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COMPREHENSIVE REVIEW ON THE PHYTOCHEMICAL CONSTITUENTS AND BIOLOGICAL ACTIVITIES OF AEGLE MARMELOS LINN

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ABSTRACT

India is one of the world's megadiverse regions, giving it a unique advantage in factory grounded drug research. Medicinal shops form the foundation of traditional systems of drug and play a vital part in the herbal assiduity, serving as a precious source for the discovery and development of new drugs. A review of the literature reveals that colorful corridor of medicinal shops similar as roots, stems, leaves, dinghy, flowers, and seeds are employed in the treatment of a wide range of diseases. Aegle marmelos contains different bioactive composites similar as alkaloids, glycosides, saponins, steroids, and coumarins like marmelosin, marmin, and imperatorin. These procession antioxidant, anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, and cardioprotective goods. Traditionally used in Ayurveda and Siddha, A. marmelos holds implicit for new remedial agents due to its wide medicinal properties. Extracts of Aegle marmelos show different pharmacological conditioning, including antioxidant, antimicrobial, antihyperglycemic,

hepatoprotective, and cardioprotective goods, attributed to its rich phytochemicals. These findings validate the traditional medicinal use of Aegle marmelos and highlight its potential for novel drug development. This review emphasizes its diverse pharmacological properties, underlining its promising therapeutic value and future role in modern medicine.

KEYWORDS: Anti-microbial activity, Hepatoprotective, Anti-diabetic, Phytochemicals, Aegle Marmelos.

INTRODUCTION

India holds immense potential for research and innovation in plant based medicine offering valuable resources for both traditional and modern healthcare. Medicinal plants serve as a vital source of phytochemicals, offering immense potential for novel drug discovery and development.[1] Medicinal plants and plant-derived formulations have been widely utilized in traditional cultures worldwide, and in recent years they have gained increasing popularity in modern society as natural, safer alternatives to synthetic chemical-based drugs.[2] The chemical constituents of Aegle marmelos and their therapeutic effects, ranging from root to fruit, are comprehensively described.[3]

Bael (Aegle marmelos (L.) Corr.) is an important Indian medicinal plant with enormous traditional value in the treatment of various diseases, from which numerous bioactive compounds have been isolated and characterized.[4]

Aegle marmelos linn corr (Bael) is an Indian medicinal plant.It is also known as Bael plant. Aegle marmelos is a slow-growing, moderately sized tree, often cultivated in temple gardens across India, where its leaves are traditionally offered in worship to Lord Shiva. It holds significant value in traditional medicine, offering various ethnomedical applications for treating numerous ailments and promoting health.[5]

The bael tree, belonging to the Rutaceae family, is a deciduous species of moderate height and is characterized by its thorny nature.[6] Bael (Aegle marmelos Linn., belonging to the family Rutaceae and widely recognized as the Bael fruit tree, is a medium-sized, fragrant plant. It typically grows up to 6 -- 7.5 meters in height with an approximate trunk circumference of 90cm to 120cm, exhibiting a slender form and somewhat fluted bole measuring 3 to 4.5 metre in length. It grows wild throughout the deciduous forests of India, ascending up to 1200 meters in the Western Himalayas, and is also distributed in the Andaman Islands.[4]

In Hindu tradition, Aegle marmelos (bael tree) is revered as sacred, symbolizing purity and devotion. It is not only valued in spiritual rituals and religious practices but is also appreciated for its cultural relevance and extensive therapeutic applications, making it significant across spiritual, cultural, and medicinal aspects. . Since ancient times, its leaves have been offered in prayers to Lord Shiva and Goddess Parvati. The tree, considered highly auspicious, is commonly planted near Shiva and Vishnu temples and even in households.[7] The Bael tree's trifoliate leaves represent the Trimurti- brahma, Vishnu, and siva -reflecting the universal role creation, preservation, destruction. This sacred symbolism highlights the tree's deep spiritual importance in Hindu tradition, making it a revered element of worship. Their spear-shaped structure resembles the Trishula, the divine weapon of Lord Shiva, further enhancing the plant's spiritual significance in Hindu tradition and making it an important symbol of devotion, purity, and divine power.[7]



Bael leaves are also distributed to devotees as prasadam in Shiva temples and serve a role similar to Tulsi leaves in Vishnu temples. Beyond its religious significance, bael possesses important medicinal properties, particularly as a cooling agent. In India, the tree blooms during April–May, soon after new leaves appear, and the fruits generally take about 10–11

months to mature, reaching ripeness between March and June of the next year.[7]

