

Aim: The Anti-Inflammatory Properties of Bael (Aegle Marmelos)

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Abstract:

Aegle marmelos (bael), a medicinal plant widely used in traditional Ayurvedic and folk medicine, exhibits significant anti-inflammatory potential supported by growing phytochemical and pharmacological evidence. Its leaves, fruit, bark, and roots contain bioactive compounds such as coumarins (marmelosin, marmin), flavonoids, alkaloids, and triterpenoids that contribute to antioxidant and cytokine-modulating activities. Preclinical studies demonstrate that A. marmelos extracts suppress key inflammatory mediators including TNF- α , IL-1 β , IL-6, COX, LOX, nitric oxide, and NF- κ B signaling pathways. In vitro models show inhibition of macrophage activation, while in vivo studies confirm reduced edema, granuloma formation, and tissue inflammation comparable to standard non-steroidal anti-inflammatory drugs. Although human clinical evidence remains limited, traditional use and animal data strongly support the plant's therapeutic relevance in conditions associated with acute and chronic inflammation. Further research is required to establish standardized extracts, determine active constituents, clarify molecular mechanisms, and conduct well-designed clinical trials. Overall, Aegle marmelos represents a promising natural source for developing safe and effective anti-inflammatory agents.

Keywords:

Aegle Marmelos, Anti-inflammatory, Bilva; Ayurveda, Pharmacology, Phytochemical, Traditional system of medicine

Objective:

To analyze the phytochemical composition of Aegle marmelos and identify the compounds responsible for its anti-inflammatory activity.

To review experimental evidence from in vitro studies that evaluate the plant's effects on inflammatory mediators and cellular responses.

To summarize findings from in vivo animal models assessing the plant's ability to reduce inflammation and related symptoms.

To explore the molecular mechanisms through which A. marmelos modulates pathways such as COX, LOX, NF- κ B, cytokines, and nitric oxide.

To compare the anti-inflammatory efficacy of A. marmelos with standard anti-inflammatory drugs where available.

To identify research gaps in current literature, including the need for standardization of extracts and clinical research in humans.

To provide recommendations for future studies aimed at validating the plant's therapeutic potential and ensuring safe, effective application

Introduction:

Aegle marmelos (commonly known as bael) is a culturally and medicinally significant plant that has been deeply rooted in traditional healing systems, particularly Ayurveda. Every part of the plant—its leaves, fruit, stem bark, and roots—has been valued for therapeutic purposes, ranging from digestive disorders to metabolic and inflammatory conditions. Over the years, growing scientific interest has focused on understanding the pharmacological basis behind these traditional uses. Inflammation is a fundamental biological response that protects the body against infections, toxins, and injuries. While acute inflammation is protective, chronic and uncontrolled inflammatory processes contribute to various diseases such as arthritis, cardiovascular disorders, metabolic syndrome, and autoimmune conditions. Due to the limitations and side effects associated with conventional anti-inflammatory drugs, there is a continued search for safer and more effective plant-based alternatives. Recent research suggests that *Aegle marmelos* possesses significant anti-inflammatory potential, primarily attributed to its rich phytochemical profile, which includes coumarins, flavonoids, alkaloids, tannins, and terpenoids. These compounds exhibit antioxidant, enzyme-inhibiting, and cytokine-modulating properties that may help regulate key inflammatory pathways. Studies using cell lines and animal models have shown promising results, demonstrating suppression of pro-inflammatory mediators such as TNF- α , IL-1 β , IL-6, nitric oxide, COX, LOX, and NF- κ B signaling. Given the increasing scientific evidence and its longstanding traditional use, a detailed review of the anti-inflammatory properties of *Aegle marmelos* is both timely and important. This review aims to synthesize existing research, highlight the plant's therapeutic potential, and identify areas where further investigation is needed to support the development of safe, standardized, and effective natural anti-inflammatory agents.

