REVIEW
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Modern perspectives on the traditional uses, phytochemical profiles, and therapeutic benefits of *Syzygium cumini*

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Abbreviations
DPPH, 2,2-diphenyl-1-picrylhydrazyl radical.

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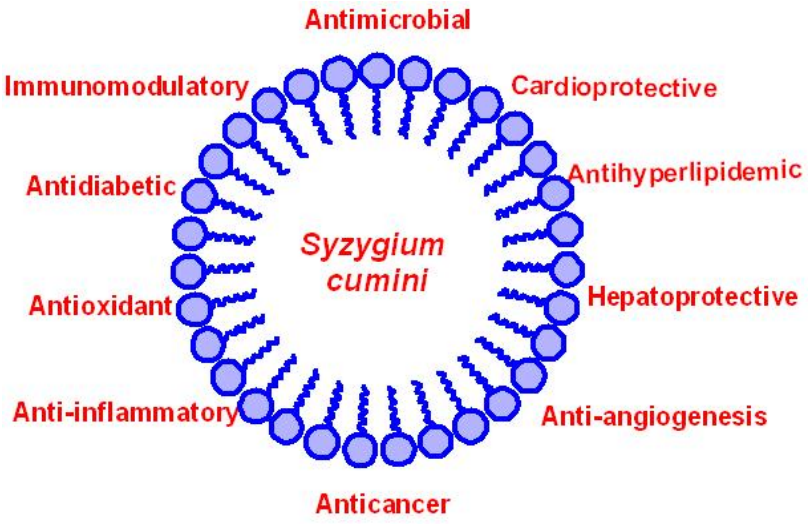
Abstract
Syzygium cumini Linn., commonly known as Jamun, is a member of the Myrtaceae family and is also referred to by synonyms such as *Eugenia djouant* Perr., *Eugenia cumini*, *Eugenia jambolana* Lam., *Syzygium jambolana* Lam., and *Myrtus cumini* Linn. This review provides an overview of its medicinal value, including taxonomical classification, geographic distribution, cultivation techniques, pharmacognostical aspects, phytochemical constituents, traditional uses, and pharmacological applications. In India, 'Ram Jamun' or 'Raja Jamun' is cultivated in the north, while the 'Paras' variety is grown in central regions. Various components of *S. cumini* fruits are utilized to enhance the nutritional quality of wines, jellies, jams, and fermented products. Rich in essential nutrients like vitamins, carbohydrates, minerals, antioxidants, and anthocyanins, *S. cumini* also contains bioactive phytoconstituents such as gallic acid, tannins, and polyphenols, which contribute to its pharmacological properties. Traditionally, black plums have been used as carminatives, diuretics, and remedies for stomach ailments, spleen enlargement, diarrhea, and urinary retention. Additionally, *S. cumini* has been historically administered to women post-abortion and is recognized for its role in managing diabetes and dysentery. Polyphenolic compounds in Jamun exhibit potential therapeutic benefits against diabetes, arthritis, cancer, asthma, and cardiovascular diseases. Given its promising ethnopharmacological profile, extensive research has been conducted on various plant parts, highlighting their antioxidant, antifungal, antibacterial, antidiabetic, and anticancer properties. This review aims to provide a comprehensive understanding of *Syzygium cumini*'s traditional and therapeutic significance, serving as a valuable resource for future research.

Keywords: antioxidant; glycaemic index; bioactive substances; pharmacological properties; gastroprotective; radical scavenger capacity



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Introduction

Herbal medicine has a long tradition of benefitting people worldwide. Drug research and design use phytochemicals derived from therapeutic plants as lead molecules. Recent years have seen a resurgence of interest in utilising knowledge of plant research for traditional medicine [1]. It has also been thoroughly documented in the international forums by the WHO report, which states that over 80% of the population in the world is dependent on plants to provide for their basic medical requirements [2]. Traditional medicinal plants continue to play a significant role in the treatment of numerous diseases in developing countries, even in the current era of computational pharmacology approaches [3]. Due to some benefits, including fewer adverse effects, improved patient compliance, relative affordability, and a long history of use, natural remedies obtained from plants are becoming more and more popular. Additionally, the use of herbal medicines offers rational solutions to a variety of diseases that would otherwise be intractable or incurable in other medical systems [4, 5].

Syzygium cumini Linn., often known as Jamun, has been extensively employed in folk and traditional medicine to treat a wide range of ailments. It is a large, very common evergreen tree native to the Indian Subcontinent that grows to a height of about 25 m. *S. cumini* is a member of the Myrtaceae family, which has 150 genera and 3,600 species spread around the world [6]. *Eugenia djouan*t Perr., *Eugenia cumini*, *Eugenia jambolana* Lam., *Syzygium jambolana* Lam. and *Myrtus cumini* Linn. are synonyms of *Syzygium cumini* [7]. The fruit matures in May or June after the March to April flowering period. However, a considerable loss of valuable nutrients occurs due to the soft texture, inadequate post-harvest management techniques, and incorrect processing [6]. In India, Jamun holds cultural and religious significance. The fruit is associated with Lord Krishna and is often offered in prayers and rituals. It is also a popular ingredient in traditional Indian cuisine and beverages. Various parts of the Jamun tree, including the fruit, seeds, bark, and leaves, have been used in traditional medicine for their potential health benefits. For example, the fruit and seeds are believed to have anti-diabetic properties and are used in Ayurvedic and traditional medicine systems. Jamun trees provide habitat and food for birds and other wildlife. They are valued for their shade and ornamental qualities in urban and rural landscapes. Beyond its cultural and ecological roles, *Syzygium cumini* is commercially cultivated for its fruit, which is in demand both locally and internationally. Its juice and products derived from the fruit are popular in various markets. The present review provides updated information on *Syzygium cumini* with an emphasis on their geographical distribution, taxonomical classification, nutritional and therapeutic phytochemistry, along pharmacological potential.

Origin and geographical distribution

East Indies or India is where *S. cumini* originated. It is indigenous to Indonesia, occurring in both wild and cultivated forms, and is available in the Philippines, Thailand, Madagascar, East and West Africa, West Indies, and some subtropical areas including California, Florida, Israel and Algeria [8].

Taxonomical classification

The taxonomical classification of *S. cumini* is given in Figure 1 [9].

The regional names of *S. cumini* are given in Table 1 [10].

