Trends in Horticulture (2023) Volume 6 Issue 2
doi: 10.24294/th.v6i2.2941

REVIEW ARTICLE

Ethnomedicinal properties of Bael *Aegle marmelos* Corrêa family Rutaceae: A review

Ganesh Chandra Jagetia

Department of Zoology, Mizoram University, Aizawl 796004, India; gc.jagetia@gmail.com

ABSTRACT

Bael or *Aegle marmelos* Corrêa is considered a sacred tree by Hindus and is offered to Lord Shiva while worshipping. It grows in the Indian subcontinent and Southeast Asia and is called by various names in different regions. Bael has been used as a traditional medicine in India and other Southeast Asian countries to treat various ailments, including diarrhea, chronic dysentery, constipation, gonorrhea, catarrh, diabetes, deafness, inflammations, ulcerated intestinal mucosa, intermittent fever, melancholia, heart palpitation, and also to control fertility. The ethnomedicinal properties of Bael are owing to its ability to synthesize alkaloids, cardiac glycosides, anthocyanins, flavonoids, steroids, saponins, terpenoids, tannins, lignins, quinones, coumarins, proteins, carbohydrates, amino acids, reducing sugars, fats, and oils. The aegeline, auroptene, umbelliferone, psoralene, marmin, imperatorin, xylorhamnoarabinogalactan I pectic polysaccharide and skimmianine are synthesized by different parts of Bael, and they have shown antibacterial, anti-inflammatory, analgesic, anti-allergic, anthelmintic, antidiabetic, anticancer, cardioprotective and neuroprotective activities in various experimental models. The present review has been written consulting various publications, and different websites including Google Scholar, Pubmed, ScienceDirect, and Google.

Keywords: *Aegle marmelos*; phytochemical; ethnomedicine; alkaloids; glycosides

ARTICLE INFO

Received: 7 October 2023
Accepted: 1 November 2023
Available online: 21 November 2023

1. Introduction

Angiosperms abound on the earth, and 80% of plants belong to Angiosperms. Approximately, 300,000–400,000 species of angiosperms are found on the earth, out of which 21,000 angiosperms are of medicinal importance. The angiosperms are of great value as they synthesize several bioactive phytochemicals and provide various medicines for human healthcare[1,2]. *Aegle marmelos* Corrêa or Bael belongs to Family Rutaceae which includes 162 genera and 2085 species of woody shrubs and trees[3]. The review has been written by gathering information from different sources, including several publications, Google Scholar, PubMed, ScienceDirect, and Google. Here, ethnomedicinal and phytochemical aspects are reviewed.

2. Horticultural importance

Bael fruit is sweet, aromatic, and consumed after the removal of its hard shell. The characteristic aroma is retained even after processing. The Jams, sherbets, nectars, toffees, ready-to-serve wine, powder, and slab are prepared from the ripened Bael fruit. The Bael is cultivated for its fruit and medicinal properties and for offering its trifoliate leaves to Lord Shiva. Several varieties of Bael including Kagzi Etawah, Kagzi Gonda, Kagzi Banarsi, Mirzapuri, Narendra Bael-1, 2, 5, and 9, Pant Sujata, and Pant Shivani are grown in India for its fruits[4]. In Thailand

and Malaysia Bael fruit and its slices are eaten as such or in the form of syrup and to make ingredients for cakes[5]. The processing of fruits of Bael generates waste products in the form of peels, seeds, and fibers which are useful in extracting many bioactive compounds[6].

3. Scientific position

Bael *Aegle marmelos* belongs to Kingdom: Plantae, Subkingdom: Tracheobionta, Super division: Spermatophyta, Division: Magnoliophyta: Class: Magnoliopsida, Subclass: Rosidae, Order: Sapindales, Family: Rutaceae, Genus Aegle Corr., Species *marmelos* (L.) Corrêa. Bael is scientifically known as *Aegle marmelos* and is also known as *Belou marmelos* (L.) Lyons, *Crateva marmelos* L., *Bilacus marmelos* (L.) Kuntze, *Crateva religiosa* Ainslie, and *Feronia pellucida* Roth.

4. Botanical profile

Bael is a subtropical plant indigenous to the Indian subcontinent and Southeast Asia, including Bangladesh, Myanmar, Pakistan, Thailand, Nepal, China, Cambodia, Fiji, Laos, Indonesia, Malaysia, Philippines, Tibet, Java, Vietnam, and Sri Lanka[7–9]. Bael grows in dry forests, plains, and hilly areas, including the outer Himalayas, Shivalik hills, and South India up to an altitude of 250–1200 m above sea level. It flourishes in a wide range of habitats and is planted throughout the world. Bael grows in all Indian states from north to south and east to west, including Andhra Pradesh, Andaman Islands, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Maharashtra, Punjab, Uttar Pradesh, Uttarakhand, Rajasthan, Madhya Pradesh, Jammu and Kashmir, Karnataka, Kerala, Tamil Nadu and West Bengal. It is usually planted near temples in India due to its religious and mythological importance. Hindus consider it a holy tree, and its trifoliate leaves are considered sacred and placed onto Lord Shiva Lingam while worshiping[10,11].

Bael is a slow-growing spiny tree reaching a height of 12–15 m and 90–120 cm in girth (**Figure 1**). The trunk of the Bael is stocky with thick, spongy, and flaking bark (**Figure 1**). Leaves of Bael are thick, broad, oblong, lanceolate, crenulated, alternate, 4–10 cm long, 2–5 cm wide, deciduous, pointed, pinnate, or ternate

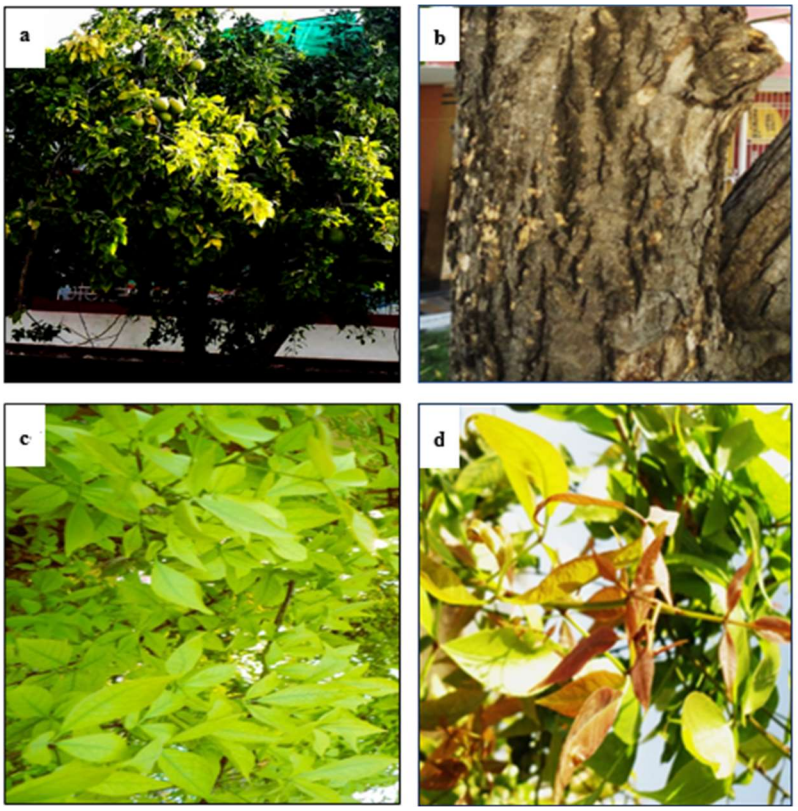

Figure 1. *Aegle marmelos* (Bael). **(a)** Tree in its natural habitat; **(b)** stem and bark; **(c)** mature leaves; **(d)** new leaves.

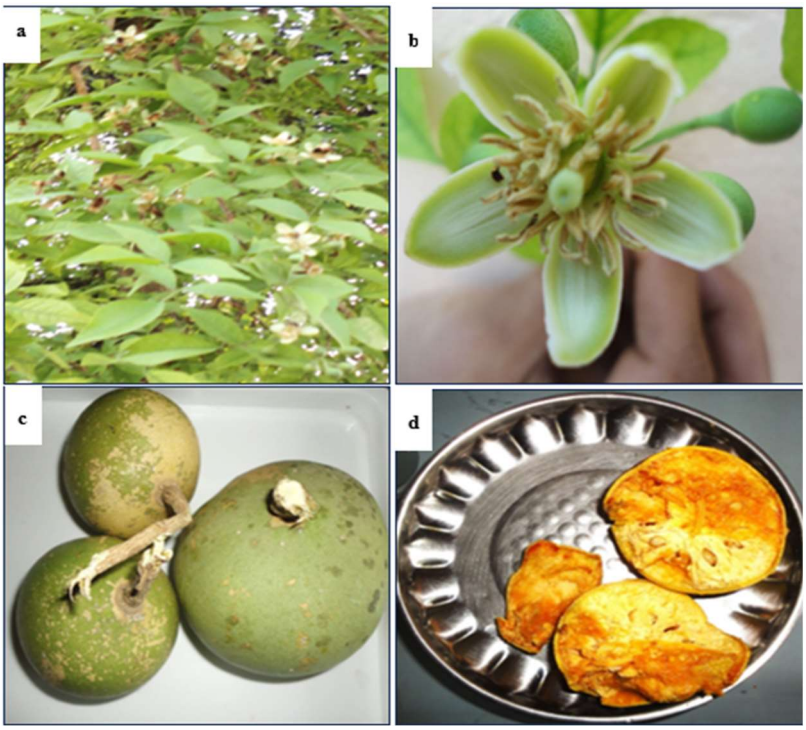

Figure 2. *Agele marmelos* (Bael). **(a)** Flower in native form; **(b)** flower closeup; **(c)** fruits and **(d)** split fruit showing seeds.

with a long petiole. Newly developing leaves are pinkish maroon and glossy (**Figure 1**). The inflorescence of Bael consists of tiny fragrant flowers that are 4–7 in number, along with juvenile branchlets having 4 convoluted fleshy petals. The petals are yellow inside and green colored outside (**Figure 2**). Flowers are 2 cm wide, erect, stalked, and lax, with a sweet aroma that appears supplemental or as terminal cymes. The flowers have five short superficial calyces with broad teeth. The ovary is elliptical to oblong and tapers into a thick short style with a capitate stigma and 50 or more stamens (**Figure 2**)[9,12,13]. Bael fruits are round, ovoid, oblong, or pyriform and 5–20 cm in diameter (**Figure 2**). The fruit rind is very hard and becomes stony when dry (hence the name wood apple), almost smooth, and light yellow, brown, or cherry red. The fruit pulp of Bael is sweet, firm brownish-red colored with 12 stony carpels containing 1 cm long, 10–50 flattened-oblong hairy seeds encased in a gummy or transparent mucilaginous substance that becomes solid after drying (**Figure 2**)[13].