Taxonomy:

Kingdom: PLANTAE

Phylum: ANGIOSPERM

Class: DICOTYLEDONS

Order: SAPINDALES

Family: RUTACEAE

Subfamily: AURANTIOIDEAE

Genus: AEGAL CORREA

Species: A.MARMELOS

Synonyms:

It has been known by various common names geographically like,

*Belos maemelos (L.)

*Golden Apple

*A.Lynos Crateva maemelos(L.)

*Indian Quince

Vernacular Names:

These are the names given or known by the locals in a particular geographical area of the Indian region or various languages like,

*Assamese : Bael, Vael

*Bengali: Bela,

*Punjabi : Bil

*Tamil: Vilvam

*Telugu : Maredu

*Urdu : Belgiri, (Bael)Bilva

*English: Bengal Quince, Bael

*Gujrati: Bill, Bilum

*Hindi : Bela, Sripthal, Bel

*Kannada: Bilva

*Malayalam: Koovalam

*Marathi: Bel, Baela

*Oriya : Bela*Punjabi

*Tamil: Vilvam

*Telugu : Maredu

*Urdu : Belgiri, (Bael)

Literature Survey:

1. Mujawar & Hiremath (2020): Evaluation of in vitro antioxidant and anti-inflammatory activities of *Aegle marmelos* leaf extracts. This study measured total phenolic and flavonoid content in aqueous and organic leaf extracts of *A. marmelos*. It also evaluated antioxidant activity (e.g., via DPPH) and anti-inflammatory capacity using in vitro assays. The aqueous extract showed particularly high phenols and flavonoids and exhibited significant anti-inflammatory effects.

2. G. N. Sharma, S. K. Dubey, N. Sati & J. Sanadya (2011): Anti-inflammatory activity and total flavonoid content of *Aegle marmelos* seeds. This research assessed aqueous and methanol extracts of *A. marmelos* seeds in carrageenan-induced paw edema and cotton-pellet granuloma models in rats. They quantified flavonoid content (using quercetin as standard) and found that methanolic extract (at doses 200–400 mg/kg) significantly reduced inflammation, indicating that flavonoids contribute to anti-inflammatory activity.

3. Mujeeb, Khan, Bajpai & Pathak (2018): Phytochemical study of *Aegle marmelos*: Chromatographic elucidation of polyphenolics and assessment of antioxidant and cytotoxic potential. Through chromatographic techniques, the authors identified and characterized polyphenolic compounds in *A. marmelos*. They also evaluated antioxidant capacity and cytotoxicity, laying groundwork for understanding which phytochemicals might be responsible for biological activity, including inflammation modulation.

4. Marmelosin (furanocoumarin) – PubMed (2018): Antioxidant and anti-inflammatory properties of marmelosin from Bael (*Aegle marmelos* L.); inhibition of TNF- α mediated inflammatory/tumor markers. Researchers isolated marmelosin from *A. marmelos* fruit and characterized it. They tested its effect on

RAW 264.7 macrophage cells and found that marmelosin strongly reduced nitric oxide (NO) and TNF- α release, inhibited NF- κ B activation, and also showed antiproliferative and apoptotic effects. This indicates a potent anti-inflammatory and immunomodulatory role for marmelosin.

5. In vitro cell-model validation – PMC (2023): Phytochemical analysis and evaluation of antioxidant, antidiabetic, and anti-inflammatory properties of *Aegle marmelos* and its validation in an in-vitro cell model. Using a rat fibroblast cell line under high-glucose conditions, this study demonstrated that *A. marmelos* leaf extract reduces reactive oxygen species (ROS) generation and downregulates the mRNA expression of inflammatory markers (iNOS and TNF- α). They also showed inhibition of protein denaturation (a proxy for anti-inflammatory activity).

