Plant Archives Vol. 25, Supplement 2, 2025 pp. 1469-1477 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-2.184

PHARMACOLOGICAL PROPERTIES OF BAEL (*AEGLE MARMELOS* L.): INSIGHTS INTO ITS ROLE IN DISEASE MANAGEMENT

Megha Raghavan[1], Shubham Jain[2*], Sushravya M. K.[3], Saurav Kumar[4], Lakwinder Singh[5], Sameer Verma[6], Aman Kumar Maurya[7] and Mahendra Pratap[8]

[1]Department of Fruit Science, College of Agriculture, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala, India
[2]Gyanveer University Sagar, M.P., India
[3]Division of Fruits and Horticultural Technology, ICAR-IARI, New Delhi, India
[4]Department of Fruit Science, SHUATS, Prayagraj, U.P., India
[5]Faculty of Agriculture, Guru Kashi University, Talwandi Sabo, Bathinda, Punjab, India
[6]Department of Horticulture (Fruit Science), ANDUA&T, Kumarganj, Ayodhya, U.P., India
[7]Department of Fruit Science, College of Horticulture and Forestry, Rani Lakshmi Bai Central Agricultural University, Jhansi, U.P., India
[8]Department of Horticulture, Post Graduate College, Ghazipur, Uttar Pradesh, India
*Corresponding author E-mail: shubhu15296@gmail.com
(Date of Receiving : 04-05-2025; Date of Acceptance : 10-07-2025)

ABSTRACT

The traditional medicinal herb *Aegle marmelos,* also referred to as Bael, has a long history of usage in the folk and Ayurvedic medicine. Its bioactive substances, which include flavonoids, alkaloids, and essential oils, have a variety of pharmacological properties, including hepatoprotective, anti-inflammatory, antidiabetic, antioxidant, and antibacterial properties. According to recent research, it may be used to treat liver ailments, metabolic disorders like diabetes, and gastrointestinal issues. The main sources of *Aegle marmelos'* medicinal qualities are its fruit, leaves, and bark. The pharmacological characteristics of bael and its implications for the management of diseases in humans are compiled in this review.

***Keywords*:** bael, antioxidants, pharmacological property, disease management,

Introduction

As the world's largest producer of medicinal plants, India is commonly referred to as the "world's botanical garden" (Shariff *et al.,* 2006). Eighty percent of people in developing nations, according to WHO estimates, rely on traditional medicines, which are mostly made from natural plants, to address their fundamental medical needs (Vines, 2004). One of the most significant medicinal herbs in India is bael (*Aegle marmelos*) (Chemexcil, 1992). The medium-sized, prickly deciduous Bael tree is a member of the Rutaceae family. Originally from India, it is currently grown in several Southeast Asian nations (Lalita *et al*., 2002). *Aegle marmelos* is frequently planted in temple gardens in India, and worshippers frequently utilize its leaves to honour Lord Shiva. It is an extremely important medicinal plant that is used for many ethnomedicinal purposes in traditional and folk medicine systems (Sekar *et al.,* 2011). In ethnomedicine, this tree's leaves, roots, stems, and fruits at all stages of maturity are utilised to treat a variety of human illnesses (Lalita *et al*., 2002). Marmelosin, luvangetin, psoralen, tannins, and marmin are the main chemical components of *Aegle marmelos* fruit (Laphookhieo *et al.,* 2010). Marmenol, marmin, marmelosin, marmelide, psoralen, alloimperatorin, rutaretin, scopoletin, aegelin, marmelin, fagarine, anhydromarmelin, and limonene are among the phytoconstituents found in *Aegle marmelos* (Das and Roy, 2012).

The *Aegle marmelos* tree frequently has spiky branches and thick, flaking bark. A gum that thickens when exposed to air is secreted by injured bark (Bhar *et al*., 2019). Heart palpitations, intermittent fever, and melancholy can all be helped by a decoction prepared from the root and bark of the *Aegle marmelos* tree. Furthermore, Dashmula, a well-known Ayurvedic remedy, contains a significant amount of Bael tree root (Kala, 2006)**.** Bark decoction, leaf extract mixed with honey, and bael extract are used as a febrifuge, to treat fever, and to control intermittent fever **(**Jyotsana *et al.*, 2010**).** The fruit has a firm, woody exocarp and is mostly yellowish-green in colour. It weighs about 77.2 grammes, has a capacity of 73 millilitres, and is about 5 to 7 centimetres in diameter. The fruits have a sphericity of 93.72 ± 2.78% and are either oval or spherical in shape (Sonawane *et al*., 2020). It has been discovered that *Aegle marmelos* fruit extract improves thyroid care. Additionally, it has demonstrated efficacy in treating piles, lowering inflammation in the rectal area, and alleviating chronic gastrointestinal diseases (Dhankhar *et al.,* 2011).

Numerous researches on bael shows that it absorbs a wide range of nutrients, such as a broad class of phytochemicals that include tannins, coumarins, alkaloids, flavonoids, and phenolic acids. Aside from these, bael is a very nutrient-dense fruit with numerous health advantages since it contains amino acids, fatty acids, various organic acids, minerals, carbs, vitamins, and fibers (Bhardwaj, 2014). The fruit may be used to treat gastrointestinal disorders, diabetes, heart difficulties, and inflammation-related conditions. Bael has also demonstrated protective properties against depression, free radical production, germs, radiation, and wounds. These documents attest to bael's inherent capacity for healing (Manandhar *et al.,* 2018). Because bael is a seasonal fruit that is primarily accessible in May and June, its health benefits may not be available throughout the year (Sharma *et al*., 2007). These issues therefore encourage the creation of various fruit-based products. Juice can be used to make a variety of drinks. Jam, slab, and bael powder are examples of dehydrated bael products. It can also be used to make tea and wine. Therefore, using bael to make a variety of items is quite profitable from the perspective of the economy.

