REVIEW ARTICLE

Bel plant: A source of pharmaceuticals and ethno medicines

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Abstract

Bel is a holy native tree of India, which has high ethnomedicinal, therapeutic, and pharmaceutical importance. Bel contains many diverse bioactive components in leaves, flowers, fruits, wood, root, and bark which show multiple biological activity and high therapeutic importance. Plant contains coumarins, marmelosin, marmesin, imperatorin, marmin, alloimperatorin, methyl ether, xanthotoxol, scoparone, scopoletin, umbelliferone, psoralen and marmelide and marmenol, aegelin, aegelenine, marmeline, dictamine, fragrine which show anticancer, antioxidant, antimicrobial, anti-plasmodial, and hepatoprotective activities. Plant possesses various polysaccharides such as galactose, arabinose, uronic acid, and L-rhamnose. Its seed oil contains palmitic, stearic, oleic, linoleic, and linolenic acids which possess very high nutritive value. Plant also possesses very high tannin contents (9%) in fruits, pulp leaves. Tannin found in leaves as skimmianine. Marmelosin, skimmianine, and umbelliferone are therapeutically important active principles. *Aegle marmelos* is also a good source of gum, wound healers, carotenoids, vitamins, sugars, and nutritive oils. The plant is used to cure digestive disorders, ulcers, headache, hypertension, diabetes, constipation, and numerous other ailments. The ripe fruits are used as a laxative, while unripe Bel fruit, promotes digestion, and cures diarrhea. *A. marmelos* contains plant essential oil which shows chemotypic and seasonal variations. In the present review article, ethnomedicinal, therapeutic, pharmaceuticals, and insecticidal properties of *A. marmelos* have been described in detail.

Key words: *Aegle marmelos*, ethnomedicinal, insecticidal properties, pharmaceuticals, therapeutic

INTRODUCTION

Aegle marmelos, commonly known as Bel, belongs to family Rutaceae. Bel is a sacred tree native to India and has great aesthetic value among Hindus as tree is worshiped in rituals by masses. The plant is also known by different names as stone apple or wood apple, bili, bilva patra, Bengal quince or golden apple.[1] The plant is mentioned as Tripatra in ancient Indian scriptures such as Yajurveda and Mahabharata.[2] Its leaves are ternate and scented named as tripatras and are used in enchantments. The plant is also figured in Aranyakas and Hindu Sahintas. This plant is as old as Hindu civilization and has great aesthetic, cultural, and medicinal value. Bel fruit looks like a skull with a white, bone-like outer shell and a soft inner part that is why it is called as Seer Phael (head-fruit) or most likely Seer Phal. Sanskrit literary books and in ritualistic literature, it is mentioned as "*ShreePhal*." Bel tree is grown in gardens mainly near to the Shiva temples for worshiping of Lord Shiva. Devotees offer scented leaves and fruits to Lord Shiva [Figure 1].

Bel tree is also called Shivadurme because it is believed that tree signifies the presence of Lord Shiva or Kailashnath.[2] In the traditional Newari culture of Nepal, Shivadurme is worshiped by young girls in fertility rituals and by a married woman to seek longevity of their husband. Both leaves and fruits are of great religious importance since the tree is regarded as one of the sacred trees of Indian heritage. Bel is a sacred tree having sacrificial importance. The plant is straight, strong, having an axillary spine. It is common belief that planting of this tree by the waysides gives long life. It is incumbent upon all Hindus to cultivate and cherish this tree, and it is sacrilege to cut it down.[3] Bel flowers are scented, and perfume is distilled from the flowers. Oil is limonene-rich and used for scenting hair. Fruit is used in the treatment of scum in vinegar manufacture. Bel tree wood is light, durable, and is used for small-scale turnery, tool and

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knife handle, pestles, and combs making. Shell of hard fruits fashioned into pill and snuff boxes. *Aegle* seeds are a good source of gum that is used as household glue and adhesive by jewelers. Fruit pulp shows detergent action and is used as a soap substitute for washing clothes. It is also used for construction as water-proofing walls-mixed with lime plaster and added to the cement. It is also used in watercolors or as protective coating for paintings. Bel fruit pulp contains 9% tannin that is used for tanning. Pulp yields a yellow dye for calico and silk fabrics.[4,5] Bel tree is recognized by different names in different languages such as in Hindi: Sriphal, Urdu: Sirphal, Oriya: Bela, Punjabi: Beel, Marathi: Kaveeth, Malayalam: Koovalam, Konkani: Gorakamli, Tamil: Vilvam, Telugu: Maredu, Belgiri (Hindi); Bilva, Shivadruma, Shivaphala, Vilva (Sanskrit), Holy Fruit, Bel, Indian Bel, Bela, Bili, Bilva, Bilwa, Belapatri, Sriphal, Vilvam, Muredu, Koovalam, Bau Nau. In Kannada, the plant is known as "Bela" or Bilva, in Oriya and Maredu (in Telugu). The plant grows throughout Southeast Asia as a naturalized species belong to India.[3] Its fruits are used in traditional medicine and as a food throughout its range.

DISTRIBUTION

Bel is found in dry forests on hills and plains of Northern, Central, and Southern India, Pakistan, Southern Nepal, Sri Lanka, Myanmar, Bangladesh, Vietnam, Laos, Cambodia, and Thailand. It is also found in Sri Lanka, Thailand, and various other regions of Southern Asia. It is cultivated throughout India, as well as in Sri Lanka, the Northern Malay Peninsula, Java, The Philippines, and Fiji. It has a reputation in India for being able to grow in places that other trees cannot grow. Bel is the only member of the monotypic genus *Aegle*.[6] It is a mid-sized, slender, aromatic, armed, gum-bearing tree growing to a height of 10-15 m. The plant grows in groups and makes a green canopy with scented air. The plant bears small flowers and edible fruits of 5-9 cm in diameter. Fruit shells are tough, and its inner mass contains brownish yellow pulp and small white seeds. Leaves are pale green of three leaflets, sessile, ovate-lanceolate, 3-5 inches long, terminal long petiolated. Flowers are of an inch in diameter, greenish, white, sweet, and scented. It copes with a wide range of soil conditions (pH range 5-10). The plant is tolerant of water logging, drought, and temperature fluctuations (from 7°C to 48°C). It requires a pronounced dry season to give fruit or in early summer [Figure 1].

ETHNOMEDICINAL USE

From demographic and social studies, it is well-recognized plant whose various parts such as fruit, root, bark, leaves as well as flowers of Bel tree have a high ethnomedicinal use. Due to its dense distribution in most of the states of India, local people use Bel fruits and leaves for wound healing, for curing digestive disorders, ulcers, headache, hypertension,

Figure 1: Bel plant with green unripe fruits

diabetes, and numerous other ailments. The ripe fruit is used as a laxative but is not digested easily. Aqueous extract of unripe Bel fruit promotes digestion and cures diarrhea. Bel fruit is recognized by different name by local people. More popular name prevalent among Newari, Tharu, and Gond is wood apple, Bela, elephant apple, and monkey fruit. The name is given because of liking of fruit by the animals. The fruit is eaten fresh or dried by the local people as a nutritive substitute and treats gastro-ulcerative problem. Fresh ripen fruit pulp is used to make a cold drink and squashes or juice that is strained and sweetened to make a drink similar to lemonade. The ripe fruits are edible; its yellow pulp is solubilized in water, sugar, and lime juice to make thanda sharbat (Hindand) to beat heat stress in hot summer. It is most preferred refreshing drink used in Uttar Pradesh, Bihar, Madhya Pradesh, Rajasthan, Odisha, and Bengal. For soft drink preparations, fruit is sliced, and sun-dried, and hard leathery slices are then immersed in water. Green fresh leaves and small shoots are eaten as salads while unripe fruits are eaten after roasting. The pulp can be eaten raw, but it is popularly scooped out and frozen, or made into jam. The seed powder is mixed with coconut milk for making a delicious, healthy beverage, or frozen into ice cream.

