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Review

Green Extraction Strategies and Profiling of Secondary Metabolites and Clinical Applications of *Aegle marmelos* (L.) Corr.

Dr. S. Lakshmi Devi*[1], Dr. S. Kannan[2], V . Kalaiyarasi[3], K. Kaviya[4], S. Keerthika[5], A. Maha Lakshmi[6], K. Manju Rekha[7]

[1,2,3,4,5,6,7] *Department of Pharmacognosy, Sri Ramakrishna Institute of Paramedical Sciences, College of Pharmacy, Coimbatore-641 044. Tamil Nadu, India.*

*Author for Correspondence: Dr. S. Lakshmi Devi
Email: ldevijponline@gmail.com

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Abstract

Aegle marmelos (L.) Corr. (Rutaceae), commonly known as Bael, is an important medicinal plant widely used in traditional Indian systems of medicine for the treatment of gastrointestinal, metabolic, inflammatory and neurological disorders. Over the past few decades, increasing scientific interest has focused on validating its traditional uses through phytochemical and pharmacological investigations. This review provides a comprehensive and systematic overview of the extraction methods, phytochemical constituents and pharmacological activities of *Aegle marmelos*. Various extraction techniques, including Soxhlet extraction, maceration and ultrasonication using aqueous and organic solvents, have been employed to isolate bioactive compounds from different parts of the plant. Phytochemical studies reveal the presence of alkaloids, coumarins, flavonoids, tannins, sterols, and triterpenoids, with aegeline, marmelosin, marmesin and β-sitosterol identified as key constituents. Pharmacological studies, primarily based on *invitro* and *invivo* models, demonstrate significant antidiabetic, antioxidant, anti-inflammatory, antimicrobial, gastroprotective, hepatoprotective, anxiolytic and antidepressant activities. Despite promising experimental evidence, limitations such as lack of extract standardization, insufficient pharmacokinetic and toxicological data and absence of controlled clinical trials restrict its clinical translation. This review highlights existing research gaps and emphasizes the need for systematic, standardized and clinically oriented studies to support the development of *Aegle marmelos* based therapeutic agents.

Keywords: *Aegle marmelos*, Antidiabetic, Antiulcer, Bael, Medicinal plant, Phytochemistry.

1. Introduction

Medicinal plants continue to play a vital role in global healthcare systems, particularly in developing countries where traditional medicine remains widely practiced. *Aegle marmelos*, belonging to the family Rutaceae, is a well-known medicinal tree native to India. It has been extensively used in the Ayurvedic, Siddha, and Unani systems of medicine for the treatment of diabetes, diarrhea[1], wound healing, inflammation, skin diseases, hypoglycemia, digestive disorders, ulcers, jaundice, cholera, typhoid, asthma, and neurological conditions [2]. Several experimental studies have been conducted to investigate its phytochemical composition and pharmacological potential. This review critically summarizes the available Phytochemical and pharmacological activity of *Aegle marmelos Fig. 1.*

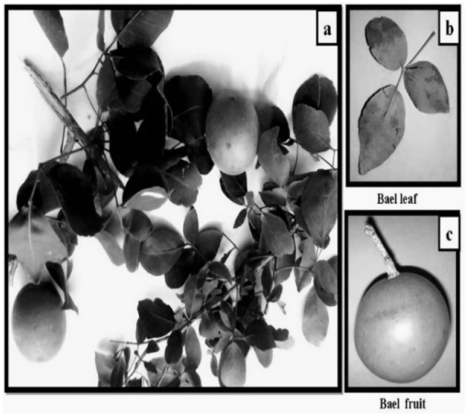

Fig 1. *Aegle marmelos* Leaf and Fruit

2. Phytochemical Constituents:

Aegle marmelos contains many bioactive compounds responsible for its medicinal properties. The leaves are rich in alkaloids, flavonoids, tannins, coumarins, and essential oils. Important alkaloids include aegeline and its derivatives. Coumarins such as marmelosin, marmesin, bergapten and umbelliferone are mainly found in fruits and roots. Other compounds such as β-sitosterol, rutin, and lupeol are also present. These phytochemicals contribute to the therapeutic effects of the plant Fig.2.