Botanical Classification

The medium-sized, aromatic, and slender *Aegle marmelos* tree is a slow-growing medicinal plant that can reach heights of around 762 cm and diameters of 90 to 120 cm (Jagtap *et al.,* 2004).

Leaf

The leaves are usually trifoliate, having three to five leaflets, and are placed alternately. According to Bhar *et al*. (2019), each leaflet is 4–10 cm long and 2–5 cm wide. The leaves turn a dark green as they mature, and the flowers are greenish-white in colour (Maity *et al.,* 2009). Bael leaves efficiently aid in clearing the bronchial passageways of mucilage discharge. In addition to treating conjunctivitis, they also help with leucorrhea, constipation, and hearing. Furthermore, bowel syndrome can be treated with bael leaf powder (Patkar *et al.,* 2012). It is proven to be highly helpful in treating asthma and jaundice (Bhar *et al.,* 2019). Bael leaves are a useful tool for clearing the bronchial tubes of mucilage discharge. Applications include treating conjunctivitis and even curing leucorrhea, constipation, and hearing. Bael leaf powder can be used to treat bowel syndrome (Sanghi *et al.,* 2017). In the therapy of beriberi, it is applied as a corrective remedy (Kumar *et al*., 2012). Numerous medicinal effects of bael leaf essential oil have been described (Mahomoodally *et al.,* 2018)

Bark

The *Aegle marmelos* tree has flaky, thick bark that frequently has spiky branches. A gum that thickens when exposed to air is secreted by injured bark (Bhar *et al*., 2019). Heart palpitations, intermittent fever, and melancholy can all be helped by a decoction prepared from the root and bark of the *Aegle marmelos* tree. Furthermore, Dashmula, a well-known Ayurvedic remedy, contains a significant amount of Bael tree root (Kala, 2006). Bark decoction, leaf extract mixed with honey, and bael extract are used as a febrifuge, to treat fever, and to control intermittent fever (Jyotsana *et al*., 2010).

Fruit

The Bael fruit has a hard shell that doesn't crack, even when mature, and is sweet and fragrant. Before the fruit is eaten, its hard shell is removed. Even after processing, the distinctive scent of Bael fruits is preserved. The ripened Bael fruit is used to make ready-to-serve wine, jams, nectars, sherbets, and toffees. The Bael fruit is used to make the slab and powder. Because of its fruit and therapeutic qualities, the bael is grown all over India. *Aegle marmelos* fruit has a firm, woody exocarp and is mostly yellowish-green in colour. It weighs about 77.2 grammes, has a capacity of 73 millilitres, and is about 5 to 7 centimetres in diameter. The fruits have a sphericity of 93.72 ± 2.78% and are either oval or spherical in shape (Sonawane *et al.,* 2020). It has been discovered that *Aegle marmelos* fruit extract improves thyroid care.

Because of its bitter taste, ripe fruit juice extract lowers blood sugar levels. Additionally, it has demonstrated efficacy in treating piles, lowering inflammation in the rectal area, and alleviating chronic gastrointestinal diseases (Dhankhar *et al.,* 2011).

Flower

The flower is used to treat epilepsy because of its astringent and antibacterial qualities (Gautam *et al.,* 2014). Conjunctivitis can be treated using marmala water, which is separated after the flower is distilled (Mani *et al.,* 2017). The ability of bael flower extract to heal wounds has been investigated (Gautam *et al.,* 2014). According to reports, nitric oxide inhibition and prostaglandin E2 (PGE2) release have been shown to enhance mRNA expression, which in turn has been shown to promote wound healing in rats (Shirwaikar *et al.,* 2003).

Nutritional Profile of Bael

Numerous researches on the nutritional makeup of bael have shown that the fruit is high in a variety of elements that are very good for human health. The fruit is said to include a variety of fatty acids, amino acids, carbs, several vitamins, and a good amount of minerals. It has a high content of sugar, glucose, and fibre (Bhardwaj and Nandal, 2015; Gupta *et al*., 2018; Nandal, 2013). Due to its high vitamin content, including vitamin A, vitamin B group, and vitamin C, bael has been shown to have antioxidant properties that help reduce colour loss and rancidity (Bhardwaj and Nandal, 2015). Iron, calcium, potassium, phosphorus, and their salts are the minerals that have been identified as being present in the fruit's edible section (Johnson,2010; Sekar *et al.,* 2011).

Unripe fruits are more beneficial for medicinal purposes than ripe ones, according to Sampathkumar *et al*., (2012). Fruit juice makes up 61.0% moisture, 1.9% mineral, 52 mg phosphorus, 610 mg potassium, 80 mg calcium, 2.9% fibre, 1.6% protein, and 55 mg carotene (Khaneghah *et al*., 2018). The protein, moisture, fat, and ash content have all been estimated using the standard AOAC (Association of Official Agricultural Chemists) technique (AOAC, 2010). The difference approach has been used to calculate the total amount of carbohydrates. It has been shown that the moisture content of bael leaves is higher (71.26%) than that of the fruit (64.04%) and seed (53.75%). The amount of fat in bael seed is higher (14.94%). The fat percentage of fruit pulp and leaves is extremely low, at 0.28% and 0.07%, respectively (Dar *et al.,* 2015). Alpha-curcumin (9.56%), alpha-zingiberene (14.41%), mycrene (1.22%), beta-sesquiphellandrene (12.85%), ethanone, 1,2-dicyclopropyl- (0.90%), 1,7-nonadiene, 4,8-dimethyl-1-nitro-, (e)- (2.25%), citronellyl propionate (4.39%), nonanoic acid, methyl ester (2.23%), phytol (50.88%), and 4,8-dimethyl-3(e),7-nonadienyl thioacetate (1.39%) are additional findings from other studies (Rajan *et al.,* 2011; Dhankhar *et al.,* 2011; Johnson, 2010).The output and composition of essential oils vary seasonally, according to a study on bael essential oil. Bael contains a new lectin, a dimeric protein that binds selectively to sialic acid, mannose, and N-acetylgalactosamine (Lim, 2012; Verma *et al.,* 2013).