THERAPEUTIC USES

Bel (*A. marmelos)*, is an important medicinal plant whose various plant parts are widely used in the traditional Indian system of medicine, the Ayurveda. Bel plant leaves are used for multiple medicinal purposes, including dyspepsia and sinusitis. Bel fruit is used to treat tuberculosis and loss of appetite.[7] In Ayurveda *ilakam* drug finds several and frequent therapeutic uses in different forms and recipes. The drug is prescribed in a number of diseases such as gastrointestinal diseases, piles, edema, jaundice, vomiting, obesity, pediatric disorders, gynecological disorders, urinary complaints, and as a rejuvenative [Table 1]. Both aerial parts and root parts of *A. marmelos* are of high medicinal value.[8] The plant is an important economic plant of subtropical climate[9] which

Table 1: Biological activity of chemical constituents isolated from *Aegle marmelos* and its associating species

Species/plant parts	Compounds isolated	Biological activity
Leaves	Alkaloids	Antifungal, anticancer
	Eugenol	Antibacterial
	Cuminaldehyde	Antibacterial
	Skimmince	Anticancer
	Geraniol	Antihelmintic
	Terpionoids	Nematicidal
	Marmelosin	Laxative, diuretic
	Lectin	Anti-invasive
	Lupeol	Anticancer
	Quercetin	Anticancer
	Flavonoids	Anticancer, antibacterial
	Tannins	Cytotoxic, insecticidal
	Saponins	Cytotoxic, insecticidal, antioxidant
	Sitosterol	Nutritive
	Coumarins	Antibacterial activity, antifungal
	Marmelosin	Antimicrobial, hepatoprotective
	Marmesin	Cytotoxic, antiulcer, antipyretic
	Imperatorin	Antifertility
	Marmin, alloimperatorin	Hypoglycemic, antimicrobial, antioxidant
	Methyl ether, xanthotoxol	Cytotoxic, anticancer
	Scoparone, scopoletin	Cytotoxic
	Umbelliferone	Antihyperglycemic, free radical scavenging
	Beta-caryophyllene	Anti-inflammatory, anticancer
	Coumarins	Antibacterial
	Alf-tocopherol	Antihyperlipidemic
	Phenylpropanoids	Antibacterial
	Limonene	Antioxidant and antimicrobial
	Terpenes	Synergistic and antagonistic interactions
	Monoterpenes	Cytotoxic and larvicidal
Seeds	Proteins	Natural sweetener, nutraceutical
	Aegeline	Nutraceutical, antioxidant
	Limonene	Cytotoxic
	Flavonoid	Anticonvulsant
	Psoralen	Antifungal
	Marmelide	Antifertility
	Marmenol	Antimicrobial
	7-geranyloxycoumarin	Antimicrobial
	Aegelin	Antipyretic, antibacterial
	Aegelenine	Antibacterial, antioxidant
	Scopoletin	Antioxidant, hepatoprotective
	Armeline	Antifungal, antidiarrheal
	Dictamine, fragrine	Cytotoxic

(Cond...)

Table 1: *(Continued...)*

Species/plant parts	Compounds isolated	Biological activity
Stem and root bark	O- methylhalfordinine, O isopentenylhalfordinol	Cytotoxic
	N-2-(4-[3',3'- dimethylallyloxy] phenyl) ethyl cinnamide	Cytotoxic
	N-2-hydroxy-2-(4-[3',3'-dimethylallyloxy] phenyl) ethyl cinnamide	Cytotoxic
	N-4 methoxystyryl cinnamide, N-2- hydroxy-2-(4-hydroxyphenyl) ethyl cinnamide	Cytotoxic
	O-(3,3-dimethylallyl) halofordinol	Cytotoxic
	N-2-ethoxy-2-(4-methoxy phenyl) ethyl cinnamide	Cytotoxic
	N-2-methoxy-2-(4-[3',3'- dimethylallyloxy] phenyl) ethylcinnamide	Cytotoxic
	N-2-methoxy-2-(4-methoxyphenyl)- ethylcinnamide	Cytotoxic
Fruit	Galactose, arabinose, uronic acid and L-Rhamnose, carotenoids	Nutritive
Roots	Psoralen, xanthotoxin scopoletin and tembamide	Anticancer, antioxidant, cytotoxic
	Compounds such as praealtin D	Antitumor, antiproliferative
	Trans-cinnamic acid	Cytotoxic
	4-methoxy benzoic acid	Nutritive, anthelmintic
	Betulinic acid	Antiallergic
	Montanin	Antioxidant, insecticidal
	α-zingiberene	
	3-Methyl-2-butenal	
	3Z-Hexenol	
	β-Funebrene	
	α-pinene	
	α-humulene	
	Limonene	
	Elemol	Antioxidant
	Piperitol	
	Isogeraniol	
	α-terpinolene+trans-linalool oxide (furanoid)	
	Caryophyllene	
	Anthraquinone antifungal	
	p-Menth-1-en-3β-5β-dio	Antidiarrheal
Seed oil	Palmitic, stearic, oleic, linoleic and linolenic acid	Nutritive
	Skimmianine. marmelosin, skimmianine, and umbelliferone	Therapeutic
	Carotenoids	Pigment
	Ascorbic acid	Nutritive
	Sitosterol	Nutritive
	Crude fibers	Anticholesterol
	α-amyrin	Protection
	Hemicelluloses	Cytosketelal
	Marmelle oil	Insecticidal

bears highly nutritive[10] and medicinal fruits.[11,12] Both ripe and unripe fruits of *A. marmelos* show multiple disease curing properties. Essential oil obtained from Bel leaves show strong antimicrobial activity against a number of pathogens.[13] It is prescribed for a smooth bowel movement to patients suffering from constipation and other gastrointestinal problems. Unripe Bel fruit is used for combating giardia and rotavirus, and to inhibit adherence and invasion of the bacteria on the gut wall (i.e., the ability to infect the gut). Leaves are used to lower high blood pressure and inflammation. Bel leaves also provide relief from menstrual problems. Bel also provides relief from cough, cold, asthma, bronchitis, influenza, and

other similar respiratory disorders. Applying a paste prepared from powdered root and butter on soles is an effective Bel home remedy for inducing sleep. Besides, the rind of Bel fruit benefits in reducing dandruff. The fruits are used as astringent, stomachic, and also in the treatment of diarrhea and dysentery. The mucilaginous substance of the fruits is used as gum and also used in making varnish. A yellow dye is obtained from the rind of the fruit.