Table:1. Phytochemical Constituents [3]

Active constituent	Phytoconstituent	Plant Part	Medicinal Property
Alkaloids	• Aegelenine • Aegeline • Aegelinosides A • Aegelinosides B • Dictamine • Ethyl cinnamamide • Ethyl cinnamate • Fragrine • Halfordinol	Fruits, Leaves	Antidiabetic, Antibacterial, Anti-inflammatory and Anticancerous
Coumarins	• Alloimperatorin • Imperatorin • Isoimperatorin • Marmelide • Marmelosin • Marmesin • Marmin • Methyl ether • Psoralen • Psoralen-a • Scoparone • Scopolentin	All parts	Antidiabetic, Antioxidant, Anti-Inflammatory and Antianalgesic

Terpenoids	• Caryophyllene • Cineol • cis-Limonene oxide • cis-Linalool oxide • Cubedol • Elemol • Epi-cubebal • Hexanylhexanoate • Humulene • Isosylvestrene • Limonene • Linalool • Methyl perilate • Myrcene • *p*-Cymene • Terpinolene • Valencene	Fruits, Leaf and Bark	Anticancer

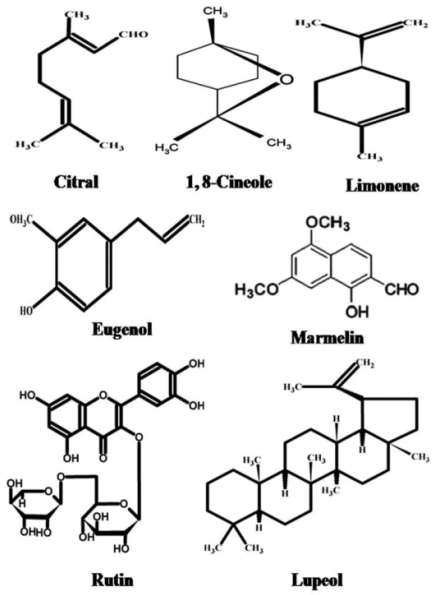

Fig.2. Structures of Phytoconstituents

3. Extraction Methods:

Different extraction methods such as Soxhlet extraction, maceration, and ultrasonication have been used to extract active compounds from *Aegle marmelos*[4]. Commonly used solvents include petroleum ether, chloroform, ethanol, methanol, and water. Soxhlet extraction and maceration methods generally give higher yields of alkaloids and coumarins.

Aqueous extraction: Fresh *Aegle marmelos* leaves were thoroughly washed and air-dried under ambient conditions (approximately 25°C) for three days. The dried leaves were then ground into a fine powder using a pestle and mortar and stored in airtight glass containers at 4 °C until further use. For aqueous extraction, the powdered material was soaked in distilled water in a 1:5 (w/v) ratio and stirred continuously overnight at room temperature. The mixture was subsequently filtered through Whatman No. 1 filter paper to remove plant debris. The resulting filtrate was freeze-dried to obtain the aqueous extract, which was stored in airtight, sterilized glass vials at −20 °C until use [5].

Soxhlet extraction: The shade-dried leaves were powdered using a mechanical grinder and passed through a 40-mesh sieve. The powdered material (140 g) was extracted with 1000 mL of chloroform using a Soxhlet apparatus at 60–70 °C for 10–12 h. The solvent used was of analytical grade. After completion of extraction, chloroform was removed by evaporation to obtain a semisolid extract. The percentage yield of the chloroform extract was found to be 11.38% (w/w). The extract was stored in sterile amber-coloured vials under refrigerated conditions until further use in experimental studies[6].

Maceration: Maceration was carried out by treating 40 g of the powdered sample with 500 mL of ethanol for 48 h, followed by filtration and evaporation of the solvent to obtain a dry extract[4].

