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Review Article **Pharmacy**

Characterization and Therapeutic Potential of Syzygium Cumini: A Review on Sources, Morphology and Future Research

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Abstract

Syzygium cumini, a commonly found tree in India, Bangladesh, Nepal and other nations of the sub- continent, is widely studied for its nutrient and therapeutic properties. The fruits of the plant are established to posses various medicinal properties which will create a remarkable breakthrough in exploring active medicinal agents for various ailments. There are medicinal activities reported from various parts of the plant. The wide scope of medicinal research on this plant has created an ardor among phytochemical experts to focus attention on exploring more areas on this plant. The article is a review on various works reported in this plant so far. Detailed verification of works published in various journals with special focus on those holding high regard to phytochemistry was done. It was understood that there are still lot of areas remaining unexplored. The article tries to bring a summarized and comprehensive information on phytochemical works done on the plant in diverse segments.

Keywords: Syzygium cumini, Jamun, Medicinal properties, Phytochemical, Tropical fruit.

INTRODUCTION

Jamun *(Syzygium cumini or Syzygium jambolana or Eugenia jambolana or Eugenia cumini)*, also commonly known as black plum, Indian blackberry, java plum, Portuguese plum, jambolana, Malabar plum. It is a tropical fruit and it is a vital indigenous plant with medicinal applications originally from India and Indonesia. Jamun tree is a tropical evergreen blooming plant from the *Myrtaceae* family. It is grown for its fruit, timber, and ornamental values. It is well known for its various therapeutically and nutritional attributes. The fruit is dark purple or black when ripe and has a sweet tart flavour. Jamun fruits are highly perishable in nature so most of them are processed. Jam, jelly, vinegar, wine, squash, and non-fermented ready to drink beverages are some of the traditional jamun fruit products. The fruit pulp can be dried and used as a food colourant. Also used as an additive in pasta, ice-cream, etc. At fully ripen stage, jamun pulp contains sugars (glucose, fructose), free amino acids, minerals (Na, K, Ca, Mn, Mg), dietary fibre, ascorbic acid, β-carotene, organic acids.

Other than the fruits, leaves and barks also have medicinal properties. They are used in diabetes, ringworm and diarrhoea. The bark is used as digestive, anthelmintic and diuretic. In addition seeds are used in various traditional and oriental systems of medicines suggest Ayurvedic, Unani and Chinese medicines as a natural substitute for the treatment of hyperglycemia, dysentery, ulcers, asthma, glycosuria and bronchitis

Jamun seeds are a potential source of bioactive compounds including hydrolysable tannins, phenolic acids, flavonoids, other phenolics, terpenoids, phloroglucinol derivatives and saponins, which have been endorsed several biological activities, such as antidiabetic, anticancer, anti-inflammatory, antioxidant, antimicrobial, antihyperlipidemic and antihypercholesterolemic, as well as cardioprotective, hepatoprotective and neuroprotective properties. High contents of carbohydrates, dietary fibre, minerals, and ascorbic acid have also been found in jamun seeds.

Geographical Source

The jamun is native to India, Burma, Ceylon and to the Andaman Islands and available throughout Indian plains as well as in Kumaon hills up to 1,600 m. It is found grown as a wild and semi-wild in tropical and subtropical parts of India viz., Punjab, Haryana, Uttar

Pradesh, Maharashtra, Rajasthan, Gujarat, Madhya Pradesh, Bihar, Chhattisgarh, Jharkhand, Karnataka, Kerala, Tamil Nadu and Andhra Pradesh. It is widely distributed in Sri Lanka, Malaysia, Thailand, Philippines and Australia.

SPECIES	COMMON NAME AND USE	DISTRIBUTION
S. aromaticum	Clove, dried flower buds commercially important	Evergreen trees cultivated in Tamil Nadu and Kerala
S. jambos	Rose-apple	Many parts of India
S. fruticosum	Wild jamun	Avenue Tree
S. claviflorum	Fruits edible	The Andamans
S. javanica	Water apple	South India and West Bengal
S. aquem	Watery rose-apple, Fruits edible	A small tree distributed in Assam and Meghalaya
S. samarangense	Wax Jambu, Fruits edible	The Andamans and many parts of India
S. zeylanicum	Fruits edible	Maharastra, Karnataka, Orissa, Kerala and Andamans
S. mappaceum	Ornamental plant	Assam, Meghalaya, Arunachal Pradesh and Tamil Nadu
S. amottlanum	Fruits edible	Western Ghats, The Nilgris, Palani and Anamalai hills
S. zeylanicum	Fruits edible	Western ghats of India

Syzygium cuminii (Java plum, Jamun):

Large, evergreen beautiful tree of the Indian subcontinent but has also naturalised throughout Southeast Asia and the Pacific Islands. It is widely cultivated in Haryana as well as the rest of the Indo-Gangetic plains on a large scale. Fruits are generally ovoid to oblong in shape, deep purple or bluish in colour, having juicy, sweet pulp and a small stone.

Syzygium jambos (Rose apple): Trees are medium, evergreen and grown in Assam, Bihar, Andhra Pradesh, Tamil Nadu, West Bengal, coastal areas of Maharashtra and Gujarat. Leaves have very small petiole and calyx persistent. Fruits are light yellow- white in colour, rose scented and seeds are polyembryonic.

Syzygium uniflora (Surinam cherry or Pitanga cherry): A small tree and bears small-sized fruits having bright red colour and aromatic flavour. The tree is found in South India.

Syzygium fruticosum: Trees are suitable for windbreak and have straight growth habit. Fruits are edible and small.

Syzygium densiflora: Suitable for use as rootstock for Syzygium cuminii. It is resistant to termites attack.

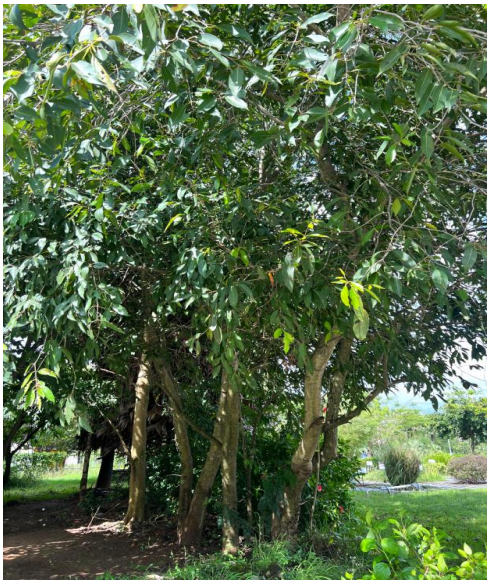
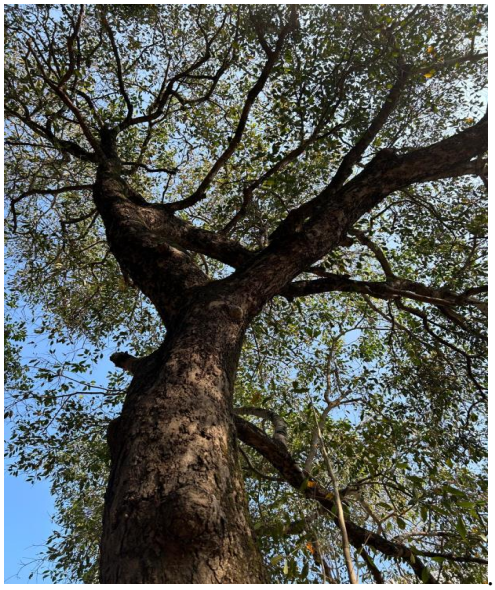
Morphology

Java plum grows quickly and forms dense foliage, providing abundant shade. The rough, dark bark near the tree's base lightens to a smoother grey higher up, and its water-resistant wood is used for construction, like railway sleepers and motor installations for wells.