Bael (Aegle marmelos) is a moderately sized deciduous tree that grows at a slow pace, typically reaching 12–15 meters in height. It bears a relatively short trunk covered with thick, soft bark that peels off in flakes and spreading branches, some of which are spiny, with the lower branches often drooping. Young suckers bear numerous stiff, straight spines. When the branches are wounded, they exude a clear, gummy sap resembling gum arabic, which hangs down in long strands before gradually solidifying. The exuded sap first tastes sweet but gradually causes throat irritation upon solidification. Initially pleasant, its sweetness changes over time, leading to discomfort, making it both distinctive in flavor and noteworthy for its irritant effect.[8]

Taxonomical classification

Kingdom	Plantae
Sub kingdom	Tracheobinota
Super division	Spermatophyta
Division	Magnoliophyta
Class	Magnoliopsida
Sub class	Rosidae
Order	Sapindales
Family	Rutaceae
Genus	Aegle
Species	Aegle marmelos
Tribe	clausenae
Common name	Bael Patra, Bael

Vernacular names

- Tamil- Vilavam
- Sanskrit- Bilvam
- English- Bael, Wood apple
- Hindi- Sriphal
- Malayalam- Koovalam
- Telungu- Maredu, Bilvamu
- Urdu- Bel
- Gujarati- Billi
- Arabic- Shul
- Japanese- Berunoki
- Nepali- Belapatra

- Chinese- Mu ju
- French- Bel indien
- Italian- Cotogno del Bengala

Scientific names

Correa, Belou marmelos[L.] Lyons Bilacus marmelos[L.] Kuntze

Crateva marmelos[L.] Crateva religiosa Ainslie and Feronia pellucida Roth

Distribution

Bael has been extensively used in traditional Indian drugs for its numerous medicinal parcels. It's native to Northern Indian but it's also set up throughout the Indian promontory as well as Srilanka, Myanmar, Bangaladesh, Thailand, Indo- China.[9] Originating in India, this tree is now widely cultivated across many regions of Southeast Asia. In India, it grows wild, especially in dry timber, external Himalayas, Shivalils, South Indian tableland.[6] It's a tropical plant and grows up to an altitude of 1,200 m above ocean position. It's extensively distributed in Nepal, Pakistan, Vietnam, Laos, Cambodia, Malaysia, Tibet, Java, Philippines and Fiji.[5] It's generally set up in Indo gangetic plains, Sub- Himalayan tracts, northeastern region and dry and evanescent timber of central and southern promontory. In India Rajasthan, Uttar Pradesh, Madhya Pradesh, Punjab, Tamil nadu, Gujarat commercially cultivated.[10]

Biological profile

Aegle marmelos is a slow-growing deciduous tree that usually grows 12–15 m tall. It has a short trunk with thick, peeling bark.

The branches spread outward, occasionally bearing spines, while young shoots often produce hard, straight thorns.[11]

Leaves

The leaves are arranged alternately, usually in clusters of three to five oval, shallowly toothed leaflets, with the terminal leaflet being larger and long-petioled. Young leaves are glossy and pinkish-maroon, while mature ones release an unpleasant odor when crushed.[11]



Flowers

The tree produces fragrant flowers in small clusters along branchlets, with recurved greenish-yellow petals and numerous stamens.[11] These are arranged in small clusters, typically comprising 4 to 7 units, and are found emerging on the tender branchlets of the plant, forming distinctive grouped structures along the young shoots.

Each bloom bears four fleshy, curved petals—green externally and yellowish within—along with numerous greenish-yellow stamens.[12]



Fruit

Fruits vary in shape, with a hard or soft rind that turns yellow on ripening, enclosing aromatic pulp divided into segments.[13]

The fruit is round, oval, oblong, or pyriform, and measures 5–20 cm across. The fruit's outer covering can range from hard and woody to relatively soft, characterized by the presence of

aromatic oil glands that impart fragrance and serve as a distinguishing feature of its rind.[12]

The pulp is sweet, resinous, and astringent, containing 10–15 seeds embedded in mucilage that hardens upon drying.[11]



Bark & spines

The bark appears pale brown to gray in color, with a smooth surface that becomes finely fissured and starts flaking as the tree matures.[11]

The branches typically carry sharp, straight spines measuring about 1.2–2.5 cm, occurring singly or in pairs.[11]

When injured, the plant releases a transparent gummy exudate similar to gum arabic, which tastes sweet at first but gradually turns irritating to the throat as it hardens.[11]



Resins

On being wounded, the tree releases a gummy exudate similar to gum Arabic, which tastes sweet at first but later causes throat irritation.[11]

