

Anti-Diabetic Properties Of *Syzygium Cumini* (Java Plum): A Comparative Review Of Seed And Leaf Extracts"

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Abstract:

Background:

Syzygium cumini (L.) Skeels, commonly known as Java plum or Jamun, is traditionally used in various systems of medicine for the management of diabetes mellitus. The plant is rich in bioactive phytoconstituents, particularly in its seeds and leaves, which may contribute to its antidiabetic potential.

Objective:

This study aims to compare the antidiabetic activity of methanol and aqueous extracts derived from the seeds and leaves of *Syzygium cumini*, with a focus on evaluating their enzyme inhibitory effects relevant to glucose metabolism.

Methods:

Phytochemical screening of the extracts was performed to identify the presence of flavonoids, tannins, alkaloids, and other secondary metabolites. Methanol and aqueous extracts of seeds and leaves were prepared and assessed for their antidiabetic activity using standard *in-vitro* enzyme inhibition assays targeting α -amylase and α -glucosidase.

Results:

Both seed and leaf extracts contained significant levels of flavonoids, alkaloids, and tannins. However, seed extracts particularly the methanol extract exhibited significantly higher inhibitory activity against α -amylase and α -glucosidase compared to the leaf extracts ($p < 0.05$), indicating a stronger antidiabetic potential.

Conclusion:

The results support the traditional use of *Syzygium cumini*, especially its seeds, in managing diabetes. The higher

enzyme inhibitory activity of seed extracts highlights their potential as a promising natural source for developing plant-based antidiabetic agents.

Keywords: *Syzygium cumini*; antidiabetic activity; α -amylase inhibition; α -glycosidase inhibition; methanol extract; diabetes mellitus.

Introduction:

The Java plum (*Syzygium cumini* L.), belonging to the Myrtaceae family, is a tropical fruit tree commonly known as jamun, jambul, black plum, Indian blackberry, or jambolan. The plant's morphological features are depicted below, with the seed and fruit shown in Fig. 1 and the leaves in Fig. 2. It is native to South and Southeast Asia, particularly India, Pakistan, Sri Lanka, and Australia, and has been traditionally recognized for its nutritional as well as medicinal importance. The fruit is a purplish-black drupe rich in anthocyanins and other phenolic constituents; however, it is highly perishable, having a shelf life of only 1-2 days under ambient conditions. Due to this limited storage stability, jamun is frequently processed into various value-added products such as juices, jams, wines, and jellies. [1-3].

Apart from its dietary applications, *Syzygium cumini* is widely recognized in traditional medicinal systems such as Ayurveda, Unani, and Chinese medicine. The typical appearance of the mature fruits is depicted in Fig. 3. Various parts of the plant-including the fruit, seed, leaves, bark, and wood-have been employed for therapeutic uses, especially in the treatment of metabolic and inflammatory conditions [4,5]. The major bioactive constituents identified in different parts of *Syzygium cumini* are summarized in Table 1. The plant exhibits a wide range of phytochemicals, including glycosides, flavonoids, anthocyanins, phenolic compounds, terpenoids, and tannins, along with essential minerals such as calcium, potassium, zinc, chromium, and vanadium [6,7]. The chemical structures of the major phytoconstituents identified in *Syzygium cumini* are presented in Table 2. These compounds are responsible for the plant's antioxidant, anti-inflammatory, antimicrobial, and antidiabetic activities.

Among the different parts of *Syzygium cumini*, the seed and leaf extracts have gained considerable scientific interest due to their antidiabetic potential. The seeds, in particular, are rich in phenolic compounds, alkaloids such as jamboline and jambosine, and flavonoids, which are known to exhibit hypoglycemic and insulin-sensitizing effects [8]. Experimental studies have shown that seed extracts can regulate glucose metabolism, promote insulin secretion, and inhibit carbohydrate-hydrolysing enzymes. Likewise, the leaves are rich in bioactive compounds such as quercetin, ellagic acid, and gallic acid, which further contribute to glucose-lowering effects and the reduction of oxidative stress [9, 10].