The young leaves start out pinkish and mature to a leathery, glossy dark green, providing nutritious fodder for livestock. The tree flowers between March and April, producing small, fragrant blossoms. The fruits mature from May to June, ripening in stages from green to pink, crimson, and finally deep black (or occasionally white, depending on the variant). Known for their mix of sweet, mildly sour, and astringent flavors, these fruits often stain the tongue purple. This tree's ornamental appeal and versatile uses make it valuable in both rural and urban environments.

Botanical Description:

a) Kingdom: Plantae
b) Subkingdom: Viridaeplantae
c) Infrakingdom: Streptophyta
d) Division: Tracheophyta
e) Subdivision: Spermatophytina
f) Infradivision: Angiospermae
g) Class: Magnliopsida
h) Superorder: Rosanae
i) Order: Myrtales
j) Family: Myrtaceae
k) Genus: Syzygium
l) Species: Cumini
m) Scientific Name: Syzigium cumini.

The morphology of the fruit of Syzygium cumini (commonly known as Jamun, Jambolan, or Java plum) includes the following features:

General Description

- Type: The fruit is a berry.
- Shape: The fruit is typically oval to oblong, sometimes ovoid.
- Size: It usually ranges from about 1–2 cm in length and 1–1.5 cm in diameter, though size can vary with the cultivar

Colour and Texture

- Colour: The fruit is green when immature and turns dark purple to almost black when ripe. Some may appear magenta or reddish-purple in certain stages of ripening.
- Texture: The outer skin is smooth and shiny, and it can appear waxy.

Flesh and Seed

- Flesh (Pulp): The pulp is juicy and can be pinkish to purple. It has a slightly astringent, sour-sweet taste, which becomes sweeter as the fruit ripens.
- Seed: Each fruit typically contains a single, large, polyembryonic seed that is either round or oblong, with a hard, greenish-brown coating. In some cases, the seed may split into two halves.
- Arrangement and Clustering
- Arrangement: The fruits grow in clusters on the tree, hanging from short stems.
- Clustering: Clusters often have several berries, though each berry remains distinct.

Other Features

- Juice: The juice is often dark purple and can stain, commonly used for natural dyes.
- Aroma and Flavor: The fruit has a mildly sweet fragrance with an astringent, sweet-tart flavour profile, becoming less astringent as it ripens.


The morphology of Syzygium cumini leaves (commonly known as Jamun or Java plum) includes the following features:

General Description

- Shape: The leaves are typically elliptical, ovate to oblong, sometimes lanceolate.
- Size: They range from about 5–12 cm in length and 2.5–6 cm in width.
- Texture: The leaves are leathery and smooth, with a glossy surface on the top side.

Margins and Venation

- Margins: The edges of the leaves are entire, meaning they lack serration or lobes.
- Venation: They exhibit a pinnate venation pattern with a prominent midrib. Secondary veins run parallel, arching towards the margins and converging near the leaf tip.

Petiole

- Length: The petiole is short, typically around 0.5–1.5 cm.
- Colour and Texture: It is green, firm, and sometimes exhibits a slight pinkish hue in young leaves.

Arrangement and Phyllotaxy

- Arrangement: Leaves are opposite and decussate, meaning they are paired at each node and arranged in a cross pattern.
- Phyllotaxy: Opposite.

Other Features

- Aroma: Crushed leaves emit a faint, turpentine-like aroma.
- Glands: Tiny, glandular dots may be visible under magnification, which sometimes give the leaves a slightly dotted appearance.

Adaptation

The leathery and glossy nature of the leaves helps reduce water loss and adapt to subtropical to tropical climates, where Syzygium cumini commonly grows.

The bark of Syzygium cumini (Jamun or Java plum) has distinctive morphological features:

General Description

- Colour: The bark is dark grey to brownish-grey, with an overall rough texture.
- Texture: Mature bark is rough and fissured, sometimes with vertical cracks and scaly patches.

Structure and Layers

- Outer Bark: The outer layer is thick and corky, providing protection against environmental stressors.
- Inner Bark: The inner bark, when exposed, has a reddish-brown to pinkish hue.
- Pattern and Shedding
- Pattern: The bark has a rough, ridged, and grooved appearance, with vertical fissures that may become deeper and more pronounced with age.
- Shedding: Older trees may shed bark in small, irregular patches, which can reveal smoother, lighter-coloured patches underneath.

Other Features

- Lenticels: Young stems and branches often have visible lenticels (small, raised pores) that help in gas exchange.
- Aromatic Properties: When scraped, the inner bark has a slight aromatic quality, similar to the leaves, due to essential oils.

The roots of Syzygium cumini, commonly known as jamun or black plum, exhibit several distinct morphological characteristics:

- Type: The root system is typically fibrous, consisting of many thin, branching roots that spread widely in the soil.
- Main Roots: The main taproot is relatively deep and robust, helping anchor the plant and access deeper soil moisture.

- Lateral Roots: Numerous lateral roots emerge from the main taproot, increasing the surface area for nutrient and water absorption.
- Root Hairs: These fine, hair-like extensions increase the absorptive capacity of the roots, aiding in nutrient uptake.
- Adaptation: The roots often exhibit adaptations to local soil conditions, such as being more shallow in compact or rocky soils.
- Mycorrhizal Associations: Syzygium cumini may form symbiotic relationships with mycorrhizal fungi, which enhance nutrient absorption, particularly phosphorus.

Conventional use of the plant for therapeutic activity

Research highlights its potential health benefits due to high antioxidant activity. Stangeland *et al*., (2009) found that Java plum seeds and fruits, commonly eaten in Uganda, have strong antioxidant properties. A preliminary study by Ndyomugyenyi (2008) identified bioactive compounds in the plant, including sterols, tannins, anthocyanins, and saponins. Additional studies by Banerjee *et al*., (2005) and Veigas *et al*., (2007) found that the fruit skin is rich in anthocyanins, with 230 mg per 100g of fruit on a dry weight basis. These compounds, particularly anthocyanins, make Java plum a powerful free radical-scavenger, suggesting potential health-promoting and disease-preventing effects. However, more research is needed to establish its overall safety profile.

The Java plum or Jamun (Syzygium cumini) plant has a rich history in traditional medicine systems like Ayurveda, Unani, and folk medicine across Asia and other tropical regions. Various parts of the plant are conventionally used to treat a range of health conditions. Here's an outline of its therapeutic uses:

1. Diabetes Management

The main plant parts used for diabetes management are seeds and fruit pulp. Uses of Jamun seeds are especially valued for their anti-diabetic properties and are used to manage blood sugar levels. They are often ground into a powder and consumed with water or other beverages. The mechanism involved in this is seeds contain compounds like jamboline and ellagic acid that help delay the conversion of starch into sugar, aiding in blood sugar control.