Bel is used to control hemorrhoids as the dose involves the intake of a combination of dried and powdered Bel leaves, dried ginger, carom seeds, and black pepper mixed in a glass of buttermilk or lukewarm water. Dried Bel leaves and pulp are used to restore appetite and eliminate helminths. Dried pulp is used in relieving spasms and to treat irritable bowel syndrome. Similarly Bel fruit pulp mixed with jiggery or cold sherbet if used once daily for 2-3 months heals constipation and indigestion. It also cures mouth ulcers. Dried slices of an unripe Bel fruit if intake with water dealing with acute or chronic diarrhea. A concoction of dried leaves in hot water reduces chronic, cough, sore throat, and hypertension. Hot leave extract acts as an expectorant. Consuming about 20 ml juice extracted from Bel leaves is valuable in managing diabetes and reducing excess urination. Similarly, a combination of ripe Bel fruit pulp, sugar, and honey regularly after dinner can cure early stage tuberculosis if taken for 40 days regularly. Bel leaves assist in reducing excessive menstruation and is a natural treatment of jaundice. A green tea of Bel leaves provides quick relief in chronic or recurring colds and related respiratory conditions. Roasted Bel leaves are used to cure asthma and relieve cough and cold [Table 1]. They also help in curing sore throat and treating chronic cough due to its function as an expectorant. Similarly, rind of Bel fruit mixed in coconut oil treat dandruff naturally. Bel leaves are used in healing stomach and mouth ulcers. Bel leaves soaked in a cup of water overnight and drinking this solution early in the morning for a few weeks improve in constipation. This mixture if intake along with 3-4 black peppercorns and drink a cup of warm milk afterward treat nausea, vomiting, and headache during summers. The extract of leaves is beneficial in the treatment of leucorrhea, conjunctivitis, and deafness. Juice of Bel flowers mixed with holy basil leaves is used to treat malaria. Regular consumption of fruit pulp is recommended for treatment of kidney complaints. Plant leaves and fruit pulp possess detoxifying powers and remove off xenobiotics from the kidney and liver or catabolize to non-toxic compounds and maintain its healthy levels. The root urka of Bel tree is used to treat ear pain. It is also used to loosen phlegm and helps eliminate the buildup in the respiratory system. Bel plant shows radio-protective effects as both leaves and fruit are used to reduce the side effects of radiotherapy [Table 1].

The unripe Bel fruit, root, leaf, and branch are used to make medicine. Fruit provides freshness and energy. This is the best laxative that is used to relieve constipation and diarrhea. Daily consumption of Bel fruit provides relief from indigestion, peptic ulcer, piles, respiratory problems, diarrhea, and dysentery. Fruit juice cleans and tones up the intestine and assists in the evacuation of even the old accumulated fecal matter from the bowels. In Ayurveda, the plant is used in the treatment of digestive disorders, wound healing, and to cure snakebites. Medicated oil prepared from leaves gives relief from recurrent cold and respiratory infections [Table 1]. In South India, juice of leaves is provided to bring relief from wheezing cough and respiratory spasm. *A. marmelos* (L.) Correa (Rutaceae) leaves show hypoglycemic, radioprotective, antidiarrheal.[14] and hepatoprotective potential [Table 1].[15] The leaf juice is mixed in warm water with a little pepper and is used to cure cold and sneezing.[16,17] But overeating of Bel fruit high doses over a period time causes bloating, flatulence, and stomach problems. Bel leaves are rich in tannins, which help to treat diarrhea, but excessive consumption of Bel home remedies prepared from Bel leaves may give rise to carcinogenic effects. Similarly, excessive consumption of leaves is quite harmful to pregnant breastfeeding mothers.

Bel is used as carminative, anti-venom, astringent, and used in thyroid-related disorders.[18] It is also used as a cardiac stimulant,[19] and to treat anemia, fractures, swollen joints, pregnancy troubles, typhoid,[18] coma,[19] colitis,[20] bleeding sores, and cramps.[21,22] A concoction of Bel leaves is used in the treatment of acute shigellosis.[23] Soup prepared from green leaves, and fruit pulp is used as diuretic, benefits in gonorrhea and conjunctivitis.[24] The leaf and Belgiri powder are used as stomachic and treatment of irritable bowel syndrome.[25] It also boosts the immune system and shows antibacterial and antiviral activity. The physiological dosage of Bel pulp reduces inflammation, suppresses cancer, and increases milk production for nursing mothers. The aqueous extract prepared by boiling the bark, leaves or roots is useful as a laxative, febrifuge, and expectorant. The extract is also useful in ophthalmia, deafness, inflammations, catarrh, diabetes, and asthmatic complaints. The fruits are used in treating diarrhea, dysentery, stomach ache, and cardiac ailments. Bel possesses diverse biological activities such as antimicrobial, hypoglycemic, astringent, antidiarrheal, anti-dysenteric, demulcent, analgesic, anti-inflammatory, antipyretic, wound-healing, insecticidal, and gastro-protective properties. Bel leaves are used to cure diabetes, increases ocular health, and help to prevent various sexual dysfunctions. Bel leaves are used to treat fevers, abdomen pain, and palpitation of the heart, urinary troubles, melancholia, anorexia, dyspepsia, diabetes, and diarrhea in Indian traditional systems of medicine. For safe use of prescriptions and for good medication guidance from Ayurvedic pharmacist or physician or other healthcare professional is highly essential to avoid any harmful effect of natural products.[26,27] Hence, for safe therapeutics, an appropriate dosage is important. Bel phytochemicals possess antineoplastic, radioprotective, chemoprotective, chemopreventive effects, anticancer,[28] anti-diabetic, anti-hyperlipidemic, antioxidant, and anti-diabetic activities.[29] Bel leaves are extensively used in the

Ayurvedic, Unani, and Siddha systems of Indian medicine as an anti-diabetic or hypoglycemic agent.[30] *A. marmelos* fruit shows radioprotective effect.[31]

Nutritional Value

Bel plant is a rich source of proteins, carbohydrates, vitamins, and minerals.[10,11,32] The plant contains important vitamins such as carotene, thiamin, riboflavin, and niacin and minerals, that is, calcium, iron, phosphorus. Plant shows a vast array of health benefits due to the presence of both macro and micronutrients such as vitamins, organic compounds including tannins, alkaloids, polyphenols, terpenes, fiber, protein, and oil. Bel pulp is a rich source vitamin C (ascorbic acid 66 mg/100 g). Major components of nutritional importance from Bel plant are listed in Table 1. The fruit pulp is blended with 30% sugar, and dehydrated powder is used for the preparation of cold drink or soft squash. Bel fruit is used for the preparation of toffee by combining the pulp with sugar, glucose, skim milk powder, and hydrogenated fat. Bel fruit processing is highly promising, and many more nutritive biproducts are made for safe dietary use. The young leaves and shoots are used as a vegetable in Thailand and as seasonal food in Indonesia. The raw Bel fruit is sour to taste and is used to make chutney while the leaves of the Bel fruit are used as salad ingredients. Bel fruit helps to destroy worms in the intestine, it is also recommended as a remedy for chronic dysentery. Fresh juice of leaves or flowers reduces the appetite while an infusion of the flowers mixed with sugar and milk is used as a cooling drink.[33] Milk and sugar added to fruit juice make it more palatable. The pulp of this fruit is used for making squash, nectar, jellies, marmalades, and candies. Mucilage from unripe seeds of Bel fruit is used as adhesive and glue. A gum-like thick substance collected from tree trunk and branches of Bel trees is used to make Feronia gum [Tables 1 and 2].