Table 1 lists the common names of Bael in different languages of the world.

Commonly bael is known as Bengal quince, Golden apple, and Wood apple in English. The Hindi name of *Aegle marmelos* is Bel. In Sanskrit, *Aegle marmelos* is known as *Bilva* and *Shivadruma*. *Aegle marmelos* is *Malura* in Pali; *Bel* in Urdu, Assamese and Gujarati; *Bela* in Bengali and Marathi; *Bilpatra*, in Kannada; *Gorakamli* in Konkani; *Baela* in Malayalam; *Belo* in Panjabi; *Katori* in Sindhi; *Bilva-pandu* in Telugu, and *Bilva* in Tamil (**Table 1**)[9,14–19].

Aegle marmelos is called as *Shul* in Arabic; *Ohshit* in Burmese, *Mu ju* in Chinese; *Slijmappelboom* in Dutch; *Bel indien* in French, *Belbaum* in German; *Maja batuh* in Indonesian; *Modjo* in Javanese; *Cotogno del Bengala* in Italian; *Berunoki* in Japanese; *Phneou* in Khmer; *Toum* in Laotian (Sino Tibetan); *Bel* in Malay; *Belapatra* in Nepali; *Bah hindi* in Persian; *Marmeleiro-da-Índia* in Portuguese; *Beli* in Sinhalese; *Bela Milva* in Spanish; *Bael* in Tagalog; *Mapin* in Thai; *Hind ayva agh* in Turkish; and *Bau nau* in Vietnamese (**Table 1**)[9,14–18,20,21].

Table 1. Colloquial names of *Agele maremlos* in various languages.

S. No.	Language	Names	Reference
1	Hindi	Bel, Bela, Bel patra, Villi, Shivadume, Shriphal	[9,14–18]
2	Sanskrit	Bilva, Bilvam, Bilva-phalam, Mahura, Shivaphala, Shivadruma, Sriphal, Pootivat, Shaelpatra, Lakshmiputra, Shivestha	[9,15–18]
3	Urdu	Bel, Bael	[9,15–18]
4	Assamese	Bel	[18]
5	Gujarati	Bel, Bilivaohal, Billi	[9,16–18]
6	Bengali,	Bael, Bela, Shriphal	[9,14–18]
7	Kannada	Bilpatra, Malura, Kumbala	[9,16–18]
8	Konkani	Gorakamli	[15]
9	Marathi	Bela, Kaveeth	[9,14–18]
10	Malayalam	Baela koovalam, Kuvalam, Maaredy, Vilvam	[1,9,15–18]
11	Oriya	Belo, Baela	[9,15–18]
12	Panjabi	Beel, Bil	[14,15]
13	Sindhi	Katori	[14]
14	Telegu	Bilva, Bilvamu, Bilva-pandu, Maradu-pandu, Malu-remu-chettu	[9,14–18]
15	Tamil	Bilva, Bilubam, Kuuviram, Villuvam, Vilvam, Vilvama, Vilva-maram, Vilva-pazham	[9,14–18]
16	Scientific	*Aegle marmelos* Corrêa, *Belou marmelos* (L.) Lyons, *Bilacus marmelos* (L.) Kuntze, *Crateva marmelos* L., *Crateva religiosa* Ainslie, and *Feronia pellucida* Roth	[9,14–18]
17	English	Bael fruit tree, bael tree, ball tree, bela tree, Bengal quince, elephant apple, golden apple, holy fruit, Indian bael, Indian quince, maredoo, quince-apple of India, stone apple, wood apple	[9,14–18]
18	Arabic	Safarjale-hindi, Shul	[9,17,18,20, 21]
19	Burmese	Ohshit, Opesheet	[9,17,18,20, 21]
20	Chinese	Mu ju, Yin du gou qi, Ying pi ju	[9,14–18]
21	Dutch	Slijmappelboom	[9,14–18]
22	French	Bel indien, Cognassier du Bengal, Coing de l'Inde, Oranger de Malabar	[9,14–18]
23	German	Belbaum, Bengalische quitte, Indische quitte, Schleimapfelbaum	[9,14–18]
24	Indonesian	Maja batuh, maja	[9,14–18]
25	Italian	Cotogno del Bengala, Cotogno d'India	[9,14–18]
26	Japanese	Berunoki, Igure marumerozu	[9,14–18]
27	Javanese	Modjo	[9,14–18]
28	Khmer	Phneou, pnoi	[9,14–18]
29	Laotian (Sino Tibetan)	Toum	[9,14–18]
30	Malay	Bel, Bila, Bilak, Maja, Maja batuh, Maja pahit	[9,14–18]
31	Nepali	Belapatra, Belpatra	[9,14–18]
32	Persian	Bah hindi, Safarjal-e-hindi, Shull	[9,14–18]
33	Portuguese	Marmeleiro-da-índia	[9,14–18]
34	Sinhalese	Beli	[9,14–18]
35	Spanish	Bela, Milva	[9,14–18]
36	Tagalog	Bael	[9,14–18]
37	Thai	Mapin, Matum	[9,14–18]
38	Turkish	Hind ayva agh	[9,14–18]
39	Vietnamese	Bau nau, Tráimam	[9,14–18]

5. Ethnomedicinal uses of Bael

Ayurveda utilizes Bael as a medicine since ancient times in India and other Southeast Asian countries also use Bael as a traditional medicine. The history of the use of Bael as ethnomedicine dates back to 5000 years and it has been mentioned in Ramayan, Charak Samhita, Upvana Vinod, and Yajur Veda[10,22,23]. The medicinal values of Bael have been appreciated by Indians for a very long time (Charaka 1500 BC). Bael has been used to control fertility, treatment of intestinal disorders, and intermittent fever, and it is given after

childbirth. It is also used as a fish poison[24]. Administration of boiled rice water mixed with unripe fruit pulp of Bael twice daily stops vomiting in women during pregnancy. Unripe fruit of Bael mixed with milk and sugar helps to treat urinogenital disorders. A mixture of sugar and half-roasted unripe fruit pulp of Bael cures abscesses and dysentery[17].

Green fruits of Bael are digestive, astringent demulcent, stomachic, and helpful in piles. One part of dried fruit powder mixed with 2 parts of mustard oil is applied to treat burns in Southern Chhattisgarh by traditional healers. Ripe fruits are given to treat diarrhea, chronic dysentery, constipation, gonorrhea, and ulcerated intestinal mucosa, and are also used as a heart and brain tonic. Ripe fruits are laxative, antiviral, and active against parasites and epilepsy. The root decoction of Bael helps to relieve intermittent fever, melancholia, and heart palpitation and it is also one of the essential components of "dashmool" an Ayurvedic medicine. The leaves of Bael are bitter, expectorant, astringent, febrifuge, and laxative. Leaves are topically applied to relieve inflammation. The 'poultice' prepared from leaves relieves ophthalmic disorders and is applied to treat ulcers. Fresh leaves help to mitigate the weakness of the heart, beriberi, and dropsy. Fresh leaf juice is laxative and is used in asthmatic complaints, eye affections, and ophthalmia. Inflammations, catarrh, diabetes, and deafness can also be treated with Bael leaves. Eating young leaves of Bael causes sterility in males and abortions in females[25]. The topical application of oil prepared by heating one teaspoon of a mixture of Bael leaf juice, one teaspoon of sesame oil, a few black pepper seeds, and half a teaspoon of kalonji (*Nigella sativa*) on the scalp increases the resistance against cough and cold. This oil can be filtered and stored for later use. The medicated Bael leaf oil relieves recurrent colds and arrests respiratory infections. Bael flower distillate acts as an antidysenteric and expectorant. It is also used as a tonic for the intestine and stomach, as a local anesthetic, and to treat epilepsy[20,23]. The drinking "sherbet" made from Bael fruit pulp for 2–3 months acts as anti-constipating and is so powerful that it can cleanse bowl of old fecal matter[17].

Bael synthesizes different secondary metabolites that may account for its various medicinal properties.

6. Phytochemistry

Table 2 presents the list of different phytochemicals detected in various parts of Bael. Bael fresh fruit pulp contains flavonoids, phenols, total carotenoids, and ascorbic acid[26]. The alcoholic extract of fruit pulp of Bael contains alkaloids, flavonoids, steroids, terpenoids, tannins, lignins, inulin, proteins, carbohydrates, amino acids, reducing sugars, fats, and oils, whereas saponins and cardiac glycosides are also detected in aqueous extract in addition to all these phytoconstituents except alkaloids[27]. The alkaloids, glycosides, phenols, saponins, tannins, terpenoids, proteins, and carbohydrates were found in the ethanol fruit pulp extract whereas the aqueous extract was devoid of saponins, and tannins but contained sterols[28]. The fruit pulp extracted in petroleum ether showed flavonoids, saponins, sterols, and tannins, whereas additionally, the benzene extract contained saponins, alkaloids, and proteins but not sterols[29]. Fruit extract of Bael in ethanol, methanol, hexane, phosphate buffer, and water contained flavonoids and phenols and the maximum quantity was estimated in the hexane extract and least in the aqueous extract[30]. The fruit pulp of Bael consists of reducing and nonreducing sugars, gallotannic acid, and oxalates[31]. Alkaloids, flavonoids, glycosides, phenols, saponins, tannins, and carbohydrates were detected in the ethanol extract of Bael fruit, whereas the aqueous extract contains glycosides, flavonoids, saponins, and polyphenols (**Table 2**)[32].