2. Anti-inflammatory and Pain Relief

The main plant parts used for anti-inflammatory treatment are leaves, bark, and seeds. Decoctions made from the leaves or bark are used in traditional medicine to reduce inflammation and relieve pain, especially in cases of arthritis and joint pain. Compounds with anti-inflammatory activity help reduce pain and swelling.

3. Fever Reduction

The main plant parts used for fever control are bark and leaves. Decoctions from the bark and leaves are used as a febrifuge (fever reducer) to manage fever and other flu-like symptoms. The plant's anti-inflammatory and antimicrobial properties help combat infection and reduce fever.

4. Blood Purification

The main plant parts used for blood purification are leaves and fruit pulp. Juice from the fruit pulp is consumed to purify the blood and improve circulation, thought to aid in detoxification and general health. The fruit's antioxidant and nutrient-rich profile is believed to support blood health and detoxification.

5. Skin Conditions and Wound Healing

The main plant parts used for wound healing are leaves and fruit pulp. Leaves are traditionally applied topically as poultices for wounds, skin ulcers, and inflammation. The fruit pulp is sometimes used as a paste to treat acne and skin infections. The antioxidant and anti-inflammatory properties help reduce oxidative stress and promote skin healing.

6. Digestive Health

The main Plant Parts used for digestive health are Bark, leaves, and fruit. The bark and leaves are commonly used to treat digestive issues such as diarrhoea, dysentery, and other gastrointestinal disturbances. A decoction or infusion of the bark and leaves is prepared to ease digestive complaints. The mechanism involved in this is tannins and other

astringent compounds in the bark and leaves help reduce inflammation and provide relief from diarrhoea.

7. Oral Health

The main plant parts used for oral health are leaves and bark. The leaves and bark are chewed or used in mouth rinses to maintain oral hygiene, treat mouth ulcers, and reduce gum inflammation. The antimicrobial and astringent properties help in reducing oral bacteria and inflammation, promoting better oral health.

8. Liver Health

The main plant parts used for liver health are seeds and bark. Traditional practitioners sometimes use Jamun extracts to support liver health and detoxify the body. Antioxidants in the seeds and bark are thought to aid in protecting liver cells from oxidative damage.

9. Boosting Immunity

The main plant parts used for boosting immunity are fruit and leaves. The fruit juice is often consumed to strengthen immunity due to its high vitamin C and antioxidant content. The fruit's antioxidants, especially anthocyanins, help neutralise free radicals and support immune function.

10. Respiratory Health

The main plant parts used for respiratory health are leaves and bark. Traditionally used to treat cough, asthma, and bronchitis. A decoction of the leaves or bark is sometimes consumed to soothe the respiratory tract. The anti-inflammatory and antimicrobial properties of the leaves and bark help reduce symptoms of respiratory ailments.

Traditional Preparations and Forms

- Powdered Seeds: Often consumed as an adjunct therapy in managing diabetes and digestion.
- Decoctions and Infusions: Made from leaves, bark, or seeds for respiratory and digestive issues.
- Juice: Extracted from the fruit and consumed fresh to support immunity, blood health, and overall well-being.
- Poultices and Pastes: Made from leaves or fruit pulp and applied to wounds, skin infections, or inflammations.

These uses are primarily based on traditional practices and may vary across cultures. While modern research supports some of these applications, especially in diabetes management and as an antioxidant source, further scientific validation could solidify its potential in modern therapeutic use.

Reported medical actions

Jamun is rich in essential nutrients, including vitamins (especially vitamin C), minerals (like iron and calcium), and antioxidants, particularly anthocyanins, which give the fruit its characteristic deep colour. It also contains bioactive compounds like polyphenols, tannins, and flavonoids, which contribute to its health benefits.

A range of pharmacological properties is possessed by various extracts of jamun which include antidiabetic, antihyperlipidemic, antihypercholesterolemic, anti-inflammatory, antimicrobial, anticancer, neuroprotective, cardioprotective, hepatoprotective and antioxidant activities as established by scientific studies.

Antidiabetic activity

Several in vivo studies showed the antidiabetic activity of jamun seeds, their extracts and phytochemicals. Study revealed that jamun seed extract preferably improves various biochemical actions, such as glucose tolerance and glucose uptake, maintains glucose homeostasis in diabetic animals, and exhibits benefits in restoring β-cells. Addition of defatted jamun seeds as well as water-soluble fiber isolated from this material to the diet of diabetic rats exerted a hypoglycemic effect (Pandey & Khan, 2002). The ethanolic extract of phenolic compounds obtained from jamun seeds significantly reduced the blood glucose level in rats (Yadav *et al*., 2010). The authors reported 41% and 44% of the mentioned reduction after oral administration of the extract. For the aqueous extract, the ability for blood glucose reduction was lower – 26% and 27% after 1 and 2 h, respectively.

A long-run human study conducted for 1 year on 99 patients with type 2 diabetes mellitus who poorly controlled blood sugar level and were administered S. cumini seed powder at a dose of 10 g/day showed decrease in fasting plasma glucose and postprandial blood sugar, thus indicating the beneficial role of jamun seed powder in controlling type 2 diabetes mellitus (Sidana *et al*., 2017). The study also confirmed the pharmaceutical value of S. cumini as a regional, traditional medicine for diabetes management.

Antihyperlipidemic and antihypercholesterolemic activity

The presence of several bioactive compounds in jamun seeds helps to regulate the blood lipid profile. Oral infusion of an alcoholic jamun seed extract (100 mg/kg body weight) in diabetic rats resulted in a significant reduction in serum lipids.

The jamun seed extract also decreased the total serum cholesterol to high-density lipoprotein (HDL) cholesterol ratio, serum low-density lipoprotein (LDL) cholesterol level and 3-hydroxy-3-methyl-glutaryl-coenzyme A (HMG-CoA) reductase activity in alloxan-induced diabetic rabbits and streptozotocin-induced diabetic rats. The plasma lipoprotein cholesterol (HDL-, LDL-, and VLDL-C) and fatty acid composition were altered in streptozotocin-induced diabetic rats when administered the ethanolic jamun seed extract.

Anti-inflammatory activity

Due to the occurrence of several bioactive compounds, jamun seed powder or its extract can act as an anti-inflamma-tory agent, decreasing both acute and chronic inflammation. It was confirmed by several in vivo studies. Bioactive compounds of ethyl acetate and methanol extracts of jamun seeds orally administered to Wistar rats with carrageenan-induced paw edema (200 and 400 mg/kg body weight) elicited anti-inflammatory effect (Kumar *et al*., 2008). Chaudhuri *et al*., (1990) used the chloroform fraction of jamun seed in a lower dose (100 mg/kg body weight) and also reported the inhibition of carrageenan-induced paw edema in rats. The inhibition of migration of leukocytes into the pleural fluid was noted. In addition, the authors observed the reduction of the weight of cotton pellet-induced granuloma.

Antimicrobial activity

The possibility of applying the jamun seed extract as a novel antimicrobial agent was confirmed by means of the agar well diffusion and microbroth dilution assays. Jasmine *et al*., (2010) found that the crude extracts of jamun seeds could act against isolated β-lactamase-producing drug-resistant bacteria. The zone of inhibition was in the range of 14–21 mm and a minimum inhibitory concentration (MIC) was in the range of 31.75–62.5 µg/mL. Eight sesquiterpenoids isolated from jamun seeds were active (100 µg/disk) against *S. aureus*. However, the same compounds at the same concentration caused no effect against *E. coli* and *C. albicans* (Liu *et al*., 2017a).