6. Root Extract Study – PubMed (2011): Evaluation of the anti-inflammatory activity of *Aegle marmelos* (Bilwa) root. This classic in vivo study assessed aqueous root extract of *A. marmelos* in both acute (carrageenan-induced paw edema) and chronic (cotton pellet granuloma) inflammation models in rats. The extract showed substantial inhibition in the acute model (~46% edema reduction), suggesting root constituents contribute to anti-inflammatory effects.

7. Flower Extract Study – PubMed (2013): Anti-inflammatory activity of dried flower extracts of *Aegle marmelos* in Wistar rats. Investigating the water extract of dried *A. marmelos* flowers, the authors found that it significantly reduced carrageenan-induced paw edema in rats. Mechanistic assays suggested that the anti-inflammatory effect involves inhibition of nitric oxide production, stabilization of cell membranes, and antioxidant/lipid peroxidation inhibition.

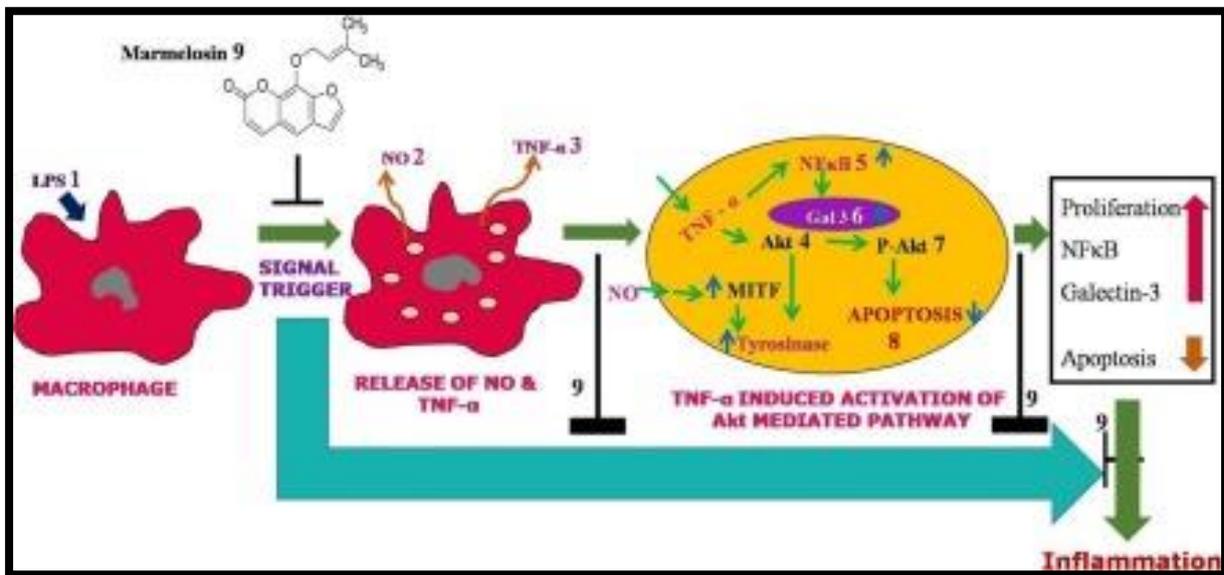
8. Systematic Review – Sivakumar, Itsaranuwat & Narendhirakannan (2024): A Systematic Review on Biochemical and Pharmacological Properties of the Active Phytochemicals Present in *Aegle marmelos* (L.). This paper synthesizes findings from over 60 studies on *A. marmelos*. It catalogs its ethnomedicinal uses, bioactive constituents (alkaloids, coumarins, flavonoids, etc.), as well as pharmacological effects including anti-inflammation, antioxidant, and other activities. The authors highlight that many of its traditional uses are validated by scientific studies but also note a lack of standardized extracts and human clinical trials.

Mechanism of Anti-inflammatory Action of *Aegle marmelos*:

The anti-inflammatory effects of *Aegle marmelos* (bael) are primarily attributed to its rich phytochemical composition, including coumarins (marmelosin, imperatorin), flavonoids, alkaloids, terpenoids, and phenolic compounds. These bioactive compounds modulate inflammation at multiple levels, targeting key enzymes, signaling pathways, and pro-inflammatory mediators.

