chamomilla* have been studied using a range of experimental liver damage models, supporting its longstanding reputation as a natural medicine with anti-inflammatory and antioxidant properties In one research, 1, 2-dimethylhydrazine (DMH), a substance known to produce liver damage associated with the advancement of intermediate-stage colorectal cancer (CRC), was used to assess the preventive properties of an aqueous extract of *M. chamomilla* in rats with chemically induced hepatotoxicity. The extract significantly reduced inflammation, cellular proliferation, and liver injury, thereby preventing secondary hepatic damage associated with CRC development [51]. Another study assessed *M. chamomilla*'s ability to protect against methotrexate-induced hepatotoxicity in rats. Methotrexate, widely used as a chemotherapeutic and immunosuppressive agent, is known to cause oxidative liver damage. Treatment with chamomile extract improved both histological and biochemical markers of liver injury, particularly at higher doses. The hepatoprotective effect was attributed to enhancement of the body's intrinsic antioxidant defense mechanisms [52]. In a separate investigation, a rat model of polycystic ovarian syndrome (PCOS) a condition often accompanied by liver and metabolic dysfunction was used to explore chamomile's liver-protective potential. Female wistar rats with PCOS were treated for 12 weeks with either metformin or chamomile extract. The group receiving chamomile showed significant liver protection, evidenced by decreased oxidative stress and reduced hepatocellular apoptosis under conditions of metabolic-induced liver impairment [53]. Additionally, the ability of *M. chamomilla* extract to shield rats' livers and kidneys from ceftriaxone-induced toxicity was examined. Chamomile extract markedly lowered biochemical indicators of renal and hepatic damage, suggesting its potential to mitigate adverse effects caused by certain antibiotics [54]. Taken together, these studies provide strong evidence that *M. chamomilla* possesses hepatoprotective properties across a variety of disease models. Its beneficial effects appear to arise from modulation of oxidative stress, inflammation, and apoptotic pathways—especially in contexts of chemically or drug-induced liver injury.

1.11. Neuroprotective effect

M. chamomilla's antioxidant and anti-inflammatory properties have sparked increased interest in its neuroprotective potential, especially in studies of neurodegeneration and brain damage. Chamomile's preventive benefits were assessed in one study using γ-irradiated mice, a model of oxidative brain injury brought on by large doses of gamma radiation. In addition to elevated levels of total thiols, lipid peroxidation (LP), nitric oxide (NO), oxidized glutathione (GSSG), protein carbonyls (PC), and acetylcholinesterase (AChE), irradiation animals demonstrated substantial decreases in endogenous antioxidant enzyme activity as compared to controls. Treatment with chamomile extract mitigated these changes by reducing lipid peroxidation, restoring glutathione (GSH) levels, and reviving antioxidant enzyme activity, suggesting that chamomile protects the brain against radiation-induced neurotoxicity by modulating oxidative stress pathways [55]. A further study examined how an ethanolic extract of *M. chamomilla* affected memory and learning deficits brought on by hippocampus cell loss. Using a shuttle box passive avoidance test, the study assessed memory function and found that the extract exerted neuroprotective effects by decreasing malondialdehyde (MDA) levels and neuronal cell death in the hippocampus, while enhancing overall antioxidant capacity. These results indicate that chamomile may strengthen the brain's oxidative defense mechanisms, thereby alleviating formaldehyde-induced memory deficits [56, 57]. Additionally, the effectiveness of an ethyl alcohol extract of chamomile was assessed using a rat model of cerebral ischemia–reperfusion (I/R)-induced motor dysfunction. After brain damage, the extract dramatically enhanced balance and motor coordination as shown by the rotarod test. A modest reduction in MDA levels in the cerebral cortex was also observed with extract administration (200 mg/kg), indicating decreased lipid peroxidation related to ischemic damage [58, 59]. Collectively, these findings highlight the neuroprotective capacity of *M. chamomilla*, which appears to act by preserving neural integrity, reducing lipid peroxidation, and modulating antioxidant defenses. Such properties suggest its potential utility in mitigating neurodegenerative processes and improving functional recovery after brain injury.

CONCLUSION

Matricaria chamomilla L. is a phytotherapeutic agent of considerable pharmacological interest owing to its broad-spectrum therapeutic effects and diverse bioactive constituents. Numerous substances, including flavonoids like apigenin, luteolin, and quercetin; sesquiterpenes like α-bisabolol and chamazulene; coumarins, polyphenols, and essential oils, are mostly responsible for the plant's pharmacological properties. These constituents exert their effects through multiple complex biochemical and molecular pathways. The strong anti-inflammatory, antioxidant, antibacterial, anticancer, hepatoprotective, and neuroprotective qualities of *M. chamomilla* have been emphasized in recent research. Critical signaling pathways such as NF-κB, COX-2, and Wnt/β-catenin are inhibited, oxidative stress markers like MDA and TOS are reduced, apoptotic processes are regulated, and pro-inflammatory cytokines like interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF-α) are modulated to achieve these therapeutic benefits. The neuropharmacological relevance of this species is further underscored by the anxiolytic and neuroregulatory effects of apigenin, which acts as a positive allosteric modulator of the GABA A receptor. Furthermore, the phytochemical diversity influenced by extraction methods, plant parts utilized, and

geographic origin underscores the necessity for stringent quality control and standardization in chamomile-derived products. Even though *M. chamomilla* has a good pharmacodynamic profile and minimal toxicity, further translational research is necessary to verify its safety and effectiveness in human populations. This includes pharmacokinetic optimization and rigorously designed randomized clinical trials. In conclusion, *M. chamomilla* holds significant promise as an evidence-based complementary therapeutic agent. To fully harness its potential within modern pharmacotherapy, future research should focus on developing standardized extracts, elucidating synergistic phytochemical interactions, and conducting comprehensive clinical evaluations.

ACKNOWLEDGEMENTS: The authors express their sincere gratitude to Al-Ameen College of Pharmacy, Department of pharmacology, for providing the necessary resources and support for completing this review. We also thank friends and mentors for their valuable guidance and suggestions throughout the preparation of this article.

Author contributions: R.M. conceived the topic and structure of the review. N.N. conducted the literature search and contributed to the drafting of the manuscript. M.C. critically revised the content. All authors approved the final manuscript.

Conflict of interest statement: The authors declared no conflict of interest.

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HOW TO CITE: Manjunath C.*, Rupeshkumar M., Nethravathi N., Nishmitha K. M., Therapeutic Potentials of Matricaria Chamomilla: A Review of Recent Pharmacological Studies, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 9, 2545-2562 https://doi.org/10.5281/zenodo.17181484