Chapter 1

Aegle marmelos (L.) Corrêa: A sacred medicinal tree

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Abstract: *Aegle marmelos* (L.) Corrêa, commonly known as Bael, is a sacred medicinal tree revered in many cultures across South Asia. This multipurpose tree holds significant ecological, medicinal, and cultural importance. It thrives in a variety of environments, from dry and semi-arid regions to tropical and subtropical climates, and plays a crucial role in soil conservation, biodiversity support, and air purification. The tree's leaves, fruits, bark, and seeds are rich in bioactive compounds such as alkaloids, flavonoids, phenolic compounds and terpenoids which exhibit a range of pharmacological activities, including anti-diabetic, anti-inflammatory, antimicrobial, analgesic, and wound-healing properties. The fruit, leaves, and bark also serve as valuable sources of food and traditional medicine, making it a vital resource for local communities in India. The tree's ability to adapt to harsh environments, combined with its medicinal and ecological contributions, highlights its immense value for sustainable agriculture, traditional medicine, and environmental conservation.

Keywords: Ayurvedic medicine, bael, bioactive compounds, ecological significance

Introduction

Humans are considered the most developed among all living species on Earth. Since ancient times, humans have adopted plants not only as a source of food but also to treat various ailments (Nayak and Kumar, 2023; Kumar *et al.*, 2023; Das *et al.*, 2024; Singh and Kumar, 2024; Jaiswal *et al.*, 2024; Jena *et al.*, 2025; Kumar, 2025). Ancient literature such as the Rigveda, Yajurveda, Atharvaveda, Charak Samhita, and Sushrut Samhita documents the use of plants for treating various health problems (Savita *et al.*, 2021). Recognizing the significance of plants and their medicinal role, numerous studies have been conducted to identify their active chemical constituents (Hebbar *et al.*, 2024; Sharma *et al.*, 2024; Bhat *et al.*, 2024a; Palei *et al.*, 2024; Jena *et al.*, 2024; Bhat *et al.*, 2024b). Traditional uses of plants often guide their application for specific diseases (Patel *et al.*, 2012; Kumar *et al.*, 2012). Over the last five decades, advanced scientific techniques have been extensively studied these plants, revealing various medicinal properties such as anticancer, antibacterial, antifungal, antidiabetic, antioxidant, hepatoprotective, haemolytic, larvicidal, and anti-inflammatory activities (Marndi *et al.*, 2024; Devi *et al.*, 2024). Among the plant species, particularly trees, *Aegle marmelos*, commonly known as Bael, Bengal quince, Golden apple, or Wood apple, belongs to the family Rutaceae, holds significant religious and medicinal value (Khanal *et al.*, 2023). Often cultivated in temple gardens, the leaves of *Aegle marmelos* are used in prayers dedicated to Lord Shiva. The fruit is utilized both as food and traditional medicine (Kanhar *et al.*, 2020). Ancient texts highlight its importance in treating ailments like diarrhea and dysentery (Kanhar *et al.*, 2020). Bael is deeply rooted in Indian culture and Hinduism. It is sacred and associated with Lord Shiva. The fruit is symbolic of Lord Shiva, and its leaves, known as Bilwa Patra, are in high demand during the 'Sawan' season.

Bael trees are commonly found near temples and Hindu homes (Kumar *et al.*, 2022; Nayak and Kumar, 2023). Bael is a medium-sized, deciduous tree that grows wild in dry forests, the outer Himalayas, Shivalik ranges, and South India at altitudes ranging from 250-1200 meters. It is also cultivated throughout the Indian subcontinent for its fruits. Every part of the Bael- root, bark, leaf, flower, fruit, seed, and even latex is used in traditional medicine (Nayak and Kumar, 2023). The plant exhibits various pharmacological activities, including anti-dyspeptic, anti-diarrheal, anti-dysenteric, hypoglycemic and anti-diabetic, antimicrobial, antifungal activities, anti-inflammatory, analgesic, antipyretic, wound-healing properties etc. Bael contains a rich array of phytochemicals, including alkaloids, tannins, essential oils, gums and resins (Swarnkar *et al.*, 2019). These compounds contribute to the plant's therapeutic potential and make it a valuable resource in traditional and modern medicine. Bael fruits possess higher nutritional value compared to other fruits. While the fully ripened fruit is less commonly used in medicine, half-ripened fruits are preferred for their medicinal properties (Patra *et al.*, 2024). The plant also plays a crucial role in environmental conservation and is integral to maintaining biodiversity. Its extensive use in Ayurveda and folk medicine underlines its therapeutic potential. The integration of Bael into both traditional and modern medicine highlights its importance as a versatile and significant medicinal plant (Kumar *et al.*, 2022).