The traditional healers in India use Bel dry powder mixed with mustard oil for the treatment of burn. One part of the powder and two parts of mustard oil are mixed and applied externally. This is commonly used to curing diarrhea and dysentery. Bel fruit is recommended for treatment of peptic ulcer or piles, digestive problems, and to beat heat stress. Bel fruit juice is recommended for blood purification and to remove toxins from liver and kidneys. It acts as an immune modulator and atone defense against toxins. Fruit contains a high level of vitamin C that also increases the strength and potency of the immune system. Bel fruit pulp provides 140 calories/100 g after consumption and acts as an energy booster that promotes organ activity and accelerates metabolic speed. Its high protein contents speed up wound healing and make body muscles stronger. *A. marmelos* is a good source of β-carotene, thiamine, and riboflavin, which are known as liver health boosters. Bel fruit also functions as an ingredient in cardiac tonics.

Phytochemicals

So far, photochemical investigations have been done so many chemical constituents isolated from various plant parts, that is, leave, fruits, wood, root, flower, and bark of *A. marmelos* (L). Its seeds contain proteins,[34] which are used as natural sweetener show high nutraceutical value.[35] Aegeline (N-[2-hydroxy-2(4-methoxyphenyl) ethyl]-3-phenyl-2-propenamide) is a known constituent of the Bel leaf and consumed as a dietary supplement for a variety of purposes.[36,37] *A. marmelos* fruit contains pectin that is used for food and pharmaceuticals purposes and to enhance dietary performance [Figure 2].[38] Marmelosin is the active constituent isolated from Bel leaves acts as a laxative, diuretic and a strong cardiac depressant. Dried fruit freed from pulp are used as pill boxes. Leaves contain an essential oil while stem yields gum and its sulfation increases nutritional use.[39] Few important bio-organic components such as ethyl cinnamide, O-3-3-(dimethylallyl) halfordinol, N-2 methoxy-2-[4-(3',3'-dimethylallyloxy) phenyl) ethyl cinnamide),[40] 24-epibrassinolide,[41] limonene,[42] p-menth-1-en-3 β-5 β-diol,[43] and p-cymene, α phellandrene,[44] aegelinoside[40] were isolated from leaves and its essential oil [Table 1 and Figure 2]. Plant contains important metabolites such as alkaloids, coumarins, marmelosin, marmesin, imperatorin, marmin, alloimperatorin, methyl ether, xanthotoxol, scoparone, scopoletin, umbelliferone, psoralen, and marmelide and steroids.[45] Other compounds such as marmenol, a 7-geranyloxycoumarin [7-(2, 6-dihydroxy-7-methoxy-7-methyl-3-octaenyloxy) coumarin],[46] aegelin, aegelenine, marmeline, dictamine, fragrine ($C_{13}H_{11}O_3N$), O-methylhalfordinine, O-isopentenylhalfordinol,[45] N-2-[4-(3',3'-dimethylallyloxy) phenyl] ethyl cinnamide, N-2-hydroxy-2-[4-(3',3'-dimethylallyloxy) phenyl] ethyl cinnamide, N-4 methoxystyryl cinnamide, N-2-hydroxy-2-(4-hydroxyphenyl) ethyl cinnamide,[47,48] O-(3,3-dimethylallyl) halofordinol, N-2-ethoxy-2-(4-methoxyphenyl) ethyl cinnamide, N-2-methoxy-2-[4-(3',3'-dimethylallyloxy) phenyl] ethylcinnamide, N-2-methoxy-2-(4-methoxyphenyl)-ethylcinnamide were also isolated from different plant parts of *A. marmelos* [Table 1 and Figure 2].[49,50] The plant fruit pulp is a rich source of various polysaccharides such as galactose, arabinose, uronic acid, and L-rhamnose.[51] It also contains very high tannin contents (9%) and carotenoids which imparts pale color. Few important tannins isolated from fruit pulp are skimmianine. Marmelosin, skimmianine, and umbelliferone have been characterized from leaves of Bel plant. Its seed oil contain few important dietary fatty acids such as palmitic, stearic, oleic, linoleic, linolenic acid,[45] ascorbic acid, sitosterol, crude fibers, tannins, α-amyrin, and carotenoids in major quantity while crude proteins occur in minor quantity. Psoralen, xanthotoxin scopoletin, and tembamide,[45,52] trans-cinnamic acid, 4-methoxy benzoic acid, betulinic acid, and montanin have been reported from root and leaves of *A. marmelos*.[53]

Table 2: Therapeutic uses of various plant parts of *Aegle marmelos* for treatment of different diseases

Plant parts	Biological activity
Leaves	Antidiabetic anti-inflammatory, wound healing, antipyretic and analgesic antifungal activity, radioprotective, spontaneous beating and calcium-paradox of myocardial cells, wound healing properties
Leaf and rind essential oil	Antioxidant and antimicrobial, antifungal nematicidal, insecticidal
	Antimicrobial, insecticidal, larvicidal activities
Poultice of leaves	Applied to inflamed parts
Bitter fresh juice	Diluted with water, used as remedy for catarrh and fever
Decoction of leaves	Used for asthma cure
Fresh juice of leaves	Sweetened with honey, used as laxative or febrifuge
Leaf paste	Stop premature hair fall
Leaf powder	Hepatoprotective, antioxidant, hypoglycemic, testicular activity
Fruit, ripe or unripe	Digestive, antiulcer, constipation, ailments, highly nutritive
Dry fruit pulp	Moistened with cold water, yields a red liquid containing mucilage used in burn
Wood	Source of soluble potassium and sodium compounds, 0.16%; phosphates of calcium and iron, 0.13%; calcium carbonate, 2.16%; Magnesium carbonate
Plant stem bark gum	Dysentery, antiulcer
Bark extract	Cytotoxic
Roots, leaves and bark	Dysentery, antiulcer, antidiabetic, anti-inflammatory, antinociceptive, antipyretic
Fruit pulp	Treatment of scum in vinegar manufacture
Fresh, ripe fruit	Edible, use for pickling or as preserves, refreshing and
	Mildly, laxative drink or sherbet
Tender fruit	For slices, immunomodulatory
Young shoots and leaves	Used as vegetable and food seasoning
Mucous fluid (SF)	Rubbed on the hair in place of oil by the rural folk
Decoction of root-bark	Used for hypochondriasis, melancholia, intermittent fever, palpitations
Sweet-scented flower extract	Used as lotion for the eyes
Infusion of flower	Used as cooling drink
Flowers	Limonene-rich oil is used as scent and perfume scenting hair
Unripe or half-ripe fruit	Used to cure diarrhea, acute dysentery, gastroprotective
Pulp ripe fruit	Pleasant laxative and a simple cure for dyspepsia
Bael-marmalade	Anticonvalescence, antidysentery or diarrhea, prevent the growth of piles
Fruit	Antituberculosis
Decoction of unripe fruit	Hemorrhoids
Powder of dried pulp	Dysentery and gripping pains
Wood	Used for small-scale turnery, tool and knife handle, pestles and combs
	Shell of hard fruits fashioned into pill and snuff boxes
Seeds	Abundant gum from the seed used as household glue and adhesive by jewelers
Fruit pulp	Show detergent action, used as a soap substitute for washing clothes
	Used to make water-proofing walls mixed with lime plaster and added to cement. Added to watercolors or as protective coating for paintings
Wild fruit pulp	Contains 9% tannin. Rind yields a yellow dye for calico and silk fabrics
Insecticidal	Leaf extract used as insecticidal against the brown plant hopper, a rice plant pest in Asia

Essential oil that isolated from Bel leaves contains more than 60 volatile constituents which show chemotypic and seasonal variations.[15] No doubt *A. marmelos* contains therapeutically important active principles [Table 1].