Phytochemicals in Bael

Bael is rich in flavonoids and polyphenols. Numerous health-promoting polyphenols have been found to be abundant in bael fruit pulp and fruit juice. Bael pulp has accumulated terpenoids, alkaloids, flavonoids, and phenolic chemicals. Alkaloids, coumarins, polysaccharides, and carotenoids are the most significant polyphenols and flavonoids. The number of polyphenols in bael varies according to its level of maturity (Gurjar *et al.,* 2019*).* These phytochemicals have numerous health advantages, ranging from demonstrating antioxidant properties to promoting the absorption of cholesterol. Caffeic acid, arbutin, cholorogenic acid, p-coumaric acid, p-coumaroyl, quinic acid, and protocatecheuic acid are among the phenolic chemicals found in bael fruit juice (Bhardwaj and Nandal, 2015). Bael fruit has yielded terpenoids, flavonoids, saponins, tannins, and glycosides (Rajan *et al.,* 2011).

Moreover, a significant number of phytochemicals are retained in bael leaves; these include rutin, β-sitosterol, γ-sitosterol, glycosides, marmeline, aegelin, marmesinin, halfordiol, phenyl ethyl cinnamamides, and lupeol (Neeraj and, Johar, 2017). The polyphenol category includes catechin, flavanols, flavones, lignin, tannins, and iso-flavones (Bhardwaj and Nandal, 2015). The bael tree's bark has yielded lignan glucoside chemicals (Ohashi *et al*.,1994). Bael has been reported to yield 6-hydroxy-1-methoxy-3-methyl anthraquinone and 7, 8-dimethoxy-1-hydroxyl2-methyl anthraquinone (Srivastava *et al*., 1996). Stem bark has been used to extract skimmiarepin A and skimmiarepin C (Samarasekera *et al*., 2004).

Pharmacological Activity

Anti-Oxidant Activity

Antioxidants are substances that shield cells from oxidative stress by scavenging free radicals. These healthy substances can be found in nature, especially in plants. Flavones, isoflavones, flavonoids, anthocyanins, coumarins, lignans, catechins, and isocatechins are the compounds that give these plants

their antioxidant properties. It is well known that *Aegle marmelos* possesses antioxidant properties that protect against a variety of free radicals (Sharmila and Vasundra, 2011). Studies reveal that the antioxidant activity of unripe fruits is higher than that of mature ones. Bael extracts in water and chloroform both have strong anti-free radical properties and inhibit the lipoxygenase enzyme (Yaqeen *et al.,* 2015). The hydroalcoholic extract of bael has been shown to have radical scavenging properties against DPPH and 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) radicals. Furthermore, bael extract can prevent the 2,2'-azobis(2-amidinopropane) dihydrochloride radical from oxidising biomolecules such as lipids, bovine serum albumin, and plasmid DNA (Nallamuthu *et al.,* 2014).

Anti-Inflammatory Activity

Significant acute and subacute anti-inflammatory action is shown by a variety of organic extracts of *Aegle marmelos* leaves (Dhankhar *et al.,* 2011). Since both lupeol and skimmianine have shown comparable qualities in their pure forms, these effects are ascribed to their existence in the leaves (Geetha and Varalakshmi, 2001). Bael fruit extract has antioxidant qualities, stabilises mast cells, and reduces inflammation. It prevents mast cell degranulation by raising superoxide dismutase levels and lowering malondialdehyde levels (Behera *et al.,* 2012). In isolated guinea pig ileum and tracheal chains, the alcoholic extract of *Aegle marmelos* leaves has a relaxing effect and reverses histamine-induced contractions, indicating possible H1 receptor inhibition (Dhankhar *et al*., 2011).

Anti-Ulcer Activity

An imbalance between mucosal protective and aggressive forces leads to ulcers, a common gastrointestinal disorder that is frequently brought on by oxidative stress, Helicobacter pylori infection, or decreased mucosal protection (Biswas *et al.,* 2003). In animal experiments, luvangetin, a pyranocoumarin present in bael seeds, has demonstrated protective properties against stomach ulcers brought on by aspirin and pylorus ligation **(**Vijaya *et al*., 2009**).** Numerous researches have demonstrated bael's anti-ulcer properties. Methanolic extract of bael has been given orally to rats that had developed gastric ulcers due to lipopolysaccharide (Ramakrishna *et al*., 2015). Another study on unripe bael fruit extract demonstrates gastro-protective effect when used to treat ethanol-induced mucosal injury; however, indomethacin and hypothermic stress-induced rat restraint have not shown this activity. The outcome suggests that the prostaglandin pathway is not followed by the gastro-protective mechanism (Dhuley, 2003).