Morphology

This tree is a deciduous species native to India, Bangladesh, Pakistan, and Sri Lanka. It generally grows up to a medium to large tree, attaining heights of 15 to 20 meters (Kumar *et al.*, 2022; Nayak and Kumar, 2023; Joshi *et al.*, 2024; Plate 1).

Trunk: The trunk is straight and cylindrical, exhibiting a moderate to thick diameter. Its bark is rough and varies in colour from light brown to grayish tones.

Root: The root system is both deep and extensive, providing stability and facilitating nutrient uptake for the tree.

Leaf: The leaves are trifoliate, comprising three leaflets. Each leaflet is broadly oval or elliptical with serrated edges. Typically, the leaves are glossy green and are arranged alternately along the branches.

Flower: The flowers are fragrant and contain both male and female reproductive structures. They are either white or pale green and grow in clusters at the leaf axils.

Fruit: The bael fruit is a notable characteristic of *A. marmelos*. It is round to oval in shape, featuring a smooth, hard, woody shell that transitions from yellowish-green to brownish as it ripens. The fruit typically measures about 5 to 10 cm in diameter. When opened, it reveals a soft, aromatic pulp that is orange in colour, containing numerous seeds embedded in sticky mucilage.

Seed: The seeds are small and oval-shaped, usually light brown to black, and are located within the fruit's pulp.

Traditional medicinal uses

All parts of *A. marmelos* are medicinally useful like leaves, fruit pulp, flower, stem bark and root bark etc. According to various Indian Ayurveda practitioners and traditional herbal healers, several parts of *A. marmelos* are used for the treatment of a number of health hazards. Each plant parts are used for the preparation of several medicines (Banerjee *et al.*, 2024; Figure 1).