Anticancer Activity

A. marmelos (L.) Correa (Bel) and its phytochemicals are used for the treatment and prevention of cancer.[28] Its

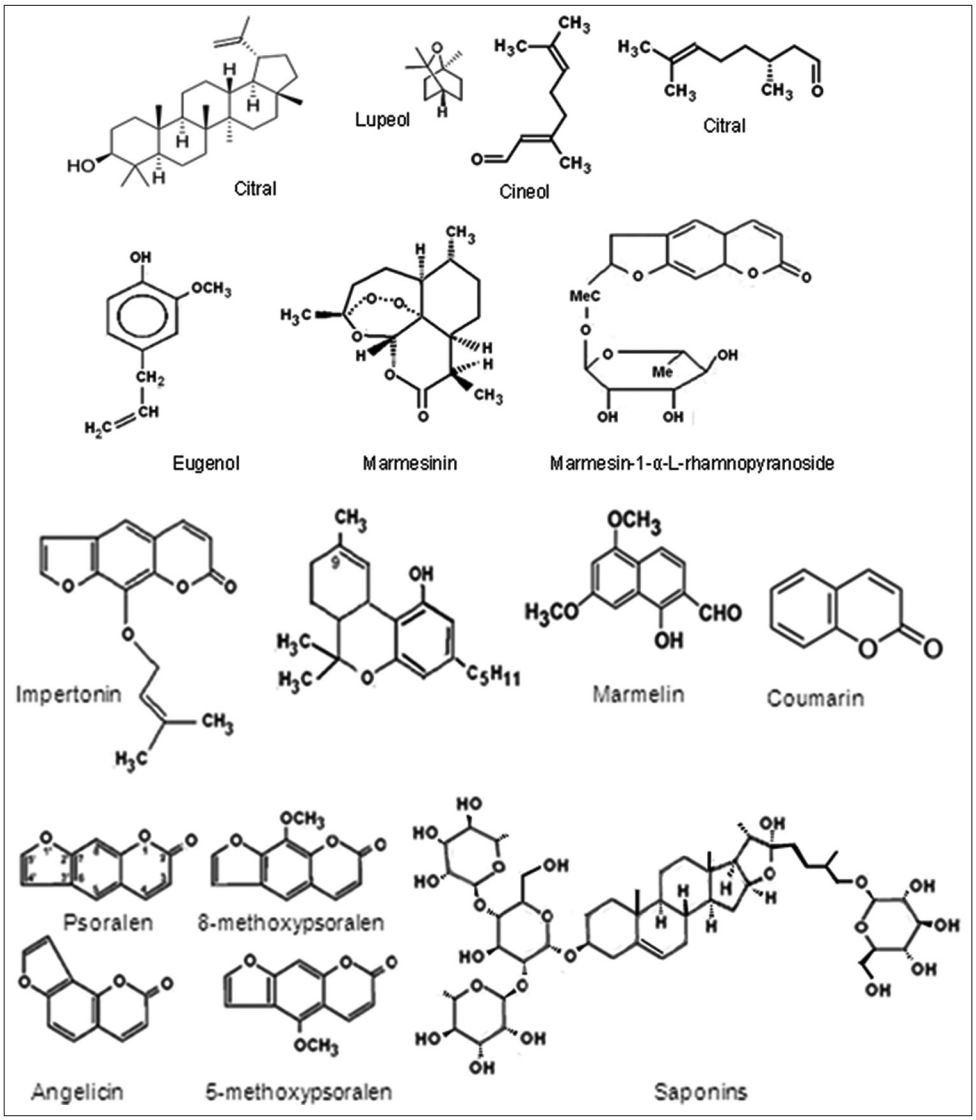

Figure 2: Major constituents isolated from various plant parts of *A. marmelos*

leaf extract suppresses N-methyl N-nitrosourea-induced hepatocarcinogenesis in BALB/c mice[15] and shows chemopreventive efficacy against murine transplantable tumors.[54] Plant displays very high antioxidant and anti-proliferative potential *in vitro* and is widely used in traditional Indian medicine to treat cancer.[55] Fruit extract of *A. marmelos* suppresses chemically induced skin carcinogenesis in mice[56] and effectively obstruct diethylnitrosamine initiated, and 2-acetyl aminofluorene promoted hepatocarcinogenesis in experimental mice.[57] Plant leaves also showed chemomodulatory effects against dimethylebenz (a) anthracene (DMBA)-induced skin tumorigenesis in Swiss albino mice[58] and restore Notch and NF-κB pathways in non-neoplastic hyperproliferating colonic epithelium.[59] 1-hydroxy-5, 7-dimethoxy-2-naphthalene-carboxaldehyde, a novel compound isolated from *A. marmelos* activate apoptosis in tumor cells.[60] *A. marmelos* (L.) Correa inhibits the proliferation of transplanted Ehrlich ascites carcinoma in mice. Fruit extract of *A. marmelos* protects mice against radiation-induced lethality,[61] inhibits *in vitro* proliferation of human breast cancer cell lines and expression of estrogen receptor alpha gene.[62] *A. marmelos* Correa shows inhibition *in vitro* proliferation of human tumor cell lines, including the leukemic K562, T-lymphoid Jurkat, B-lymphoid Raji, erythroleukemic HEL, melanoma Colo38, and breast cancer MCF7 and MDA-MB-231 cell lines.[63] *A. marmelos* plant shows effect on biotransformation enzyme systems and protection against free-radical-mediated damage in mice.[64] It lowers down oxidative stress[65] and shows modulation of doxorubicin (DOX)-induced genotoxicity in mouse bone marrow.[66]

Bel plant shows the protective role on aspirin-induced gastroduodenal ulceration in albino rat model due to its possible involvement as an antioxidant.[67,68] Plant extracts effect Notch and Wnt/β-catenin pathways which involve in the regulation of hyperplasia and/or colitis in response to bacterial infection.[59,69] Similarly, a lectin isolated from *A. marmelos* fruit shows the effect on adherence and invasion of Shigella to HT29 cells.[70] More often, putative components,

such as xanthorrhizol and marmelosin from *A. marmelos*, impart immunoprophylactic and antitumor effects in transplantable tumor models.[54] Geranyloxycoumarins from *A. marmelos* act as mitochondria poisons and inhibit respiration. It suppresses protein translation and hypoxic signaling via the hyperphosphorylation and inactivation of translation initiation factor eukaryotic initiation factors 2α and eukaryotic elongation factor 2.[71,72]

A. marmelos shows chemopreventive potential against chemically induced skin carcinogenesis.[58] Its various concentrations shows reduction in DOX-induced genotoxic effects in mice bone marrow.[66] Lupeol, a triterpenoid, a major bioactive component of *A. marmelos* stimulate the decoy effect of RA4 DNA sequences and increase ERα gene expression in MDA-MB-231 ERα-negative breast cancer cells, and inhibit cell proliferation.[73] Ethanolic extract of *A. marmelos* root showed the dose-dependent antiulcer effect in rat model,[74] while methanolic and aqueous extract of *A. marmelos* seeds were found effective in indomethacin-, stress-, and pylorus ligation-induced ulceration models.[75] The fruit extract also shows antiulcer activity with a reduction in gastric juice volume, free acidity, total acidity, and increase in pH. This antiulcer activity may be attributed due to the presence of quercetin-like (flavonoid) contents in *A. marmelos*. It also shows promising anti-HIV potential.[76]