Antidepressant Activity

Synthetic medications that can have negative side effects like sleepiness, ataxia, sleeplessness, and libido problems are frequently used to treat depression, a mood-related condition. Bael and other natural sources are thought to be safer substitutes **(**Goodman *et al*., 1996**).** Bael improved the antidepressant effectiveness of imipramine and fluoxetine, according to studies conducted on mice given anxiolytic drugs utilizing tail suspension and elevated plus maze tests (Kothari *et al*., 2010). Its mechanism is linked to serotonin receptor agonistic activity (Kumar *et al.,* 2015)

Antimicrobial Activity

Antibacterial, anticancer, antiviral, anti-inflammatory, and antifungal properties are among the many harmful species against which bael is said to offer exceptional protection (Sharma *et al*., 2007). According to reports, *Aegle marmelos* inhibits a variety of harmful germs and has long been used to cure infectious disorders. Its antibacterial properties against bacteria and fungi have been shown in several in vitro investigation*s* (Sivaraj *et al.,* 2011)

Bael-derived marmelide has demonstrated antiviral effectiveness against Coxsackieviruses B1–B6 in 96-hour plaque inhibition tests, with no harmful effects on host cells (Lalita *et al*., 2002). Bael extract's rate of inhibition changes with concentration; a dose of 0.05% extract may eradicate 100% of fungus, whereas doses of 0.04% and 0.03% extract can inhibit 90% and 75% of fungi, respectively (Rana *et al.,* 1977). Intestinal parasites such as *Ascaris lumbricoides* and *Entamoeba histolytica* can be avoided with bael powder. *Aspergillus* species and *Candida albicans* have demonstrated antimicrobial action by 1-methyl-2-(3'-methyl-but-2'-enyloxy)-anthraquinone, an anthraquinone derived from bael seed, according to a disc diffusion assay with a MIC value of 6.25 µg/disc. Bael leaf extract was also reported to inhibit filariae (Sahare *et al.,* 2008).

A quinone-like molecule that was isolated from bael was found to be effective against *P. aeruginosa* and *Escherichia coli*. This substance found in bael also inhibits *A. clavatus, A. niger, Penicillium roqueforti*, *C. albicans*, and *A. oryzae* (Rejiniemon *et al*., 2014). Ipenem and bael together exhibit a very strong inhibitory impact on *Acinetobacter baumannii* strains, whereas the antibiotic alone has a less pronounced effect. The microbiological activity of bael extract and its essential oils is examined in a study using several solvents, including methanol, ethanol, ethyl acetate,

petroleum ether, n-hexane, and dichloromethane. The minimal inhibitory concentration is found using the disc diffusion approach. The outcome demonstrates that several bael extracts have antibacterial action against the various microorganisms being studied (Rejiniemon *et al*., 2014). Bael fruit juice has been shown to suppress *Micrococcus luteus, Entercococcus faecalis, Streptococcus faecalis,* and *Klebsiella pneumonia.*

Wound Healing Activity

A collagen lattice is formed as a result of inflammation, cell division, and contraction during the wound-healing process. Flavonoids, alkaloids, essential oils, and sterols found in bael improve hydroxyproline content, stimulate wound contraction, improve epithelialisation, and increase tensile strength (Ilango and Chitra, 2010; Shirwaikar *et al.,* 2003). Nitrofurazone and *Aegle marmelos* both have wound-healing qualities. Its phytochemicals increase antioxidant activity, which speeds up the healing process (Veerappan *et al.,* 2007).

Antidiabetic Activity

According to (Ceriello, 2006), diabetes mellitus is a common metabolic disease that is frequently brought on by stressful lives, poor diets, and genetic factors. In diabetic rats, *Aegle marmelos* extract raises plasma insulin and liver glycogen while lowering blood glucose and glycosylated haemoglobin levels (Kamalakkannan and Prince, 2005). Bael's amino acids and dietary-fibre aid in regulating the absorption of sugar. It has been demonstrated that bael is more efficacious than glibenclamide at a dosage of 250 mg/kg. (Kamalakkannan and Prince, 2005).

Anti-Cancer Activity

Cancer is a serious worldwide health issue, and its therapies are frequently costly and fraught with serious adverse consequences (Jagetia *et al.,* 2005). Bael has demonstrated promise as a non-toxic and reasonably priced cancer treatment option. In tests like the methyl thiazolyl tetrazolium (MTT) assay and the brine shrimp lethality experiment, it exhibits cytotoxicity against tumour cell lines (Costa-Lotufo *et al.,* 2005). Bael inhibits the growth of a number of human cancer cell lines, such as erythroleukemic HEL20, leukemic K562, T-lymphoid Jurkat, and beta-lymphoid Raji. It is antiproliferative, but only at higher concentrations does it affect breast cancer cell lines such as MCF-7 and MDA-MB-231 (Costa-Lotufo *et al.,* 2005). At the active site of HSULF-2, the phytochemicals marmesin and marmelosin found in bael interact to potentially have anticancer effects (Banerjee *et al.,* 2024).

According to a study, bael's lupeol has a surprising effect on the RA4 DNA sequence by increasing ERα expression in ERα-negative MDA-MB-231 cells, which can stop cancer cells from proliferating (Lambertini *et al*., 2004). Bael extract has anti-cancer properties via strengthening the body's immune system (Patel and Asdaq; 2010). Bael extract may be able to delay the genotoxic effects of doxorubicin treatment when given to mouse bone marrow. When doxorubicin is administered after five days of treatment, the increase in normochromatic erythrocyte and micronucleated polychromatic frequency that results from doxorubicin treatment is reduced (Venkatesh *et al*., 2007). Citral, eugenol, and d-limolene derived from bael extract have all demonstrated anti-neoplastic properties (Baliga *et al.,* 2013). Human melanoma 451Lu cells, B162F2 cells, WM35 cells, human epidermoid carcinoma A431 cells, prostate cancer cell lines LNCaP, hepatocellular carcinoma SMMC7721 cells, and human pancreatic adenocarcinoma cells AsPC-120 CWR22R_1 and PC-3 are all affected by the antineoplastic actions of lupeol in bael. It has been discovered that luteol inhibits the expression of cyclin D2, cyclin D1, and eDk2, which stops the G1-S phase of the cell cycle (Prasad *et al*., 2008).