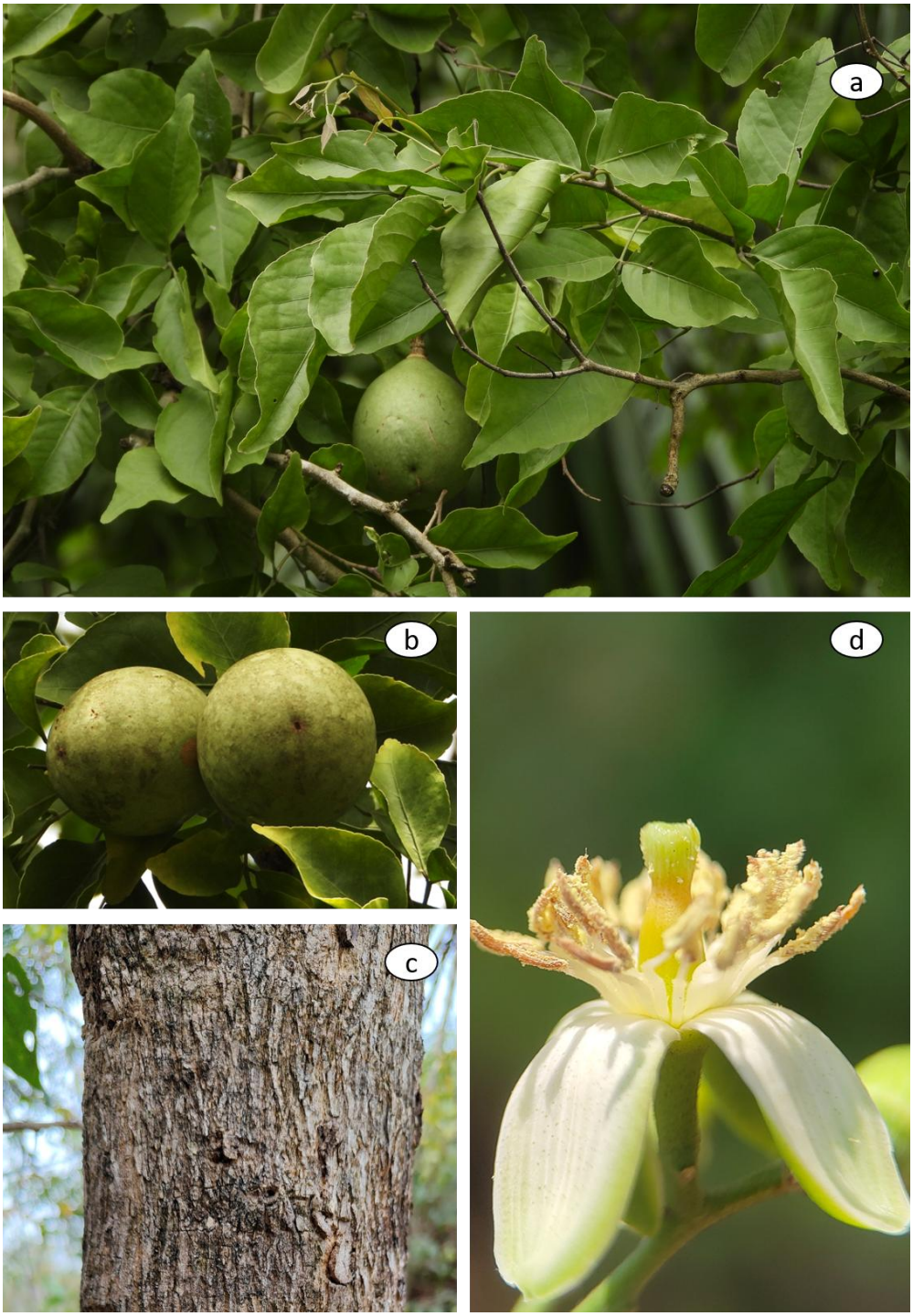


Plate 1: Vegetative parts of *A. marmelos*, a) leaves and fruit, b) fruits, c) bark, d) flower

Leaves: Leaves are known for their mild laxative properties and are used to relieve fever, catarrh, and asthma. A decoction of the leaves acts as a febrifuge, reducing fever, and as an expectorant, helping to clear bronchial secretions. Leaf juice mixed with black pepper is effective against dropsy, jaundice, and constipation. Hot poultice made from leaves are applied to alleviate inflammation in conditions such as ophthalmia, acute bronchitis, and other body inflammations. In West Bengal, fresh leaves are used as a remedy for beriberi. A decoction of the leaves is used to reduce fever and expectorant. It is particularly used for asthmatic complaints (Dhankhar *et al.*, 2011; Pathirana *et al.*, 2020).

Root and bark: The roots and bark have notable medicinal properties. A decoction of the root is beneficial in treating intermittent fevers, hypochondriasis, and heart palpitations. It is mixed with sugar and rice to relieve diarrhea and gastric irritability in children. The root is an integral component of "Dashmoola," a popular Ayurvedic formulation used for improving appetite and addressing postpartum conditions. The bark and root are also utilized as a remedy for melancholia and intermittent fevers, and the root bark has been employed as a fish poison. Root and bark decoction is useful for treating fevers as well as heart disorders (Atul *et al.*, 2012; Gavali *et al.*, 2024).

Flowers: Flowers of *A. marmelos* are used as a digestive tonic and are effective in treating dysentery and diabetes. They have diaphoretic properties, promoting sweating, and serve as a local anesthetic. Additionally, the flowers are employed in the treatment of epilepsy (Atul *et al.*, 2012; Monika *et al.*, 2023).

Fruits: The fruit is one of the most versatile parts of the plant, used in both unripe and ripe forms. The unripe fruit, with its astringent properties, is

valuable for treating dysentery, diarrhea, and stomachaches. Traditional healers in southern Chhattisgarh utilize a dry powder made from the fruit combined with mustard oil to treat burn injuries. This mixture, consisting of one part powder to two parts mustard oil, is applied externally. Additionally, the fruit is employed in addressing gastric issues, constipation, as a laxative, tonic, digestive aid, stomachic, and for conditions affecting the brain and heart, as well as for ulcers, antiviral purposes, intestinal parasites, gonorrhea, and epilepsy. It is also effective against intestinal parasites like *Entamoeba histolytica* and *Ascaris lumbricoides*. Powdered unripe fruit mixed with rice water is used to prevent vomiting during pregnancy. Ripe fruits are aromatic, cooling, and nutritive, making them suitable for digestive issues, chronic dysentery, and ulcers. They also serve as a tonic for the brain and heart. The fruit pulp is used in beverages and marmalade, while the powder is known for its anti-cancer and anti proliferative activities (Kumar *et al.*, 2012). The unripe fruit is used as astringent, in dysentery, stomachache, diarrhea, tonic, digestive, demulcent, described as cardiacal, restorative, and given in piles, Decoction of unripe fruit is astringent, useful in diarrhea and chronic dysentery. Unripe fruit pulp mixed with milk and sugar cures urogenital disorders. For the treatment of dysentery and abscesses, half-roasted unripe pulp mixed with sugar is used. The plant's parts are used in Ayurvedic formulations like Dasamoola and Chyavanprash, which are effective against chronic ailments. The root decoction is given for fever and heart conditions, while the leaf poultices are used to treat ulcers and eye diseases. The medicinal properties of *A. marmelos* make it a valuable plant in traditional and modern medicine, addressing a wide array of conditions from gastrointestinal disorders to chronic illnesses like diabetes and cancer (Dhankhar *et al.*, 2011; Patel *et al.*, 2012).