Aqueous fruit extract possesses flavonoids, alkaloids, glycosides, saponins, sterols, terpenoids, phenolic compounds, proteins, carbohydrates, and amino acids[33]. Extraction of unripe Bael fruit in water, chloroform, ethyl acetate, and methanol led to the detection of flavonoids, glycosides, alkaloids, terpenoids, saponins, proteins, carbohydrates, and amino acids in all extracts except saponins in aqueous extract. The triterpenoids were also analyzed in the methanol extract, whereas petroleum ether extract contained steroids as well as triterpenoids[34]. The aqueous and methanol ripe Bael fruit pulp extracts consist of coumarins, alkaloids, flavonoids, glycosides, phenolics, saponins, tannins, and proteins[35]. The methanol and aqueous extracts of

Bael fruit showed the presence of alkaloids, flavonoids, phenols, saponins tannins, and terpenoids. However, anthocyanins and phlobatannins were absent in both the extracts of Bael fruit[36]. Hydroethanolic extract of Bael fruit and peel showed the presence of alkaloids, coumarins, glycoside phenol, tannins, terpenoids, resins, carbohydrates, and proteins[37]. Alkaloids, flavonoids, glycosides, terpenoids, phlobatannins, and reducing sugars were detected in the aqueous extract of Bael fruit (**Table 2**)[38].

Total phenol and flavonoid contents were least in the Bael root (1.7281 ± 0.049 and 1.087 ± 0.002 mg/g), more in the stem (7.4693 ± 0.047 and 1.400 ± 0.029 mg/g), and maximum (9.8367 ± 0.0235 and 8.248 ± 0.029 mg/g) in the leaf, all parts extracted in methanol (**Table 2**)[39]. The Bael leaves extracted in n-hexane showed the presence of cardiac glycosides, steroids, triterpenoids, and pseudotannins, whereas the aqueous extract possessed alkaloids, anthraquinone glycosides, catechins, fixed oils, fats, furanoids, proteins, phenolics and saponins[40]. Phytochemical analysis of chloroform Bael leaf extract led to the detection of coumarins, alkaloids, emodins, diterpenes, anthocyanins, cardiac glycosides, fatty acids, flavonoids, phlobatannins, glycosides, phenols, saponins, tannins, carbohydrates, amino acids, and proteins[41]. The flavonoids, alkaloids, tannins, saponins, terpenoids, carotenoids, cardiac glycosides, and reducing sugars were identified in the aqueous and methanol Bael leaf extracts[42]. Bael leaf extracted in ethanol, methanol, ethyl acetate, water, and phosphate buffer did exhibit flavonoids and phenols with a maximum quantity found in the methanol leaf extract, lesser in the ethanol extract, and least in the aqueous extract[30]. Cardiac glycosides, tannins, and saponins were determined in ethanol, chloroform, and water extracts of Bael leaf, whereas chloroform and water extracts contained only flavonoids and steroids were found only in ethanol extract (**Table 2**)[43]. Bael leaf and seeds extracted in petroleum ether, chloroform, methanol, and water consisted of alkaloids in all fractions of extracts but not in chloroform and aqueous extracts. All Bael leaf extracts were devoid of tannins except in the chloroform and petroleum ether seed extracts (**Table 2**)[44]. Flavonoids, phenol, carbohydrates, and tannins were detected in the ethanol extract of Bael leaf (**Table 2**)[45].

Quantitative estimation of water extract of Bael leaf showed the presence of 64.0 ± 0.05 mg/g flavonoids, 15.58 ± 0.05 mg/g alkaloids, and 30.34 ± 0.01 mg/g phenols[46]. The alkaloids, phenolic compounds, tannins, and sterols were detected in the aqueous and methanol leaf extracts of Bael (**Table 2**)[47]. The phenols, steroids, alkaloids, tannins, flavonoids, saponins, and carbohydrates were identified in the aqueous Bael leaf extract whereas saponins were absent in the acetone and ethanol extracts. The tannins could not be detected in the ethanol leaf extract[48]. Alkaloids, terpenoids, tannins, saponins, steroids, coumarins, leucoanthocyanins, and carbohydrates were identified in the aqueous and ethanol extracts of Bael leaves and stem bark. The stem bark extract possessed proteins and reducing sugars in addition to these phytochemicals, however, coumarins were absent[49]. Bael leaves extracted in methanol and ethanol did contain flavonoids, tannins, alkaloids, saponins, steroids, glycosides, phlobatannins, quinones, coumarins, and proteins, except sugars and flavonoids in the ethanol extract. The acetone extract showed terpenoids in addition to all the phytochemicals detected for methanol extract but not the steroids. The terpenoids, flavonoids, saponins, tannins, steroids, glycosides, phlobatannins, quinones coumarins, sugars, and proteins were detected in the chloroform extract[50]. The ethyl acetate extract of the Bael stem showed the presence of alkaloids (**Table 2**)[51].

The alkaloids, flavonoids, phenolic compounds, and saponins have been reported from the aqueous leaf extract of Bael[52]. The water extract of Bael leaf consisted 16.36 mg rutin equivalent total flavonoids and 31.38 gallic acid equivalent total phenolics (**Table 2**)[53]. The Bael roots extracted in water and ethanol possess alkaloids, flavonoids, saponins proteins, and tannins (**Table 2**)[54]. The water and methanol Bael seed extracts possessed alkaloids, flavonoids, glycosides, phenolics, steroids, tannins, carbohydrates, proteins, amino acids, volatile oils, and fats (**Table 2**)[55]. Alkaloids, flavonoids, glycosides, phenols, tannins, sterols, terpenoids, carbohydrates, proteins, and amino acids were identified in the ethanol, ethyl acetate, and water extracts of the stem bark of Bael (**Table 2**)[56]. The phenols, quinones, reducing sugars, saponins, sugars, tannins, and triterpenoids were determined in Bael root and small twig ethanol and water extracts (except aqueous extract).

The aqueous extract also contained alkaloids and the ethanol extract contained coumarins additionally[57]. Anthocyanins, glycosides, alkaloids, cardiac glycosides, flavonoids, saponins, terpenoids, and tannins have been reported in the 60% ethanol extract of Bael leaf[58]. The flavonoids, alkaloids, glycosides, phenols, and carbohydrates were determined in the methanol extract of Bael leaf, however, phytosterols could not be detected (**Table 2**)[59].

Table 2. Different phytochemicals detected in Bael (*Aegle marmeols*).

Plant part	Extract type	Phytochemicals	References
Fruit	Aqueous, ethanol, hexane, petroleum ether, methanol, acetone	Alkaloids, anthocyanins, cardiac glycosides, flavonoids, glycosides, steroids, terpenoids, tannins, lignins, carotenoids, ascorbic acid, phenols, polyphenols, phlobatannins, saponins, sterols, inulin, proteins, carbohydrates, amino acids, reducing sugars, nonreducing sugars, gallotannic acid, oxalates, fat, and oils	[26–38,58,59]
Root	Ethanol and aqueous	Phenols, flavonoids, alkaloids, proteins, quinones, reducing sugars, saponins, sugars, tannins, triterpenoids, and coumarins	[39,54]
Stem	Aqueous ethanol, ethyl acetate	Alkaloids, flavonoids, glycosides, phenols, tannins, sterols, terpenoids, carbohydrates, proteins, and amino acids	[39,51,56]
Leaf	Aqueous, chloroform, ethanol, hexane, petroleum ether, methanol, acetone, ethyl acetate, phosphate buffer	Alkaloids, flavonoids, anthraquinone glycosides, cardiac glycosides, catechins, coumarins, diterpenes, emodins, fixed oils, fats, furanoids, leucoanthocyanins, steroids, sterols, triterpenoids, pseudotannins, proteins, phenolics, carbohydrates, fatty acids, phlobatannins, quinones, tannins, terpenoids, reducing sugars, sugars and saponins	[30,39–43,46–53]
Seed	Aqueous and methanol	Alkaloids, flavonoids, glycosides, phenolics, steroids, tannins, carbohydrates, proteins, amino acids, volatile oils, and fats	[55]

7. Nutritional aspect

The nutritional profile of Bael fruit has been studied by several authors who have reported the presence of different nutrients in varying amounts. Minerals like 31.8 mg/100 g phosphorus, 85 mg/100 g calcium, and 0.6 mg/100 g iron, and vitamins A (0.055), B2 (1.2), and C (8) mg/100 g have been detected in the Bael fruit. 31.8% carbohydrates, 2.9% fibers, 1.8% proteins, and 0.3% fats were detected in Bael fruit with a calorific value of 137 Kcal/g[60]. The nutritional contents of Bael leaf, fruit pulp, and seeds have been estimated and carbohydrates were found to be 24.96%, 34.35%, and 18.88%, respectively. The fat contents were the least in leaf (0.07%), fruit pulp (0.28%), and maximum in seeds (14.94%). The amount of protein was highest in seeds (9.75%), followed by fruit pulp (1.87%), and least in leaves (1.07%). The seeds have the highest calorific value of 244 Kcal, followed by fruit pulp of 139 Kcal, and the least in leaf (99 Kcal). The pH of 6.62 for seeds, 5.5 for fruit pulp, and 6.12 for leaves has been reported. Vitamin C was highest in fruit pulp (73.2), leaves (4.84), and seeds (3.38) mg/100g. Vitamin B1, B2, and B3 contents in leaves were 0.03, 0.02, and 0.17 mg% in leaves, 0.16, 0.18, and 0.87 mg% in fruit pulp, and 0.77, 0.23, and 1.42 mg% in Bael seeds, respectively[61].