Anti-inflammatory activity

Significant acute and subacute anti-inflammatory activity is exhibited by several organic extracts of *A. marmelos* leaves (Dhankhar *et al*., 2011). *A. marmelos* had strong anti-inflammatory action in both acute and chronic inflammatory animal models, suggesting that it may be a viable anti-inflammatory drug (Benni *et al.,* 2011). Since both lupeol and skimmianine have demonstrated the same potentialities in pure form, these activities may be caused by the presence of these chemicals in the leaves. Histamine receptor activation is necessary for the expression of allergies and asthma. In isolated guinea pig ileum and tracheal chain, the alcoholic extract of *A. marmelos* leaves showed a good relaxant effect and counteracted histamine-induced contractions, indicating that these effects may be due to suppression of H1 receptor activity (Dhankhar *et al*., 2011).

Other Applications of Bael

The unripe seed contains gum that can be used with cement to plaster buildings or waterproof them, or it can be used as an adhesive for jewellery. The yellow dye made from tannin can be used to dye silk materials for textile patterns. The Dutch of Ceylon have utilised Mermelle oil. Bael could be used to prepare carts and stop scum from forming. It is used to make combs,

pestles, small-scale turnery, and tool and knife handles. There is insecticidal action against brown planthoppers (Afreen *et al.,* 2016). The hazardous metal chromium (VI) may be extracted from the aqueous solution using activated carbon derived from the bael fruit shell (Anandkumar *et al.,* 2009). Bael can be used to extract lead (II) from spent batteries that include other metals (Chakravarty *et al*., 2010).

Future Prospects

Development of standardized extracts: The creation of standardised Bael extracts suitable for use in pharmaceutical products and clinical trials need to be the top priority of future research. The main bioactive components in Bael can be identified and measured with the aid of developments in analytical techniques like mass spectrometry (MS) and high-performance liquid chromatography (HPLC). Standardised extracts would make it possible to create trustworthy dosage forms for medical use and guarantee the uniformity of therapeutic effects.

Clinical trials for efficacy and safety: Randomised controlled clinical trials (RCTs) must be carefully planned in order to prove Bael's safety and therapeutic efficacy in people. Numerous illnesses, such as diabetes, gastrointestinal issues, inflammation, and infections, should be the focus of this research. Clinical research should also investigate the best dosage, mode of administration, and course of treatment in order to optimise therapeutic results and reduce hazards.

Exploration of synergistic effects: Bael may have synergistic benefits when taken with other herbal remedies or traditional pharmaceutical medications because of its diverse array of bioactive components. Subsequent studies might concentrate on how bael might work in concert with other conventional plants to improve its therapeutic benefits and lessen any possible negative effects. Examining Bael's function in polyherbal formulations may lead to new clinical uses for the plant.

Summary and Conclusion

Bael has acquired highly promising therapeutic properties, making them deserving of further examination. Examining the phytochemistry of fruit revealed a wealth of phytochemicals, particularly flavonoids, phenols, alkaloids, coumarins, and essential oils, as well as their remarkable ability to treat a wide range of illnesses naturally. Bael's non-toxic behaviour has been shown by clinical testing, guaranteeing a very safe and side-effect-free pharmacological use. Additionally, the plant is quite easy to grow and doesn't need any extra attention, which highlights the fruit's economic value. Consequently, farmers ought to be encouraged to cultivate this plant. Although the presence of bioactive chemicals in bael has been the subject of countless research to date, the majority of their molecular mechanisms of action remain unclear. Focus must be placed on keeping the fruit by creating alternative items and exporting them, in addition to consuming fresh juice. Even though bael has been used extensively in traditional medicine since ancient times, further study is needed to understand how the fruit's bioactive chemicals work and to promote its use globally so that everyone can benefit from its remarkable health advantages.

The review study on *Aegle marmelos* (Bael) goes into great detail about the plant's centuries-old medicinal value in ancient systems such as Ayurveda. *Aegle marmelos,* which originated in India, is an important part of South Asia's ethnomedical environment. Its leaves, bark, and fruits are used to cure a wide range of illnesses. The main chemical components and their pharmacological properties are highlighted in the study. Bael has a variety of medicinal benefits, such as anti-inflammatory, anti-ulcer, and antioxidant qualities. Compounds like flavonoids and coumarins, which have shown promise in scavenging free radicals and reducing oxidative stress, are responsible for its particularly noteworthy antioxidant action. Additionally, research showing bael's effectiveness in enzyme inhibition and mast cell stabilisation supports its anti-inflammatory properties. The study emphasises the primary chemical constituents and their pharmacological characteristics. Bael offers several health advantages, including anti-inflammatory, anti-ulcer, and antioxidant properties. Its very notable antioxidant activity is caused by compounds like flavonoids and coumarins, which have demonstrated promise in scavenging free radicals and lowering oxidative stress. Furthermore, studies demonstrating bael's efficacy in stabilising mast cells and inhibiting enzymes bolster its anti-inflammatory qualities.

References

Afreen, S. M. M. S., Premakumar, K., & Inthujaa, Y. (2016). Preparation of Ready-To-Serve (RTS) beverage from carrot with sour-orange Juices. *Int. J. Innov. Res. Sci. Eng. Technol*, **5**(2), 1992-1998.