According to Santos *et al*., (2020), phenolic extracts of jamun seeds were activite against *Aeromonas hydrophila, Chromobacterium violaceum, E. coli, Pseudomonas aerugi-nosa, Salmonella enterica serovar Typhimurium, Serratia marcescens, Listeria monocytogenes, and S. aureus*. The strongest antimicrobial activity was reported in the case of *S. aureus*.

The research conducted by Chandrasekaran & Venkatesalu (2004) showed antifungal activity of bioactive compounds extracted from jamun seeds using water and methanol. Extracts were active against such dermatophytic fungi as *Candida albicans, Trichophyton rubrum, T. mentagrophytes, Microsporum gypseum,* and *Aspergillus niger*.

Anticancer activity

Jamun seed extract exhibited protection in albino mice against peroxidative damage contributing to skin cancer (Parmar *et al*., 2010). The oral intake of extracts (125 mg/kg body weight) reduced tumour burden, number of papilloma cells and their size.

Neuroprotective properties

The antiamnestic effect of the jamun seed methanolic extract was evaluated in a rat model by Alikatte *et al*., (2012). The extract administration (200 and 400 mg/kg) exerted positive effects on short-term or working memory and reversed cognitive impairments in rats. In brains of rats treated with extracts, the level of lipid peroxidation was lower and the activities of superoxide dismutase and catalase higher than in the control group. The authors also reported suppression of acetylcholinesterase activity in experimental groups.

Cardio and hepatoprotective properties

The methanolic jamun seed extract administered to mice at the dose of 200 mg/kg body weight revealed the protective and recovery ability on cardiac tissue due to its capability to decrease myocardial necrosis biomarkers such as aspartate aminotransferase (AST), alanine transaminase (ALT), uric acid, creatine phosphokinase (CPK), and lactate dehydrogenase (LDH) (Nahid *et al*., 2017).

Hepatoprotective effect of the methanolic seed extract was reported when administered at doses of 100, 200 and 400 mg/kg to Wistar albino rats treated with carbon tetrachlo-ride dosages. The extract significantly reversed the elevated marker enzymes (glutamic oxaloacetic transaminase (GOT), glutamic pyruvic transaminase (GPT), alkaline phosphatase (ALP), acid phosphatase (ACP) and bilirubin), which were comparable even with those of the Liv.52®-treated group. Likewise, the methanolic jamun seed extract when administered at a dose of 200 mg/kg body weight to diabetic rats, exhibited hepatoprotective effect by significantly increasing the protein concentration, ALT, AST, ALP and bilirubin levels, and reducing enhanced liver enzymes even more than in the rats treated with the gliclazide (25 mg/kg).

Antioxidant Activity

The antioxidant potential of jamun seeds was analysed by several in vitro methods, using various techniques for the extraction of bioactive compounds. The phenolics (gallic acid, ellagic acid, ferulic acid, (+)-catechin, and quercetin) of seeds originated from underutilised indigenous black jamun landraces found in the Gir forest region of India showed significant antiradical activity against DPPH• (Gajera *et al*., 2017).

The in vivo experiment carried out by Bitencourt *et al*., (2017) demonstrated the antioxidant potential of the jamun seed extract. Candida albicans-infected diabetic rats were treated for three weeks with an aqueous seed extract and the same extract in the form of nanoparticles with a daily dose of 100 mg/kg. The crude extract and its nanoparticle form were able to decrease levels of thiobarbituric acid reactive substances (TBARS) in serum, kidney, liver, and pancreas of the treated groups when compared to control animals.

Isolation and characterization of various parts of *Syzygium cumini*

The bioactive phytoconstituents of Java plum include jambosine, gallic acid, quercetin, β-sitosterol, ferulic acid, guaiacol, resorcinol, p-coumaric acid, corilagin, ellagic acid, catechin, epicatechin, tannic acid, 4,6 hexahydroxydiphenoyl glucose, 3,6-hexahydroxy diphenoylglucose, 1-galloyl glucose, and 3-galloyl glucose. Hence, isolation and analysis is of crucial importance.

Considering all the potential beneficial effects of the major bioactive factors such as the extraction methods of Jamun seeds, solvents used in extraction, and duration of extraction cause significant changes in extracted bioactive constituents and reaction kinetics. This naturally leads to the potential health benefits, which are medicinal properties, attributed to Jamun seeds. The most common and important methods used to extract the major bioactive components of Jamun seed are Soxhlet extraction (SJE) and gas chromatography–mass spectroscopy (GC-MS) are the main methods in Jamun seed oil analysis.

Methodology:

1. Collection:

Fresh leaves, bark, seeds, or fruit of Syzygium cumini are collected, washed, and dried. These parts are then ground into a fine powder.

2. Extraction:

Syzygium cumini extracts can be prepared using various solvents like methanol, ethanol, acetone, or aqueous solutions, depending on the targeted compounds. The powdered plant material is subjected to Soxhlet extraction or maceration, where the solvent is allowed to interact with the plant material to dissolve the phytochemicals. After extraction, the mixture is filtered, and the solvent is evaporated using a rotary evaporator, leaving behind the crude extract.

3. Isolation of Active Compounds:

Thin Layer Chromatography (TLC) and Column Chromatography are commonly employed to separate the compounds in the crude extract. Fractions from column chromatography can be analyzed and purified further. High-Performance Liquid Chromatography (HPLC) and Gas Chromatography-Mass Spectrometry (GC-MS) can be used to identify and quantify the bioactive compounds.

4. Characterization of Phytochemicals:

- **UV-Visible Spectroscopy:** Used for preliminary analysis of phenolic and flavonoid content.
- **Fourier-Transform Infrared Spectroscopy (FTIR**): Helps identify functional groups present in the isolated compounds.
- **Nuclear Magnetic Resonance (NMR) Spectroscopy:** Provides detailed structural information about the isolated compounds.
- **Mass Spectrometry (MS):** Helps determine the molecular weight and composition of isolated compounds.

Analysis of Phytochemical includes:

Alkaloids

- Dragendroff's Test: Filtrates were treated with Dragendroff's reagent (solution of Potassium Bismuth Iodide). Formation of red precipitate indicates the presence of alkaloids.
- Mayer's Test: To a few ml of plant sample extract, two drops of Mayer's reagent are added along the sides of the test tube. Appearance of white creamy precipitate indicates the presence of alkaloids.
- Wagner's Test: A few drops of Wagner's reagent are added to few ml of plant extract along the sides of test tube. A reddish- Brown precipitate confirms the test as positive.

Flavonoids

- Alkaline Reagent Test: Extracts were treated with few drops of sodium hydroxide solution. Formation of intense yellow colour, which becomes colourless in addition to dilute acid, indicates the presence of flavonoids.
- Froth Test: The extract (50 mg) is diluted with distilled water and made up to 20 ml. The suspension is shaken in a graduated cylinder for 15 minutes. A two cm layer of foam indicates the presence of saponins.

Tannins

- Ferric Chloride Test: The extract (50 mg) is dissolved in 5 ml of distilled water. To this few drops of neutral ferric chloride solution are added. A dark green colour indicates the presence of phenolic compounds.