Diabetes mellitus is a long-term metabolic disorder marked by elevated blood glucose levels and impaired insulin function, and it remains a significant global health challenge. In recent years, there has been growing interest in plant-based therapies as safer and more affordable alternatives or supportive options alongside conventional antidiabetic medications. In this regard, *Syzygium cumini* has emerged as a promising natural source of bioactive compounds that can help regulate blood glucose levels through multiple pathways, including

enhancing antioxidant defenses, inhibiting key enzymes involved in glucose metabolism, and protecting pancreatic β -cells [11,12].

In light of the expanding research on *Syzygium cumini*, there is a clear need to consolidate and evaluate the existing evidence regarding the antidiabetic efficacy of its various plant parts. This review, therefore, aims to provide a critical comparison of the antidiabetic potential of seed and leaf extracts of *Syzygium cumini*, with particular emphasis on their phytochemical profiles, mechanisms of action, and overall therapeutic relevance.

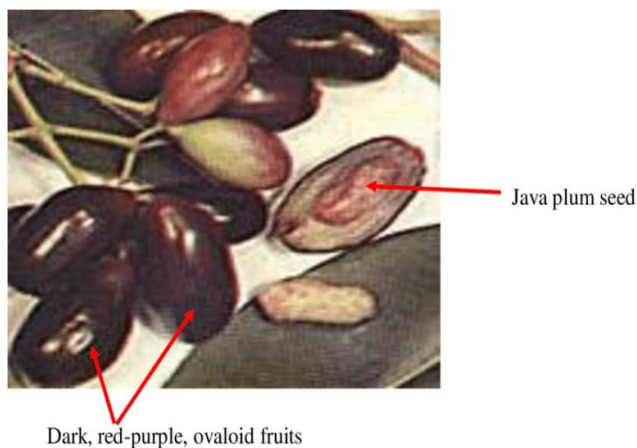


Figure 1: Seeds and fruits of *Syzygium cumini*

Figure 2: Leaves of *Syzygium cumini*



Figure 3: Fruit of *Syzygium cumini*

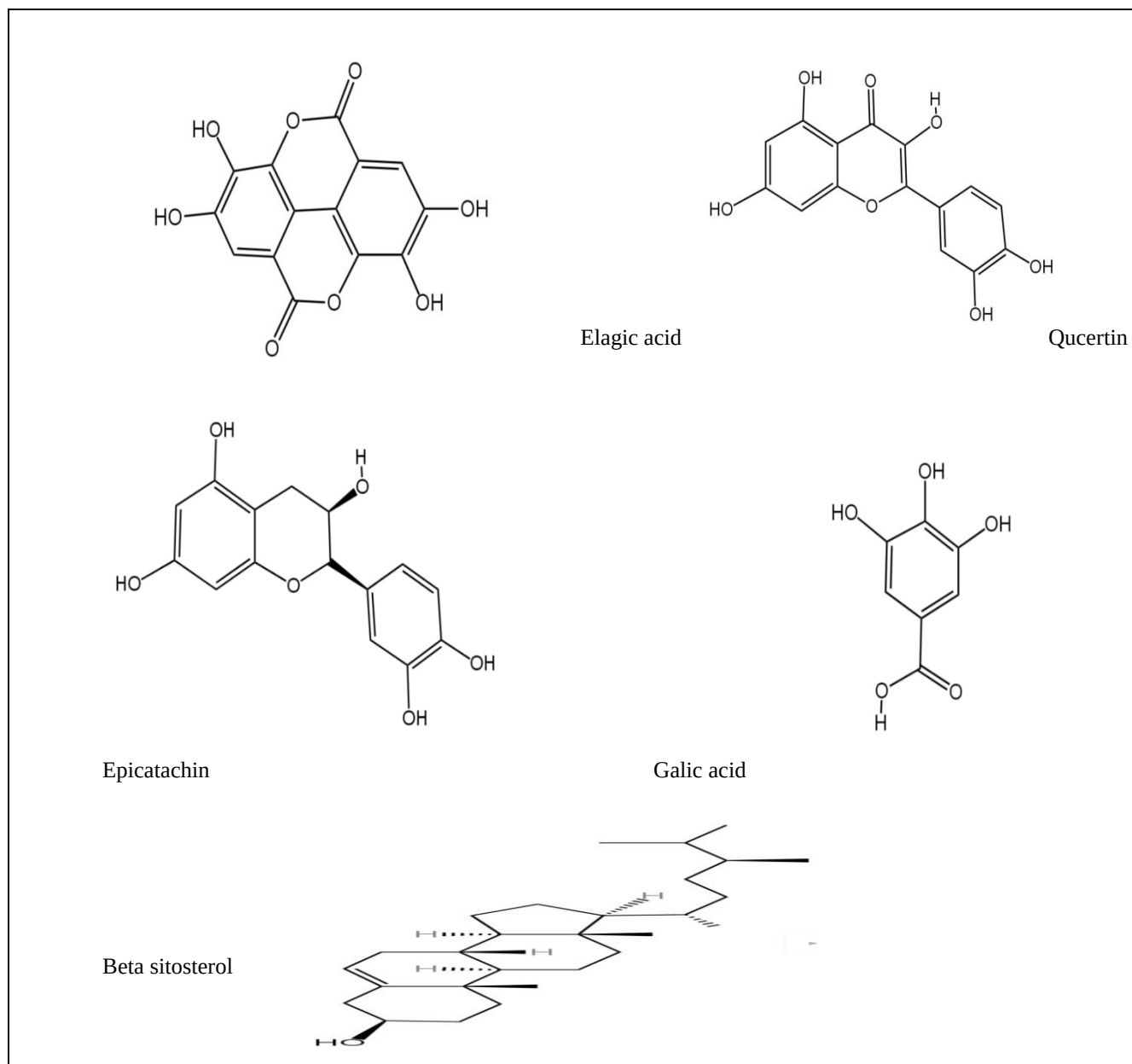
TABLE 1: Major Bioactive constituents of *Syzygium cumini*

Sample Characteristics	Collected From	Main Bioactive Constituent	Reference
Dry Jamun seed powder	Maharashtra, India	Phenolic compounds (TPC) (mg/g DE) Tannic acid: 188.5 - 5.6 Gallic acid: 90.8 -2.7 Ellagic acid: 36.0 - 1.1 Caffeic acid: 26.07 -0.8 Catechin: 9.05-0.27	[14]

		Quercetin: 1.54-0.04 Epicatechin: 0.42-0.01 p-coumaric acid: 0.26 - 0.03 TPC (mg GAE/g DE): 415-10 TFC (mg/g DE): 44.1- 1.4	