ETHNOBIOLOGICAL USES

Whole plant

Used traditionally for abdominal pain, abscesses, backache, breast pain, dog and snake bites, cholera, constipation, cramps, convulsions, diabetes, diarrhoea, dysentery, fever, eye problems, gastric troubles, jaundice, nausea, vomiting, "Recurrent fever, cardiac problems, digestive disturbances, and skin lesions.[13][14]

Leaves

Applied for abscesses, backache, abdominal disorders, vomiting, cuts, wounds, ulcers, cholera, diarrhoea, eye complaints, and nervous disorders. They are also used as a hair tonic, cardiotonic, in acute bronchitis, during childbirth, and for animal injuries. In veterinary medicine, they treat wounds, kill worms, and serve as fodder for livestock. Experimentally, they stimulate respiration and muscle contraction in animals.[13][14]

Stem

It has traditionally been employed in crafting pestles, which are essential tools used in oil extraction processes and sugar mills, highlighting its practical applications in traditional industries.[15]

Roots

Employed for gastric problems, heart conditions, intermittent fever, dog bites, rheumatism, and as antiamoebic and hypoglycaemic agents.[16]

Bark

Remedies for stomach disorders, fever, and cardiac issues.[16]

Fruit

Used for diarrhoea, dysentery, constipation, gastric disorders, ulcers, epilepsy, gonorrhoea, intestinal worms, and viral infections. It also acts as a digestive, tonic, stomachic, and laxative. Additionally, fruits are consumed fresh or processed into jam, preserves, or toys.[17]

Seeds

It has long been recognized in traditional medicine for its effectiveness in reducing fever, earning value as a natural febrifuge with notable therapeutic and cultural importance.[13]

Wood

Crafted into beads, especially worn by lower caste communities.[17]

Chemical constituents in Aegle marmelos

The leaves of Aegle marmelos are rich in diverse phytochemicals and have been reported to contain a wide range of compounds. The plant contains several alkaloids, including halfordinine, ethylcinnamamide, marmeline, aegeline, aegelenine, dictamine, fragrine, O-methylhalfordinine, O-isopentanylhalfordiniol, and N-4-methoxy styryl cinnamide.Other identified groups include cardiac glycosides, terpenoids (α-phellandrene, p-cymene, limonene), saponins, and tannins such as skimmianine and umbelliferone. Leaves also contain carotenoids, coumarins (including marmelosin, marmesin, imperatorin, marmin, alloimperatorin methylether, xanthotoxol, scoparone, scopoletin, psoralen, and marmelide), polysaccharides (galactose, arabinose, uronic acid, and L-rhamnose), along with flavonoids and steroids.[21]

Pulp derived from the fruits of A. marmelos is similarly abundant in bioactive constituents such as steroids, terpenoids, flavonoids, phenolics, lignin, fats, oils, inulin, proteins, carbohydrates, alkaloids, and cardiac glycosides.[21] Specific compounds isolated from various parts of the plant highlight its chemical diversity:

The leaves are rich in bioactive constituents including skimmianine, aegeline, lupeol, cineole, citral, citronellal, cuminaldehyde, eugenol, marmesinine, α-phellandrene, and p-cymene.[21]

Similarly, the bark provides significant phytochemicals such as skimmianine, fagarine, and marmin, contributing to the plant's medicinal properties and therapeutic potential.[21]

Fruit is reported to have marmelosin, luvangetin, aurapten, psoralen, marmelide, tannins, α-phellandrene, and p-cymene.[21]

The seeds are a good source of oil, composed mainly of fatty acids like palmitic, stearic, oleic, linoleic, and linolenic acids.[21]

Beyond its diverse phytochemical composition, the plant is also a source of vital minerals, further enhancing its nutritional profile and supporting both medicinal significance and traditional therapeutic applications. Quantitative studies show the presence of phosphorus (0.137%), potassium (0.746%), calcium (0.188%), magnesium (0.127%), and iron (0.007%). This broad chemical profile explains the extensive therapeutic applications attributed to A. marmelos in traditional medicine.[21]

Pharmacological activities of chemical constituents in A.marmelos

Pharmacological activities of Alkaloids

Alkaloids are bioactive compounds with diverse pharmacological properties. In plants, they serve as protective agents, helping to deter herbivores and inhibit the growth of harmful microbes. Many possess antibacterial, antifungal, antiviral, and cytotoxic activities, while some function as phytoalexins. In animals, several alkaloids are highly toxic and can even be lethal when ingested. Certain compounds, such as nicotine and anabasine, are widely used as natural insecticides due to their strong neurotoxic action.[18]