The presence of reducing sugars in pericarp, and fruit pulp was 0.92% and 4.42%, non-reducing sugars were 0.91% and 9.93%, and total sugars were about 1.83% and 14.35%, respectively. Various minerals are also detected in the pericarp, fruit pulp, and seeds. The Bael fruit pulp showed phosphorus 51.6, potassium 603. calcium 78, magnesium 4, iron 0.55, copper 0.19, and zinc 0.28 mg/100g whereas the pericarp contained phosphorus 2.8, potassium 210. calcium 6, magnesium 0.91, iron 0.02, and zinc 0.02 mg/100g. The contents of phosphorus were 3.3, potassium 108. magnesium 0.82, iron 0.08, copper 0.0.1, and zinc 0.03 mg/100g[31]. Analysis of Bael fruit powder showed the presence of 74.31% carbohydrates, 4.35% proteins, 1.54 fats, 49.09% vitamin C, 184 ppm sodium, 1596 ppm potassium, 94.9 ppm calcium, 243 ppm magnesium, 18.24 ppm iron 1.39 ppm zinc, and 1.34 ppm copper[62]. The nutrient estimation of Bael fruit showed 2.79% proteins, 29.21% carbohydrates, 5.79% fibers, 7.52% reducing sugars, 13.52% total sugar, 4.72% titratable acidity, and a pH of 4.62. The minerals like phosphorus (49.32), copper (0.48), calcium (82), iron (1.23), and zinc (7.3) mg/100 g were also detected in the Bael fruit[63]. Analysis of premature, half-mature, and mature Bael fruit

showed 41.7%, 41.38%, and 36.80% carbohydrates, 8.81%, 7.74%, and 7.52% proteins, 1.23%, 1.37% and 1,36% crude fibers, 1.04%, 1.15%, and 1.38% fats, 3.08%, 4.65% and 6.94% Total sugar, and pH 5.45, 6.47, and 6.35, respectively. The different elements including sodium (35.67, 25.56, and 21.8), potassium (139.61, 103.45, and 76.64), calcium (146.49, 136.65, and 130.73), iron (11.6, 8.55 and 7.38) and zinc (8.44, 7.8, and 6.83) mg/100g were detected in premature, half mature, and mature Bael fruits, respectively. The Bael fruit contained thiamine (1.83, 1.4, and 1.24), riboflavin (1.14, 1, and 1.02), and vitamin C (48.62,41.61 and 33.80) mg/100 g in premature, half mature and mature fruit, respectively[36].

8. Active chemical components

Bael synthesizes several secondary metabolites that have been isolated from its different parts (**Table 3**).

Table 3. Various secondary metabolites synthesized by *Aegle marmelos* (Bael).

	Plant part/extract type	Secondary metabolites	References
1	Leaf Methanol ethanol and chloroform	O-(3,3-dimethylallyl-halfurdinol, N-2-ethoxy-2-(4-methoxyphenyl) ethyl cinnamamide, N-2-methoxy-2-[4-(3',3'-bimethylallyloxy) phenyl]ethylcinnamtimide and N-2-methoxy-2-(4-methoxy-phenyl)ethylcinnamamide, marmenol or 7-geranyloxycoumarin [7-(2,6-dihydroxy-7-methoxy-7-methyl-3-octaenyloxy)coumarin], betulinic acid, praealtin D, 4-methoxy benzoic acid, trans-cinnamic acid, valencic acid, N-ρ-cis- and trans-coumaroyltyramine, montanine, rutaretin, anhydromarmeline, aegelinosides A and B, tembamide, dehydromarmeline, aegeline, and O-methylether aegeline	[64–66]
2	Leaf oil	α-pinene, β-pinene, sabinene, myrcene, limonene, (Z)-β-ocimene, γ-terpinene, ρ-menth-l,3,8-triene, linalool, piperitone, myrtenol, terpinen-4-ol, piperitol, trans-carveol, ρ-menth-4(8)-en-l-ol, cis-carveol, sabinol, myrtenyl acetate, ρ-menth-1 -en-BP,5P-diol, ρ-caryophyllene, α-humulene, α-elemene, ar-curcumene and caryophyllene oxide	[67–69]
3	Stem Petroleum ether, chloroform, ethyl acetate, methanol, ethanol, and water	Umbelliferone, psoralene, marmin, imperatorin, and skimmianine	[70]
4	Root Methanol, dichloromethane, chloroform	Decursinol, marmesin, marmin, haplopine, skimmianine, γ-fagarine, xanthotoxin, umbelliferone, lupeol, aegle-marmelosine, psoralene, imperatorin, and skimmianine	[24,71,72]
5	Fruit Acetone, methanol	Alloimperatorin, imperatorin, β-sitosterol, marmelin, aegeline, O-methylhalfordinol, O-iso-pentennylhalfordinol, imperatorin, and xanthotoxin, O-(3,3-dimethylallyl)-halfordinol, aegeline, marmeline, xanthotoxol, valencic acid, vanillic acid, rutin, 4-hydroxybenzeneacetic acid; 5-oxo-pyrrolidine-2-carboxylic acid methyl ester, 1-[3-methyl-3-butenyl] pyrrolidine; trans-sinapyl alcohol; 5-[hydroxymethyl]-2-furaldehyde and 2,4- dihydroxy-2,5-dimethyl-3[2H]-furan-3-one	[73–76]
6	Seed Ethanol	Galactose, glucose, arabinose, rhamnose, 2-isopropenyl-4-methyl-1-oxa-cyclopenta[b]anthracene-5,10-dione and (+)-4-(20-hydroxy-30-methyl-but-30-enyloxy)-8H-[1,3]dioxolo[4,5-h]chromen-8-one, 1-methyl-2-(30-methyl-but-20-enyloxy)-anthraquinone, imperatorin, β-sitosterol, plumbagin, β-sitosterol glucoside, stigmasterol, vanillin, and salicin	[77,78]

8.1. Leaves

The alkaloids O-(3,3-dimethylallyl-halfurdinol, N-2-ethoxy-2-(4-methoxyphenyl) ethyl cinnamamide, N-2-methoxy-2-[4-(3',3'-bimethylallyloxy)phenyl]ethylcinnamtimide and N-2-methoxy-2-(4-methoxy-phenyl)ethylcinnamamide have been isolated from the methanol and ethanol extracts of Bael leaves[64]. The marmenol or 7-geranyloxycoumarin [7-(2,6-dihydroxy-7-methoxy-7-methyl-3-octaenyloxy)coumarin], betulinic acid, praealtin D, 4-methoxy benzoic acid, trans-cinnamic acid, valencic acid, N-ρ-cis- and trans- coumaroyltyramine, montanine, and rutaretin have been separated from the methanol extract of Bael leaves[65]. Anhydromarmeline (14 mg), aegelinosides A and B (50 mg), tembamide (8 mg), dehydromarmeline (11 mg), aegeline (65 mg), and O-methylether aegeline (20 mg) have been isolated from the chloroform leaf extract of Bael **(Figure 3** and **Table 3)**[66].

Bael leaf oil contains α-pinene, β-pinene, sabinene, myrcene, limonene, (Z)-β-ocimene, γ-terpinene, ρ-menth-l,3,8-triene, linalool, piperitone, myrtenol, terpinen-4-ol, piperitol, trans-carveol, ρ-menth-4(8)-en-l-ol,

cis-carveol, sabinol, myrtenyl acetate, ρ-menth-1-en-BP,5P-diol, ρ-caryophyllene, α-humulene, α-elemene, ar-curcumene and caryophyllene oxide (**Table 3**)[67–69].

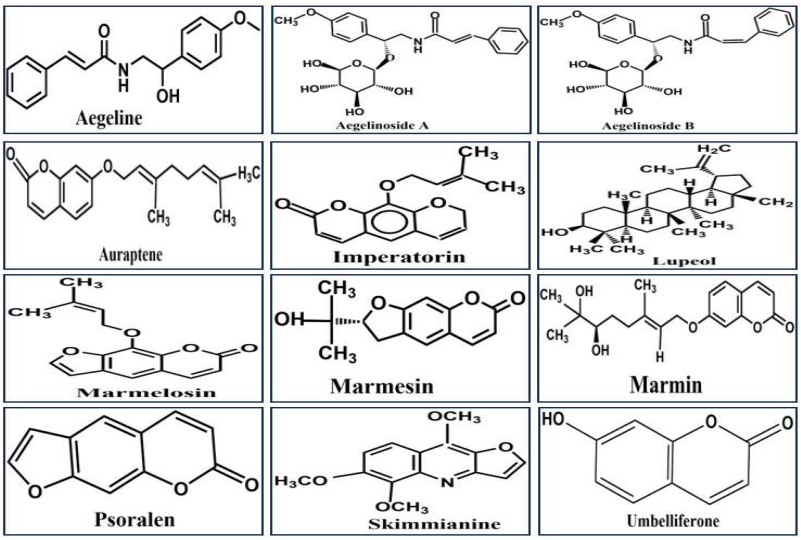

Figure 3. The chemical structure of important secondary metabolites synthesized by *Agele marmelos* (Bael).

8.2. Stem

Umbelliferone, psoralene, marmin, imperatorin, and skimmianine have been isolated from the stem bark of Bael extracted in petroleum ether, chloroform, ethyl acetate, methanol, ethanol, and water (**Figure 3**). The amount of these phytochemicals was least in the petroleum ether extract whereas their quantity was highest in methanol, ethanol, chloroform, ethyl acetate, and water in this order (**Table 3**)[70].