Glycosides

For 50 mg of extract is hydrolysed with concentrated hydrochloric acid for 2 hours on a water bath, filtered and the hydrolysate is subjected to the following tests:

- Legal's Test: 50 mg of extract is dissolved in pyridine; sodium nitroprusside solution is added and made alkaline using 10% NaOH. Presence of glycoside is indicated by the pink colour.

Phenols

- Lead Acetate Test: The extract (50 mg) is dissolved in distilled water and to this 3 ml of 10% lead acetate solution is added. A bulky white precipitate indicates the presence of phenolic compounds.

Proteins

The extract (100 mg) is dissolved in 10 ml of distilled water and filtered through Whatman No. 1 filter paper and the filtrate is subjected to test for proteins.

- Millon's Test: To 2 ml of filtrate few drops of Millon's reagent are added. A white precipitate indicates the presence of proteins.

Carbohydrates

- Molisch's Test: To 2 ml of plant sample extract, two drops of alcoholic solution of naphthol are added. The mixture is shaken well and a few drops of concentrated sulphuric acid is added slowly along the sides of the test tube. A violet ring indicates the presence of carbohydrates.

Phytosterols

- Libermann-Burchard's Test: Extracts were treated with chloroform and filtered. The filtrates were treated with few drops of acetic anhydride, boiled and cooled. Con. Sulphuric acid was added.

Antioxidant Assay

The antioxidant assay was performed using the potassium ferrocyanide reducing method by Oyaizu using Ascorbic Acid (1%) as standard. Aliquots of the extract were taken in a test tube and made up to a volume of 1 ml with distilled water. Then 2.5 ml of Phosphate buffer and 2.5 ml of potassium ferricyanide were added to each of the tubes, and incubation was carried out for 20 min at 50°C in a water bath 2.5 ml of 2.5 ml + Fecl3 = 2.5 ml3. The concentration of the sample was calculated by using the following formula, (O.D= Optical Density).

$$\text{Concentration of the sample (mg/ml)} = \frac{\text{concentration of standard X O.D of sample}}{\text{O.D of standard}}$$

Table shows presence of different chemical constituents

Sr. No.	Test	Aqueous	Methanol	Ethyl Acetate	Ethanol
1	Alkaloid's	+	+	+	+
2	Flavonoids	+	+	+	+
3	Saponins	+	++	+	+
4	Tannins	-	-	-	+
5	Glycosides	+	+	+	+
6	Phenols	-	-	-	-
7	Proteins	+	+	+	+
8	Steroids	-	-	-	-

Extraction:

Dried leaf powder (50 g for each solvent) was soaked separately in 250ml of each solvent namely: distilled water, ethanol, methanol, ethyl acetate, in a flask. The five flasks were covered and then kept at room temperature for around one week. After that, the separate solutions were filtered by Whatman filter paper (no.1). Each filtrate was collected in a round bottom flask and was subjected to evaporation to achieve a gummy appearance. Then the gummy substance of each solvent was dried at room temperature. The powdered extracts were weighed and stored at 400C for further work. From 50 g dried leaf powder, 7 g (14%) of extract was finally obtained from aqueous extract; 7.8 g (15.6%) of extract from ethanolic extract; 7.3 g (14.6%) from methanolic extract; 6.9 g (g (12.6%) from hexane extraction.

Fig: Extraction by decoction method

TLC of gallic acid: This separation process consists of two phases: a stationary phase and a mobile phase. The mobile phase consists of the mixture to be separated which percolates through the stationary phase. These two phases can be solid-liquid, liquid-liquid or gas-liquid.

Thin Layer Chromatography: (TLC) is a solid-liquid form of chromatography where the stationary phase is a polar absorbent and the mobile phase can be a single solvent or combination of solvents.

Principle:

Thin Layer Chromatography (TLC) is a type of chromatography which is based upon the distribution of biomolecules between two immiscible phases. In TLC the stationary phase is a polar absorbent, like finely ground alumina (Al2O3) or silica (SiO2) particles which are coated on a glass slide or plastic sheet to create a thin layer of the particular stationary phase.

The solvent (mobile phase) is allowed to move up the plate by capillary action through the adsorbent at its own rate and as a result differential partitioning occurs between the components of the mixture dissolved in the solvent and the stationary adsorbent phase. The more strongly a given component of a mixture is adsorbed onto the stationary phase, the less time it will spend in the mobile phase and the more slowly it will migrate up the plate. When the solvent front has moved to within about 1 cm of the top end of the adsorbent, the plate should be removed from the developing chamber. If the components of the sample are coloured, they can be observed directly.

Mobile phase used

Ethyl acetate, formic acid, glacial acetic acid, and water in varying ratios was tried. The mobile phase toluene: ethyl acetate: formic acid: methanol (2.5:2:0.9:0.3)

Sr. NO.	Chemical	Solvent /Mobile phase	RF value
1	Galic acid	phase toluene: ethyl acetate: formic acid: methanol (2.5:2:0.9:0.3)	0.35/10=0.35
2	Ellagic acid	phase toluene: ethyl acetate: formic acid: methanol (2.5:2:0.9:0.3)	0.19\10=1.9

Extraction Java plum containing gallic acid by decoction method. For verification of that gallic acid TLC is performed in which RF value. From which identification of Gallic acid from java plum and Extraction of Gallic Acid from Java Plum Leaves has been done.

Different methods are used in the analysis of the bioactive components of Jamun seed. While the most common traditional methods are the conventional solvent extraction method and SJE, modern methods include UJE or MJE, ultrafiltration, solid-phase microextraction, and supercritical fluid extraction.

Carmo Brito *et al*., emphasised that ethanol 95% with 1% of HCl (v/v) is the most efficient extraction method to extract anthocyanins from Jamun fruits. In another study, as a result of analysis using different extraction methods, the total phenolic contents (mg GAE/100 g), flavonoid content (mg quercetin equivalents (QE)/100 g), and total anthocyanin contents (mg cyanidin-3-glucoside equivalent (CYE)/g) were obtained with the highest amount in the ethanol extracts of both Jamun fruit and seeds. This was followed by methanol and water extracts. In addition to the extraction technique and the characteristics of the solvent used, pH is also one of the important factors in the analysis of bioactive components; especially anthocyanins.