Alkaloids commonly influence the nervous system, one of the key control pathways in animals.[18] For example, plants containing protoberberine alkaloids have traditional uses in Chinese medicine as analgesics, sedatives, antiseptics, and stomach remedies. In Indian and Islamic medicine, such plants are applied for treating bleeding disorders, eye ailments, and as uterine muscle relaxants. Both quaternary alkaloids and their tetrahydro derivatives show notable biological effects; compounds like palmatine, jatrorrhizine, and tetrahydropalmatine demonstrate antimalarial, analgesic, sedative, bradycardial, and hypotensive properties.[19]

Pharmacological activities of Terpenoids

Terpenoids represent a broad group of naturally occurring compounds known for roles. Terpenoids contribute to insect resistance, act as antioxidants, and support immune system regulation.[20] They also play roles in anti-aging processes, protect neural function, and may reduce the risk of degenerative disorders. Owing to this extensive pharmacological spectrum, terpenoids are being increasingly recognized as valuable candidates for modern drug discovery and therapeutic development.[20] their diverse medicinal properties. They demonstrate significant antitumor, anti-inflammatory, antibacterial, antiviral, antimalarial, hypoglycemic, and cardioprotective activities, while also enhancing transdermal absorption of drugs. Beyond these well-established effects, research highlights their broader biological

Pharmacological activities of Flavonoids

Flavonoids exhibit a broad spectrum of therapeutic effects, including antioxidant, anti-inflammatory, antimicrobial, antidiabetic, antiviral, antithrombotic, anticancer, antimutagenic, hepatoprotective, and anti-allergic activities, making them valuable natural compounds for preventing and managing various health conditions.[22]

Pharmacological activities of tannins

Tannins possess anti-inflammatory, anti-aging, and anti-proliferative properties. They help lower the risk of cancer, cardiovascular conditions, and neurodegenerative disorders, including Alzheimer's disease.[23]

Pharmacological activites of coumarin

Coumarin derivatives have attracted considerable attention due to their diverse biological and pharmacological activities. Both natural and synthetic coumarins have been reported to exhibit anti-inflammatory, anticoagulant, and anticancer properties, among others. Among these, the anticancer activity of coumarins is regarded as particularly significant. Recent studies suggest that the interaction of coumarins with G-quadruplex structures may provide a novel target for regulating proto-oncogenes, thereby opening new avenues in cancer therapeutics.

It also has the Alzheimer 's disease Inhibition , anti- oxidant activity, anti HIV, anti bacterial and used as rheumatoid arthritis.[24]

Pharmacological activities of Steroids

The most notable activities identified include antineoplastic, antisecretory, antiviral, antidiabetic, anti-ischemic, anxiolytic (for phobic disorders), regulation of lipid metabolism, and several others.[25]

Pharmacological activities of Cardiac glycosides

Cardiac glycosides are mainly employed in managing heart failure. Beyond their cardiotonic goods, certain cardiac glycosides have also been delved for implicit antitumor exertion. Also, studies have reported that some members of this class exhibit inhibitory goods against rhinovirus.[26]

Pharmacological activities of Saponins

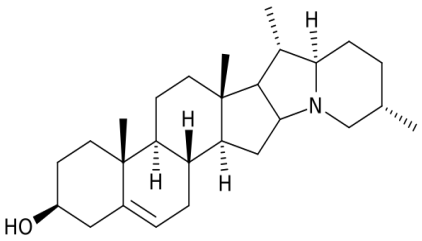
Saponins are naturally occurring compounds known for their structural diversity and wide biological roles. They possess cholesterol-lowering, anticancer, antioxidant, and immune-boosting activities. Research shows they can hinder protein digestion, reduce blood sugar, and affect reproduction in animals. Additionally, saponins display antifungal, antiviral, analgesic, and anti-nociceptive effects, while also being harmful to protozoans, molluscs, and some cold-blooded species.[27]

Pharmacological activities of phenylpropanoids

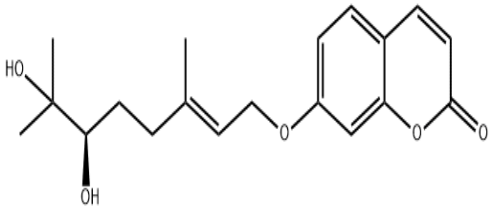
Natural phenylpropanoid glycosides have been evaluated through various pharmacological assays and are known to exhibit a wide range of activities, including antioxidant, anti-inflammatory, wound-healing, antimicrobial, and antitumor/chemopreventive effects.[28]