Ultrasonication: Ultrasonic-assisted extraction was performed using *Aegle marmelos* leaves. A known quantity of dried plant material (40 g) was transferred into a conical flask containing methanol (500 mL). The mixture was subjected to ultrasonication in an ultrasonic bath (Barson, USA)

at ambient temperature (25 °C) for 30 minutes. After extraction, the solution was filtered and the filtrate was concentrated to dryness under reduced pressure using a vacuum evaporator. The dried extract was weighed to determine the extractive yield. The extraction procedure was repeated six times to ensure maximum recovery of active constituents [(4).]

Successive Solvent Extraction (Multiple Solvents): Shade-dried *A. marmelos* leaf powder was sequentially extracted at room temperature with different solvents of increasing polarity (methanol, ethanol, ethyl acetate, hexane, chloroform). Each solvent extraction was repeated three times, and the combined extracts were vacuum-dried at 40 °C to yield solvent-specific extracts [(7)].

4. Pharmacological activity

Plant Part	Pharmacological Category	Activity	Research Status	Key Remarks (Vancouver in-text citation)
Leaves	Metabolic	Antidiabetic	Studied	Enzyme inhibition and STZ/alloxan-induced diabetic animal models reported [8,9]
	Oxidative stress	Antioxidant	Studied	Strong radical scavenging activity demonstrated through DPPH, FRAP and ABTS assays [10,11]
	Inflammatory disorders	Anti-inflammatory	Studied	COX/LOX inhibition and limited in vivo anti-inflammatory models reported [12]
	Infectious diseases	Antibacterial	Studied	Broad-spectrum antibacterial activity against Gram-positive and Gram-negative organisms [8]
	Infectious diseases	Antifungal	Studied	Limited antifungal activity against *Candida* species reported [9]
	Hepatic system	Hepatoprotective	Studied	Reduction of elevated liver enzymes in toxin-induced hepatotoxicity models [8]
	Cancer	Anticancer	Studied	In vitro cytotoxicity against breast, colon and liver cancer cell lines [13]
	Nervous system	Anxiolytic / Antidepressant	Studied	Behavioral studies in rodents showing anxiolytic and antidepressant-like effects [9]
	Nervous system	Neuroprotective (mechanistic)	Not adequately studied	Lack of mechanistic studies using disease-specific neurodegenerative models [14]
	Immune system	Immuno modulatory	Poorly studied	Few animal studies; immunological mechanisms remain unclear [8]
	Safety & kinetics	Pharmacokinetics / ADME	Not studied	No reports on absorption, distribution, metabolism or excretion of phytoconstituents
	Clinical	Human clinical trials	Not studied	Absence of controlled clinical investigations
	Gastrointestinal	Antidiarrheal	Studied	Significant antidiarrheal activity in castor oil-induced diarrhoea models [15]