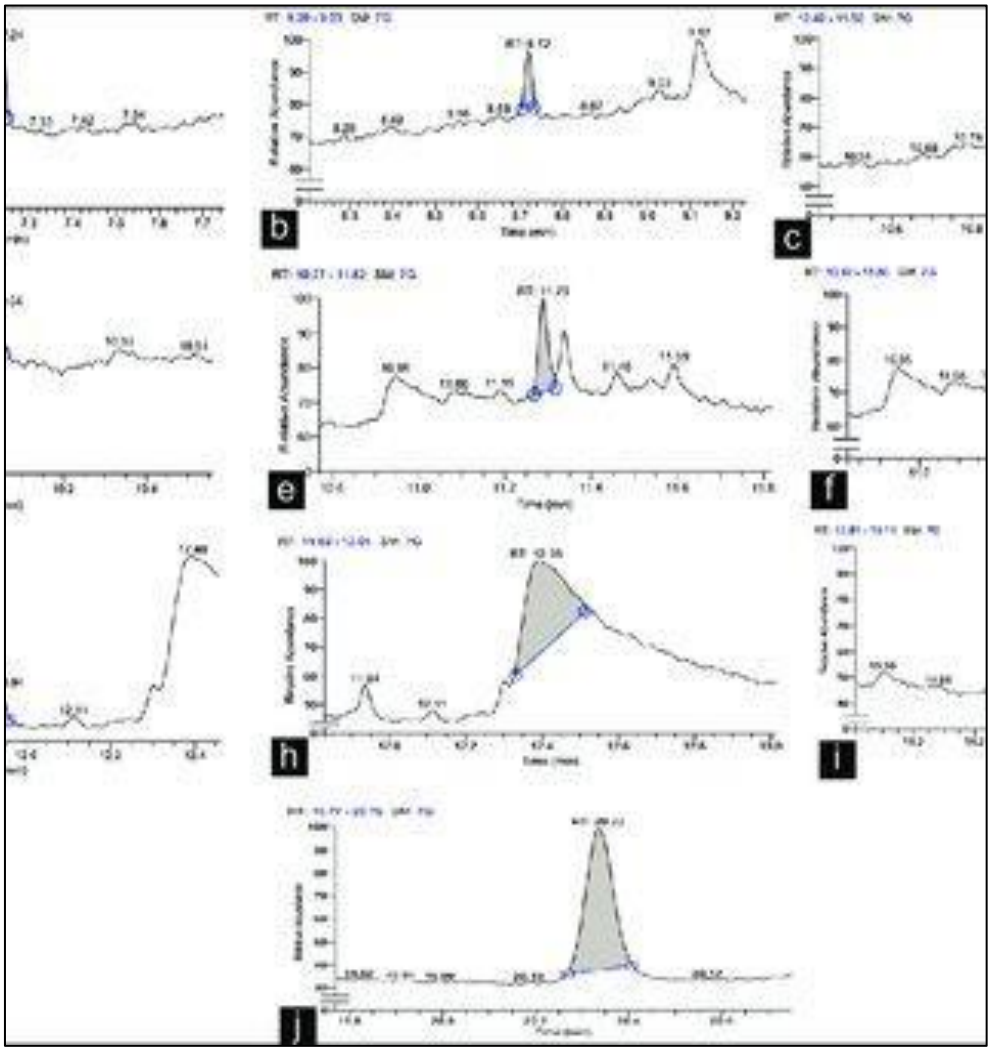
GC-MC method of analysis:

Black plum seed powder is subjected to the Soxhlet extraction process using hexane as a solvent to obtain black palm seed extract. GC-MS is a unique method for the analysis and measures the quantity of organic volatile and semi-volatile compounds. GS is employed to separate mixtures into individual components employing a temperature-controlled capillary column. MS is applied to recognize a variety of components from their mass spectra. In the present study, black plum seed powder is used for extraction and analysis to study the constituents. Black plum seed extract is extracted by solvent extraction technique using Soxhlet extractor with hexane as a solvent.

SPECIFICATIONS AND CONDITIONS DURING GC-MS ANALYSIS

- Run time (min) 54.09
- Injection volume(µl) 1.00
- Scans 6439
- Low mass (m/z) 40
- High mass (m/z) 400
- Gas Helium
- Solvent Hexane

The work presented relates to the study of GC-MS analysis of the extracts of black plum seed obtained using solvent extraction with hexane as a solvent. The extract is found to contain many medicinally active compounds. Ten compounds are identified and details presented, five of which are found to exhibit antimicrobial activity against different diseases. The medicinally active compounds can be isolated and considered for the preparation of medicine.



Gas chromatography Prominent peaks of Szygium cumini

Areas to be explored

In exploring the Java plum (*Syzygium cumini*), also known as jambolan, jambul, or jamun, several parts of the plant and fields of study can be investigated, given its importance in traditional medicine, nutrition, and agriculture. Here's a breakdown of the plant parts and the relevant studies associated with each:

Parts of the Java Plum

1. Fruit:

- **Pulp**: Contains sugars, vitamins, and antioxidants, which give the fruit its nutritional value and medicinal potential.
- **Seed**: Known for anti-diabetic properties, rich in bioactive compounds like alkaloids, glycosides, and flavonoids.
- **Skin/Peel**: High in anthocyanins, which are pigments with antioxidant properties.

2. Leaves:

Leaves of Jamun are used in traditional medicine for their antimicrobial, anti-inflammatory, and hypoglycemic properties. The leaves of Syzygium cumini are rich in bioactive compounds.

Phytochemical Composition: Jamun leaves contain various bioactive compounds like flavonoids, terpenoids, tannins, and essential oils. A comprehensive phytochemical analysis could help identify and quantify these compounds, and studying how they vary by season, geography, and soil type could yield useful insights into optimal harvesting times and environmental factors affecting phytochemical yields.

Antidiabetic Properties: The hypoglycemic potential of Jamun leaves is well recognized in traditional medicine. Research can examine how leaf extracts influence blood glucose regulation, insulin sensitivity, or pancreatic function, contributing to natural therapies or adjunctive treatments for diabetes management.

Antimicrobial and Antiviral Properties: Jamun leaves have been traditionally used for their antimicrobial activity. Investigating their efficacy against bacteria, fungi, and viruses could provide natural solutions to antibiotic-resistant infections, as well as applications in developing organic disinfectants, sanitizers, and preservative solutions.

Antioxidant and Anti-inflammatory Potential: The leaves' high levels of antioxidants make them a candidate for studying anti-aging effects and managing chronic inflammation-related conditions, such as arthritis or cardiovascular disease. These findings could support their use in nutraceuticals or functional foods.

Anti-ulcer and Gastrointestinal Health: Jamun leaves are known for their anti-ulcer properties. Research could focus on their effects on gastrointestinal health, such as improving digestion, balancing gut flora, or protecting the gastric lining, which could lead to the development of natural treatments for ulcers or gut inflammation.

Skin and Wound Healing: Due to their antibacterial and antioxidant properties, Jamun leaves may have applications in skincare, particularly in wound-healing formulations or anti-acne products. Research could explore topical applications and study the effects on skin conditions like eczema, psoriasis, and minor wounds.

Anti-cancer Potential: Initial studies on the anti-cancer properties of Jamun leaves suggest that their polyphenolic compounds might inhibit or slow cancer cell growth. Research in this area could help develop plant-based treatments or supportive therapies in oncology.

Insect Repellent and Pest Control: Jamun leaves possess compounds with insect-repellent properties, making them a natural candidate for pest control research. Studies could explore their effectiveness in repelling or controlling pests in agricultural settings or in the formulation of eco-friendly mosquito repellents.

Agricultural Applications and Soil Health: The bioactive compounds in Jamun leaves can potentially enhance soil health or act as natural fertilisers when decomposed. Research could study how leaf mulches or extracts impact plant growth, soil fertility, and pest resistance, benefiting sustainable agricultural practices.

Environmental and Ecological Impact: Studying the ecological roles of Jamun leaves, such as their decomposition in soil and interactions with local fauna, could provide insights into their contribution to ecosystem health and biodiversity support, especially in tropical and subtropical regions.

Cosmetic and Personal Care Applications: With their antioxidant and anti-inflammatory properties, Jamun leaves may be suitable for skincare products aimed at anti-aging, skin brightening, or acne treatments. Research could focus on developing natural, leaf-based formulations for cosmetics.