Anandkumar, J., & Mandal, B. (2009). Removal of Cr (VI) from aqueous solution using Bael fruit (*Aegle marmelos* correa) shell as an adsorbent. *Journal of hazardous materials*, **168**(2-3), 633-640.

Baliga, M. S., Thilakchand, K. R., Rai, M. P., Rao, S., & Venkatesh, P. (2013). *Aegle marmelos* (L.) Correa (Bael) and its phytochemicals in the treatment and prevention of cancer. *Integrative cancer therapies*, **12**(3), 187-196.

Banerjee, A., Jain, S., Singh, A., Dhakad, A., Singh, A. E., Pandey, A., & Mani, G. (2024). A Review: Medicinal

Properties and Health Benefits of Bael (*Aegle marmelos*). *Journal of Scientific Research and Reports*, **30**(6), 773-786.

Behera, J. P., Mohanty, B., Ramani, Y. R., Rath, B., & Pradhan, S. (2012). Effect of aqueous extract of *Aegle marmelos* unripe fruit on inflammatory bowel disease. *Indian Journal of Pharmacology*, **44**(5), 614-618.

Benni, J. M., Jayanthi, M. K., & Suresha, R. N. (2011). Evaluation of the anti-inflammatory activity of *Aegle marmelos* (Bilwa) root. *Indian journal of pharmacology*, **43**(4), 393-397.

Bhar, K., Mondal, S., & Suresh, P. (2019). An eye-catching review of *Aegle marmelos* L.(golden apple). *Pharmacognosy Journal*, **11**(2).

Bhardwaj, R. L., & Nandal, U. (2015). Nutritional and therapeutic potential of bael (*Aegle marmelos* Corr.) fruit juice: a review. *Nutrition & Food Science*, **45**(6), 895-919.

Bhardwaj, R.L. (2014). Role of bael fruit juice in nutritional security of Sirohi tribals. *Benchmark Survey Report of Sirohi Tribals, Krishi Vigyan Kendra, AU, Jodhpur*, 11-37.

Biswas, K., Bandyopadhyay, U., Chattopadhyay, I., Varadaraj, A., Ali, E., & Banerjee, R. K. (2003). A novel antioxidant and antiapoptotic role of omeprazole to block gastric ulcer through scavenging of hydroxyl radical. *Journal of Biological Chemistry*, **278**(13), 10993-11001.

Ceriello, A. (2006). Oxidative stress and diabetes-associated complications. *Endocrine Practice*, **12**, 60-62.

Chakravarty, S., Mohanty, A., Sudha, T. N., Upadhyay, A. K., Konar, J., Sircar, J. K., ... & Gupta, K. K. (2010). Removal of Pb (II) ions from aqueous solution by adsorption using bael leaves (*Aegle marmelos*). *Journal of hazardous materials*, **173**(1-3), 502-509.

Chemexcil. (1992). Selected Medicinal Plants of India. Bombay (India): Basic Chemicals, Pharmaceutical, and Cosmetic Export Promotion Council.

Costa-Lotufo, L. V., Khan, M. T. H., Ather, A., Wilke, D. V., Jimenez, P. C., Pessoa, C., ... & de Moraes, M. O. (2005). Studies of the anticancer potential of plants used in Bangladeshi folk medicine. *Journal of ethnopharmacology*, **99**(1), 21-30.

Dar, N. G., Saleem, N., Ali Soomro, U., Afzal, W., Naqvi, B., & Jamil, K. (2015). Nutritional Exploration of Leaves. *Seed and Fruit of Bael*.

Das, S. K., & Roy, C. (2012). The protective role of *Aegle marmelos* on aspirin–induced gastro-duodenal ulceration in albino rat model: a possible involvement of antioxidants. *Saudi Journal of Gastroenterology*, **18**(3), 188-194.

Dhankhar, S., Ruhil, S., Balhara, M., Dhankhar, S., & Chhillar, A. K. (2011). *Aegle marmelos* (Linn.) Correa: A potential source of Phytomedicine. *J Med Plant Res*, **5**(9), 1497-1507.

Dhuley, J. N. (2003). Investigation on the gastroprotective and antidiarrhoeal properties of *Aegle marmelos* unripe fruit extract. *Hindustan antibiotics bulletin*, **45**(1-4), 41-46.

Gautam, M. K., Purohit, V., Agarwal, M., Singh, A., & Goel, R. K. (2014). In vivo healing potential of *Aegle marmelos* in excision, incision, and dead space wound models. *The Scientific World Journal*, **2014**(1), 740107.

Geetha, T., & Varalakshmi, P. (2001). Anti-inflammatory activity of lupeol and lupeol linoleate in rats. *Journal of ethnopharmacology*, **76**(1), 77-80.

Goodman, L. S. (1996). *Goodman and Gilman's the pharmacological basis of therapeutics* (Vol. 1549, pp. 1361-1373). New York: McGraw-Hill.

Gurjar, P.S., Bhattacherjee, A.K., Singh, A., Dikshit, A., & Singh, V.K. (2019). Characterization of nutraceuticals in bael powder prepared from fruits harvested at different developmental stages.

Gupta, D., John, P. P., Kumar, P., & Jain, J. (2018). Evaluation of antioxidant activity of unripe *Aegle marmelos* corr. Fruits. *Journal of Applied Pharmaceutical Sciences and Research*, 4-7.

Aoac, I. (2010). Official methods of analysis of AOAC international, 18^ ed. *AOAC Int*, **6**(382), 90022-5.

Ilango, K., & Chitra, V. (2010). Wound healing and anti-oxidant activities of the fruit pulp of Limonia acidissima Linn (Rutaceae) in rats. *Tropical Journal of Pharmaceutical Research*, **9**(3).