8.3. Root

Root bark of Bael contains the coumarin decursinol, marmesin, marmin, and the alkaloids, haplopine, skimmianine, γ-fagarine, xanthotoxin, umbelliferone and lupeol (**Figure 3**)[24]. Aegle-marmelosine has been isolated from the dichloromethane extract of roots and twigs of Bael[71]. Umbelliferone, psoralene, marmin, imperatorin, and skimmianine (**Figure 3**) were detected in the methanol extract of Bael root bark (**Table 3**)[72].

8.4. Fruit

The furanocoumarin, alloimperatorin, imperatorin and β-sitosterol were isolated from Bael fruit[73]. The acetone extract of unripe fruit of Bael showed marmelin, aegeline, O-methylhalfordinol, O-iso-pentennylhalfordinol, alloimperatorin, imperatorin, and xanthotoxin[74]. The methanol extract of hard shell of bael fruit contains 4-hydroxybenzeneacetic acid, 5-oxo-pyrrolidine-2-carboxylic acid methyl ester, 1-[3-methyl-3-butenyl] pyrrolidine, trans-sinapyl alcohol, 5-[hydroxymethyl]-2-furaldehyde, and 2,4-dihydroxy-2,5-dimethyl-3[2H]-furan-3-one[75]. The acetone extract of Bael fruit showed the presence of O-(3,3-dimethylallyl)halfordinol, aegeline, marmeline, imperatorin (**Figure 3**), xanthotoxol, valencic acid, vanillic acid, and rutin (**Table 3**)[76].

8.5. Seeds

The ethanol Bael seed extract showed the presence of galactose, glucose, arabinose, and rhamnose[77]. 2-isopropenyl-4-methyl-1-oxa-cyclopenta[b]anthracene-5,10-dione and (+)-4-(20-hydroxy-30-methyl-but-30-enyloxy)-8H-[1,3]dioxolo[4,5-h]chromen-8-one, 1-methyl-2-(30-methyl-but-20-enyloxy)-anthraquinone, imperatorin (**Figure 3**), β-sitosterol, plumbagin, β-sitosterol glucoside, stigmasterol, vanillin, and salicin have been isolated from the Bael seeds[78].

9. Experimental studies

The ethnomedicinal applications of Bael in the treatment of various human diseases have been corroborated by several experimental studies and numerous active secondary metabolites isolated from Bael have been evaluated for their medicinal activities experimentally **Table 4**.

The coumarins marmelosin and marmin (coumarins) isolated from Bael fruit pulp inhibited the growth of *Mycobacterium tuberculosis* H37Ra, *Mycobacterium bovis, Staphylococcus aureus*, *Bacillus subtilis,* and *Escherichia coli* whereas marmelosin was ineffective against *Staphylococcus aureus* (**Table 4**)[79]. Marmelosin has shown anti-inflammatory activity where it attenuated nitric oxide (NO) formation, TNF-α, nuclear factor kappa B (NF-κB), tyrosinase, and galectin-3 in Raw 264.7 mouse leukemic macrophage cells (**Table 4**)[80].

The marmelosin exhibited antioxidant activity by inhibiting the generation of DPPH radicals depending on its concentration. Mamelosin also protects human buccal mucosa cells (HBMC), and red blood cells (RBC) against hydrogen peroxide(H_2O_2)-induced DNA damage in HBMC and morphological changes in RBC, respectively (**Table 4**)[80].

The alkaloid Aegeline isolated from Bael leaf has shown an antiallergic effect by inhibiting dinitrophenylated bovine serum albumin (DNP24-BSA), thapsigargin, and ionomycin-induced histamine release from rat basophilic leukemia (RBL-2H3) cells, and this effect was more pronounced against Ca^{2+} stimulants thapsigargin and ionomycin (**Table 4**)[81]. Marmin, isolated from the Bael root bark also exhibited a similar effect in RBL-2H3 and rat peritoneal mast cells (RPMC) H_2O_2 treated cells[82]. RBL-2H3 cells exposed to marmin showed attrition in the histamine synthesis stimulated by DNP24-BSA and phorbol myristate acetate (**Table 4**)[82].

Aegeline, an alkaloid extracted from Bael leaf has been reported to act against diabetes by significantly depleting blood glucose levels in sucrose-challenged streptozotocin-induced diabetic albino rats from 90 min to 24 h (**Table 4**)[83]. Marmelosin from Bael and its derivatives including 9-[(2-methylprop-1-en-1-yl)peroxy]-5-nitro-7H-furo[3,2-*g*]chromen-7-one, 9-[(2-methylprop-1-en-1-yl)peroxy]-5-nitro-7H-furo[3,2-*g*]chromen-7-one, 9-[(2-methyl prop-1-en-1-yl)peroxy]-7-oxo-7H-furo[3,2-*g*]chromene-5-sulfonic acid and 5-bromo-9-[(2-methylprop-1-en-1-yl)peroxy]-7H-furo[3,2-*g*]chromen-7-one significantly depleted blood glucose level in alloxan-induced diabetic Wistar rats indicating their antidiabetic potential (**Table 4**)[84].

Aegeline has been reported to exert analgesic action by reducing the mechanical and pressure-induced pain in Swiss albino mice and serum IL-6, and iNOS in the spinal cord. Aegeline also depleted monoamine oxidase activity, and lipid peroxidation in the mouse brain accompanied by a rise in GSH (**Table 4**)[85].

Marmin from Bael suppressed metacholine-induced smooth muscle contraction in the guinea pig isolated ileum in vitro by antagonizing (ACh)M3 receptors where 100 µg/mL was more effective than 10 µg/mL marmin **(Table 4)**[86].

The ethanol extract of Bael leaf and aegeline killed *Taenia solium* in vitro where the aegeline was more effective than the ethanol leaf extract[87]. The active fraction isolated from chloroform Bael leaf extract completely inhibited the motility of *Setaria cervi* parasite in a concentration-dependent manner with an IC_{50} of 0.015 mg/mL, whereas the highest dose of 0.08 mg/ml completely inhibited the parasite within 2 h indicating its anthelmintic action (**Table 4**)[88].

Ethyl acetate and hexane fractions of methanol extract of Bael root and its active components, including lupeol, auraptene, skimmianine, and umbelliferone have shown cardioprotective effects by reducing the spontaneous beating of mouse embryonic myocardial cells in vitro. The auraptene reduced the calcium-induced membrane blebs, and shrinkage of the myocardial cells (**Table 4**)[89].

The Bael is also analgesic and neuroprotective as 70% methanol extract of fruit pulp and aegeline attenuated forced swim-induced depression in Swiss albino mice indicated by monoamine oxidase A inhibition and reduction in lipid peroxidation, and elevation in GSH in the mice brain, The extract and aegeline also decreased IL-6 in serum and iNOS expression in the spinal cord of mice (**Table 4**)[85].

Antileishmanial activity of coumarin auroptene was studied against *Leishmania major* Friedlin promastigotes and auroptene killed the *Leishmania* promastigotes in a concentration-dependent manner with an LD_{50} of 30 µM (**Table 4**)[90].

Hydroalcoholic extract of Bael fruit and active principle marmelosin have been reported to protect against the chromium-induced elevation in lactate dehydrogenase, NO, reactive oxygen species generation, nuclear damage, and loss of mitochondrial membrane potential in HepG2 cells. Chromium treatment reduced BCl2 expression and upregulated the expression of Bax, caspase 3, and growth arrest and DNA damage (Gadd45) genes which were reversed by pretreatment with Bael leaf extract and marmelosin in HepG2 cells (**Table 4**)[91].

The Bael has been shown to inhibit chemical carcinogenesis in vivo and in vitro where the methanol Bael fruit pulp extract and marmelosin, marmesinin, and aegeline have been reported to suppress the CYP3A4 activity dose-dependently in human liver microsomes. The fruit pulp extract, marmelosin, marmesinin, and 8-hydroxypsoralen also reduced the CYP1A2 activity in human liver microsomes (**Table 4**)[92]. Xylorhamnoarabinogalactan I pectic polysaccharide, a Bael pectic polysaccharide (BAPP1) isolated from Bael fruit inhibited the activities of tyrosinase and galectin-3 in vitro, and the ultraviolet light and 7,12-dimethylbenz(a)-anthracene (DMBA)-induced skin carcinogenesis in Swiss albino mice. BAPP1 also suppressed the serum IL-10, IL-17, NF-κB, and VEGF dose-dependently in the carcinogen-treated mice. The BAPP1 also protected the DMBA-indued decline in the gut Lactobacillus by ~5 folds. BAPP1 concentration-dependently arrested cell proliferation (IC_{50} 11.9 ± 0.24 µg/mL) and NO formation in B16F10 cells (**Table 4**)[93].

Aegeline, aegelbine A and B isolated from chloroform and petroleum ether extracts of Bael leaf inhibited the proliferation of HepG-2, PC-3, A549, and MCF-7 cells. Aegeline and aegelbine B selectively attenuated the proliferation of MCF-7 cells with IC_{50} of 73.7 and 63.5 µg/mL, respectively[94]. Marmelosin inhibited the proliferation of cultured Raw 264.7 mouse leukemic macrophage cells concentration-dependently (10–30 µM) with an IC_{50} of 6.24 ± 0.16 µM (**Table 4**)[80].

10. Conclusions

The Bael is a sacred tree of immense medicinal and economic importance. It is used in the treatment of various human diseases and also used to make jams and sherbets. Bael is found in the Indian subcontinent and Southeast Asia. The Bael contains alkaloids, glycosides, flavonoids, sterols, phenols, terpenoids, saponins, proteins, carbohydrates, anthocyanins, coumarins, diterpenes, emodins, fatty acids, and amino acids. The medicinal properties seem to be due to the presence of various phytochemicals in Bael. Bael contains carbohydrates, proteins, fibers, fats, vitamins, and minerals in varying quantities which is the source of energy in Bael fruits. The active components isolated from different parts of Bael include marmelosin, marmin, aegeline, lupeol, auraptene, skimmianine, umbelliferone, marmesinin, 8-hydroxypsoralen and xylorhamno-arabinogalactan I pectic polysaccharide are found to be antibacterial, antiallergic, anthelmintic, anti-inflammatory, antileishmanial, antioxidant, antidiabetic, analgesic, antispasmodic, antiproliferative, cardioprotective, cytoprotective and chemopreventive in vitro and in vivo. The scientific evaluation of Bael and its active phytochemicals validates its ethnomedicinal use in the treatment of different human ailments. Future studies need to be directed to investigate the different activities of isolated secondary metabolites synthesized by Bael and their molecular mechanism of action. This will help to develop these secondary metabolites as future drug candidates.