	Gastrointestinal	Gastroprotective / Anti-ulcer	Studied	Protective effects in ethanol- and NSAID-induced ulcer models [8]
Fruit (unripe & ripe)	Metabolic	Antidiabetic	Studied	Moderate hypoglycaemic activity compared with leaf extracts [9]
	Oxidative stress	Antioxidant	Studied	High phenolic and flavonoid content contributing to antioxidant activity [11]
	Infectious diseases	Antibacterial	Studied	Activity mainly reported against enteric pathogens [8]
	Inflammatory disorders	Anti-inflammatory	Studied	Predominantly supported by in vitro evidence [12]
	Metabolic	Anti-obesity/ Lipid-lowering	Not adequately studied	Lack of systematic experimental and long-term studies
	Infectious diseases	Antiviral (modern viruses)	Not studied	No reports against influenza, HIV or SARS-CoV-2
	Cardiovascular	Cardioprotective	Partially studied	Mostly review-based claims with limited experimental validation [11]
	Safety & kinetics	Pharmacokinetics / ADME	Not studied	Bioavailability data absent
Bark	Oxidative stress	Antioxidant	Studied	Moderate radical scavenging activity reported [8]
	Inflammatory disorders	Anti-inflammatory	Studied	Limited in vivo validation available [12]
	Infectious diseases	Antibacterial	Studied	Narrow-spectrum antibacterial activity reported [9]
	Hepatic system	Hepatoprotective	Studied	Few animal studies demonstrating hepatoprotection [8]
	Cancer	Anticancer	Poorly studied	Only preliminary cytotoxic screening reported
	Immune system	Immuno modulatory	Not studied	No focused investigations available
Roots	Oxidative stress	Antioxidant	Studied	Mild to moderate antioxidant activity reported [8]
	Inflammatory disorders	Anti-inflammatory	Studied	Limited experimental evidence available [12]
	Metabolic	Antidiabetic	Poorly studied	Mostly traditional claims with minimal experimental validation
	Nervous system	Neuroprotective	Not studied	No experimental reports available
Seeds	Oxidative stress	Antioxidant	Studied	Antioxidant activity mainly reported from seed oil extracts.
	Infectious diseases	Antibacterial	Studied	Limited antibacterial screening studies reported
	Metabolic	Lipid-lowering/ Anti-obesity	Not studied	No experimental evidence available
	Cancer	Anticancer	Not studied	No cytotoxic or mechanistic studies reported
All parts	Standardization	Extract standardization & quality control	Not studied	Lack of validated standardization markers and protocols

5. Result and Discussion

Studies on *Aegle marmelos* indicate that various plant parts contain pharmacologically active phytochemicals that support its traditional medicinal applications. Extraction methods such as Soxhlet extraction, maceration, ultrasonication, aqueous extraction, and successive solvent extraction effectively yielded bioactive constituents. Organic solvents including chloroform, methanol, and ethanol demonstrated higher efficiency for extracting alkaloids and coumarins, whereas aqueous extraction favored polar compounds such as flavonoids and tannins. Differences in solvent polarity and extraction technique significantly influenced phytochemical yield and composition [4–7]

Phytochemical screening confirmed the presence of major bioactive groups including alkaloids (aegeline), coumarins (marmelosin, marmesin), flavonoids (rutin), terpenoids (limonene, caryophyllene), sterols (β-sitosterol), tannins, and essential oils. Leaves and fruits were identified as the richest sources of these compounds. These constituents are closely associated with the pharmacological effects observed in experimental investigations [3,8,11]

Pharmacological studies demonstrate significant antidiabetic, antioxidant, anti-inflammatory, antimicrobial, gastroprotective, hepatoprotective, neurobehavioral, and in vitro anticancer activities. Antidiabetic effects were evidenced by reductions in blood glucose levels in chemically induced diabetic animal models [8,9]. Antioxidant capacity was validated using DPPH, FRAP, and ABTS assays [10,11]. Anti-inflammatory activity was associated with inhibition of COX and LOX pathways [12]. Gastroprotective and anti-ulcer effects were demonstrated in experimental ulcer models [15,17], while hepatoprotective activity was shown by normalization of liver enzymes in toxin-induced liver injury [8]. Behavioral studies revealed anxiolytic and antidepressant-like effects [6,9]. Cytotoxic activity against various cancer cell lines was reported in vitro [13,16]. However, most findings originate from laboratory and animal models, with minimal clinical validation.

Despite promising results, significant limitations remain, including lack of extract standardization, insufficient pharmacokinetic and toxicity data, limited mechanistic understanding, and absence of controlled human clinical trials. These gaps restrict translation into evidence-based therapeutic use.

Aegle marmelos possesses broad-spectrum pharmacological potential supported by its rich phytochemical composition. Although preclinical findings substantiate many traditional claims, further research focusing on standardization, safety assessment, mechanistic studies, and well-designed clinical trials is essential to establish its role in modern medicine.