Jambolana fruits, in the mature stage	Viçosa, Minas Gerais, Brazil	TPC (mg GAE/g): 22.59 -0.79	[15]
Jamun seed extracts	National Institute of Pharmaceutical Education and Research's gardens, S.A.S. Nagar, India	TPC (g/GAE): 0.07-0.12. Total anthocyanins (g): not detected Soluble sugar (g): 0.001. Free ellagic acid (mg): 36.34-44.25.	[16]
Jamun seed coat (fresh weight basis) a and ethanol extract of the seed coat (dry weight)	Three locations within Thiruvananthapuram, Kerala province, south India	Total free phenol (g/kg): 8.1-0.8 a and 270.0-3.4 b. Flavonoids(g/kg): 0.41-0.08 and 25.30-0.37	[17]
Fresh Jamun seeds, 4 different extracts (ethanol, aqueous, ethyl acetate, acetone)	Tiruchirappalli, India	TPC contents (mg GAE/g) Ethanol: 471.67-29.3 Aqueous: 168.33-7.64 Ethyl acetate: 375- 40.93 Acetone: 230-25 TFC contents (mg quercetin/g) Ethanol: 114.88-5.36 Aqueous: 65.31-1.77 Ethyl acetate: 138.26 -6.58 Acetone: 103.86-3.67 Antioxidant activity (IC50 values, g/mL) Aqueous: 25.02 Ethanol: 24.53 Acetone: 24.29 Ethyl acetate: 24.42	[18]
Jaman fruit parts	Potowar region of Pakistan	TPC (mg GAE/g): 4812.03 - 10.67 TFC (mg quercetin/100 g): 2380 -5.08 Anthocyanin(mg cyanidin 3-rutinoside equivalent/100g): 272.26-6.04	[19]
Jamun seed extracts	Different natural habitats, India	Phenolic substances (g/g plant material, dry weight) Gallic acid: 646 Quercetin: 98 Kaempferol: 59 Ellagic acid: 38 Caffeic acid, ferulic acid, and rutin: not shown AOA: 85.49-0.8% TPC: 108.79-1.0 mg/g	[20]
Jamun seed ethanol/water extract (80:20 v/v)	Central Sericulture Research and Training Institute, Central Silk Board, Mysore, India	TPC (mg GAE/g dry weight): 55.54-2.06 TFC (mg CE/g dry weight): 5.09-0.28	[21]