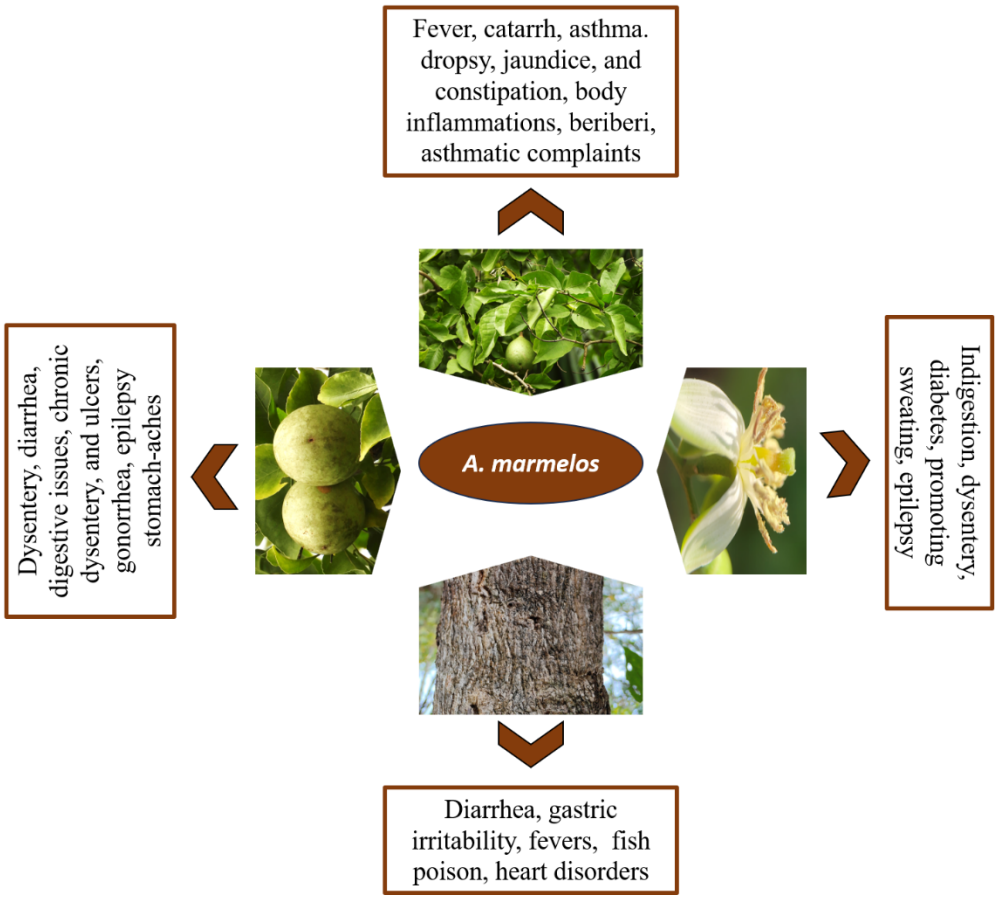


Figure 1: Medicinal uses of different parts of *A. marmelos*

Pharmacological potential

The medicinal attributes of *A. marmelos* encompass a wide range of therapeutic effects, including anti-arthritis activity, anti-inflammatory, anti-diarrheal, anti-oxidant, anti-microbial, anti-hyperlipidemic, antifungal, bactericidal activity, analgesic activity, insecticidal, wound-healing activities etc (Singh *et al.*, 2019).