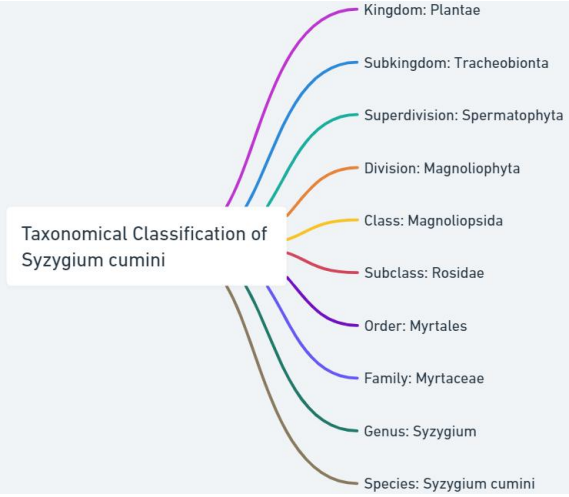

Figure 1 Taxonomical classification of *Syzygium cumini* regional names

Table 1 Regional names of *Syzygium cumini*

Language	Name
Hindi	Jamuna
Assamese	Jam
Gujarati	Jambu, Jamun
Bengali	Jaam, Kalojam
Orissa	Jamu
Sanskrit	Mahajambu, Ksudrajambu
Tamil	Naval
Marathi	Jambul
Urdu	Jamun
Malayalam	Njaval
English	Jambul tree
Punjabi	Jaamun
Telugu	Neredu

Morphology/Physiology

Syzygium cumini, commonly known as Jamun or Java plum, displays distinctive morphology and physiology that contribute to its growth, reproduction, and adaptation to its environment (Figure 2, Figure 3A–3D). Here are the key aspects of its morphology and physiology:

Active growth period – Year round
Flower colour – Green
Foliage colour – Green
Foliage texture – Medium
Fruit/Seed colour – Black
Growth form – Single stem
Growth rate – Rapid
Height mature – 60 feet
Life span – Long
Nitrogen fixation – None
Shape and orientation – Erect
Toxicity – None

Growth requirements

pH range – 5.0–7.0
Planting density per acre – 200–400
Root depth, minimum – 36 inches
Tolerance to salinity – Low
Tolerance to shade – Intermediate
Temperature (min.) – 49 ˚F

Reproduction

Bloom period – Spring
Fruit/Seed period – Spring–Summer
Seed spread rate – Moderate [11]

Cultivation and collection

Soil. A variety of soil types can support the growth of the Jamun tree. Plant growth and yield potential are both enhanced by deep loams and well-drained soils. Such soils also hold onto enough moisture, which is advantageous for healthy fruiting and optimal growth. Jamun may flourish in both wet and salinized environments. On very heavy or light sandy soils, it is not feasible to cultivate Jamun.

Climate. The climates that Jamun prefers to grow in are tropical and subtropical. Additionally, it grows at an altitude of 1,300 m in lower Himalayan ranges. At the time of fruit setting and towering, the Jamun needs dry weather. Early rainfall is thought to be advantageous for fruit ripening and ensuring that its size, colour, and tastedevelop optimally in subtropical regions.

Figure 2 *Syzygium cumini* tree. The tree in the pictureis indeed a *Syzygium cumini*, commonly known as the Java plum, Malabar plum, or black plum. This species is native to the Indian subcontinent and adjoining regions of Southeast Asia. The tree appears to be mature, with a dense canopy of green leaves, and it seems well-established in its location. *Syzygium cumini* trees are known for their fruit, which is a purple to black drupe with a unique taste and is often used in traditional medicine and cooking. The tree itself is robust, with a thick trunk and a dense canopy that provides substantial shade.

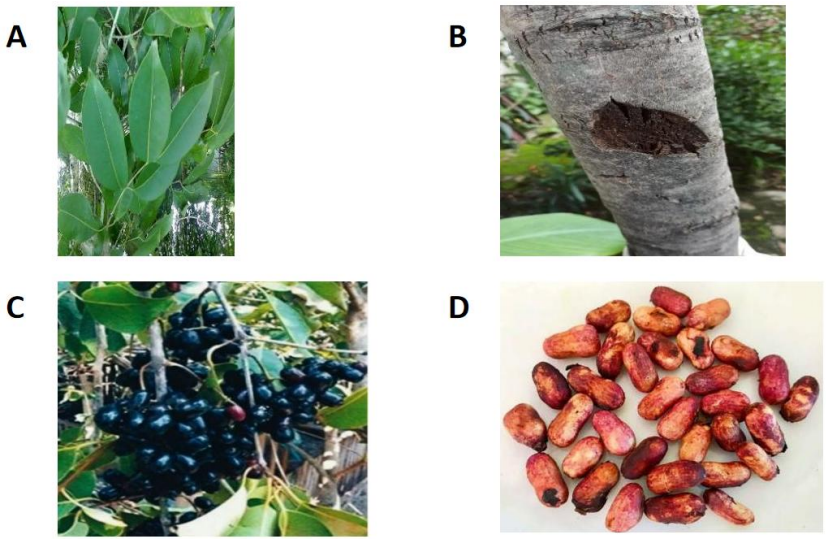

Figure 3 Various parts of *Syzygium cumini*. (A) Leaves. (B) Stem bark. (C) Ripe Jamun fruits. (D) Jamun seeds.

Propagation. There are two ways to propagate Jamuns: by seed and by vegetative means. Polyembryony makes it possible for parents to become realised through seed. The use of seeds for proliferation is still favoured, even though the vegetative methods used in the majority of cases have had some success. However, it is not advisable to propagate seeds since it causes late bearing. There is no dormancy in the seeds. You could plant new seeds. It usually takes 10 to 15 days for seeds to germinate. It is best to transplant seedlings in the spring or in the monsoon season to use as rootstock. Jamun can be propagated economically and conveniently. On seedling stocks that are one year old and have a thickness of 10 to 14 mm, budding is practised. In locations with little rainfall, July and August are the optimum months for budding. Budding activities are started in early May or early June in locations where rains can start quickly and are severe. The budding techniques of shielding, patching, and forkert have been particularly effective. In comparison to shielding or "T" budding, the forkert method offers the potential for greater success. It involves inarching pot-raised seedlings for one year with parent Jamun trees using wooden stands between June and July.

The number of air layers in spring can be raised to about 60% when 500 ppm of indole butyric acid is used in lanolin paste rather than in the rainy season. A misty climate in Jamun facilitates rooting through cutting. The best results are obtained with semi-hardwood cuttings from the spring flush of *S.jambos* and *S.javanica* that have been treated with 2,000 ppm indole butyric acid.

Planting. Since Jamun trees are evergreen, they can be planted both in the spring and during the monsoon. Due to the adverse weather conditions experienced in May and June, the trees planted in February–March often die soon after planting, making the latter season the better time to plant. The land is thoroughly ploughed and prepared before planting. Pits measuring 1 m × 1 m × 1 m are excavated at a distance of 10 m in both directions. Generally, the process of excavating pits is finished prior to the start of monsoon season. 25% of the pit is filled with compost or well-rotted farmyard manure, and the remaining 75% is top soil. It is also common to plant Jamun trees near farm dwellings and wells as shade trees. In addition to providing fruit, they offer a welcome shadow.