Jagetia, G. C., Venkatesh, P., & Baliga, M. S. (2005). *Aegle marmelos* (L.) C ORREA Inhibits the Proliferation of Transplanted Ehrlich Ascites Carcinoma in Mice. *Biological and Pharmaceutical Bulletin*, **28**(1), 58-64.

Jagtap, A. G., Shirke, S. S., & Phadke, A. S. (2004). Effect of polyherbal formulation on experimental models of inflammatory bowel diseases. *Journal of ethnopharmacology*, **90**(2-3), 195-204.

Johnson, M. (2010). Biochemical variation studies in *Aegle marmelos* L. Corr: a medicinally important plant. *J Chem Pharm Res*, **2**(6), 454-462.

Jyotsana Sharma, J. S., Painuli, R. M., & Gaur, R. D. (2010). Plants used by the rural communities of district Shahjahanpur, Uttar Pradesh.

Kala, C. P. (2006). Ethnobotany and ethnoconservation of *Aegle marmelos* (L.) Correa.

Kamalakkannan, N., & Prince, P. S. M. (2005). The effect of *Aegle marmelos* fruit extract in streptozotocin diabetes: a histopathological study. *Journal of herbal pharmacotherapy*, ***5***(3), 87-96.

Khaneghah, A. M., Martins, L. M., von Hertwig, A. M., Bertoldo, R., & Sant'Ana, A. S. (2018). Deoxynivalenol and its masked forms: Characteristics, incidence, control and fate during wheat and wheat based products processing-A review. *Trends in Food Science & Technology*, **71**, 13-24.

Kothari, S., Minda, M., & Tonpay, S. D. (2010). Anxiolytic and antidepressant activities of methanol extract of *Aegle marmelos* leaves in mice. *Indian J Physiol Pharmacol*, **54**(4), 318-328.

Kumar, K. S., Umadevi, M., Bhowmik, D., Singh, D. M., & Dutta, A. S. (2012). Recent trends in medicinal uses and health benefits of Indian traditional herbs *Aegle marmelos*. *The Pharma Innovation*, **1**(4).

Kumar, S., Mahaseth, R. K., Tiwari, M., Sehgal, R., Rajora, P., & Mathur, R. (2015). Interaction of aqueous leaf extract of *Aegle marmelos* (L.) Corr. with cholinergic, serotonergic and adrenergic receptors: An: ex vivo: study. *Indian journal of pharmacology*, **47**(1), 109-113.

Lalita Badam, L. B., Bedekar, S. S., Sonawane, K. B., & Joshi, S. P. (2002). In vitro antiviral activity of Bael (*Aegle marmelos* Corr) upon human coxsackieviruses B1-B6.

Lambertini, E., Piva, R., Khan, M. T. H., Lampronti, I., Bianchi, N., Borgatti, M., & Gambari, R. (2004). Effects of extracts from Bangladeshi medicinal plants on in vitro proliferation of human breast cancer cell lines and

expression of estrogen receptor α gene. *International Journal of oncology*, **24**(2), 419-423.

Laphookhieo, S., Phungpanya, C., Tantapakul, C., Techa, S., Tha-in, S., & Narmdorkmai, W. (2011). Chemical constituents from *Aegle marmelos*. *Journal of the Brazilian Chemical Society*, **22**, 176-178.

Lim, T.K. (2012). *Edible medicinal and non-medicinal plants* (Vol. 1, pp. 285-292). Dordrecht, The Netherlands:: Springer.

Mahomoodally, M. F., Mollica, A., Stefanucci, A., Aumeeruddy, M. Z., Poorneeka, R., & Zengin, G. (2018). Volatile components, pharmacological profile, and computational studies of essential oil from *Aegle marmelos* (Bael) leaves: A functional approach. *Industrial Crops and Products*, **126**, 13-21.

Maity, P., Hansda, D., Bandyopadhyay, U., & Mishra, D. K. (2009). Biological activities of crude extracts and chemical constituents of Bael, *Aegle marmelos* (L.) Corr.

Manandhar, B., Paudel, K. R., Sharma, B., & Karki, R. (2018). Phytochemical profile and pharmacological activity of *Aegle marmelos* Linn. *Journal of integrative medicine*, **16**(3), 153-163.

Mani, A., Singh, A., Jain, N., & Misra, S. (2017). Flowering, fruiting and physio-chemical characteristics of bael (*Aegle marmelos* correa.) grown in northern districts of West Bengal. *Curr. J. Appl*, **23**(3), 1-8.

Nandal, U. (2013). *Handbook of Foods and Nutritional Biochemistry*. Agrobios (India).

Nallamuthu, I., Tamatam, A., & Khanum, F. (2014). Effect of hydroalcoholic extract of *Aegle marmelos* fruit on radical scavenging activity and exercise-endurance capacity in mice. *Pharmaceutical Biology*, **52**(5), 551-559.

Neeraj, V. B., & Johar, V. (2017). Bael (*Aegle marmelos*) extraordinary species of India: a review. *Int. J. Curr. Microbiol. Appl. Sci*, **6**(3), 1870-1887.

Ohashi, K., Watanabe, H., Okumura, Y., Uji, T., & KITAGAWA, I. (1994). Indonesian medicinal plants. XII. Four isomaric lignan-glucosides from the bark of *Aegle marmelos* (Rutaceae). *Chemical and pharmaceutical bulletin*, **42**(9), 1924-1926.

Patel, P., & Asdaq, S. M. B. (2010). Immunomodulatory activity of methanolic fruit extract of *Aegle marmelos* in experimental animals. *Saudi Pharmaceutical Journal*, **18**(3), 161-165.