		DPPH content (IC50 values):0.40mg/mL TAC: 3.33-0.10 mm GAE 1g of extract	
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TABLE 2: Chemical structures of key phytoconstituents of *Syzygium cumini*



ETHODOLOGY:

PREPARATION AND EXTRACTION PROCEDURE OF *SYZYGIUM CUMINI*

1) Seeds:

Approximately 50 g of dried *Syzygium Cumini* powder was extracted using 50% methanol at a material-to-solvent ratio of 1:10 (w/v). The mixture was macerated at room temperature ($28 \pm 2^\circ\text{C}$) in a water bath shaker set at 100 rpm, followed by filtration through Whatman filter paper. This extraction process was repeated three times. The pooled extracts were then concentrated using a rotary vacuum evaporator to remove the methanol, resulting in a solvent-free extract. The obtained extract was further partitioned with ethyl acetate using a separating funnel. Subsequently, half of the ethyl acetate fraction was subjected to hydrolysis with 7% H_2SO_4 (1:10 v/v) under reflux for four hours. Ultimately, three fractions were obtained the aqueous fraction, the ethyl acetate fraction, and the hydrolysed ethyl acetate fraction [23].

The extraction was performed using a standard laboratory Quick fit distillation setup consisting of a 1 L distillation flask and a condenser. Continuous stirring was maintained at 700 rpm using a Teflon-coated magnetic stirrer. Once the desired temperature was attained, an appropriate volume of distilled water along with a measured quantity of dried *Syzygium cumini* (jamun) seed powder was introduced into the flask. The mixture was then extracted for a specified period. Upon completion, the extract was allowed to cool to room temperature ($25 \pm 1^\circ\text{C}$) and was subsequently filtered through Whatman No.1 filter paper to obtain a clear aqueous extract [24].

Approximately 300 mL of petroleum ether (boiling range: $40\text{--}60^\circ\text{C}$) was added to a round-bottom flask. A thimble containing 10 g of crushed seed material was placed in the Soxhlet apparatus, and the extraction was carried out at a 60°C temperature for about 30 minutes. After extraction, the thimble was removed, dried in an oven, cooled in a desiccator, and weighed. The process was repeated until maximum extraction was achieved. A similar procedure was also performed using 5 g of seed sample. Upon completion of the extraction, the resulting mixture (miscella) was subjected to solvent recovery. After cooling, the extracted oil was collected and stored in a vial [25].