Antioxidant Activity

Umbelliferon-α-D-glucopyranosyl-(2I→1II)-α-D-glucopyranoside (UFD) from *A. marmelos* Correa shows free radical scavenging activity in normal and streptozotocin (STZ)-induced diabetic rats.[30,77] It acts as a bifunctional inducer since it induces both phase I and phase II enzyme systems. UFD significantly decrease the activity of lactate dehydrogenase and formation of malondialdehyde in the liver. *A. marmelos* plays an important role in cytoprotection as well as protection against pro-oxidant-induced membrane damage. *A. marmelos* extract was found effective in inducing glutathione S-transferase, DT-diaphorase, superoxide dismutase, and catalase in the lung. These significant changes occur in body fluids display levels of drug-catabolism. Leaf extract also protects antioxidant defense system and restore histological changes of pancreatic β-cells in STZ-induced diabetic rat[78] and gastroduodenal ulceration.[67] *A. marmelos* Correa (Bael) fruit shows antioxidants activity[79] in STZ,[80] and alloxan-induced diabetic rats.[81] Bel is used to remove oxidative stress and cure diabetes by local people [Table 1].[55]

Anti-diabetic Activity

Leaf extract of *A. marmelos* is an important medicine in Ayurveda for diabetes. It enhances the ability to utilize the external glucose load in the body by stimulation of glucose uptake similar to insulin.[81,82] Interestingly, Bel leaf extract significantly cut down blood urea and cholesterol in experimental diabetic animals[83] (Karunanayake and Welihinda, 1984), mainly rats.[84] Extract also decreases oxidative stress in experimental diabetic animals as indicated by significant reduction in lipid peroxidation, conjugated diene and hydroperoxide level and increased levels of superoxide dismutase, catalase, glutathione peroxidase, and glutathione levels in serum as well as liver.[78-80,85-89] Juice of leaves is employed as an anti-diabetic drug in the Unani system of medicine.[89] Leaf extract from *A. marmelos* shows the anti-diabetic and anti-hyperlipidemic effect of allopolyherbal formulation in oral glucose tolerance test and STZ-induced diabetic rat model.[90,91] It significantly enhances glycemic control, protects the pancreas from degeneration, and shows antioxidant and hepatoprotective effects. It contains umbelliferon-α-D-glucopyranosyl-(2(I)→1(II))-α-D-glucopyranoside that cut down extra glucose level in STZ-induced diabetic rats.[29] *A. marmelos* (L.) Correa also shows ameliorative effects in alloxan induced early stage diabetic nephropathy and cardiomyopathy in rats.[14]

A. marmelos extract does inhibition of aldose reductase and shows its protective role in diabetic cataract. It also shows *in vitro* inhibitory effects on intestinal α-glucosidase and pancreatic α-amylase.[92] Its leaf extract also prevents secondary complications in STZ-induced diabetic rats due to the presence of limonene as a potent anti-glycating agent.[93] Limonene is also reported as a potent anti-glycating agent and is non-toxic at the concentration used.[91] Bel extracts were found to reduce blood sugar and showed hypoglycemic and antioxidant activity in alloxan-induced diabetic rats.[80,81] Similarly synthetic triterpenoid (lupeol) and their derivatives showed anti-hyperglycemic and anti-dyslipidemic activity *in vivo*.[94] More specifically, upregulation of proliferator-activated receptor γ (PPARγ) by *A. marmelos* ameliorates insulin resistance and β-cells dysfunction in high-fat diet fed- STZ-induced Type 2 diabetic rats.[95] Bark extract shows hypoglycemic and β-cells regenerative effects in STZ-induced diabetic rats.[96] Moreover, overall hypoglycemic effects of some plant extracts are possibly mediated through inhibition in corticosteroid concentration [Table 1].

A. marmelos (L.), Correa leaf extract improves tissue antioxidant defense system and restores histological changes of pancreatic β-cells in STZ-induced diabetic rats.[78,97,98] The plant contains umbelliferone which influence on membrane-bound ATPases in STZ-induced diabetic rats[99] and increases functionality effect on tail tendon collagen. It also restores hemostatic function in STZ-diabetic rats[100,101] and works as an anti-hyperglycemic and anti-dyslipidemic agent.[102] Alcoholic leaf extracts of *A. marmelos* restored enzymatic activities of diabetic rats.[103] Both crude extracts and chemical constituents of Bel[101] are used to prepare herbal drugs to treat ischemic heart disease in patients with diabetes.[104] It's green leafy porridges are used to control hypo and hyperglycemic responses.[105]

Plant shows the inhibitory potential of traditional herbs on α-amylase activity[106] and cut down profile of aldose

reductase, and display anti-cataract and free radical scavenging activity and shows amelioration of diabetes complications.[14,107] Similarly, phenylethyl cinnamides: A new series of α-glucosidase inhibitors was isolated from the leaves of *A. marmelos*.[108] Leaf extract significantly decreased muscarinic M1 receptor gene expression in the cerebral cortex of STZ-induced diabetic rats and shows wider therapeutic function.[109] *A. marmelos* seed extract shows hypoglycemic and anti-hyperglycemic activity in normal and diabetic rats.[110] Leaf extract shows anti-hyperlipidemic activities[90] and anti-diabetogenic properties and lowers down diabetic effects in STZ-induced diabetes in experimental rats.[111] The plant contains enough mineral content and is used in the treatment of diabetes mellitus.[112] Similar effects of *A. marmelos* fruit extract are reported in STZ diabetic rats.[87] The plant extract also cut down level of tissue antioxidants in STZ diabetic rats.[80,113,114] Umbelliferone β-D-galactopyranoside isolated from *A. marmelos* shows anti-diabetic, anti-hyperlipidemic, and anti-oxidative activity. The chloroform extract of *A. marmelos* demonstrated anti-diabetic anti-glycating and antioxidant activity, effectively preventing kidney damage and the establishment of cataracts. Hence, the plant is used for management of Type 2 diabetes.[87] *A. marmelos* seed extract showed hypoglycemic and anti-hyperglycemic activity in normal and diabetic rats.[110] Its low doses or herbal formulation causes activation of Glut-4, PI3 kinase, and PPARγ in L6 myotubes.[115,116]

Anti-inflammatory

Dried flower, root,[116] and leaf extracts[117] of *A. marmelos* showed anti-inflammatory activity in Wistar rats.[118] Similarly, nickel nanoparticles phytofabricated from aqueous leaf extracts of *A. marmelos* Correa showed *in-vitro* anti-inflammatory activity.[119] Aqueous extract of *A. marmelos* unripe fruit shows anti-inflammatory effect[120] against bowel disease[121] in an experimental model.[122] Beta caryophyllene and caryophyllene oxide, isolated from *A. marmelos*, work as potent anti-inflammatory agents against lymphoma and neuroblastoma cells.[123] These did not show modulation of expression of interleukin-8 gene in bronchial epithelial cells by 5-methoxypsoralen.[124] Similar immunomodulatory effect of *A. marmelos* leaf extract was observed in freshwater fish *Cyprinus carpio*, *Catla catla,*[125] and other experimental animals[126] infected by bacterial pathogen *Aeromonas hydrophila*.[125] Similar immunomodulatory activity of methanolic fruit extract of *A. marmelos* was found in experimental animals.[127] Ethanolic extract of leaves of *A. marmelos* (Linn.) showed lipid lowering activity in hyperlipidemic models of Wistar albino rats.[128] Bel leaves showed chemomodulatory effects against DMBA-induced skin tumorigenesis in Swiss albino mice.[129] *A. marmelos* fruit aqueous extract aqueous methanolic fraction (AMF) prevented inflammatory changes and β-cell damage along with a reduction in mitochondrial and endoplasmic reticulum swelling. Plant shows a protective effect of AMF in Type 2 diabetic rats that is due to the preservation of β-cell function and insulin-sensitivity through increased PPARγ.