Fertilizer application. Manure is generally not applied to Jamun trees. This is due to the fact that they can withstand considerable neglect and not that they do not need manuring or are unresponsive to it. There should be an annual dose of roughly 19 kg of forage manure applied prior to bearing period and during the bearing period, the dose has to be raised to 75 kg per tree bearing fruits. It usually takes 8 to 10 years for seedling Jamuns to produce fruit, while grafted or budded trees take 6 to 7 years. A rich soil tends to cause trees to grow more vegetatively, which delays fruiting. Manure and fertiliser should not be given to trees showing such a tendency, and irrigation should be restricted in September–October and again in February–March. This aids in the development of fruit buds, flowering, and fruit setting. There may be times when even more extreme measures will have to be taken, such as root trimming and ringing if the above method doesn't work. The growing of Jamun trees, therefore, requires careful manure and fertilization, and so the dosages should be adjusted in accordance with the trees' growth and fruiting.

Irrigation. It is necessary to water the Jamun trees frequently during the early stages of their development. An average of 8 to 10 irrigations is required per year for young trees. Once they have become established, irrigation intervals can be reduced greatly. During the fruit ripening period in May and June, mature trees need only about half the number of applications. The soil may just need occasional irrigation in the fall and winter when it becomes dry. It will also prevent trees from being damaged by winter frost.

Flowering and fruiting. Branches bear flowers in the leaf axils. The first week of March is when flowers start to bloom in North Indian conditions and it lasts until the end of April. At the start of the season, pollen fertility is higher. It is one day after anthesis when the stigma is most receptive. Jamuns are cross-pollinated by honey bees, houseflies, and wind. When hand pollination is performed one day after anthesis, the maximum fruit set can be attained. Fruit set declines sharply thereafter.

In the first 3–4 weeks after blooming, the flowers and fruits drop heavily. Later reduction in natural drop of fruit can be achieved by applying gibberellic acid 60 ppm twice, first at the time of full bloom and then after a period of 2 weeks of initial fruit setting. A Jamun's growth pattern and development of the fruit can be categorised into three stages. During the first stage, fruit grows slowly after 15–52 days of fruit set; during the second stage, fruits grow rapidly after 52–58 days of fruit set; and during the third stage, fruits grow slowly with little weight gain after 58–60 days of fruit set.

Harvesting and yield. It usually takes 8 to 10 years for seedling Jamuns to produce fruit, while grafted trees take 6 to 7 years. Commercial bearing, however, doesn't begin until 8–10 years of implanting and lasts until the tree reaches the age of 50–60 years. The ripening of fruit occurs in June and July. Ripe fruits exhibit deep purple or black colour when they are full size.

Because ripe fruit can't be left on trees, it should be picked as soon as it ripens. Using sling bags, the ripe fruits are manually picked one at a time by climbing the tree. Fruits should be protected from any harm at all costs. The annual yield for a grafted tree is between 60–70 kg, while a seedling tree yields about 80–100 kg per year [12–14].

Storage and marketing. There is a high perishability factor associated with the fruits. Normal storage conditions do not allow them to be stored for longer than three to four days. But prior cooling of fruits and placing them in environmental conditions of 8–10 °C low temperature and 85–90% relative humidity allow their storage in plastic bags for up to three weeks. Packing and shipping of fruit to market occurs almost every day. Healthy and well-ripened fruits are selected for marketing. Unripe, damaged, and diseased fruits are thrown away. Following the selection of the fruits, they are carefully packaged and sent to the markets in wooden baskets [15, 16].

Pharmacognostical description

It is a large thickly foliated, evergreen tree with thick, woody-scaled, greyish-brown bark.

Leaves. The leaves are oblong-ovate to elliptic or obovate-elliptic in shape, 6 to 12 cm in length, smooth and shiny, with a large number of nerves fusing within the margin, and slightly leathery. The tip is broad and less acuminate.

Flowers. Flowers are round or oblong in shape, aromatic, with fragrance having white-pink or greenish-white colour, possessing a cross-sectional area of about 1 cm, branched clusters at the stem terminals, and found in dichotomous paniculate cymes.

Calyx. The calyx is approximately 4 mm long, four toothed with a funnel shape.

Corolla (petals). The petals stick and fall all together as a small disk.

Stamens. The stamens are abundant and about as long as the calyx.

Fruits. The fruit is delicious, ovoid, 1.5–3.5 cm in length, dark purple or almost black, dark purplish-red, lustrous, delectable fruits with flesh that ranges from white to lavender. One enormous seed, measuring 2 cm long, is present in the fruit. In Hindu mythology, the fruit has been referred to as the "Fruit of Gods." In addition to its raw consumption, it can be made into jams, jelly, fermented drinks, wine, and other useful products. The size and quality of fruit can vary based on the fruit variety and environmental factors. The fruit's dimensions show a great deal of variation.

The pharmacognostical description of *S. cumini*. Depending on fruit size, *S. cumini* comes in two varieties: small and big; the smaller variety has a round shape with sweet flesh and a large seed containing anthocyanins, tannins, and acids in high amounts. The bigger type has an ovoid shape with sourish flesh with a small seed having tannins, anthocyanins, and acids in lesser amounts. The 'Ram Jamun' or 'Raja Jamun' is the most frequently found *S. cumini* variety in north India having oblong fruit with small seeds showing dark purple colour, and one more variety of *S. cumini* found in central India is 'Paras' which do not possess seeds [6, 17–19]. The pharmacognostical description of *Syzgium cumini* is shown in Figure 4.

Nutritional content of *Syzygium cumini*

S. *cumini* comprises several important components such as vitamins, carbohydrates, minerals, antioxidants and anthocyanins. Gallic acid, tannins, and polyphenol content all have an impact on the colour and taste of fruits [6, 20, 21]. The nutritional content of *Syzygium cumini* is shown in Figure 5.

Nutritional composition of the fruit

A 100 g serving of the fruit contains 14 g of carbohydrates, 0.12–0.28 g of fat, 0.35–0.85 g of fiber, 0.15–0.72 g of protein, and 60 kcal of energy. An average 100 g of the fruit provides 14.5–26.18 mg of sodium, 50–75 mg of potassium, 12–30 mg of magnesium, 15–17 mg of phosphorous, 8.5–18.5 mg of calcium, 0.27 mg of copper, 8–9 mg of chlorine, 2.8 g of folic acid, 0.26 mg of zinc, 0.22–1.66 mg of iron, 3.3 mg of cyanocobalamine, 0.008–0.01 mg of riboflavin, 0.09 mg of thiamine, 0.22–0.30 mg of niacin and contains high amounts of anthocyanins (731 mg per 100 g).