1. Inhibition of Pro-inflammatory Cytokines: marmelos extracts suppress the production and release of tumor necrosis factor-alpha (TNF- α), interleukin-1 beta (IL-1 β), and interleukin-6 (IL-6) in macrophages and fibroblast cells. This reduces the recruitment and activation of immune cells at sites of inflammation.

Research Through Innovation



2. **Suppression of Enzymatic Mediators (COX & LOX):** Cyclooxygenase (COX) and lipoxygenase (LOX) are key enzymes in the synthesis of prostaglandins and leukotrienes, which promote inflammation. marmelos have been shown to inhibit COX and LOX activity, reducing prostaglandin and leukotriene levels, which alleviates edema and tissue inflammation.

3. **Modulation of NF-κB Signaling:** NF-κB is a transcription factor that regulates genes encoding pro-inflammatory cytokines, adhesion molecules, and enzymes like iNOS and COX-Marmelosin and other coumarins inhibit NF-κB activation, leading to reduced transcription of inflammatory genes and lower production of pro-inflammatory mediators.

4. **Nitric Oxide (NO) Inhibition:** Overproduction of nitric oxide by inducible nitric oxide synthase (iNOS) contributes to inflammation and tissue damage. marmelos extracts inhibit iNOS expression and NO production in activated macrophages, reducing oxidative stress and inflammation.

5. **Antioxidant Activity:** Reactive oxygen species (ROS) play a key role in propagating inflammation. Flavonoids and phenolic compounds in *A. marmelos* scavenge ROS, reducing oxidative stress and preventing activation of inflammatory signaling pathways

6. **Membrane Stabilization:** marmelos leaf and fruit extracts stabilize lysosomal and red blood cell membranes, preventing the release of inflammatory mediators and enzymes that contribute to tissue damage.



Plant Description:

A. marmelos is a slow-growing, medium sized tree, up to 12 to 15 m tall with short trunk, thick, soft, flaking bark, and spreading, sometimes spiny branches, the lower ones drooping.

It consist of the below mentioned parts likes,

Sr.No	hh	description
1	<p>Leaf</p> 	<p>Leaves are applied to inflamed parts and are very efficacious in the form of poultice to unhealthy ulcers</p> <p>*Young leaves are eaten and said to cause sterility or even abortion.</p> <p>*Juice of fresh leaves has a laxative action and also employed in asthmatic complaints, ophthalmia and other eye affections.</p> <p>*Decoction of leaves is used as a febrifuge and expectorant.</p> <p>*. Leaves are also use in Abscess, backache, abdominal disorders, vomiting, cut and wounds, dropsy, beriberi, weakness of heart, cholera, diarrhea, cardio tonic, blood sugar, injuries caused by animals, nervous disorders, hair tonic, acute bronchitis,</p>
	<p>Root (bark)</p> 	<p>*Root bark is used in intermittent fever and as fish poison, as a remedy for palpitation of heat and melancholia.</p> <p>*Juice of the bark with a little cumin in milk is valued as remedy for poverty of seminal fluid.</p> <p>*The alcoholic extract of roots having hypoglycemic activity</p> <p>*It is also used in dog bite, gastric troubles, heart disorders, intermittent fevers, antiameobic, hypoglycemic</p>
	<p>Flower</p> 	<p>*Distillation of flowers yielded a drug used as tonic for stomach and intestine, anti- dysenteric, antidiabetic, diaphoretic and as local anaesthetic</p> <p>*. It is also used in epilepsy and as expectorant.</p>
	<p>Seeds</p> 	<p>*Seed oil exhibits antibacterial activity against different strains of vibriosd and inhibits the growth of Vibrio cholerae, Staphylococcus aureus</p> <p>*. Essential oil exhibits antifungal activity against fungi, Eeratocystis paradoxa and cephalosporium sacchari etc.</p>