Anti-spermatogenic Activity

The leaf extract possesses anti-spermatogenic activity as it inhibits spermatogenesis and decreases sperm motility in rats.[58] Leaf extract causes a significant decrease in weights of testes, epididymis, seminal vesicle, ventral prostate, and vas deferens, with significant reduction of serum testosterone.[130]

Anti-diarrhea and Anti-dysentery

A. marmelos unripe fruit pulp is traditionally used to cure diarrhea and dysentery.[13] Both root and leaf extracts of Bel show[131] gastroprotective and antidiarrheal activities[132] against oil induced diarrhea in animal models.[133] Unripe fruit reduces rapid flush and limit sensation to defecate, blood, and mucus. The dry powdered leaves and fruit pulp is specially recommended in sub-acute, chronic, and amoebic dysentery. For quick results and to combat diarrhea dried fruit or its powder is found a better remedy. For this purpose, unripe green fruits are sliced and dried in the sun. These dried fruit slices are milled to convert into powder and preserved in air-tight bottles. The unripe fruit is also baked used with jaggery or brown sugar.[134] Juice of green fruit pulp is used to have relief in acute dysentery. Fine fruit powder with a cold water stop blood release and resume stools to make it more feculent and solid.[135] The mucus also disappears after continued use of Belgiri. It is also a valuable remedy for chronic dysenteric conditions characterized by alternate diarrhea and constipation.[133,136] Methanolic extract *A. marmelos* found active against castor oil-induced diarrhea in mice.[133]

Antimicrobial Activity

Bel extract shows antimicrobial activity against various species such as *Staphylococcus aureus, Staphylococcus epidermidis, Proteus vulgaris, Escherichia coli, Salmonella typhimurium,* and *Bacillus subtilis*. It also manifests antiviral activities against Ranikhet disease virus HIV.[76,137] Leaf essential oil of Bel exhibits variable efficiency against different fungal isolates and shows concentration and time-dependent inhibition of spore germination in drug-resistant fungus, *Fusarium udum.*[138] Leaf and seed essential oil of Bel contain many chemical constituents[139] which show antimicrobial activity against different bacteria, fungi, and viruses.[140] Its fruit extract protects from bacteria generated colitis in experimental animals.[141] These are used to control soft rot bacteria of potato.[142] Leaves of *A. marmelos*[143] contain alkaloid and coumarins and showed antibacterial activity.[144] Essential

oil of *A. marmelos* was showed good antimicrobial activity against fungi mainly postharvest microbial infestations and aflatoxin contamination of food commodities.[145] A novel antifungal anthraquinone was isolated from seeds of *A. marmelos* Correa (family Rutaceae).[140] The plant also shows antienteric potential against multi-drug resistant *Salmonella typhi*.[146] Aqueous extract of *A. marmelos* displays differential expression of ompC and ompF in multidrug-resistant *Shigella dysenteriae* and *Shigella flexneri* and altering its susceptibility toward β-lactam antibiotics.[147] The plant contains umbelliferone, psoralen, and eugenol[148] which showed antimicrobial activity.[149] Bel extract shows *in vitro* antiviral activity (*A. marmelos* Correa) upon human coxsackie viruses B1-B6[150] and used for the treatment of acute shigellosis.[23] Bel leaves show antifungal potential against *Candida albicans, Penicillium chrysogenum*, *Aspergillus niger,* and *Fusarium solani*. Methanolic, ethanolic and chloroform extracts of Bel fruit showed strong antifungal activity against most of the fungal strains.[151] Plant shows antibacterial and antifungal activity *in vitro*[139] and is proved to be a potential source of antimicrobial agents.[152]

Hepatoprotective Activity

Umbelliferon-α-D-glucopyranosyl-(2(I)→1(II))-α-D-glucopyranoside showed hepatoprotective effects in STZ-induced diabetic rats[29] and showed the potential of *A. marmelos* Correa against carbon tetrachloride (CCl4)-induced oxidative stress and early tumor events.[137] It's leaf extract shows a reduction in N-methyl N-nitrosourea-induced hepatocarcinogenesis in BALB/c mice.[15] Ethanolic extract of Bel leaves show hepatoprotective effects[153] in CCl4-induced mice.[154,155]

Cardio-protective Effects

The leaf extract of *A. marmelos* showed preventing effects in isoprenaline isoproterenol (ISO)-induced myocardial infarction in rats.[156] It shows a significant increase in creatine kinase and lactate dehydrogenase but decrease significantly in the heart of isoprenaline-treated rats. Bel is also used as a cardiac depressant and in palpitation.[24,157,158] Compounds purified from Bel have been proven to be biologically active against several major diseases including cancer, diabetes, and cardiovascular diseases.[65] Leaf extract shows anti-hyperglycemic and anti-hyperlipidemic activities. It also improve hypolipidemic effect and minimizing the cardiovascular risk factors associated with diabetes.[90] It also improves diabetic cardiomyopathy in rat.[14] *A. marmelos* (bael), has been found to be useful in diabetes associated with ischemic heart disease.[143] Periplogenin-3-O–D-glucopyranosyl-(1→6)-D-glucopyaranosyl-(1→4)-D-cymaropyranoside, isolated from *A. marmelos* protects DOX-induced cardiovascular morbidities and hepatotoxicity in rats.[159]

Anti-hyperlipidemic

A. marmelos leaf extract shows hyperlipidemic activity in rats in a dose-dependent manner. It causes a significant reduction in total cholesterol, triglycerides, low-density lipoprotein, very-low-density lipoprotein, and significantly increased high-density lipoprotein.[160] It's unripe fruits also shows anti-dyslipidemic effect against ISO-induced cardiac stressed rats and restore ISO-induced myocardial infarction.[161] *A. marmelos* leaf extract pretreatment increased the activity of Na(+)K(+) ATPase and decreased the activity of Ca(2+) ATPase in the heart and aorta simultaneously.[156]

Neuroprotective Activity

A. marmelose extracts show alterations in hippocampal serotonergic activity and display downregulation of *cereBellar* serotonergic receptors and improve INSR function in STZ-induced diabetic rats.[97,98] *A. marmelos* Correa leaf extract prevents secondary complications in STZ-induced diabetic rats. Plant contains limonene that acts as a potent anti-glycating agent.[93] Periplogenin-3-O-D-glucopyranosyl-(1- and GT; 6)-D-glucopyaranosyl-(1- and GT; 4)-D-cymaropyranoside, isolated from *A. marmelos* protects DOX-induced cardiovascular problems and hepatotoxicity in rats.[159] Semisynthetic dietary supplements-geranyloxycoumarins from *A. marmelos* were identified as mitochondria poisons.[71,72] *A. marmelos* extract and α-tocopherol significantly effect on serum lipids, lipid peroxides, and cardiac enzyme levels in rats with ISO-induced myocardial infarction.[162] Plant shows aldose reductase inhibition, anti-cataract, and free radical scavenging activity amelioration of diabetes complications.[107] Plant shows immunostimulant activity against white spot syndrome virus infection in black tiger shrimp.[163]