Nutritional composition of the seed

100 g of seed includes 41.4 g of carbohydrates, 2.3–16.9 g of fiber, 6.3–8.5 g of protein, 2.04 g of ash, 0.83–1.18 g of fat, 361.30 mg of polyphenols, 168.24 mg of tannins, 0.41 mg of calcium and 0.17 mg of phosphorus. Lauric (1.1%), malvalic (1.3%), sterculic (1.76%), vernolic acid (3.2%), palmitic (4.5%), stearic (6.7%), linoleic (16.3%), myristic (31.5%) and oleic (32.4%) are among the fatty oils found in the fruit.

Nutritional composition of leaf

In 100 g, the leaf holds 9.2 g of protein, 4.5 g of fat, 17 g of crude fiber, 0.19 mg of phosphorus, and 1.3 mg of calcium. It also contains essential oils which contribute to the leaf's pleasant smell.

Phytochemical investigation of *S. cumini*

Traditional medicinal plant *S. cumini* contains a variety of biologically active compounds that are dispersed across the entire plant. Myricetin, isoquercetin, glucoside, anthocyanins, ellagic acid, and kaempferol are among the many chemicals found in Jamun. The positive benefits of vitamin C, anthocyanins, and flavonoids are strengthened by the presence of sugar, mineral salts, and vitamins C and PP in java plums. These bioactive substances have the ability to prevent or lessen metabolic disorders and other diseases. Numerous in vitro and in vivo pharmacological investigations have demonstrated the plant's health-protective benefits and functional qualities [22, 23]. The major phytoconstituents found in different parts of *S. cumini* are presented in Table 2 and Figure 6 [24, 25].

Table 2 Phytoconstituents reported from different parts of *Syzygium cumini*

Sr. No.	Plant parts	Constituents
1.	Root	Glycosides, flavonoids and isorhamnetin 3-o-rutinoside.
2.	Bark	Myricetin, quercetin, β-sitosterol, ellagic acid, gallic acid and kaempferol, flavonoids, bergenins and tannins.
3.	Fruit	Citric acid, gallic acid, mallic acid, fructose, glucose, raffinose. The sourness of fruits may be due to gallic acid. Malvidin-3-laminaribioside and delphinidin-3-gentiobioside are the anthocyanins that may be responsible for the colour of the fruits.
4.	Flower	Oleanolic acid, ellagic acid and trace amounts of flavanol sisoquercetin, quercetin, kaempferol and myricetin; myricetin-3-L arabinoside and quercetin galactosides.
5.	Leaves	Myricetin, quercetin, acylatedflavonol glycosides, esterase, triterpenoids and tannin.
6.	Seed	Quercetin, glycosides, pale-yellow coloured essential oil in trace amounts, albumin, fat, chlorophyll, resin, jambosine, ellagic acid, gallic acid. β-sitosterol is present in the seed fat's unsaponifiable matter.

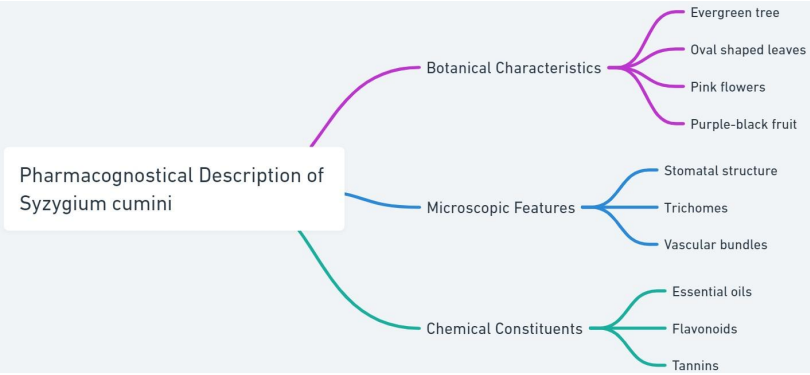

Figure 4 Pharmacognostical description of *Syzygium cumini*

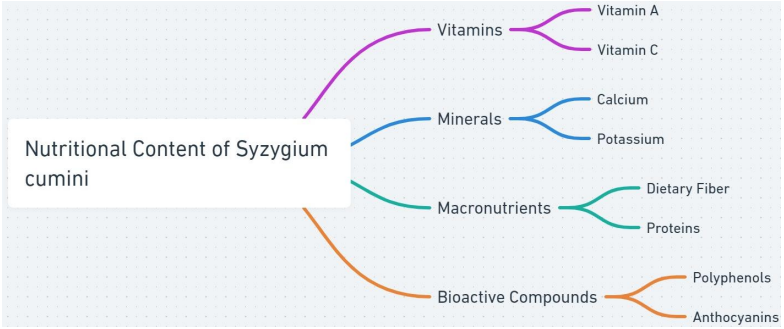

Figure 5 Nutritional content of *Syzygium cumini*

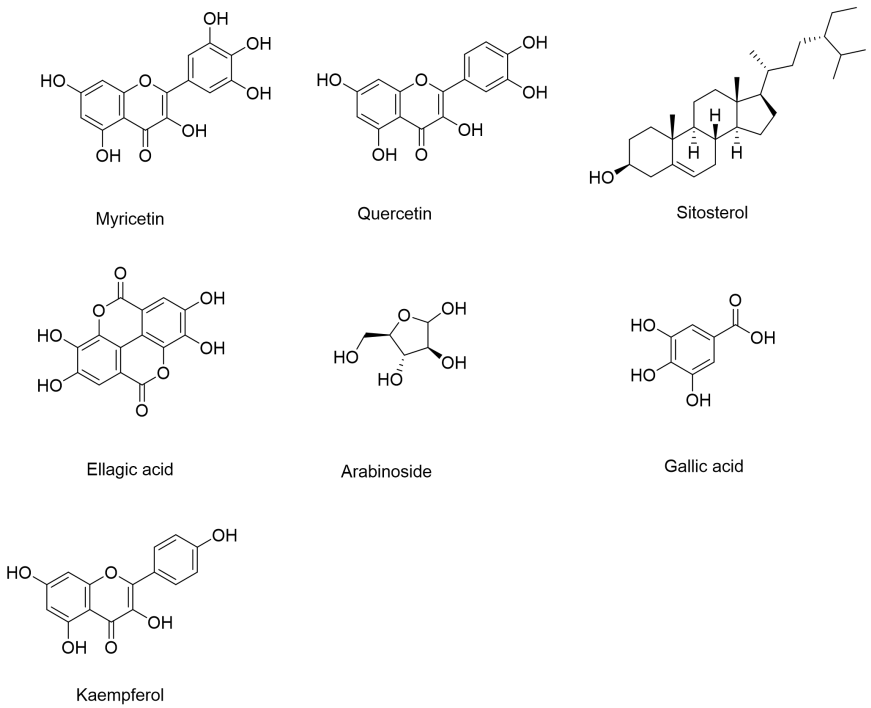

Figure 6 Structure of different phytoconstituents from different parts of *Syzygium cumini*