<p>Fruit (Ripe)</p> 	<p>*The ripe fruit promotes digestion and is helpful in treating inflammation of rectum. *The ripe fruit extract showed antiviral activity against ranikhet disease virus *Pulp of ripe fruit is sweet, cooling, aromatic and nutritive when taken fresh *Fruit pulp is used as prevention during cholera epidemics, also given to prevent the growth of piles, useful in patients suffering from chronic dysenteric condition characterized by alternate diarrhea and constipation relieves. *Fress juice is bitter and pungent fruit extract which lower the blood sugar.</p>
<p>Fruit (Unripe)</p> 	<p>Fine powder of unripe fruit showed significant effect on intestinal parasites *Unripe fruit is used as an astringent in dysentery, stomachache in diarrhea, tonic, digeetive, demulcent, described as cardiactal, restorative, given in piles</p>

Chemical Composition:

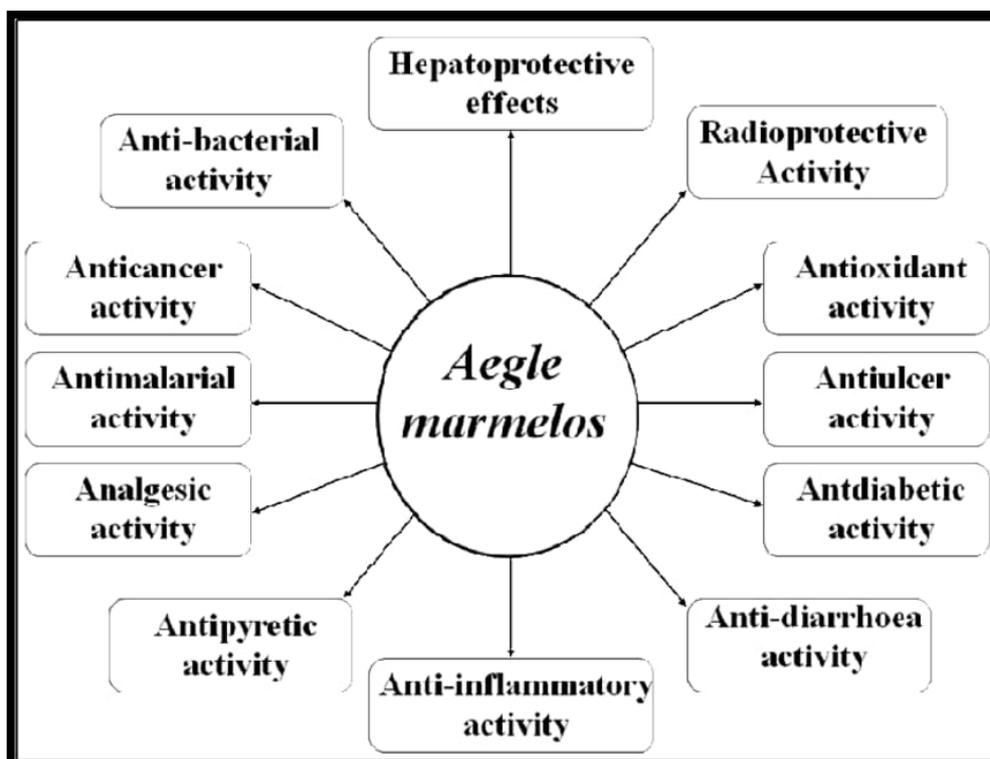
There are various chemical compositions in the every part of the plant Aegle Marmelos and are noted down below,