Radioprotective Effect

A. marmelos (L.) Correa also shows radioprotective effect against gamma radiation and plant extracts are used to restore radiation-induced therapeutic injuries.[14,164] Bel slows down radiation-induced ill-effects and works as a non-toxic radioprotective agent. Treatment with extract of Bel reduces the severity of symptoms of radiation-induced sickness and increases survival in mice.[28] This radioprotective action of Bel plant is due to free-radical scavenging activity and arrest of lipid peroxidation accompanied by an elevation in glutathione concentration in liver, kidney, stomach, and intestine.[164,165] *A. marmelos* (L.) shows hypoglycemic, radioprotective, antidiarrheal effects.[14]

Antipyretic Activity

Bel plant *A. marmelos* crude extracts and its chemical constituents show antipyretic effects[65] and display protective

role against aspirin-induced gastroduodenal ulceration in albino rat model.[67] Leaf extract of *A. marmelos* Correa shows antipyretic properties[118] and display wound healing effects on experimental colitis.[141] Reversible changes also observed in the antifertility induced by *A. marmelos* in male albino rats.[58] Bel extract exhibit antipyretic, anti-inflammatory, and analgesic activities. It also shows significant inhibition of the carrageenan-induced paw edema, cotton-pellet granuloma, and paw itching in mice and rats.[118] It is also used as a febrifuge in the night and intermittent fever[8,22,24] and shows anticonvulsant effect.[14]

Analgesic Activity

A. marmelos methanolic leaf[118] extract shows analgesic activity.[85,166,167] The solvent extracts also produced marked analgesic activity by reduction the early and late phases of paw licking in mice.[118] Plant extract shows a significant reduction in hyperpyrexia in rats. Its phytochemicals involve in opioid and monoaminergic pain pathways. Notch and NF-κB pathways in non-neoplastic hyperproliferating colonic epithelium.[59]

Anti-lipidemic

Ethanolic extract of leaves of *A. marmelos* showed lipid lowering activity in hyperlipidemic models of Wistar albino rats.[129] Leaf extract activates apoptosis due to the presence of 1-hydroxy-5,7-dimethoxy-2-naphthalene-carboxaldehyde.[59] Plant extracts decrease muscarinic M1 receptor gene expression in the cerebral cortex of STZ-induced diabetic rats and improve therapeutic function. *A. marmelos* leaf extract contains anti-dyslipidemic agents that shows preventive effect against isoprenaline-induced myocardial infarction in rats.[168] Linear furanocoumarin protects rat myocardium against lipid peroxidation and membrane damage during the experimental myocardial injury.[169]

Anti-filarial and Antimalarial

A. marmelos extracts showed the anti-filarial effect and are traditionally used to treat *Brugia malayi* microfilariae.[170,171] Decoction of *A. marmelos* plant leaves is traditionally used as an antimalarial agent in the South India.[172,173]

Insecticidal

A. marmelos extracts show high insecticidal activity against ticks and flukes.[174] These also showed oviposition-deterrent, ovicidal, and repellent properties against filarial vector *Culex tritaeniorhynchus* Giles (Diptera: Culicidae).[174] and Japanese encephalitis vector, *C. tritaeniorhynchus* and malarial vector *Anopheles subpictus* Grassi (Diptera: Culicidae).[174] Skimmiarepins A and C isolated from the stem bark of *A. marmelos* Correa (Rutaceae) exhibit moderate insecticidal activity against *Phaedon cochleariae* and *Musca domestica* in comparison with natural pyrethrum extract. The two epimeric acetates of skimmiarepin C found both found less active.[175] *A. marmelos* L. crude chloroform, dichloromethane, and methanol extracts of the leaves and roots showed larvicidal activity in *Aedes aegypti* L. and *Anopheles stephensi*.[176] Leaf extract is used as insecticidal against the brown planthopper, a rice plant pest in Asia while leaf oil shows high insecticidal effects against different stored grain insect pests.[83]

It shows wider control against infestation caused in stored gram by *Callosobruchus chinensis* (L.) (Bruchidae), wheat by *Rhyzopertha dominica* (F.) (Bostrychidae), *Sitophilus oryzae* (L.) (Curculionidae) and *Tribolium castaneum* (Herbst) (Tenebrionidae) upon fumigation with 500 µg/mL (ppm) of essential oil in close chambers. The oil significantly enhanced feeding deterrence in insects and reduced the grain damage as well as weight loss in fumigated gram and wheat samples. The essential oil significantly reduces oviposition and adult emergence of *C. chinensis* in treated cowpea seeds. Limonene (88%) was found to be the major component found in the oil that does a significant reduction in oviposition and adult emergence of *C. chinensis*.[177] Nickel nanoparticles phytofabricated from aqueous leaf extracts of *A. marmelos* Correa were found larvicidal in nature[120] against mosquito species, *A. aegypti, A. stephensi,*[176] *A. subpictus Grassi* (*Diptera: Culicidae),*[178-183] and larvae of *Culex pipens*.[184] *A. marmelos* showed anti-termite activity against white termite (*Reticulitermes verginicus*).[185]

CONCLUSION

Bel contains diverse bioactive components in leaves, flowers, fruits, wood, root, and bark which show multiple biological activity and high therapeutic importance. Plant contains coumarins, marmelosin, marmesin, imperatorin, marmin, alloimperatorin, methyl ether, xanthotoxol, scoparone, scopoletin, umbelliferone, psoralen, and marmelide and marmenol, aegelin, aegelenine, marmeline, dictamine, fragrine which show different biological activities such as anticancer, antioxidant, antimicrobial, anti-plasmodial, and hepatoprotective. The plant possesses various polysaccharides such as galactose, arabinose, uronic acid, and L-rhamnose and seed oil that contains palmitic, stearic, oleic, linoleic, and linolenic acids which have very nutritive value. The fruit pulp of wild Bel plant also possesses very high tannin contents (9%). Plant leaves contain skimmianine, marmelosin, carotenoids, and umbelliferone which are therapeutically important active principles of Bel plant. *A. marmelos* plant leaves contain an essential oil that shows chemotypic and seasonal variations. Bel fruit restores digestive health and destroy worms in the intestine. It is a good remedy for digestive disorders and recommended for chronic dysentery. Plant unripe fruits are used for the

treatment of diarrhea, dysentery, fever, diabetes, and to cure peptic ulcer or piles. Aqueous extract of ripen Bel fruit shows the laxative property. It is used to avoid constipation, discomfort, provide relieve from pain, and other associated health risks. Its leaves are used to reduce inflammation, appetite and water thrust. Dried flower, root, leaf extracts showed anti-inflammatory, anti-spermatogenic activity, improve and protect tissue antioxidant defense system. *A. marmelos* crude extracts and its chemical constituents show multiple biological activities such as antipyretic, analgesic activity, radioprotective, anti-diabetic, anti-hyperlipidemic, hepatoprotective, antimicrobial activity against various species such as *S. aureus, S. epidermidis, P. vulgaris, E. coli, S. typhimurium,* and *B. subtilis*. It also manifests antiviral activities and found active against viruses such as Ranikhet disease virus and HIV. Plant shows anti-filarial, antimalarial, antifungal, and anti-parasitic activities. Its leaf essential oil contains limonene and other active constituents [Table 1] which significantly cut down feeding, oviposition, and adult emergence in stored grain pests. The plant is a good source of Feronia gum, nutrients, pharmaceuticals, and essential oil.

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