Traditional uses

An essential fruit of the summer, the Jamun or black plum also has various therapeutic and physiological benefits. Black plums are known to ease stomach pain, work as carminatives, and have antiscorbutic properties as well as diuretic properties. There are many health benefits to using black plum vinegar, including reducing spleen enlargement, in diarrhoea, and in urinary retention problems. Polyphenolic compounds in Jamum's products are effective against diabetes, arthritis, cancer, asthma, and heart disease [12, 26]. There is a long medicinal history associated with different parts of *S. cumini* trees and they contain constituents with important taxonomical properties. It finds numerous uses in Ayurvedic, Siddha, and Unani medicine [27]. Because of its digestive and astringent actions, various parts of this herb are employed in Ayurvedic medicine to treat conditions such as cancer, mouth blisters, colic, piles, diarrhoea, pimples, asthma, sore throats, ulcers, and thirst. Different parts of this plant are used for treating bedwetting in children, for making teeth and gums stronger, as a liver booster, for blood cleansing, and for eliminating ringworm infection from scalps in Unani medicine [28]. In India and southern Brazil, the extract of leaves in water is used as an alternative to regular water, and tea brewed from leaves, seeds, and bark is used to treat diabetes, kidney issues, and diarrhoea. Leaf juice is used to treat insect bites; seed juice is used for the treatment of sore throats, ulcers, and gastrointestinal disorders [6]. The black plum fruit and its leaves are beneficial to diabetics as they possess anti-diabetic features. Keeping your blood sugar levels stable is made easier by the fruit's ability to convert starch into energy. The low glycemic index of black plum makes it ideal for sugar patients to eat it regularly during the summer months. It eases symptoms such as frequent urination and thrusting associated with diabetes. Diabetic patients can also benefit from seeds, bark, and leaf extracts [29]. Iron and vitamin C are adequate in black plums. Iron helps increase the haemoglobin count. Its iron content makes it a blood purifier and therefore it is beneficial for skin and beauty [30]. Iron content can be helpful when a lady loses blood throughout her menstrual cycle. The high iron content of Jamun fruit makes it ideal for people suffering from anaemia and jaundice [31]. The traditional uses are presented in Figure 7.

Below are some surprising and amazing health benefits associated with this juice:

(1) Diarrhoea and other digestive disorders can be treated with it.

(2) It can be used to treat digestive problems when combined with curd.

(3) The black plum juice can be applied to the teeth or consumed to solve tooth-related problems.

(4) Jamun juice is helpful in treating piles.

(5) Asthma and cough can be relieved by drinking fresh fruit juice.

(6) The immune system is enhanced by Jamun juice.

(7) Besides protecting you from cold, it also has anti-ageing properties [32].

Pharmacological actions of *Syzygium cumini*

The pharmacological properties of *Syzygium cumini* include anti-diabetic, anti-inflammatory, antimicrobial, antibacterial, antifungal, antioxidant, antigenotoxic, anti-leishmanial, brine shrimp lethality, antihyperlipidemic, central nervous system, antiallergic, antifertility, gastroprotective, and radioprotective properties (Table 3) [33, 34].

Antimicrobial. Different parts of *Syzygium cumini* can be utilised for their antimicrobial and antibacterial activities. It has been that the fruit extract possesses antibacterial action against *Pseudomonas aeruginosa.* Gram-positive and Gram-negative bacteria can both be effectively treated with *S. cumini* root extract. The root extract of *S. cumini in* ethanol exhibits maximum inhibitory action against *St. aureus*, *E. coli*, and *St. Epidermidis* [35]. Antibacterial activity against *V. cholera*, *P. aeruginosa*, and *Solanum nigrum* has also been found in the petroleum ether, ethyl acetate, and methanolic seed extracts of *S. cumini*. The effective potential has been demonstrated against Gram-positive bacteria using seed water extract with concentrations ranging from 1.75–8 mg/mL [36].

S. epidermidis, *B. cereus*, and *S. typhi* are all inhibited in growth by Jamun's fruit extracts in methanol, diethyl ether, and water respectively [37]. The growth of *B. subtilis*, *E. coli*, *S. aureus*, and *P. aeruginosa* is found to be inhibited by the ethanolic extract of *S. cumini* seeds [38]. The fruit extract of Jamun possesses activity against *P. aeruginosa* whereas antibacterial activity is exhibited against many strains of bacteria, including *Staphylococcus saprophyticus*, *S. aureus*, and *Proteus vulgaris* by the *S. cumini's* leaf and stem's aqueous extract and antifungal activity is also noted for *Penicillium chrysogenum* and *Candida albicans.* Gram-positive bacteria are shown to be more sensitive to the root extract of Jamun than Gram-negative bacteria [36, 39].

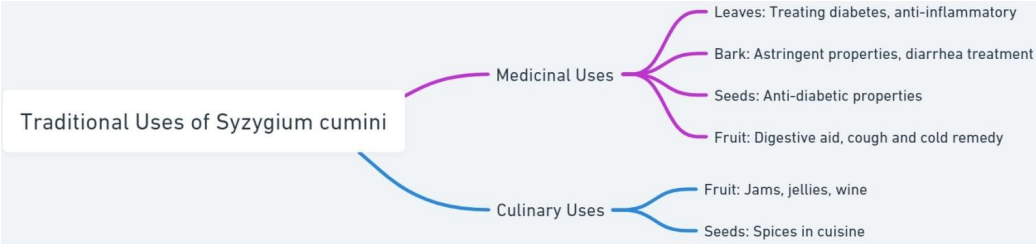

Figure 7 Traditional uses of *Syzygium cumini*

Table 3 Pharmacological effects of different bioactive compounds/extracts of *Syzygium cumini*

Bioactive compounds/extracts	Pharmacological effects	Mechanism of action
Polyphenols (e.g., ellagic acid)	Antioxidant	Scavenging free radicals and reducing oxidative stress
Anthocyanins	Anti-inflammatory	Inhibition of pro-inflammatory mediators like TNF-α, IL-6, and COX enzymes
Flavonoids (e.g., quercetin)	Antidiabetic	Enhances insulin sensitivity, modulates glucose metabolism
Tannins	Antimicrobial	Disrupts bacterial cell walls and inhibits biofilm formation
Ethanolic leaf extracts	Hepatoprotective	Reduces liver enzyme markers (AST, ALT) and protects against liver damage
Seed extracts	Antihyperlipidemic	Lowers LDL cholesterol and increases HDL cholesterol levels
Essential oils	Antifungal	Disruption of fungal cell membrane integrity
Saponins	Immunomodulatory	Enhances immune response through activation of macrophages and T-cells
Methanolic bark extracts	Anticancer	Induces apoptosis and inhibits tumor cell proliferation
Aqueous fruit pulp extracts	Cardioprotective	Enhances antioxidant enzymes and reduces lipid peroxidation

TNF-α, tumor necrosis factor-alpha; IL-6, interleukin-6; COX, cyclooxygenase; AST, aspartate aminotransferase; ALT, alanine aminotransferase; LDL, low-density lipoprotein; HDL, high-density lipoprotein.