Anti-arthritis activity: The Bael plant exhibits potent anti-arthritis properties. A methanolic extract derived from its leaves was tested on Wistar albino rats with collagen-induced arthritis. The treatment resulted in a

significant reduction in histopathological and radiological damage, indicating its potential to manage arthritis effectively (Swarnkar *et al.*, 2019).

Anti-inflammatory effects: The aqueous extract of Bael root bark significantly reduced inflammation in models of paw edema and granuloma formation, achieving inhibition rates of 46% and 9.2%, respectively. Young roots aged 2–3 years from Gujarat and 1 year from Odisha demonstrated the strongest anti-inflammatory activity by suppressing pro-inflammatory cytokines and enhancing anti-inflammatory cytokines like IL-2. Anti-inflammatory effects were comparable across stems, leaves, and mature roots, with Marmelosin, a key bioactive compound, playing a prominent role. Additionally, dried flower extracts reduced nitric oxide production, increased peritoneal cell infiltration, and alleviated histamine-induced urticaria in rats (Benni *et al.*, 2011; Singh *et al.*, 2019).

Anti-diarrheal properties: The antidiarrheal activity of *A. marmelos* addresses diseases such as cholera and dysentery caused by pathogens like *Vibrio cholerae* and *E. coli*. Research demonstrated that hot water-soluble pectic polysaccharides from semi ripe fruit pulp exhibited a dose-dependent antidiarrheal effect (Jhajhria and Kumar, 2016).

Antioxidant activities: Antioxidant activity of bael is due to the presence of flavones, isoflavones, flavonoids, anthocyanin, coumarin, lignans, catechins and isocatechins. *A. marmelos* is extensively reported to possess antioxidant activity against a variety of free radicals (Sekar *et al.*, 2011).

Antimicrobial activities: *A. marmelos* exhibits broad-spectrum antimicrobial properties, effectively inhibiting various pathogenic microorganisms. Leaf extracts prepared using petroleum ether, ethanol, and aqueous solutions have demonstrated activity against *Escherichia coli*, *Streptococcus pneumoniae*, *Salmonella typhi*, *Proteus vulgaris*, and

Klebsiella pneumoniae. Petroleum ether and aqueous extracts also showed antifungal activity against *Fusarium oxysporum*, while ethanolic extracts were effective against *Penicillium chrysogenum* (Sivaraj *et al.*, 2011). Additionally, the leaf extracts displayed fungicidal effects against dermatophytes such as *Trichophyton mentagrophytes*, *T. rubrum*, *Microsporum canis*, *M. gypseum*, and *Epidermophyton floccosum* (Balakumar *et al.*, 2011). Methanolic extracts have shown significant antimicrobial activity against *Bacillus subtilis*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Proteus mirabilis*, *E. coli*, and *Salmonella* species (Poonkothai and Saravanan, 2008).

Anti-hyperlipidemic activity: Bael extract has been reported to promote the utilization of elevated fatty acids, leading to their reduction. This reduction in fatty acid levels serves as a critical pathway for the consumption of higher glucose molecules, indicating potential benefits for managing hyperlipidemia and glucose metabolism (Patel *et al.*, 2012; Jhajhria and Kumar, 2016).

Antifungal activity: The antifungal properties of *Aegle marmelos* are noteworthy, with extracts inhibiting fungal pathogens such as *Fusarium oxysporum* and *Penicillium chrysogenum*. Additionally, the plant demonstrates fungicidal activity against dermatophytic fungi including *Trichophyton mentagrophytes*, *T. rubrum*, *Microsporum canis*, *M. gypseum*, and *Epidermophyton floccosum*. These findings highlight the broad-spectrum antifungal potential of Bael extracts (Poonkothai and Saravanan, 2008).

Bactericidal activity: Methanolic leaf extracts of *A. marmelos* have shown pronounced bactericidal activity against various bacterial pathogens, including *Bacillus subtilis*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Proteus mirabilis*, *Escherichia coli*, and *Salmonella* species. This indicates

the potential of *A. marmelos* extracts for combating bacterial infections effectively.

Analgesic activity: The methanolic extract from the leaves of *A. marmelos* was evaluated for its analgesic properties using writhing and tail immersion tests in mice. Administered at a dose of 200 mg/kg, the extract exhibited significant analgesic effects, suggesting its potential as a natural pain reliever (Shankarananth *et al.*, 2007).