Sr.No	Chemical Consitituent	Activity	Examples
1	Alkaloids	*It inhibit the release of histamine and followingly reduce the inflammation and shows a anti-inflammatory action in case of respiratory disease it induce the histamine release and shows the Bronchodilation	1. Aegeline 2. Fragine 3. Aegelenine, etc.
2	Coumarins	*They shows various pharmacological actions like anti-cancer, anti- oxidant, anti- inflammation, anti-HIV, anti-coagulant, anti-bacterial, analgesic.	1. Marmin, 2. Marmelide, 3. Psoralen, 4. Imperatonin
3	Terpenoids	It shows the pharmacological action like Anti-fungal, Anti-bacterial in the case of the fungal or bacterial infections.	1. Cineol, 2. Caryophllene,
4	Tannins	By inhibiting the cell wall synthesis it stops the growth of bacterial cells and shows the anti-bacterial action.	1. Skimmianine
5	Saponins	It stops the leakage of proteins and certain enzymes from the cell and	1. Glycyrrhizin

		works on the physical damage of cell and toxic effect	
6	Flavonoids	Its show the Anti-microbial activity	1. Carotenoids 2. Polysaccharids

Pharmacological Action:

A. marmelos is one of the most widely used medicinal and nutraceutical plant in the family Rutaceae. In recent history this plants is reported for various medicinal properties Which are mentioned in Figure.



From the above mentioned pharmacological action the mostly seen action of the species Aegle Marmelos are Anti-bacterial , Anti-Diabetic , Anti-Fungal , Anti-Inflammatory which are described below,

1. Anti-Bacterial action: Various extracts of Bael leaves, roots and fruits have been reported to be active against many bacterial strains. The antibacterial activity may be due to the presence of Eugenol because these compounds have already shown their activities against various bacterial strains.
2. Anti-Diabetic action: marmelos has been use to control diabetes in traditional medicinal system. The aqueous and alcoholic extract of the fruit part showed hyperglycemia activity. This antidiabetic effect is probably due to the presence of Coumarins in the fruit extract, which potentiate the insulin secretion from existing beta cells of the isles of Langerhans.
3. Anti-Fungal action: The essential oil isolated from the leaves of Bael tree has proved to antifungal activity against various animal and human fungi like *T. rubrum* , *Microsporum gypseum* , *M. cookie* , etc. Thus it exhibits the antifungal activity by lowering the vegetative fungal body inside the host or in solid medium.
4. Anti-Inflammatory action: Pain and inflammation is a common complaint in most patients suffering from disease conditions. Inflammation is a host defense mechanism to combat or overcome the invading pathogen or the foreign particles. Non-steroidal anti- inflammatory drugs (NSAIDs) make up one of the

largest groups of drugs used for pain and inflammation. Currently available anti-inflammatory agents are associated with unwanted side effects and have their own limitations.

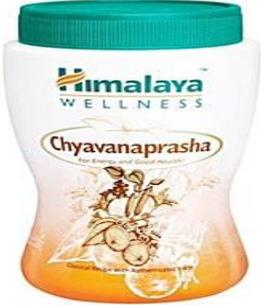
The added advantages of indigenous medicinal treatment would include its complementary nature to the conventional treatment making latter safer, well tolerated and economical remedy for acute and chronic inflammatory conditions. *Aegle marmelos* (Bilwa) is an Indian plant, which has enormous therapeutic value in traditional systems of medicine. From the various studies, methanol extract of *Aegle marmelos* leaves showed significant anti-inflammatory activity at a dose of 100 mg/kg. However, studies on aqueous extract of root and its evaluation in different anti-inflammatory models are sparse. Different organic extracts of the Bael leaves possess highly significant acute and subacute anti-inflammatory activities. These activities may be due to the presence of Lupeol and Skimmianine in the leaves because both the compounds have shown the same potentialities in pure form. Activation of histamine receptor is essential for allergic and asthmatic manifestation. The alcoholic extract of Bael leaves antagonized the histamine – induced contractions and demonstrated positive relaxant effect.