Pharmacological activities of carbohydrates

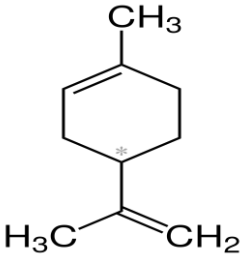
Therapeutic agents derived from carbohydrates consist of polysaccharides and oligosaccharides with anti-inflammatory, anticoagulant, and antithrombotic potential, obtained from both natural and synthetic origins. Furthermore, research has shown that monosaccharides, whether natural or synthetic, possess notable in vivo anti-inflammatory and cardioprotective activities.[29]



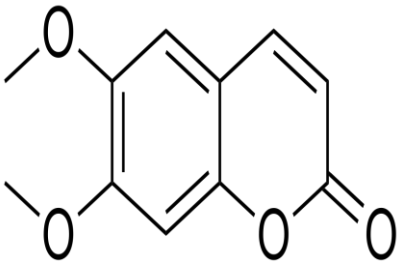
Aegeline



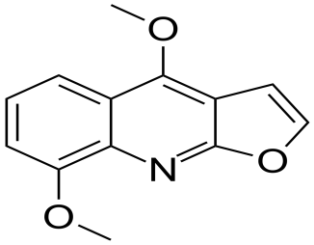
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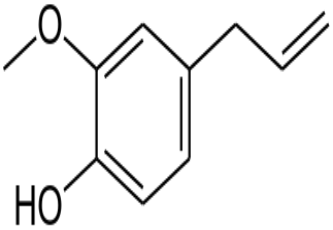
Limonene



Scoparone

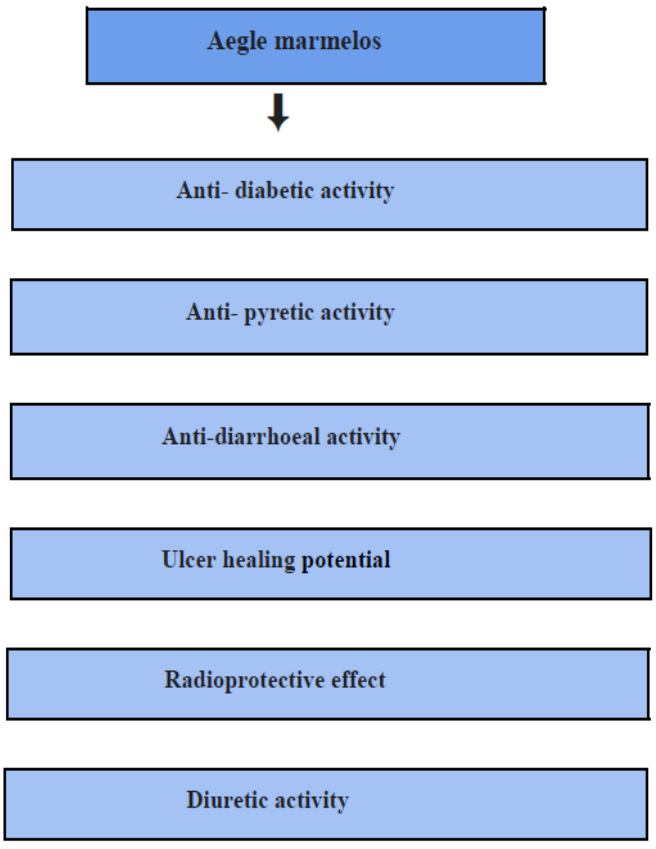


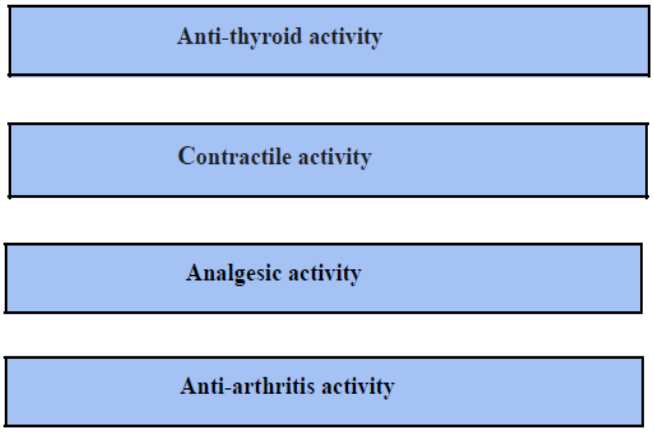
Fagarine



Eugenol

Pharmacological activities of Aegle marmelos





The present research aimed to evaluate the effectiveness of callus tissue derived from Aegle marmelos leaf explants in controlling diabetes, in comparison with the natural plant material. Extracts from both the leaf and callus significantly reduced blood glucose levels in streptozotocin-induced diabetic rabbits. Among all the tested extracts, those obtained with methanol showed the highest anti-diabetic activity. These findings indicate that A. marmelos callus culture developed in vitro possesses comparable potential to the natural leaf extract for diabetes management.[30]