A known quantity of powdered plant material was placed in a round-bottom flask and extracted with methanol under reflux on a water bath at 70°C for 1.5 hours. This extraction was repeated twice using fresh solvent each time. The extracts were filtered through filter paper, and the combined methanolic extracts were concentrated under vacuum (400 mmHg) at 60°C to obtain a dry residue. This residue was then subjected to successive extraction with demineralized water under similar reflux conditions (two extractions, each for 1.5 hours). The aqueous extracts were pooled, concentrated, and dried under vacuum (600 mmHg) at 75°C to yield the successive water extract.[26]

Extraction was carried out using an ultrasonicator, where 1 g of jamun seed powder was treated with 30 mL of ethanol to optimize extraction conditions. After extraction, the samples were centrifuged at 8000 RPM for 15 minutes at 4°C . The supernatant was then concentrated using a rotary evaporator to remove the solvent. The obtained extract was stored at -20°C until further analysis [27].

A total of 200 g of *Syzygium cumini* seed powder was placed in a white cotton bag and loaded into a Soxhlet apparatus. The material was extracted with 1000 mL of petroleum ether for 24 hours. The process was repeated twice using the same procedure to ensure complete extraction. The combined extracts were then filtered and concentrated by evaporating the solvent at 40°C until dryness. The resulting concentrated extract was

collected in a 20 mL vial and weighed, yielding 20.92 g of petroleum ether extract. The extract was subsequently stored for further experimental use [28].

2) Leaves:

50 g of dried leaf powder was soaked individually in 250 mL of each of the following solvents: distilled water, ethanol, methanol, and ethyl acetate. After being covered, the five flasks were left at room temperature for approximately a week. Whatman filter paper (no.1) was then used to filter the distinct solutions. To create a gummy appearance, each filtrate was gathered in a round-bottom flask and allowed to evaporate. Each solvent's gooey material was then allowed to dry at ambient temperature. For future use, the powdered extracts were weighed and kept at 400°C. From 50 g of dried leaf powder, the extraction yields were as follows: 7 g (14%) for the aqueous extract, 7.8 g (15.6%) for the ethanolic extract, 7.3 g (14.6%) for the methanolic extract, and 6.9 g (12.6%) for the hexane extract [29].

Fresh Java plum leaves (approximately 2.5 kg, equivalent to 1 kg dry weight) were thoroughly washed, cut into small pieces, and shade-dried. After complete drying, the leaves were ground into a coarse powder. To ensure complete extraction, maceration was performed for three days at room temperature in a dark container using 96% ethanol at a 1:10 ratio. This was followed by an additional three-day re-maceration. The combined extracts were then concentrated under reduced pressure using a rotary evaporator at 40°C, yielding approximately 48 g of a pure, viscous extract [30].

Five kilograms of *Syzygium cumini* (Jamblang) leaves were extracted using the maceration technique. Ethanol was selected as the solvent due to its cost-effectiveness, widespread use in the Indonesian herbal industry, and its efficiency in extracting polar compounds. Notably, polar constituents such as myricetin and brazilin were identified in *Syzygium cumini*. The ethanolic extract was subsequently concentrated using a rotary evaporator to obtain the crude extract, which was further condensed using a water bath. The final extract was stored at room temperature for future use [31].

An ethanolic extract of *Syzygium cumini* leaves was prepared by mixing 10 g of powdered leaves with 100 mL of ethanol. The mixture was stirred for 90 minutes and then kept in the dark for 72 hours. Afterward, it was filtered, concentrated using a rotary evaporator, and dried in an oven at 37°C for 24 hours. The extraction yield was found to be 21%. The dried extract was stored at room temperature in a desiccator for further use [32].

Pharmacological activities of *Syzygium cumini*

The pharmacological properties of *Syzygium cumini* have been extensively investigated and supported by both experimental and clinical studies. The mechanisms of action are illustrated in Fig. 5. Several experimental studies have demonstrated that different parts of *Syzygium cumini* especially the fruits, seeds, and stem bark possess significant hypoglycaemic and antihyperglycemic activities. Both clinical and preclinical investigations confirm that the seeds and fruits are effective in lowering blood glucose levels and improving glucose tolerance [33]. Despite considerable advancements in modern diabetic therapies, natural remedies derived from *Syzygium cumini* continue to receive attention due to their multi-targeted mechanisms and minimal side effects.