Ethnobotanical Studies and Traditional Medicine: Research on the traditional uses of Jamun leaves across various cultures could preserve valuable ethnobotanical knowledge and inspire modern applications in natural medicine. Comparative studies could examine the leaves, different uses across regions and investigate any new potential applications.

Green Chemistry and Extraction Techniques: Research on optimising the extraction of bioactive compounds from Jamun leaves, using green chemistry or sustainable methods, could benefit both pharmaceutical and cosmetic industries, offering eco-friendly processes to obtain these valuable compounds.

3. Bark:

The bark of the Syzygium cumini (Jamun) tree is often used in herbal medicine for treating sore throat, diarrhoea, and digestive issues, as it has tannins and other astringent compounds.

Phytochemical Composition: Jamun bark contains tannins, flavonoids, triterpenoids, and other polyphenolic compounds. Detailed phytochemical analysis can help uncover the specific bioactive compounds that contribute to its medicinal potential. Research could also explore how these compounds vary across regions or due to environmental factors.

Antidiabetic Potential: The hypoglycemic properties of Jamun bark have been noted in traditional medicine. Studies could investigate how these properties influence glucose metabolism and examine its potential for managing diabetes and insulin sensitivity.

Wound Healing and Dermatological Uses: Jamun bark has long been used for wound healing due to its astringent and antimicrobial properties. Research could explore its effectiveness in topical applications, potentially leading to the development of natural wound-healing creams, ointments, or anti-scarring treatments.

Antioxidant and Anti-inflammatory Properties: The high polyphenol content in the bark suggests strong antioxidant potential. Research in this area could focus on its application in preventing oxidative stress-related diseases and inflammation, especially for conditions like arthritis or chronic skin inflammation.

Antimicrobial and Antifungal Activity: Jamun bark extracts are traditionally used for their antimicrobial effects. Studying these properties can help determine their efficacy against a wide range of bacterial and fungal

pathogens, which could be valuable in developing natural preservatives or disinfectants.

Cancer Research: Certain studies indicate that compounds in Jamun bark may possess anticancer properties. Research could investigate its cytotoxic effects on various cancer cell lines, potentially contributing to the development of plant-based cancer therapies or adjunctive treatments in oncology.

Anti-diarrheal and Gastrointestinal Health: Jamun bark is traditionally used for gastrointestinal ailments like diarrhoea and dysentery. Exploring the bark's effects on the digestive system and its potential to balance gut flora could help develop natural treatments for gastrointestinal issues.

Astringent and Oral Health Applications: Due to its astringent properties, Jamun bark is used traditionally for oral health, particularly in treating gum infections and toothaches. Research could look into developing natural oral hygiene products, such as mouthwashes or tooth powders, that utilise its antibacterial properties.

Cosmetic Applications: Given its antioxidant and anti-inflammatory qualities, research could explore Jamun bark's potential in skincare, especially for anti-aging, acne treatments, and products aimed at reducing hyperpigmentation or scarring.

Environmental and Ecological Impact: Jamun bark could also be explored for its role in traditional natural dyes and tannin extraction. Additionally, research could focus on its ecological role in local ecosystems, such as supporting microbial communities in the soil or contributing to soil stabilisation.

Ethnobotanical and Traditional Medicine Studies: Documenting and validating the traditional uses of Jamun bark can preserve indigenous knowledge and reveal new potential applications. Ethnobotanical studies could explore how different cultures have used Jamun bark, leading to a better understanding of its full medicinal potential.

Biodegradable Natural Dyes and Tannins: Due to the presence of tannins, Jamun bark can be explored as a natural dye source for textiles or leather. This could be particularly valuable in sustainable and eco-friendly industries focused on reducing synthetic chemical use.

Research on these areas would provide a more complete understanding of Jamun bark's bioactive properties and possible applications, especially as the demand for sustainable, plant-based solutions grows across health, environmental, and cosmetic industries.

4. Flowers:

The flower of the Syzygium cumini the tree, commonly known as the Jamun or Indian Blackberry, has various potential research avenues due to its unique chemical composition and medicinal properties. Here are some interesting research areas for Jamun flowers:


- **Phytochemical Analysis:** Jamun flowers are known to contain flavonoids, phenols, tannins, and essential oils. Detailed analysis of these compounds can reveal antioxidant, anti-inflammatory, and antimicrobial properties, which may have potential applications in pharmaceuticals and nutraceuticals.
- **Antimicrobial and Antifungal Properties**: Studies can focus on the efficacy of Jamun flower extracts against various pathogens. With the rise in antibiotic resistance, the antimicrobial properties of natural sources like Jamun flowers may offer new, natural solutions to common microbial infections.
- **Antioxidant Potential:** Research on the flower's antioxidant potential could help in developing anti-aging or protective skin formulations. Antioxidants play a vital role in preventing cellular damage, making them valuable in skincare and in managing oxidative stress-related diseases.
- **Diabetes Management:** The Jamun fruit is well-known for its hypoglycemic properties, and studies could examine if similar properties

exist in the flowers. Research could focus on the potential for using Jamun flower extracts in diabetes prevention or management due to their influence on blood glucose levels.

- **Environmental Benefits and Pollination:** Studies on the ecological role of Jamun flowers, such as their role in supporting pollinator species or their impact on biodiversity, could provide insights into their environmental importance, especially in tropical and subtropical ecosystems.
- **Pharmaceutical and Cosmetic Applications:** With increasing demand for natural ingredients in cosmetics and wellness products, research could explore Jamun flower extracts in formulations like creams, lotions, or health supplements due to their potential health benefits.
- **Nutritional and Functional Foods:** Jamun flowers may also be explored as an additive in functional foods. Research could focus on incorporating their bioactive compounds into food products that offer additional health benefits, especially for consumers looking for natural health-enhancing ingredients.

5. Roots:

Traditionally Roots used in some cultures for treating ailments, though less researched scientifically. Here are some promising areas of research for the roots of the Jamun plant:

Phytochemical Composition: Jamun roots contain alkaloids, glycosides, flavonoids, tannins, and saponins. Analysing these compounds can provide insights into their bioactivity, medicinal potential, and possible applications in pharmaceuticals. Research can also explore how these phytochemicals vary with factors such as soil type, climate, and seasonal changes.

Antidiabetic Potential: The Jamun fruit an koi d seeds are already studied for their hypoglycemic properties. Research on the roots could reveal similar or complementary properties, which may contribute to blood sugar regulation. This could be particularly valuable in traditional and alternative medicine, where plant roots are often used for managing diabetes.

Antimicrobial and Antifungal Activity: Jamun roots have been traditionally used for their antimicrobial properties. Investigating the root extract's effectiveness against bacteria, fungi, and possibly viruses could pave the way for developing natural antimicrobial agents, especially in the face of antibiotic resistance.

Anti-inflammatory and Analgesic Properties: The Jamun root is believed to possess anti-inflammatory properties. Research could focus on the mechanisms through which these properties work, potentially leading to natural treatments for inflammation-related conditions such as arthritis or muscle pain.

Antioxidant Capacity: Like other parts of the plant, Jamun roots may have antioxidant properties. Studying this aspect can help identify potential uses in counteracting oxidative stress, a key factor in many chronic diseases. Such findings could open pathways for its use in functional foods or supplements.