Aegle marmelos Corr. (Rutaceae) is an important plant in Indian Ayurvedic medicine, traditionally prescribed for managing diabetes mellitus. In this study, aqueous seed extracts were orally administered to normal, sub-diabetic (normal fasting blood glucose but impaired glucose tolerance), and mildly diabetic (fasting blood glucose 120–250 mg/dl) rats at doses of 100, 250, and 500 mg/kg. Among the tested doses, 250 mg/kg proved to be the most effective, lowering blood glucose levels by 35.1% in healthy rats within 6 hours. The same dose also produced a significant decrease in glucose levels—41.2% in sub-diabetic and 33.2% in mildly diabetic animals—during the glucose tolerance test after 2 hours. Furthermore, in severely diabetic rats (fasting blood glucose >250 mg/dl), 14 days of treatment with 250 mg/kg extract reduced fasting glucose by 60.84% and urinary sugar by 75% compared to pretreatment values. In addition, the extract lowered total cholesterol by 25.49%, reduced LDL and triglycerides by 53.97% and 45.77% respectively, and raised HDL by 33.43%. These findings suggest that the aqueous seed extract of Aegle marmelos has shown significant antidiabetic and lipid-lowering effects in studies conducted on diabetic rats.[31]

Wound healing potential

This investigation focused on assessing the wound-healing potential of Aegle marmelos seeds. Ointments were formulated using methanolic and aqueous extracts mixed with white soft paraffin at concentrations of 5% (w/w) and 10% (w/w). These formulations were performed in rats using excision and incision wound models. The treatment groups showed a notable improvement in wound contraction, tensile strength, and a reduction in epithelialization time. Among them, ointments containing the methanolic extract demonstrated highly significant wound-healing activity ($p < 0.01$) at both concentrations across all models.</mark> Similarly, ointments prepared with the aqueous extract also exhibited significant wound-healing effects ($p < 0.05$) at the same concentrations.</mark>.[32]

This study evaluated the wound-healing activity of Aegle marmelos fruit pulp extract (AME) using excision, incision, and dead space wound models in rats. AME was administered orally at a dose of 200 mg/kg once daily, with the treatment duration varying according to the wound type. The extract was assessed for its effects on wound contraction, epithelialization time, scar formation, tensile strength, and tissue histology.By day 20, rats treated with AME showed complete wound closure and epithelialization, which occurred earlier than in control animals (day 24). Treatment also reduced the epithelialization period and scar area, while significantly improving wound-breaking strength. Biochemical analysis of granulation tissue revealed elevated collagen content (33.7–64.4%, $P < 0.001$) and antioxidant activity (13.0–38.8%, $P < 0.05$ to $P < 0.001$).</mark> In contrast, oxidative stress markers (55.0–55.6%, $P < 0.001$) and myeloperoxidase levels (21.3%, $P < 0.001$) were significantly reduced.</mark>These findings suggest that Aegle marmelos supports wound healing by promoting connective tissue growth, boosting antioxidant activity, and reducing tissue injury from free radicals and inflammatory enzymes.[33]

Anti-diarrhoeal activity

Aegle marmelos has long been used in traditional medicine as a remedy for diarrhoea, but its exact mechanism of action against infectious types of the disease remains unclear. This study assessed the antimicrobial activity and effects on major diarrheal pathogens using a hot aqueous extract (decoction) derived from the dried pulp of unripe fruits. Although the extract showed only mild direct antimicrobial activity, it significantly interfered with bacterial adhesion to the intestinal epithelium and also reduced both the production and activity of certain enterotoxins. These results suggest that Aegle marmelos possesses anti-diarrheal

properties that may result from multiple mechanisms, supporting its traditional use documented in Ayurvedic texts and its continued relevance in community-based treatments of diarrhoeal disorders.[34]