Anti-allergic activity. The anti-allergic effect of *Syzygium cumini* can be attributed to its inhibitory effect on mast cell degranulation, serotonin, and histamine effects, as well as its inhibitory effect on the aggregation of eosinophils in the allergic pleurisy model [9, 40].

Anti-inflammatory activity. Owing majorly to its stem and seeds *S. cumini* has a strong anti-inflammatory potential and does not cause any side effects to the gastric mucosa and other systems [41]. In folk medicine, the bark, seeds, and fruits of *S. cumini* have been used to treat both acute and chronic inflammation [42]. Anti-arthritis properties are present in *S. cumini*. It has been proved that aqueous seed extract is efficient against human neutrophils. Similar to this, hepatitis B vaccine-induced inflammation in human lymphocytes and monocytes has been observed to be alleviated by the fruit's flavonoid extract [43].

Anti-hyperlipidemic. Investigations into *S. cumini*'s various parts have focused on their potential to decrease cholesterol. According to studies, the seed extract enriched with flavonoids lowers low-density lipoprotein levels and raises high-density lipoprotein levels in rats, exhibiting anti-lipidemic characteristics. *S. cumini* extract also aids in lowering serum lipid levels [44]. Methanolic extract from *S. cumini* seeds has been reported to have anti-hyperglycemic and anti-hyperlipidemic properties [45].

A flavonoid-rich extract derived from *Syzygium cumini* seeds at a dose of 300 mg/kg/day for 15 days was observed to reduce total cholesterol, low-density lipoprotein-cholesterol, and triacylglycerol levels while elevating high-density lipoprotein-cholesterol levels [46]. Similar lipid-lowering effects were demonstrated with the administration of aqueous extracts from the fruit at doses of 100 and 200 mg/kg [47], hydroalcoholic extracts from the seed kernel at a dose of 100 mg/kg/day for 30 days [48], and Dihar, an Indian herbal mixture containing *S. cumini*, at a dose of 100 mg/kg/day for 6 weeks [49]. These studies utilized dyslipidemia secondary to streptozotocin-induced diabetes as an animal model to evaluate the antihyperlipidemic activity of *S. cumini*. This effect has been primarily attributed to the inhibition of 3-hydroxy-3-methyl-glutaryl-CoA reductase, the enzyme responsible for cholesterol synthesis [50]. The flavonoids present in *S. cumini* are presumed to contribute to this activity, as this class of compounds has been shown to enhance the expression of cAMP-dependent phosphokinase, which inhibits 3-hydroxy-3-methyl-glutaryl-CoA reductase [51]. However, these effects may also involve a reduction in the intestinal absorption of cholesterol and increased clearance of free fatty acids and triacylglycerols due to improved insulin action. Preliminary findings from our group suggest that the hydroethanolic extract of *S. cumini* leaves inhibits both the activity and expression of the hepatic microsomal triglyceride-transfer protein, which is regulated by insulin signaling pathways [52]. Nevertheless, recent research has shown that quercetin prevents the differentiation of OP9 mouse stromal cells into adipocytes by downregulating adipogenic genes [53].

Cardio-protective. There have been claims that *S. cumini* has cardio-protective properties. The methanolic extract of its seed has been shown in studies to have cardio-protective benefits in rats with myocardial infarction induced by isoproterenol. Protection depending on the concentration was obtained against myocardial infarction after oral feeding for 30 days. It was shown that the methanolic extract of *S. cumini* seeds can help diabetic rats recover from liver and heart damage [54].

Anti-diabetic activity. *S. cumini*'s fruit, seed, stem, and bark have anti-hypoglycemic properties [55]. The plant's seed contains jamboline which makes it the most efficient portion to treat diabetes. The inhibition of the conversion of starch into glucose by jambolineleads to elevation in insulin production by the β-cells of the pancreas [56]. At the time of increased glucose levels in the blood, the conversion of starch into sugar can be checked by ellagic acid [57]. Dried alcoholic extract and compounds isolated from the n-hexane fraction of Jamun leaves have anti-diabetic and blood sugar-lowering effects [58]. The antidiabetic mechanism of action of *Syzygium cumini* is shown in Figure 8.

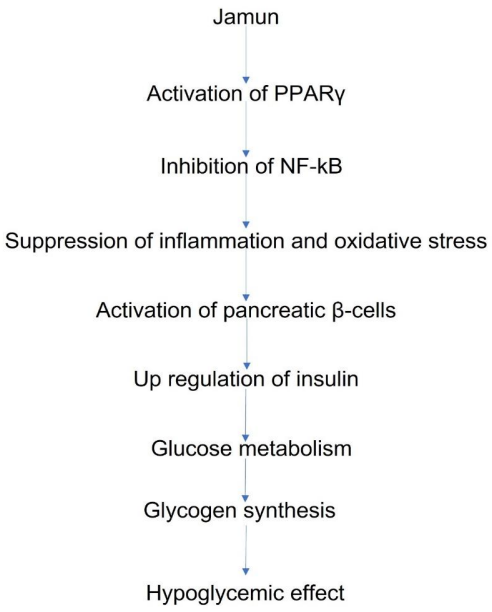

Figure 8 Antidiabetic mechanism of action of *Syzygium cumini*. PPARγ, peroxisome proliferator-activated receptor gamma; NF-κB, nuclear factor kappa B.

Diabetes mellitus arises from insulin deficiency, disrupting the endocrine system and carbohydrate metabolism [59]. Plants are known to contain pancreatic alpha-amylase inhibitors, which play a crucial role in diabetes treatment by inhibiting starch digestion [60]. Gajera et al. investigated the antidiabetic properties of methanolic and aqueous extracts from all parts of the Jamun plant, focusing on phenolic constituents. They screened for alpha-amylase inhibitors using porcine pancreatic alpha-amylase and conducted inhibition assays using the di-nitro salicylic acid method.