Table 4. Medicinal activities of various active components of *Aegle marmelos* (Bael).

S. No.	Active component	Medicinal activity	References
1	Marmelosin (coumarin)	Antibacterial inhibition of *Mycobacterium bovis, Bacillus subtilis,* and *Escherichia coli* growth	[79]
2	Marmin (coumarin)	Antibacterial inhibition of *Mycobacterium bovis, Staphylococcus aureus*, *Bacillus subtilis,* and *Escherichia coli* growth	[79]
3	Marmelosin (coumarin)	Anti-inflammatory suppression of NO formation, TNF-α, nuclear factor kappa B (NF-κB), tyrosinase, and galectin-3 in Raw 264.7 mouse leukemic macrophage cells	[80]
4	Marmelosin (coumarin)	Antioxidant inhibition of DPPH and cytoprotective to human buccal mucosa and rat RBC	[80]
5	Aegeline (alkaloid)	Antiallergic prevented histamine release in RBL-2H3 cells	[81,82,95]
6	Aegeline (alkaloid) Marmelosin, 9-[(2-methylprop-1-en-1-yl)peroxy]-5-nitro-7H-furo[3,2-*g*]chromen-7-one, 9-[(2-methylprop-1-en-1-yl)peroxy]-5-nitro-7H-furo[3,2-*g*]chromen-7-one, 9-[(2-methyl prop-1-en-1-yl) peroxy]-7-oxo-7H-furo[3,2-*g*]chromene-5-sulfonic acid and 5-bromo-9-[(2-methylprop-1-en-1-yl)peroxy]-7H-furo[3,2-*g*]chromen-7-one	Antidiabetic in rats-reduced blood sugar	[83,84]
7	Marmin (coumarin)	Antispasmodic in guinea pig isolated ileum	[86]
8	Aegeline (alkaloid)	Analgesic action in Swiss albino mice. Reduced serum IL-6, and iNOS in the spinal cord. Decreased monoamine oxidase activity and lipid peroxidation and increased GSH in the mouse brain	[85]
9	Marmelosin (coumarin)	Protects against metal toxicity by inhibiting lactate dehydrogenase, NO, reactive oxygen species generation, nuclear damage, loss of mitochondrial membrane potential, Bax, caspase 3, and growth arrest and DNA damage (Gadd45) genes	[91]
10	Ethanol extract of Bael leaf, aegeline and active fraction	Anthelmintic killed *Taenia solium and Setaria cervi*	[87,88]
11	Methanol extract of Bael root, lupeol, umbelliferone, skimmianine, (alkaloids) and auraptene (coumarin)	Cardioprotective in cultured embryonic myocardial cells	[91]
12	Aegeline (alkaloid)	Neuroprotective in mice decreased monoamine oxidase A and lipid peroxidation and increased GSH in the brain. Decreased IL-6 and iNOS expression in the spinal cord	[85]
13	Auroptene (coumarin)	Killed parasite *Leishmania major* promastigotes	[90]
14	Marmelosin, marmesinin, aegeline and 8-hydroxypsoralen Xylorhamnoarabinogalactan I pectic polysaccharide	Chemopreventive inhibition of CYP3A4 and CYP1A2 activity in human liver microsomes Inhibition of tyrosinase and galectin-3 activity in vitro, skin carcinogenesis, IL-10, IL-17, NF-κB, and VEGF in carcinogen treated mice. Decreased proliferation and NO formation in B16F10 cells	[92,93]
15	Aegeline, aegelbine A and B (alkaloid) Marmelosin (coumarin)	Cytotoxic—inhibited the proliferation of HepG-2, PC-3, A549, and MCF-7 cells. Inhibited proliferation of Raw 264.7 cells	[80,94]

Acknowledgments

This work was supported by the University Grants Commission, New Delhi, India under Non-SAP Program No. F4-10/2010(BSR) UGC.

Conflict of interest

The author declares no conflict of interest.

References

1. Crepet WL. Progress in understanding angiosperm history, success, and relationships: Darwin's abominably "perplexing phenomenon". *Proceedings of the National Academy of Sciences* 2000; 97(24): 12939–12941. doi: 10.1073/pnas.97.24.12939
2. Stevenson DW, Zimmermann MH, Stevens P, et al. Angiosperm. Available online: https://www.britannica.com/plant/angiosperm (accessed on 2 November 2023).
3. Groppo M, Afonso LF, Pirani JR. A review of systematics studies in the *Citrus* family (Rutaceae, Sapindales), with emphasis on American groups. *Brazilian Journal of Botany* 2022; 45(1): 181–200. doi: 10.1007/s40415-021-00784-y
4. Singh A, Sharma HK, Kaushal P, Upadhyay A. Bael (*Aegle marmelos* Correa) products processing: A review. *African Journal of Food Science* 2014; 8(5): 204–215. doi: 10.5897/AJFS2013.1119
5. Bel-Rhlid R, Berger RG, Blank I. Bio-mediated generation of food flavors—Towards sustainable flavor production inspired by nature. *Trends in Food Science & Technology* 2018; 78: 134–143. doi: 10.1016/j.tifs.2018.06.004
6. Sonawane A, Pathak S, Pradhan RC. Bioactive compounds in bael fruit pulp waste: Ultrasound-assisted extraction, characterization, modeling, and optimization approaches. *Biointerface Research in Applied Chemistry* 2021; 11(2): 9318–9334. doi: 10.33263/BRIAC112.93189334
7. Sharma PC, Bhatia V, Bansal N, Sharma A. A review on Bael tree. *Natural Product Radiance* 2007; 6(2): 171–178.
8. Singh AK, Singh S, Saroj PL, et al. Research status of bael (*Aegle marmelos*) in India: A review. *Indian Journal of Agricultural Science*s 2019; 89(10): 1563–1571. doi: 10.56093/ijas.v89i10.94576
9. Akbar S. *Agele marmelos* (L.) Corrêa (Rutaceae). In: *Handbook of 200 Medicinal Plants: A Comprehensive Review of Their Traditional Medical Uses and Scientific Justifications*, 1st ed. Springer; 2020. pp. 109–122. doi: 10.1007/978-3-030-16807-0
10. Roy SK, Singh RN. Bael fruit (*Aegle marmelos*)—A potential fruit for processing. *Economic Botany* 1979; 33: 203–212. doi: 10.1007/BF02858290
11. Mali SS, Dhumal RL, Havaldar VD, et al. A systematic review on *Aegle marmelos* (Bael). *Research Journal of Pharmacognosy and Phytochemistry* 2020; 12(1): 31–36. doi: 10.5958/0975-4385.2020.00007.2
12. Sharma N, Dubey W. History and taxonomy of *Aegle marmelos*: A review. *International Journal of Pure and Applied Bioscience* 2013; 1(6): 7–13.
13. Pathirana CK, Madhujith T, Eeswara J. Bael (*Aegle marmelos* L. Corrêa), a medicinal tree with immense economic potentials. *Advances in Agriculture* 2020; 2020: 8814018. doi: 10.1155/2020/8814018
14. Kumar KPS, Umadevi M, Bhowmik D, et al. Recent trends in medicinal uses and health benefits of Indian traditional herbs *Aegle marmelos*. *The Pharma Innovation* 2012; 1(4): 57–65.
15. Swathi G. *Aegle marmelos (Bael): A Hand Book on Sacred Bilwa Plant with Medicinal Properties*. International E—Publication; 2014.
16. Hazra K, Dutta S, Kumar Mandal A, et al. Comprehensive dossier on Ayurvedic medicinal plant *Aegle marmelos* (L.) Corrêa.: A review. *The Pharmaceutical & Chemical Journal* 2017; 4(3): 55–74.
17. Bhar K, Mondal S, Suresh P. An eye-catching review of *Aegle marmelos* L. (Golden Apple). *Pharmacognosy Journal* 2019; 11(2): 207–224. doi: 10.5530/pj.2019.11.34
18. Choudhary S, Chaudhary G, Kaurav H. *Aegle marmelos* (bael patra): An ayurvedic plant with ethnomedicinal value. *International Journal of Research in Ayurveda and Pharmacy* 2021; 12(3): 147–156. doi: 10.7897/2277-4343.120392
19. Balkrishna A. *Flora of Morni Hills (Research & Possibilities)*. Divya Yoga Mandir Trust; 2018. 581p.
20. Dhankhar S, Ruhil S, Balhara M, et al. *Aegle marmelos* (Linn.) Correa: A potential source of Phytomedicine. *Journal of Medicinal Plants Research* 2011; 5(9): 1497–1507.
21. Vasava D, Kher MM, Nataraj M, Teixeira da Silva JA. Bael tree (*Aegle marmelos* (L.) Corrêa): Importance, biology, propagation, and future perspectives. *Trees* 2018; 32: 1165–1198. doi: 10.1007/S00468-018-1754-4
22. Chopra RN, Nayar SL, Chopra IC, et al. *Glossary of Indian Medicinal Plants*. National Institute of Science Communication and Information Resources; 2002.
23. Jagetia GC, Venkatesh P, Baliga MS. *Aegle marmelos* (L.) Correa inhibits the proliferation of transplanted Ehrlich ascites carcinoma in mice. *Biological and Pharmaceutical Bulletin* 2005; 28(1): 58–64. doi: 10.1248/bpb.28.58
24. Basu D, Sen R. Alkaloids and coumarins from root-bark of *Aegle marmelos*. *Phytochemistry* 1974; 13(10): 2329–2330. doi: 10.1016/0031-9422(74)85057-0
25. Kirtikar K, Basu B. *Indian Medicinal Plants*, 2nd ed. Oriental Enterprises; 2001. Volume 4.
26. Charoensiddhi S, Anprung P. Bioactive compounds and volatile compounds of Thai bael fruit (*Aegle marmelos* (L.) Correa) as a valuable source for functional food ingredients. *International Food Research Journal* 2008; 15(3): 287–295.
27. Rajan S, Gokila M, Jency P, et al. Antioxidant and phytochemical properties of *Aegle marmelos* fruit pulp. *International Journal of Current Pharmaceutical Research* 2011; 3(2): 65–70.
28. Rafiqkhan M, Radhakrishnan D, Mohamed M, et al. Phytochemical screening of *Aegle marmelos* (L.) correa fruit