Patkar, A. N., Desai, N. V., Ranage, A. A., & Kalekar, K. S. (2012). A review on *Aegle marmelos*: a potential medicinal tree. *International Research Journal of Pharmacy*, **3**(8), 86-91.

Prasad, S., Nigam, N., Kalra, N., & Shukla, Y. (2008). Regulation of signaling pathways involved in lupeol induced inhibition of proliferation and induction of apoptosis in human prostate cancer cells. *Molecular carcinogenesis*, **47**(12), 916-924.

Rajan, S., Gokila, M., Jency, P., Brindha, P., & Sujatha, R. K. (2011). Antioxidant and phytochemical properties of *Aegle marmelos* fruit pulp. *Int J Curr Pharm Res*, **3**(2), 65-70.

Ramakrishna, Y. G., Savithri, K., Kist, M., & Devaraj, S. N. (2015). *Aegle marmelos* fruit extract attenuates Helicobacter pylori Lipopolysaccharide induced oxidative stress in Sprague Dawley rats. *BMC complementary and alternative medicine*, **15**, 1-10.

Rana, B. K., Singh, U. P., & Taneja, V. (1997). Antifungal activity and kinetics of inhibition by essential oil isolated from leaves of *Aegle marmelos*. *Journal of ethnopharmacology*, **57**(1), 29-34.

Rejiniemon, T. S., Arasu, M. V., Duraipandiyan, V., Ponmurugan, K., Al-Dhabi, N. A., Arokiyaraj, S., ... & Choi, K. C. (2014). In-vitro antimicrobial, antibiofilm, cytotoxic, antifeedant and larvicidal properties of novel quinone isolated from *Aegle marmelos* (Linn.) Correa. *Annals of clinical microbiology and antimicrobials*, **13**, 1-9.

Sahare, K. N., Anandhraman, V., Meshram, V. G., Meshram, S. U., Reddy, M. V. R., Tumane, P. M., & Goswami, K. (2008). Anti-microfilarial activity of methanolic extract of Vitex negundo and *Aegle marmelos* and their phytochemical analysis.

Samarasekera, J. R., Khambay, B. P., & Hemalal, K. P. (2004). A new insecticidal protolimonoid from *Aegle marmelos*. *Natural Product Research*, **18**(2), 117-122.

Sanghi, S. B., & Mushtaq, S. (2017). *Aegle marmelos* a potential medicinal tree: an overview. *International Journal of Research Granthaalayah*, *5*(8), 63-66.

Sekar, D. K., Kumar, G., Karthik, L., & Rao, K. B. (2011). A review on pharmacological and phytochemical properties of *Aegle marmelos* (L.) Corr. Serr. (Rutaceae). *Asian Journal of Plant Science and Research*, **1**(2), 8-17.

Shariff, N., Sudarshana, M. S., Umesha, S., & Hariprasad, P. (2006). Antimicrobial activity of Rauvolfia tetraphylla and Physalis minima leaf and callus extracts. *African Journal of Biotechnology*, **5**(10).

Sharma, P. C., Bhatia, V., Bansal, N., & Sharma, A. (2007). A review on Bael tree.

Sharmila, S., & Devi, P. V. (2011). Comparison of invitro antioxidant activity of the ethanolic extract of ripe and unripe fruit of *Aegle marmelos.*

Shirwaikar, A., Shenoy, R., Udupa, A. L., Udupa, S. L., & Shetty, S. (2003). Wound healing property of ethanolic extract of leaves of Hyptis suaveolens with supportive role of antioxidant enzymes.

Sivaraj, R., Balakrishnan, A., Thenmozhi, M., & Venckatesh, R. (2011). Antimicrobial activity of *Aegle marmelos*, Ruta graveolens, Opuntia dellini, Euphorbia royleena and Euphorbia antiquorum. *Journal of Pharmacy research*, **4**(5), 1507.

Sonawane, A., Pathak, S. S., & Pradhan, R. C. (2020). Physical, thermal, and mechanical properties of bael fruit. *Journal of Food Process Engineering*, **43**(6), e13393.

Srivastava, S. D., Srivastava, S., & Srivastava, S. K. (1996). New anthraquinones from the heartwood of *Aegle marmelos.*

Veerappan, A., Miyazaki, S., Kadarkaraisamy, M., & Ranganathan, D. (2007). Acute and subacute toxicity studies of *Aegle marmelos* Corr., an Indian medicinal plant. *Phytomedicine*, **14**(2-3), 209-215.

Venkatesh, P., Shantala, B., Jagetia, G. C., Rao, K. K., & Baliga, M. S. (2007). Modulation of doxorubicin-induced genotoxicity by *Aegle marmelos* in mouse bone marrow: a micronucleus study. *Integrative Cancer Therapies*, **6**(1), 42-53.

Verma, S., Bahorun, T., Singh, R. K., Aruoma, O. I., & Kumar, A. (2013). Effect of *Aegle marmelos* leaf extract on N-methyl N-nitrosourea-induced hepatocarcinogensis in Balb/c mice. *Pharmaceutical Biology*, **51**(10), 1272-1281.

Vijaya, C., Ramanathan, M., & Suresh, B. (2009). Lipid lowering activity of ethanolic extract of leaves of *Aegle marmelos* (Linn.) in hyperlipidaemic models of Wistar albino rats.

Vines, G. (2004). *Herbal harvests with a future: towards sustainable sources for medicinal plants*. Plantlife International.

Yaqeen, Z., Rehman, Z.U., & Fatima, N. (2015). Pharmacological rational of dry ripe fruit of *Aegle marmelos* L. as an anti-nociceptive agent in different painful conditions. *Pak. J. Pharm. Sci*, **28**(2), 515-519.