Among the extracts, methanolic extracts from the pulp of medium to small-sized *Syzygium cumini* fruit exhibited higher antidiabetic potential compared to aqueous extracts, albeit lower than the methanolic extract from the kernel [61]. Notably, methanolic pulp extracts from very small-sized *Syzygium cumini* fruits displayed maximum antidiabetic activity. These small-sized fruits were further assessed for their IC_{50} values, indicating the concentration of fruit extract needed to inhibit porcine pancreatic alpha-amylase activity by 50%. The methanolic pulp extracts showed the highest IC_{50} value of 270 mg/mL, suggesting a moderate potential for antidiabetic activity.

Additionally, Ayyanar et al. reported that the aqueous extract of *Syzygium cumini* fruit reduced blood glucose levels by approximately 20% and increased serum insulin levels in both normal and diabetic rats. Furthermore, the fruit extract was found to reduce the risk of atherosclerosis development in diabetic patients by diminishing the action of free radicals in the same study [62].

Anticancer. Cancer is a group of diseases with abnormal cell division and is a matter of serious concern because of its resulting high death rate. In vitro testing for the cytotoxic properties of *S. cumini* has been done on different parts of the plant. Using an 3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide assay, it was observed that the crude extract of its skin more effectively induced its cytotoxic effects in HeLa (HPV-18 positive) cells than SiHac (HPV-16 positive) cells [63]. Similarly, HeLa cells exposed to 50% methanol extract exhibited apoptosis [64].

Cancer, a non-communicable disease, ranks second only to cardiovascular disease as a leading cause of human mortality. Treatment typically involves surgery, radiotherapy, chemotherapy, or a combination thereof. In advanced stages, chemotherapy becomes the primary option, making it a vital modality in cancer treatment.

A significant portion (47%) of cancer treatment drugs are either derived from natural sources or are semisynthetic derivatives. Various parts of *Syzygium cumini* have been investigated for their cytotoxic effects in vitro using a diverse range of cell lines. Specifically, the cytotoxicity of *Syzygium cumini* fruit skin crude extract was examined in HeLa and SiHa cells using the 3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide assay, revealing a cytotoxic impact on both cell types. Although the effect was more pronounced in HeLa cells compared to SiHa cells, the 50% methanol extract displayed greater apoptosis in HeLa cells than in SiHa cells [65].

Freeze-dried extract from *Syzygium cumini* fruit pulp demonstrated a concentration- and time-dependent inhibition of cell proliferation and growth in MCF-7 and MDA-MB-231 breast cancer cells while showing lesser effectiveness in MCF-10A cells. Although the extract did not induce apoptosis in untransformed MCF-10A breast cells, it effectively triggered apoptotic cell death in both MCF-7 and MDA-MB-231 breast cancer. Similarly, ethyl acetate and methanol extracts from *Syzygium cumini* seeds exhibited a concentration-dependent reduction in cell survival and increased cytotoxicity in MCF-7 cells, with ethyl acetate extract showing slightly superior efficacy compared to the methanol extract. Comparable results were observed for DNA fragmentation, a marker of apoptosis [66].

Syzygium cumini fruit extract exhibited a concentration-dependent cytotoxic effect on HCT-116 colon cancer cells. Additionally, the extract induced apoptosis in both HCT-116 cells and colon cancer stem cells by promoting DNA fragmentation, as evidenced by terminal deoxynucleotidyl transferase dUTP nick-end labeling assay and caspase 3/7 activity [67]. Furthermore, the methanol extract of *Syzygium cumini* fruit demonstrated increased cytotoxicity and inhibition of cell proliferation in H460 lung cancer cells in a concentration-dependent manner, with an IC_{50} of 35.2 μg/mL [68].

Antioxidant. To determine the radical scavenger capacity of *Syzygium cumini* using 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) assay, k_2 (rate constant for second order) was evaluated, followed by comparisons with natural and synthetic antioxidants. At 25 ˚C, *S. cumini* exhibits excellent antioxidant activity in methanol with a k_2 value of 16.2 L/(mol·g·s) [12]. Based on in vitro assessment using various methods, *S. cumini* leaf and seed extracts demonstrated significant antioxidant activity. Different solvents including chloroform, n-hexane, ethyl acetate, water, and butanol were used to fractionate the extracts of *S. cumini* bark, leaves, and seeds in methanol. Free radical scavenging and antioxidant activities of these fractions were investigated. Polar fractions, namely ethyl acetate and water, showed the best results [69]. Extraction in methanol and water revealed high antioxidant activity in seeds and their parts [70].

The efficacy of anthocyanins as antioxidants hinges on their aglycone component [71]. Antioxidants are crucial in mitigating

reactive oxygen species formation through radical scavenging, deactivation of redox-active transition metals, and modulation of specific signaling pathways involved in cellular defence [72]. The detrimental effects of reactive oxygen species on cells have been linked to the onset and progression of various diseases like type 2 diabetes, atherosclerosis, and cancer [73]. Given the potent antioxidant compounds present in *Syzygium cumini* fruit, it emerges as a promising nutraceutical. *Syzygium cumini* is rich in antioxidants such as ascorbic acid, anthocyanins, and total phenols [74]. Kapoor et al. reported antioxidant activities of freeze-dried and hot air-dried *S. cumini* powder at 88.34% and 83.53%, respectively. Freeze-drying, as noted by Mitra et al., minimizes anthocyanin loss due to the absence of liquid water [75]. The scavenging activity of major anthocyanidins from *S. cumini* pulp follows a descending order: Dp > Pt > Cy > Pe > Mv with EC_{50} values of 15.5, 21, 45, 46, 61, and 65 µg/mL, respectively. Du et al. explored the antioxidant activity of mulberry anthocyanins using the DPPH assay, finding varying radical scavenging rates against DPPH radicals (0.1 mM) for different cyanidin glycosides [76].

Hepatoprotective. The liver plays a crucial role in metabolizing substances and detoxifying the body, but factors such as viral infections, alcohol consumption, and liver injuries pose significant concerns, leading to liver diseases. Anthocyanins, known for their antioxidant properties, have been reported to contribute to liver health and offer hepatoprotective effects [77]. Ethanolic extracts of *Syzygium cumini* pulp have demonstrated protective activity against paracetamol-induced hepatotoxicity in rats. These extracts safeguarded rat hepatocytes from in vitro toxicity induced by carbon tetrachloride [78]. Additionally, Donepudi et al. found that *S. cumini* fruit extract reduced serum alanine aminotransferase levels by up to 60%, indicating its effectiveness in treating hepatocellular injury [79].

Radio-protective. One of the widely utilised cancer therapies is radiotherapy, however, it has serious underlying side effects that harm healthy tissues. *S. cumini* has been reported to possess radio-protective properties and it shields healthy cells from harmful and damaging effects [80].