Environmental Applications: The roots of Jamun trees can be researched for soil remediation, erosion prevention, and their role in ecosystems. Their impact on soil health and interaction with microbial communities could be explored in detail, especially given the Jamun tree's adaptability to various soil types.

Traditional and Ethnobotanical Uses: Jamun roots have been used traditionally to treat a range of ailments. Ethnobotanical studies could document traditional knowledge and validate these uses scientifically, preserving valuable indigenous knowledge and possibly uncovering new medicinal applications.

Cancer Research: Early studies suggest that compounds in *Syzygium cumini* have anticancer potential. Research on root extracts could explore whether specific compounds may inhibit or slow down cancer cell growth, offering alternative or complementary therapies in oncology.

Cosmetic and Dermatological Applications: Due to the root's potential antioxidant and antimicrobial effects, research could examine its application in skincare or haircare products. The roots may contribute to formulations aimed at treating skin conditions or enhancing skin health.

Heavy Metal Detoxification: Some plant roots have been studied for their ability to absorb and tolerate heavy metals. Research on the Jamun root's ability to absorb, retain, or help detoxify heavy metals from the soil could be useful in phytoremediation and environmental cleanup projects.

Fields of Study

1. Phytochemistry:

Study of the chemical compounds, especially bioactive components, in different parts of the plant. Investigation into flavonoids, alkaloids, terpenes, anthocyanins, and phenolics.

2. Pharmacology and Toxicology:

Examining the medicinal properties, therapeutic effects, and potential toxicity of extracts.Areas include anti-diabetic, anti-inflammatory, antioxidant, antimicrobial, and anti-cancer effects.

3. Nutritional Studies:

Analysing the fruit's nutritional profile, including vitamin, mineral, and fibre content. Focus on its potential benefits for diet, especially regarding blood sugar regulation.

4. Agricultural and Environmental Studies:

Understanding the cultivation conditions, soil requirements, and pest management. Impact on biodiversity, as Java plum trees support various insect and bird species.

5. Food Science:

Developing products like juices, jams, wines, and dietary supplements from the fruit. Study of shelf-life, preservation techniques, and enhancing palatability.

6. Ethnobotany and Traditional Medicine:

Documenting its traditional uses across cultures for insights into potential pharmacological applications. Studying preparation methods in traditional medicine to explore potential scientific validation.

Additional Areas of Interest

Genetics and Breeding: Breeding for better yield, disease resistance, and nutritional profile. Genetic analysis for understanding adaptation to different climates.

Environmental Impact and Ecosystem Services:

Examining its role in supporting wildlife, improving soil quality, and adapting to climate resilience.

Each of these fields offers a vast range of research opportunities, especially for those interested in the multifaceted uses of Java plum.

Specific research areas on the Java plum (*Syzygium cumini*) often focus on its unique bioactive properties, ecological impact, and applications in food and medicine. Here are some of the targeted research areas:

1. Anti-Diabetic Research

- Area: Studying the seed and fruit extracts for managing blood sugar levels.
- Focus: Effects on insulin sensitivity, glucose metabolism, and glycemic control.
- Methods: In vitro (lab) and in vivo (animal/human) studies to understand active compounds like jamboline and ellagic acid.

2. Antioxidant and Anti-Inflammatory Studies

- Area: Investigating the high antioxidant content, particularly in the fruit peel and pulp.
- Focus: Analysis of anthocyanins, polyphenols, and flavonoids in reducing oxidative stress and inflammation.
- Methods: Using chemical assays (e.g., DPPH, FRAP) and cell culture studies to measure antioxidant capacities.

3. Antimicrobial and Antiviral Studies

- Area: Exploring leaf and bark extracts for antimicrobial and antiviral properties.
- Focus: Testing effectiveness against bacteria (e.g., E. coli, *Staphylococcus aureus*) and potential use as a natural preservative.
- Methods: Microbiological assays and comparing extract effectiveness with synthetic antimicrobials.

4. Cancer Research

- Area: Examining the potential anticancer effects of Java plum compounds.
- Focus: Investigating effects on cell proliferation, apoptosis (cell death), and metastasis.
- Methods: In vitro studies using cancer cell lines (e.g., breast, colon) and in vivo models to assess anti-tumor activity.

5. Nutritional Composition and Food Product Development

- Area: Assessing nutrient profiles and creating food products like jams, juices, and wine.
- Focus: Determining vitamin, mineral, and fibre content and developing value-added products.
- Methods: Nutritional analysis, sensory evaluation, and studying preservation techniques.

6. Genetic and Breeding Studies

- Area: Improving cultivars for disease resistance, yield, and nutritional profile.
- Focus: Genomic studies to understand variations and breed for specific traits.
- Methods: Genotyping, genome sequencing, and traditional breeding combined with genetic markers.

7. Traditional Medicine and Ethnobotanical Research

- Area: Documenting traditional uses across various cultures.
- Focus: Investigating applications in treating diabetes, respiratory conditions, and digestive disorders.
- Methods: Ethnobotanical surveys, interviews, and collaboration with indigenous practitioners.

8. Ecological Impact and Climate Adaptability

- Area: Studying the Java plum's role in ecosystems, its adaptability, and climate resilience.
- Focus: Assessing its benefits in soil improvement, carbon sequestration, and as a food source for wildlife.
- Methods: Field studies in diverse ecosystems, soil and biodiversity assessments, and climate modelling.

9. Toxicological Assessment

- Area: Ensuring safety in medicinal or supplemental use of Java plum extracts.

- Focus: Determining safe dosages, potential toxicity, and side effects, especially for prolonged use.
- Methods: Toxicity assays, animal testing, and dose-response studies for pharmacological safety.

Each of these areas combines advanced lab methods with practical applications, offering diverse avenues for scientists across fields like pharmacology, nutrition, environmental science, and ethnobotany.

Conclusion and Future Prospective Directions

According to the review, the seed of the jamun fruit has a richly-varied composition of bioactive compounds, include-terpenoids, phenolic compounds and saponins with high contents of gallic acid, ellagic acid and hydrolysable tannins.

These compounds are responsible for the extensive biological activities of jamun seeds and their extracts. Jamun seeds appear to be a low-cost source of a natural antidiabetic agent, although their antioxidant, anti-inflammatory antimicrobial potential is becoming more and more appreciated. As modern techniques for the extraction, separation and purification of jamun seeds bioactives are developed, it seems that powder, extracts and fractions may soon be harnessed in the production of functional foods and nutraceuticals intended for people at risk of diabetes, cancer, cardiovascular, hepatic and neurodegenerative diseases, and bacterial and microbial infections.

Range of pharmacological properties is possessed by various extracts of jamun which include antidiabetic, antihyperlipidemic, antihypercholesterolemic, anticancer, cardioprotective, hepatoprotective, neuroprotective, anti-inflammatory, antioxidant, and antimicrobial activities.

Nevertheless, more research is needed to elucidate the molecular mechanisms of the health-beneficial activities of jamun seed compounds. The biological activity of saponins and lignans from jamun seeds, and the bioavailability of bioactive compounds are still poorly understood. In addition, the nutritional value of jamun seeds seems to be still little known, especially in terms of proteins, their amino acid composition and biological value. Clinical trials of jamun seed-based goods on humans, taking into account all safety concerns, will increase the value of jamun seeds for use in the food and non-food industries.

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