This study investigated both the in vitro and in vivo antidiarrhoeal effects of the chloroform extract derived from the root of Aegle marmelos (Correa) Linn. Antimicrobial activity was assessed using agar dilution and disc diffusion methods, while animal experiments were conducted in rats to evaluate therapeutic efficacy. Among the 35 diarrhoeagenic strains tested, the extract showed the strongest activity against Vibrio cholerae, followed by Escherichia coli and Shigella species. The in vitro results indicated an efficacy comparable to that of ciprofloxacin. In addition, rats treated with A. marmelos root extract (AMRE) demonstrated significant protection against castor oil–induced diarrhoea, confirming its antidiarrhoeal potential.[35]

Diuretic activity

The diuretic effects of aqueous extracts from the stem bark, leaves, and fruits of Aegle marmelos (100 mg/kg) were tested in rats, mice, guinea pigs, and rabbits. In acute metabolic studies, the stem bark extract influenced water intake within 4 hours of administration. Under forced diuresis conditions, it reduced urine output volume between 1 and 4 hours after treatment, indicating potential diuretic-modulating properties.[36]

Anti-ulcer activity

Aegle marmelos Linn, a well-known plant in Indian traditional medicine, is recognized for its potential role in managing gastric ulcers.This study aimed to scientifically evaluate its efficacy against gastric ulcers. An aqueous leaf extract was prepared and administered orally to experimental animals at a dose of 1 g/kg body weight for 21 days. Various parameters, including gastric secretion volume, ulcer index, pH, total acidity, pepsin activity, hexose, and hexosamine levels, were assessed. Results revealed a marked decrease in ulcer count, gastric juice volume, and acidity, along with a significant rise in pH and hexosamine content. Pepsin activity and hexose levels, however, remained largely unaffected. Histopathological observations further confirmed the protective effects of the extract, supporting its potential antiulcer properties.[37]

Analgesic activity

Relieving pain has always been one of the foremost goals of medical science. Numerous

synthetic anti-inflammatory and analgesic drugs, such as aspirin, indomethacin, and phenylbutazone, are currently used in clinical practice. However, their prolonged use is often associated with adverse effects, which has encouraged researchers to explore safer alternatives. The global search for new molecules and therapeutic agents with comparable or superior efficacy, but fewer side effects, is still ongoing. In this context, medicinal plants have gained significant attention due to their natural origin, safety profile, and long history of use in traditional healing systems.[38]

Among these, Aegle marmelos (commonly known as Bael) holds a prominent place in traditional and folklore medicine as well as in cultural and religious practices. Different parts of the plant, including its roots, leaves, flowers, fruits, and seeds, have been studied extensively for their diverse pharmacological activities. Research findings suggest that Aegle marmelos exhibits multiple beneficial effects, such as analgesic, anti-inflammatory, and antipyretic actions, along with antidiabetic, antioxidant, and hepatoprotective properties. These attributes support its therapeutic potential against a wide range of health conditions, particularly those involving pain, inflammation, and oxidative stress.[38]

Given its broad spectrum of bioactive compounds and relatively low risk of side effects compared to many synthetic drugs, Aegle marmelos continues to be an important candidate for the development of novel plant-based medicines. Further scientific validation and clinical evaluation of its extracts and phytoconstituents may pave the way for safer, more effective alternatives in modern therapeutics.[38]

Anti-pyretic activity

Non-steroidal anti-inflammatory drugs (NSAIDs) remain the most widely used therapeutic option for the treatment of fever. Despite their effectiveness, their long-term use is associated with adverse effects, including hepatic and renal toxicity, inhibition of COX-1 enzymes leading to gastrointestinal disturbances, and an increased risk of thrombotic events. These limitations have encouraged researchers to focus on identifying safer and more effective antipyretic agents from natural sources, particularly medicinal plants.

Aegle marmelos (commonly known as Bael), belonging to the family Rutaceae, is a well-known medicinal plant used extensively in Ayurveda, Siddha, and traditional folk medicine. It has been employed in the management of various ailments, including fever. The present study was designed to assess the antipyretic potential of Aegle marmelos (L.) Correa

leaves using different experimental models of pyrexia in albino rats.[39]

Initially, pyrexia was induced by subcutaneous administration of a 12.5% yeast suspension, and rectal temperatures were recorded at fixed time intervals. Treatment with ethanolic extracts of Aegle marmelos leaves at doses of 200 mg/kg and 400 mg/kg body weight produced a significant ($p<0.001$) reduction in elevated body temperature, with the</mark> effect being dose dependent. The study further evaluated the activity using TAB vaccine-induced pyrexia in rats, which supported the findings.[39]

Interestingly, the antipyretic action of the extracts was found to be comparable to that of paracetamol (100 mg/kg, p.o.), a widely used standard antipyretic drug. These results suggest that Aegle marmelos leaves possess promising antipyretic properties, supporting their traditional use and potential as a safer herbal alternative to conventional NSAIDs.[39]