Insecticidal activity: Essential oil from the leaves of *A. marmelos* effectively managed insect infestations in stored grains, including gram and wheat. Pests included *Callosobruchus chinensis*, *Rhyzopertha dominica*, *Sitophilus oryzae*, and *Tribolium castaneum* (Benni *et al.*, 2011; Singh *et al.*, 2019).

Wound healing activity: The methanolic extract of *A. marmelos* showed significant wound-healing properties when applied topically. In excision and incision models in rats, the extract, formulated as an ointment or injection, accelerated epithelialization, increased wound contraction rates, and enhanced tensile strength in wounds. These effects were comparable to the standard drug nitrofurazone, demonstrating the extract's efficacy in promoting wound repair and healing (Jhajhria and Kumar, 2016; Shukla *et al.*, 2024).

Bioactive compounds

The Bael fruit is a rich source of bioactive compounds, including fibers, carotenoids, phenolics, terpenoids, coumarins, flavonoids, Psoralen, Marmelide, Marmelosin, Tannin, Phenol, Luvangetin, and Auraptenand alkaloids (Patkar *et al.*, 2012; Shukla *et al.*, 2024). Its leaves contain phytochemicals such as Skimmianine, Aeglin, Rutin, β-sitosterol, Flavone,

Lupeol, Cineol, Citral, Glycoside, O-isopentenyl, Hallordiol, Mameline, Citronellal, and Eugenol. The bark is rich in alkaloids, including Fagarine, Marmin, and Furoquinoline (Patra *et al.*, 2024; Vaithiyalingam *et al.*, 2024). Seeds contain essential oils like D-limonene, α-D-phellandrene, Cineol, Citronellal, Citral, p-cymene, and Cumin aldehyde. The roots are composed of terpenes, halopine, coumarins, and alkaloids. Additionally, Bael pulp is a nutritional powerhouse, containing protein, carbohydrates, fats, dietary fibers, and vitamins (A, B1, B2, B3), along with minerals such as calcium, phosphorus, and iron (Venthodika *et al.*, 2020). The presence of biologically active compounds such as carotenoids, flavonoids, alkaloids, terpenoids, and coumarins underscores its therapeutic potential (Charoensiddhi and Anprung, 2008; Biswas *et al.*, 2023).

Ecological Importance

A. marmelos holds cultural importance, particularly in South Asia, where it is considered sacred and used in religious rituals. This cultural reverence helps ensure its conservation and widespread planting (Kumar *et al.*, 2022). It serves as a valuable environmental asset due to its unique ecological functions. It acts as a "sink" for chemical pollutants by absorbing toxic gases from the atmosphere and neutralizing or rendering them inert, contributing significantly to air purification. Known as a "climate purifier," the tree emits a higher percentage of oxygen under sunlight compared to many other plant species, enhancing air quality, and supporting a healthier ecosystem (Niraj *et al.*, 2017). Additionally, its spiny branches make it an effective natural barrier, often used in live fencing to protect agricultural fields and prevent animal intrusion. These attributes underline the Bael tree's crucial role in promoting environmental sustainability and ecological balance. The leaves of *A. marmelos* serve as a food source for various caterpillars and moths,

including the Lime butterfly (*Papilio demoleus*), the Common Mormon (*Papilio polytes*), and pests such as the Citrus Leaf miner (*Phyllocnistis citrella*), Citrus Leaf Roller (*Psorosticha zizyphi*), snout moth (*Metallosticha plumbeifasciella*), and Citrus Pock (*Prays endocarpa*) (Patel *et al.*, 2012). These herbivorous insects feed on the leaves, which can sometimes lead to damage, affecting the plant's health and foliage. However, this interaction also plays a role in the local food web, supporting populations of predatory insects and other natural enemies that help control pest numbers (Kumar *et al.*, 2022).

Conclusion

Bael, is not only a sacred tree with deep-rooted cultural significance but also a powerhouse of medicinal and ecological benefits. Its rich bioactive compounds, such as alkaloids, flavonoids, and terpenoids, provide extensive therapeutic properties, making it a valuable resource in traditional medicine for treating various ailments. Ecologically, it plays a pivotal role in soil conservation, air purification, and supporting biodiversity. Its ability to adapt to diverse environments, coupled with its cultural reverence, underscores its importance in sustainable agriculture, ecological balance, and community well-being. As both a sacred tree and a medicinal plant, *A. marmelos* offers immense potential for future research, conservation efforts, and sustainable use, benefiting both human health and the environment.

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