The protective effect of *Syzygium cumini* seed kernel extract on tissue antioxidant status was evaluated in male Wistar rats with streptozotocin induced diabetes. Diabetes was induced by a single intraperitoneal injection of STZ (approximately 55 mg/kg), leading to insulin deficiency and hyperglycemia. The diabetic rats were then treated orally with an ethanolic extract of *Syzygium cumini* seed kernel, and results were compared with a group receiving glibenclamide, a standard antidiabetic drug. Various biochemical and physiological parameters were assessed, including blood glucose, glycosylated hemoglobin (HbA1c), plasma insulin, body weight, and total hemoglobin levels. Antioxidant status was evaluated by measuring the activities of glutathione peroxidase, catalase, and superoxide dismutase (SOD), along with levels of reduced glutathione (GSH), lipid peroxidation, and hydroperoxides in liver and kidney tissues. Histopathological examinations were also performed to assess structural changes in these organs. Administration of *Syzygium cumini* seed kernel extract in diabetic rats resulted in a marked improvement in antioxidant enzyme activities, reduction in lipid peroxidation, normalization of glucose and insulin levels, and preservation of tissue architecture. [34]

In this study, the antihyperglycemic potential of *Eugenia jambolana* (EJ) was evaluated using diabetic rodent models induced by streptozotocin and alloxan. Both male and female albino mice (30-50 g) and albino Wistar rats (150-200 g) were used. Diabetes of varying severity was induced using different doses of diabetogenic agents: a single intravenous dose of alloxan (32 mg/kg) produced mild diabetes in rats, while a higher dose (120 mg/kg) induced moderate diabetes. Severe diabetes in mice was induced by an intraperitoneal injection of STZ (150 mg/kg). Animals were selected based on elevated plasma glucose levels (>175 mg/dL for mild, >250 mg/dL for moderate, and >300 mg/dL for severe diabetes). Seed kernel extracts of *Eugenia jambolana* were prepared in 1% carboxymethylcellulose and administered orally at doses of 50, 100, and 200 mg/kg/day for aqueous and alcoholic extracts, and 100-200 mg/kg/day for lyophilized powder. Treatment commenced 48 hours after diabetes induction and continued for 21 days in rats and 50 days in mice. Antidiabetic efficacy was assessed by measuring plasma glucose levels, activities of key hepatic carbohydrate-metabolizing enzymes (glucokinase, hexokinase, glucose-6-phosphatase, and phosphofructokinase), and glycogen content in the liver, heart, brain, and skeletal muscles. Haematological parameters, including RBC, WBC, haemoglobin (Hb), haematocrit (HCT), mean corpuscular volume (MCV), and mean corpuscular haemoglobin (MCH), were also evaluated. Statistical analysis was performed using one-way ANOVA. The findings demonstrated that *Eugenia jambolana* significantly reduced hyperglycemia and restored normal activity of carbohydrate-metabolizing enzymes in both alloxan and STZ-induced diabetic models [35]

Syzygium cumini is regarded as an effective natural remedy for the management of diabetes. Its seeds contain alkaloids such as jamboline and jambosine, which are believed to enhance insulin secretion, reduce glucose release into the bloodstream, and improve carbohydrate metabolism. Diabetes mellitus is a chronic endocrine disorder characterized by persistent hyperglycemia resulting from impaired insulin secretion, often accompanied by disturbances in lipid and protein metabolism. [36].

Syzygium cumini seeds contain approximately 6.3-8.5% protein and are rich in various bioactive compounds, including quercetin and rutin, which possess strong antioxidant properties. These constituents play an important role in regulating glucose metabolism, enhancing insulin sensitivity, and mitigating oxidative stress under diabetic conditions. As a result, *Syzygium cumini* seed extracts exhibit antidiabetic, antihyperlipidemic,

hepatoprotective, and antioxidant activities, thereby supporting overall metabolic health. [37]. Other pharmacological activities of *Syzygium cumini* reported in experimental studies are summarized in **Table 3**.