Marketed pharmaceutical Formulation:

Indian medicinal plants are considered a vast source of several pharmacologically active principles and compounds and that are commonly used in home remedies against multiple ailments. Amongst those plants, bael has enormous traditional uses against various ailments and many bioactive compounds have been isolated from this plant. The leaves, bark, roots, fruits and seeds are an integral part of Indian traditional system of medicine.

‘Ayurveda’ and various folk medicine to treat myriad ailments. Compounds like skimmianine, aegelin, lupeol, cineole, citral, citronellal, cuminaldehyde (4- isopropylbenzaldehyde), eugenol, marmesinin, marmelosin, luvangetin, aurapten, psoralen, marmelide, fagarine, marmin and tanin have been proved to be biologically active against antiulcer, antidiabetic, antihyperlipidaemic, antioxidant, anticancer, antimicrobial, radioprotective, anti-inflammatory, antipyretic, analgesic and antispermatogenic. Some of the products are listed and showed below.

Product	Company
1. Vilwadi Gulika 	M.V.R Ayurveda
2. Ojamin (Anti-diabetic drug) 	Tates remedies
3. Bily giri capsule	Ayurvedic sanjivan

	
<p>4. Chyawanprash</p> 	<p>Himalaya</p>
<p>5. Entrostat syrup</p> 	<p>Ambika medico</p>
<p>5. Bael candy</p> 	<p>Patanjali</p>
<p>6. Bael murabba</p> 	<p>Patanjal</p>
<p>7. Glucomap</p> 	<p>Maharishi ayurveda</p>

<p>8. Manasamithravatakram</p> 	<p>Oushadhi</p>
<p>9. Baek bar (burfi)</p> 	<p>Khandelwal food product</p>

Summary

Aegle marmelos (Bael) is a traditional medicinal tree containing bioactive compounds such as coumarins, flavonoids, alkaloids, and terpenoids, which contribute to its anti-inflammatory, antioxidant, antibacterial, and antidiabetic effects. It alleviates inflammation by suppressing pro-inflammatory cytokines (TNF- α , IL-1 β , IL-6), inhibiting COX and LOX enzymes, regulating NF- κ B pathways, and reducing nitric oxide production, while also neutralizing reactive oxygen species and stabilizing cell membranes. Various parts of the plant—including leaves, fruit, roots, bark, seeds, and flowers—demonstrate pharmacological activity. Animal studies indicate that its anti-inflammatory effects are comparable to conventional NSAIDs. Although preclinical evidence and traditional use support its therapeutic benefits, human clinical trials and standardized formulations are still limited. Bael is incorporated into several Ayurvedic preparations such as Chyawanprash, Bilv giri capsules, and Vilwadi Gulika.

Conclusion :

Aegle marmelos (Bael) is a traditionally significant medicinal plant with a broad spectrum of therapeutic properties, particularly its anti-inflammatory, antioxidant, antibacterial, and antidiabetic effects. Its pharmacological activity is largely attributed to bioactive compounds such as coumarins, flavonoids, alkaloids, terpenoids, saponins, and tannins. Research indicates that these constituents can modulate inflammatory pathways, inhibit pro-inflammatory cytokines (TNF- α , IL-1 β , IL-6), suppress COX and LOX enzymes, regulate NF- κ B signaling, and reduce nitric oxide and oxidative stress. Various parts of the plant—including leaves, fruits, roots, bark, seeds, and flowers—have demonstrated therapeutic potential in preclinical studies. The anti-inflammatory effects observed are often comparable to standard NSAIDs, highlighting its relevance as a natural alternative. Despite extensive traditional use and promising laboratory evidence, human clinical trials and standardized formulations remain limited. Further studies are required to identify active constituents, elucidate precise molecular mechanisms, and confirm safety and efficacy in humans. Incorporating Bael into modern medicinal practices could provide a safe, cost-effective, and complementary approach for managing both acute and chronic inflammatory conditions. Overall, *Aegle marmelos* represents a valuable plant-based resource for developing effective natural therapies.

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