Immunomodulatory activity

Aegle marmelos is a well-known medicinal plant recognized for its wide range of therapeutic properties, including its role as an immunomodulatory agent. Previous studies have identified several bioactive compounds within the plant, such as alkaloids, phenolics, flavonoids, coumarins, terpenoids, and antioxidants, which contribute to its pharmacological activities. Due to these constituents, Aegle marmelos has the potential to modulate immune responses by stimulating antibody production, particularly immunoglobulins such as IgM and IgG.[40]

The present investigation examines the effect of Aegle marmelos leaf filtrate on immune response by evaluating IgM and IgG levels in Rattus norvegicus following administration of 2% sheep red blood cells, aiming to evaluate its potential as a natural immunomodulatory agent. A total of 30 rats were allocated into five groups. The negative control group was maintained on a regular diet, whereas the positive control group was administered a 2% SRBC injection. The treatment groups were administered SRBC 2% combined with Aegle marmelos filtrate at concentrations of 25% (P1), 50% (P2), and 75% (P3).[40]

Results indicated that the filtrate enhanced IgM titers, with the most pronounced effect observed at the 75% concentration, though the increase was not statistically significant. However, none of the treatment groups showed a significant change in IgG levels when compared with the control group.[40]

Anti-cancer

Cancer is characterized by the uncontrolled growth and proliferation of abnormal cells, posing a significant challenge in clinical treatment. Conventional therapies, although effective to some extent, are often associated with limitations and adverse effects, which has led to growing interest in alternative medicines derived from plants. Aegle marmelos, a medicinal plant widely used in traditional systems, has attracted attention for its potential anticancer properties alongside its other pharmacological activities.[41]

In the present investigation, the cytotoxic effect of Aegle marmelos leaf extract was evaluated against MCF7 breast cancer cells. Treatment with the extract resulted in a concentration-dependent reduction in cell viability, decreasing from nearly 100% to about 50% as the concentration increased from 100 to 600µg/mL. Furthermore, molecular analysis revealed a marked downregulation of Wnt mRNA expression in MCF7 cells upon exposure to the extract. A similar trend was observed with β-catenin mRNA expression, which also showed a significant reduction following treatment. These findings indicate that Aegle marmelos interferes with the Wnt/β-catenin signaling pathway, ultimately promoting cell death in breast cancer cells.[41]

In conclusion, Aegle marmelos demonstrates promising anticancer potential by modulating molecular pathways while also exhibiting hepato-renal protective effects. Thus, it holds promise as a safe and novel therapeutic option against breast cancer.[41]

Anti-arthritis activity

The present research investigated the anti-arthritic potential of the aqueous leaf extract of Aegle marmelos (AEAM) using a formaldehyde-induced arthritis model in rats. Arthritis was evaluated by monitoring paw swelling, changes in paw diameter, and the percentage inhibition of paw volume. Administration of AEAM produced a significant reduction in paw inflammation and diameter, indicating a protective effect against joint swelling and tissue damage. These findings suggest that AEAM effectively reduces inflammatory responses associated with arthritis. The beneficial activity observed in this study can be attributed to the presence of bioactive phytoconstituents, particularly alkaloids, flavonoids, and saponins, which are known for their anti-inflammatory and antioxidant actions. Overall, the results provide scientific support for the traditional use of Aegle marmelos in managing arthritic conditions and highlight its therapeutic potential as a natural anti-arthritic agent, making it a promising candidate for further pharmacological evaluation.[42]

CONCLUSION

The present review highlights that *Aegle marmelos* (Bael) is a valuable medicinal plant possessing diverse phytochemical constituents such as alkaloids, flavonoids, tannins, saponins, and coumarins. These bioactive compounds contribute to a wide range of pharmacological activities, including anti-asthmatic, antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and hepatoprotective effects. The traditional and scientific evidence collectively supports the therapeutic potential of *Aegle marmelos* in modern medicine. Although *Aegle marmelos* has shown promising anti-asthmatic potential in preliminary studies, further research is needed to explore its specific mechanisms of action on the respiratory system. Detailed pharmacological and clinical investigations should be conducted to identify the active constituents responsible for bronchodilation and anti-inflammatory effects. Standardization of extracts, dose optimization, and evaluation of toxicity profiles are also essential to ensure safety and efficacy. Advanced studies such as molecular docking, in vivo asthma models, and human clinical trials can help validate its traditional use and promote the development of novel herbal formulations for asthma management.

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