pulp: A potential source of ethnomedicine. *World Journal of Pharmaceutical Research* 2013; 2(6): 2919–2927.
29. Laddha CS, Kunjalwar SG, Itankar PR, Tauqeer M. Nutritional and phytochemical assesment of wild edible fruit of *Aegle marmelo*s (Linn.) used by the tribes of Bhiwapur Tahsil Nagpur district, India. *Asian Journal of Pharmaceutical Clinical Research* 2015; 8(1): 76–78.
30. Kejariwal M. Evaluation of antioxidant potential and phytochemical investigations on *Aegle marmelos* (L.) Corr. *Bulletin of Environment, Pharmacology and Life Sciences* 2016; 5(2): 42–52.
31. Kaur A, Kalia M. Physico chemical analysis of Bael (*Aegle Marmelos*) fruit pulp, seed and pericarp. *Chemical Science Review and Letters* 2017; 6(22): 1213–1218.
32. Gupta A, Thomas T, Khan S. Physicochemical, phytochemical screening and antimicrobial activity of *Aegle marmelos*. *Pharmaceutical and Biosciences Journal* 2018; 6(3): 17–24. doi: 10.20510/ukjpb/6/i3/173548
33. Chaubey A, Dubey A. Phytochemical profiling and antioxidant activity of aqueous extract of *Aegle marmelos* fruit shell. In: Proceedings of the MOL2NET'18, Conference on Molecular, Biomedical, Computational Sciences and Engineering; 15 January 2018–20 January 2019; Cambridge, UK & Duluth, USA. doi: 10.3390/MOL2NET-04-05432
34. Sivakumar G, Gopalasatheeskumar K, Gowtham K, et al. Phytochemical analysis, antioxidant and antiarthritic activities of different solvent extract of *Aegle marmelos* l. Unripe fruit. *Research Journal of Pharmacy and Technology* 2020; 13(6): 2759–2763. doi: 10.5958/0974-360X.2020.00490.4
35. Thaware P, Karale P, Karale M, Chavan P. Phytochemical screening and pharmacological evaluation of *Aegle marmelos* fruit. *Indian Drugs* 2020; 57(4): 59–64.
36. Sarkar A, Rashid M, Musarrat M, Billah M. Phytochemicals and nutritional constituent evaluation of Bael (*Aegle marmelos*) fruit pulp at different development stage. *Asian Food Science Journal* 2021; 20(1): 78–86. doi: 10.9734/afsj/2021/v20i130257
37. Ganpat SP, Jagdish SD, Onkarappa GR. Quantitative phytochemical analysis and in vitro study of antioxidant and anti-inflammatory activities of *Aegle marmelos* fruit with peel and without peel: A comparative evaluation. *International Journal of Pharmaceutical Investigation* 2022; 12(1): 15–19. doi: 10.5530/ijpi.2022.1.3
38. Kudlur DS, Meghashree AM, Vinutha SA, et al. One pot synthesis of CuO-NiO nanoparticles using *Aegle marmelos* fruit extract and their antimicrobial activity. *Materialstoday: Proceedings* 2023; 89: 1–7. doi: 10.1016/j.matpr.2023.03.256
39. Siddique NA, Mujeeb M, Najmi AK, Akram M. Evaluation of antioxidant activity, quantitative estimation of phenols and flavonoids in different parts of *Aegle marmelos*. *African Journal of Plant Science* 2010; 4(1): 1–5.
40. Hameed MA, Faheem A, Koay YC, Fathima S. Phytochemical screening, anti-pyretic and antidiarrhoeal activities of the n-hexane and aqueous extracts of the leaves of *Aegle marmelos*. *Archives of Pharmacy Practice* 2011; 2(3): 90–94.
41. Ariharan VN, Prasad PN. Quantitative phytochemical analysis on leaf extract of *Aegle marmelos*. *Journal of Chemical and Pharmaceutical Research* 2014; 6(3): 1100–1104.
42. Mujeeb F, Bajpai P, Pathak N. Phytochemical evaluation, antimicrobial activity, and determination of bioactive components from leaves of *Aegle marmelos*. *BioMed Research International* 2014; 2014: 497606. doi: 10.1155/2014/497606
43. Asaduzzaman M, Nahar L, FazleyRabbi M, et al. Phytochemicals, nutritonal constituents, anti-bacterial and hypoglycemic activity of *Aegle marmelos* Lin. leaf extract in alloxan induced diabetic rats. *Journal of Nutrition & Food Sciences* 2016; 6(4): 1000533. doi: 10.4172/2155-9600.1000533
44. Shantaram BP, Ramachandra BS, Eknath GA. Preliminary phytochemical analysis of seeds and leaves of *Aegle marmelos* extracts and in-vitro assessment of their antibacterial activity. *International Journal of Pharma Research and Health Sciences* 2016; 4(4): 1315–1319. doi: 10.21276/ijprhs.2016.04.13
45. Raja WW, Khan SH. Estimation of some phytoconstituents and evaluation of antioxidant activity in *Aegle marmelos* leaves extract. *Journal of Pharmacognosy and Phytochemistry* 2017; 6(1): 37–40.
46. Asghar N, Mushtaq Z, Arshad MU, et al. Phytochemical composition, antilipidemic and antihypercholestrolemic perspectives of Bael leaf extracts. *Lipids in Health and Disease* 2018; 17(1): 68. doi: 10.1186/S12944-018-0713-9
47. Gade R, Deshmukh AA, Patil MK, et al. Comparative study of phytochemical analysis and extractive value of *Aegle marmelos*, *Bauhinia racemosa* and *Psidium guajava*. *Journal of Pharmacognosy and Phytochemistry* 2018; 7(5): 2904–2907.
48. Veer B, Singh R. Phytochemical screening and antioxidant activities of *Aegle marmelos* leaves. *Analytical Chemistry Letters* 2019; 9(4): 478–485. doi: 10.1080/22297928.2019.1657946
49. Sahu AK, Kar BR, Deepthi K, et al. Gas chromatography and mass spectroscopy analysis and phytochemical characterization of *Aegle marmelos* (Bael) leaf, stem and its screening of antimicrobial activity. *GSC Biological and Pharmaceutical Sciences* 2019; 8(3): 122–130. doi: 10.30574/gscbps.2019.8.3.0159
50. Seemaisamy R, Faruck LH, Gattu S, et al. Anti-microbial and anti-cancer activity of *Aegle marmelos* and gas chromatography coupled spectrometry analysis of their chemical constituents. *International Journal of Pharmaceutical Sciences and Research* 2019; 10(1): 373–380. doi: 10.13040/IJPSR.0975-8232.10(1).373-80
51. Syahrir M, Kadola E, Salempa P. Isolation and identification of secondary metabolites in ethyl acetate extract from the Maja bark (*Aegle marmelos* Linn.). *Pharmaciana* 2021; 11(1): 15–24. doi: 10.12928/pharmaciana.v11i1.17875
52. Anandhu KS, Jose M, Kuriakose S, Jayalakshmi PM. Phytochemical analysis and in vitro antidiabetic activity of