Reference:

1. Prajapat RP, Gupta V, Soni B, Choudhary D, Ram V, Bhandari A. Extraction and isolation of marmelosin from *Aegle marmelos*, synthesis and evaluation of their derivative as antidiabetic agent. Der Pharmacia Lettre. 2012;4(4):1085–1092.

2. Gavimath CC, Ramachandra YL, Padmalatha Rai S, Sudeep HV, Sujan PS, Ganapathy B, Kavitha BT. Antibacterial activity of Aegle marmelos correa leaves extract. Asian J Bio Sci. 2008 Oct;3(2):333–336.

3. Pathirana CK, Madhujith T, Eswara J. Bael (*Aegle marmelos* L. Corrêa), a medicinal tree with immense economic potentials. **Adv Agric.** 2020; 2020:8814018. doi:10.1155/2020/8814018.

4. Karmase A, Prasanna K, Rasabattula S, Bhutani KK. Quantification and comparison of extraction methods for alkaloids in *Aegle marmelos* leaves by HPLC.Nat Prod Commun. 2014;9(7):981–983

5. Asghar N, Mushtaq Z, Arshad MU, Imran M, Ahmad RS, Hussain SM. *Phytochemical composition, antilipidemic and antihypercholestrolemic perspectives of Bael leaf extracts*. **Lipids Health Dis**. 2018 Apr 3; 17:68. doi:10.1186/s12944-018-0713-9.

6. Kothari S, Minda M, Tonpay SD. Anxiolytic and antidepressant activities of methanol extract of *Aegle marmelos* leaves in mice. Indian J Physiol Pharmacol. 2010;54(4):318–328.

7. Gaikwad MB, Dhumal SK, Dighe AD, Dhoot PP, Gadakh TH, Narote PR. A review on pharmacognostic and anti-acne property of bael (*Aegle marmelos*) gel formulation and its evaluation. **Int J Sci Dev Res.** 2024 Apr;9(4).

8. Maity P, Hansda D, Bandyopadhyay U, Mishra DK. Biological activities of crude extracts and chemical constituents of *Aegle marmelos*. **Indian J Exp Biol.** 2009;47(11):849–861.

9. Sharma GN, Dubey SK, Sharma P, Sati N. Medicinal values of bael (*Aegle marmelos*) (L.) Corr.: A review. **Int J Curr Pharm Rev Res.** 2011;2(1):12–22.

10. Jagetia GC, Venkatesh P. Antioxidant activity of *Aegle marmelos* leaf extract. **Indian J Exp Biol.** 2004;42(6):603–609.

11. Baliga MS, Bhat HP, Joseph N, Fazal F. Phytochemistry and medicinal uses of the bael fruit (*Aegle marmelos* Correa): A review. **Food Res Int.** 2011;44(7):1768–1782.

12. Arul V, Miyazaki S, Dhananjayan R. Studies on the anti-inflammatory, antipyretic and analgesic

15. Brijesh S, Daswani PG, Tetali P, Antia NH, Birdi TJ. Studies on antidiarrheal activity of *Aegle marmelos* unripe fruit. **BMC Complement Altern Med.** 2009; 9:47.

16. Baliga MS, Thilakchand KR, Venkatesh P. Aegle marmelos (L.) Correa (Bael) and its properties of *Aegle marmelos*. **J Ethnopharmacol.** 2005;96(1–2):159–163.

13. Lampronti I, Martello D, Bianchi N, et al. Anticancer activity of *Aegle marmelos* extracts in human cancer cell lines. **Planta Med.** 2003;69(8):742–746.

14. Baliga MS, Rao S, Rai MP, D'Souza P. Radio-protective effects of *Aegle marmelos*. **J Environ Pathol Toxicol Oncol.** 2010;29(1):73–84.
phytochemicals in the treatment and prevention of cancer. Integr Cancer Ther. 2012 Oct 21. doi:10.1177/1534735412451320.

17. Ilavarasan R, Monideen S, Vijayalakshmi M. Antiulcer activity of *Aegle marmelos* Linn.Anc Sci Life. 2002;21(4):256–259.