Gastro-protective. Ulcer, a frequent gastrointestinal disorder, significantly impacts a large portion of the population. *S. cumini* alters cellular functions to exhibit gastro-protective effects. According to preclinical studies, fruits have gastroprotective properties in rats with diabetes induced by streptozotocin as well as in normal rats [81]. According to Ramirez and Roa's findings, rats provided with tannins isolated from *S. cumini* were protective from gastric ulcers induced by HCl/ethanol. Treatment with tannins significantly minimizes damage to the gastric mucosa [82].

Preservation. Because of its antioxidant and antibacterial effects, *S. cumini* leaf extract can be used as a natural preservative in the pharmaceutical and food industries [83].

Oral property. The antibacterial properties of the extract from *S. cumini* leaves assist to strengthen and protect the gums and teeth against various infections. The branches are applied to whiten the teeth. The ashes of Jamun leaves are used in making toothpaste and manjan [84].

Hair growth property. When combined with an oleaginous base and applied to albino mice's shaved skin, the ethanolic fruit pulp extract exhibits a more significant impact on hair growth activity than the seed extract. The fruit pulp extract from *S. cumini* is highly effective in stimulating hair growth [85].

Coloring property. The bark of *S. cumini* contains 13–19% tannins. It provides brown dye used for colouring. High levels of anthocyanin content in *S. cumini* fruit make it a useful source of natural colourants for the pharmaceutical industry [24, 86].

Antipyretic property. Dried seed extracts in chloroform have shown antipyretic properties. Pyrexia caused by yeast can be effectively treated in rats by administering 50 mg/kg doses of ethanol extracts of dried seeds intraperitoneally [87, 88].

Antifertility property. A significant reduction in fertilizing capacity of male albino rats has been demonstrated by the antifertility effects of oleanolic acid extracted from flowers of *S. cumini* without any considerable changes in body or reproductive organ weights. Spermatocyte conversion into spermatids is significantly reduced and an early meiotic halt of spermatogenesis leads to reduced sperm count without causing any abnormality in spermatogenic cells, Sertoli cells, or leydig interstitial cells [89]. The main pharmacological actions of *Syzygium cumini* are shown in Figure 9.

Animal studies with formulation

In experimental diabetic animals, a polyherbal formulation containing powdered aqueous extracts of seven antidiabetic plants alongside *S. cumini* proved effective when administered orally at a dose of 1,600 mg/kg over long-term therapy [90]. Furthermore, the antidiabetic activity of both the hydroalcoholic extract of the seed and the phytosome derived from it was assessed, revealing significant efficacy in managing diabetes [91].

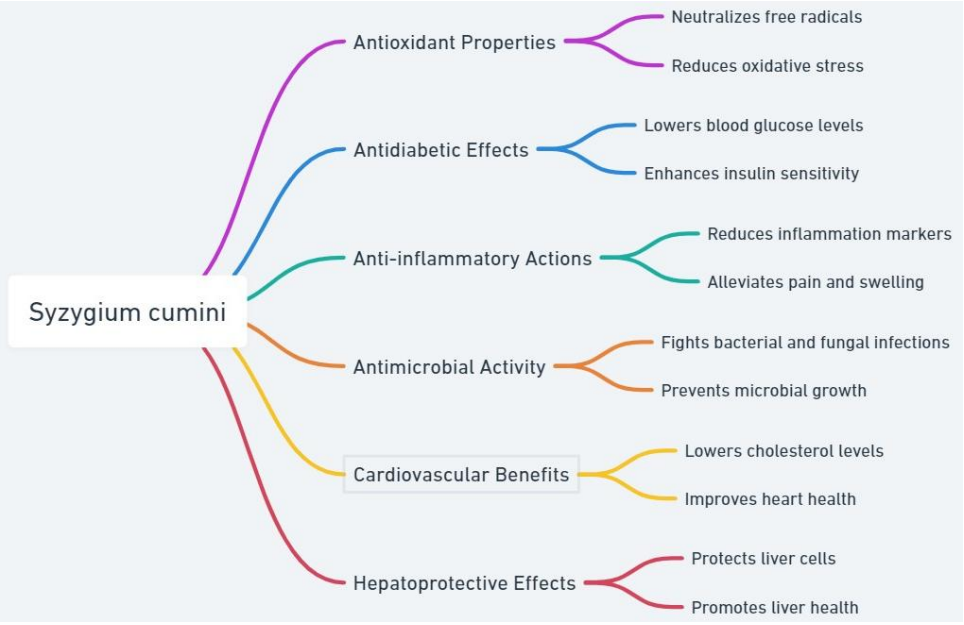

Figure 9 Pharmacological actions of *Syzygium cumini*

Toxicity

Consuming excess amounts of *S. cumini* may lead to symptoms such as cough, sputum accumulation in the lungs, body pain, and fever [39]. However, there is a lack of scientifically validated toxicity data obtained from animal or human experiments. Given that many people around the world regularly consume the fruits in substantial quantities, serious toxicity concerns about this plant may not be prevalent.

Clinical studies

Despite extensive research on the pharmacological properties of *Syzygium cumini*, clinical trials examining its efficacy remain limited [92]. An early study by Srivastava et al. demonstrated that acute administration of encapsulated seed powder (4–24 g) to patients with severe diabetes led to a notable reduction in both fasting and post-prandial blood glucose levels [93]. Similarly, Kohli and Singh supported the effects of seed powder (12 g/day for 3 months) on patients with type 2 diabetes mellitus, showing a 30% decrease in serum glucose levels alongside improvements in classical diabetes symptoms like polyphagia, polyuria, and polydipsia [94].

However, contrasting results were reported by Teixeira et al. who found that a single administration of decocted dried powdered leaves of *S. cumini* (2 g in 250 mL water) did not affect serum glucose levels in young normoglycemic patients [95]. In a subsequent study, Teixeira et al. administered the same decoction to type 2 diabetic patients for 28 days, observing no significant effect on glucose levels [96].

Despite these conflicting findings, the extensive preclinical evidence on the cardiometabolic properties of *S. cumini* underscores the importance of well-designed trials to efficiently assess its therapeutic potential in humans. Furthermore, standardizing extraction methods and characterizing the phytochemicals present in the extracts are crucial steps for the success of such trials.

Conclusion

S. cumini, with dark purplish-red, lustrous, and delectable fruits, is widely recognised for its nutritional qualities owing to the abundance of high carbohydrate, fibre, and vitamin content. They also include a variety of phytochemicals like polyphenols, tannins, etc. that have therapeutic uses. Except for their antidiabetic properties, their pharmacological capability is not well documented. The review could help pharmacists create a herbal drug that is pharmacologically effective.

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