aqueous extract of *Lagerstroemia speciosa* and *Aegle marmelos*. *Research Journal of Pharmacy and Technology* 2021; 14(9): 4697–4701. doi: 10.52711/0974-360X.2021.00816
53. Ahmad W, Amir M, Ahmad A, et al. *Aegle marmelos* leaf extract phytochemical analysis, cytotoxicity, in vitro antioxidant and antidiabetic activities. *Plants* 2021; 10(12): 2573. doi: 10.3390/plants10122573
54. Tripathi M, Shukla PK, SIkarwar RLS, et al. Pharmacognostic evaluation of Bilva [*Aegle marmelos* (L.) Correa] root bark. *Indian Journal of Traditional Knowledge* 2019; 18(4): 670–676.
55. Sharma GN, Dubey SK, Sati N, Sanadya J. Phytochemical screening and estimation of total phenolic content in *Aegle marmelos* seeds. *International Journal of Pharmaceutical and Clinical Research* 2011; 2(3): 27–29.
56. Dheeba B, Sampathkumar P, Sathiya Priya RR, Kannan M. Phytochemical studies and evaluation of antioxidant potential of various extracts of *Aegle marmelos* bark. *Pharmacologyonline* 2010; 3: 831–839.
57. Meena AK, Ilavarasan R, Singh R, Parashar D, et al. Evolution of pharmacological activity with molecular docking of active constituents present in roots and small branches of *Aegle marmelos*: A comparative study using HPLC, GC-MS, LC-MS. *Phytomedicine Plus* 2022; 2(1): 100210. doi: 10.1016/j.phyplu.2021.100210
58. Sharma A, Singh T, Pathak D, et al. Antidepressive-like effect of *Aegle marmelos* leaf extract in chronic unpredictable mild stress-induced depression-like behaviour in rats. *BioMed Research International* 2022; 2022: 6479953. doi: 10.1155/2022/6479953
59. Kumar DR, Awasthi K. Phytochemical analysis of *Aegle marmelos* leaves: A comparative study. *European Chemical Bulletin* 2023; 12(S8): 3576–3582.
60. Rathore M. Nutrient content of important fruit trees from arid zone of Rajasthan. *Journal of Horticulture and Forestry* 2009; 1(7): 103–108.
61. Lakht-e-Zehra A, Dar NG, Saleem N, et al. Nutritional exploration of leaves, seed and fruit of bael (*Aegle marmelos* L.) grown in Karachi region. *Pakistan Journal of Biochemistry and Molecular Biology* 2015; 48(3): 61–65.
62. Sharma K, Chauhan ES. Nutritional and phytochemical evaluation of fruit pulp powder of *Aegle marmelos* (Bael). *Journal of Chemical and Pharmaceutical Sciences* 2017; 10(2): 809–814.
63. Uttarwar VV, Taur AT, Sawate AR. Studies on evaluation of physicochemical and nutritional properties of bael fruit (*Aegle marmelos*). *Journal of Pharmacognosy and Phytochemistry* 2018; 7(3): 547–549.
64. Manandhar MD, Shoeb A, Kapil RS, Popli SP. New alkaloids from *Aegle marmelos*. *Phytochemistry* 1978; 17(10): 1814–1815. doi: 10.1016/S0031-9422(00)88714-2
65. Ali MS, Pervez MK. Marmenol: A 7-geranyloxycoumarin from the leaves of *Aegle marmelos* Corr. *Natural Product Research* 2004; 18(2): 141–146. doi: 10.1080/14786410310001608037
66. Phuwapraisirisan P, Puksasook T, Jong-aramruang J, Kokpol U. Phenylethyl cinnamides: A new series of α-glucosidase inhibitors from the leaves of *Aegle marmelos*. *Bioorganic & Medicinal Chemistry Letters* 2008; 18(18): 4956–4958. doi: 10.1016/j.bmcl.2008.08.024
67. Garg SN, Siddiqui MS, Agarwal SK. p-Menth-1-en-3β,5β-diol, a new constituent of *Aegle marmelos* leaf oil. *Journal of Essential Oil Research* 1995; 7(3): 283–286. doi: 10.1080/10412905.1995.9698520
68. Kaur HP, Garg SN, Sashidhara KV, et al. Chemical composition of the essential oil of the twigs and leaves of *Aegle marmelos*. *Journal of Essential Oil Research* 2006; 18(3): 288–289. doi: 10.1080/10412905.2006.9699091
69. Mahomoodally MF, Mollica A, Stefanucci A, et al. Volatile components, pharmacological profile, and computational studies of essential oil from *Aegle marmelos* (Bael) leaves: A functional approach. *Industrial Crops and Products* 2018; 126: 13–21. doi: 10.1016/j.indcrop.2018.09.054
70. Gajbhiye NA, Makasana J, Dhanani T, Saravanan R. Development and validation of LC—ESI—MS/MS method for simultaneous determination of four coumarin derivatives and an alkaloid from root and stem bark of *Aegle marmelos* Correa. *Acta Chromatographica* 2016; 28(4): 473–488. doi: 10.1556/1326.2016.28.4.6
71. Laphookhieo S, Phungpanya C, Tantapakul C, et al. Chemical constituents from *Aegle marmelos*. *Journal of the Brazilian Chemical Society* 2011; 22(1): 176–178. doi: 10.1590/S0103-50532011000100024
72. Gajbhiye NA, Makasana J, Thorat T. Simultaneous determination of marmin, skimmianine, umbelliferone, psoralene, and imperatorin in the root bark of *Aegle marmelos* by high-performance thin-layer chromatography. *Journal of Planar Chromatography* 2012; 25: 306–313. doi: 10.1556/JPC.25.2012.4.5
73. Chatterjee A, Saha SK. Isolation of alloimperatorin and ß-sitosterol from the fruits of *Aegle rnarrnelos*. *Journal of the Indian Chemical Society* 1957; 34: 228–230.
74. Sharma BR, Sharma P. Constituents of *Aegle marmelos*. II. Alkaloids and coumarin from fruits. *Planta Medica* 1981; 43(1): 102–103.
75. Chaubey A, Dubey AK. Chemistry and antioxidant potential of phytoconstituents from *Aegle Marmelos* fruit-shell. *Current Drug Metabolism* 2020; 21(7): 525–533. doi: 10.2174/1389200221666200711161056
76. Hye JK, Young JS, Khin MH, Kee DY. Chemical constituents from *Aegle marmelos* fruits. *Natural Product Sciences* 2021; 27(4): 240–249. doi: 10.20307/nps.2021.27.4.240
77. Mandal PK, Mukherjee AK. Studies on bael (*Aegle marmelos*) seed glycoproteins. *Carbohydrate Research* 1981; 90(2): 233–241. doi: 10.1016/S0008-6215(00)85922-4
78. Mishra BB, Singh DD, Kishore N, et al. Antifungal constituents isolated from the seeds of *Aegle marmelos*. *Phytochemistry* 2010; 71(2–3): 230–234. doi: 10.1016/j.phytochem.2009.10.013
79. Chinchansure AA, Shamnani N, Arkile M, et al. Antimycobacterium activity of coumarins from fruit pulp of

Aegle marmelos (L.) Correa. *International Journal of Basic and Applied Chemical Sciences* 2015; 5(3): 39–44.
80. Pynam H, Dharmesh SM. Antioxidant and anti-inflammatory properties of marmelosin from Bael (*Aegle marmelos* L.); Inhibition of TNF-α mediated inflammatory/tumor markers. *Biomedicine & Pharmacotherapy* 2018; 106: 98–108. doi: 10.1016/j.biopha.2018.06.053
81. Nugroho AE, Riyanto S, Sukari MA, Maeyama K. Anti-allergic effects of marmin, a coumarine isolated from *Aegle marmelos* Correa: In vitro study. *International Journal of Phytomedicine* 2011; 3(1): 84–97.
82. Nugroho AE, Abdi N, Riyanto S, et al. Effects of marmin isolated from *Aegle marmelos* Correa on L-histidine decarboxylase enzyme in RBL-2 H3 cells. *The Thai Journal of Pharmaceutical Sciences* 2011; 35(1): 1–7.
83. Narender T, Shweta S, Tiwari P, et al. Antihyperglycemic and antidyslipidemic agent from *Aegle marmelo*s. *Bioorganic & Medicinal Chemistry Letters* 2007; 17(6): 1808–1811. doi: 10.1016/j.bmcl.2006.12.037
84. Ram PP, Varun G, Balram S, et al. 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.
85. Singh AP, Singh L, Singh P, Bhatti R. Biological evaluation of *Aegle marmelos* fruit extract and isolated aegeline in alleviating pain−depression dyad: In silico analysis of aegeline on MAO-A and iNOS. *ACS Omega* 2021; 6(3): 2034–2044. doi: 10.1021/acsomega.0c04739
86. Noviarsito P, Riyanto S, Nugroho AE. Marmin of *Aegle Marmelos* Correa antagonizes $AChM_3$ receptors: In silico and in vitro studies on isolated guinea pig illeum smooth muscle. *Journal of Mathematical and Fundamental Sciences* 2014; 46(3): 278–289. doi: 10.5614/j.math.fund.sci.2014.46.3.6
87. Murugaiah K, Venkatachalam R. Antispasmolytic and anti helminthiasis activity of aegeline isolated from *Aegle marmelos leaves*. *Journal of Global Biosciences* 2015; 4(1): 1235–1238.
88. Sahare KN. Antifilarial screening and oxidative role of isolated fraction from *Aegle marmelos* Corr. leaves extract. *Biosciences Biotechnology Research Asia* 2021; 18(2): 395–401. doi: 10.13005/bbra/2926
89. Kakiuchi N, Senaratne LRE, Huang SL, et al. Effects of constituents of Beli (*Aegle marmelos*) on spontaneous beating and calcium-paradox of myocardial cells. *Planta Medica* 1991; 57(1): 43–46. doi: 10.1055/S-2006-960014
90. Napolitano HB, Silva M, Ellena J, et al. Aurapten, a coumarin with growth inhibition against *Leishmania major* promastigotes. *Brazilian Journal of Medical and Biological Research* 2004; 37(12): 1847–1852. doi: 10.1590/S0100-879X2004001200010
91. Katram N, Garlapati PK, Yadavalli C, et al. *Aegle marmelos* extract rich in marmelosin exacted ameliorative effect against chromium-induced oxidative stress and apoptosis through regulation of Gadd45 in HepG2 cell line. *Journal of Food Biochemistry* 2021; 45(4): e13704. doi: 10.1111/jfbc.13704
92. Manda VK, Avula B, Chittiboyina AG, et al. Inhibition of CYP3A4 and CYP1A2 by *Aegle marmelos* and its constituents. *Xenobiotica* 2016; 46(2): 117–125. doi: 10.3109/00498254.2015.1053006
93. Pynam H, Dharmesh SM. A xylorhamnoarabinogalactan I from Bael (*Aegle marmelos* L.) modulates UV/DMBA induced skin cancer via galectin-3 & gut microbiota. *Journal of Functional Foods* 2019; 60: 103425. doi: 10.1016/j.jff.2019.103425
94. Mohammed MMD, Ibrahim NA, El-Sakhawy FS, et al. Two new cytotoxic furoquinoline alkaloids isolated from *Aegle marmelos* (Linn.) Correa. *Natural Product Research* 2016; 30(22): 2559–2566. doi: 10.1080/14786419.2015.1126262
95. Nugroho AE, Riyanto S, Sukari MA, Maeyama K. Effects of aegeline, a main alkaloid of *Aegle Marmelos* Correa leaves, on the histamine release from mast cells. *Pakistan Journal of Pharmaceutical Sciences* 2011; 24(3): 359–367.