Table 3: Other pharmacological Activities of *Syzygium cumini*

Biological Properties	Animal Model	Experimental Design	References
Antidiabetic effect: There was a significant decrease in blood glucose and HbA1c levels, and an increase in serum insulin levels and hemoglobin, toward normal levels. Hypolipidemic effect: the blood levels of total cholesterol, triglyceride, and LDL-c were reduced considerably, and an increase in the levels of HDL-c were observed. Antioxidant activity: The levels of superoxide dismutase, catalase, glutathione peroxidase, reduced glutathione, and Thio barbituric acid reactive substances were reversed significantly to near normal. Hepatoprotective activity: The serum glutamic oxaloacetic transaminase and serum glutamic pyruvic transaminase significantly decreased.	Male Wister albino rats (150–200 g), 2-3 months of age	4 weeks; 4 groups (n = 6) (1) Control-citrate buffer (0.1, pH 4.5; i.p) (2) Positive control-STZ-induced diabetic rats. (3) STZ-induced diabetic rats + 200 mg <i>Syzygium cumini</i> /kg b.w. orally, once weekly. (4) STZ-induced diabetic rats + 200 mg <i>C.zeylanicum</i>/kg b.w. orally, once weekly.	[38]
Antiamnesic activity: Improved cognitive deficit, decreased the time required for a successful labyrinth test, ameliorated memory impairment improves the response to oxidative stress, inhibits acetylcholinesterase activity. Thus, it is comparable to the effect of piracetam. Dose dependency: Better results with higher dosage.	Male albino Wistar rats (150-200 g), 6-8 weeks of age	8 days; 5 groups (n = 6) (1)Control-only vehicle (2) Positive control-only Vehicle + scopolamine (1mg/kg, i.p.) induced amnesia. (3) Standard drug-piracetam (200mg/kg,i.p) +scopolamine. (4) Methanolic extract of <i>Syzygium cumini</i>(200mg/kg,p.o) +Scopolamine. (5) Methanolic extract of <i>Syzygium cumini</i>(400mg/kg,p.o) + scopolamine.	[39]
Antidiabetic effect: Low blood glucose concentrations were observed in both treated groups after 60 days. Better results were observed in the seed-treated rats. The diet	Sprague-Dawley rats	Normal: 60 days; 3 groups (n = 5): (1) Control (2) 3% of lyophilized seed powder (3) 3% of lyophilized pulp powder. Hyperglycemic:	[40]

affected insulin levels momentarily.		60 days; 3 groups (n = 5). (1) Control + 40% sucrose. (2) 3% of lyophilized seed powder + 40% sucrose. (3) 3% of lyophilized pulp powder + 40% sucrose.	
Antidiabetic effect: Glucose levels were reduced significantly and serum insulin levels also improved. Hypolipidemic effect: a reduction in total cholesterol, LDL-c, and serum triglyceride, and increased serum HDL-c were observed. Hepatoprotective activity: The extract treatment did not show any statistically significant reduction in serum creatinine and serum urea. However, the protein concentration increased significantly, even more than that of the rats treated with the gliclazide, and a reduction in the ALT, AST, ALP, and bilirubin levels was observed. A liver section revealed normal hepatic tissue.	Wistar albino rats of either sex (230-250 g), 8-10 weeks of age with diabetes (Alloxan=150 mg/kg).	14 days; 5 groups (n = 6): (1) Control-only vehicle. (2) Diabetic control-only vehicle. (3) Diabetic + methanolic extract of <i>Syzygium cumini</i> seeds (100 mg/kg, p.o.) (4) Diabetic + methanolic extract of <i>Syzygium cumini</i> seeds (200 mg/kg, p.o.) (5) Diabetic + gliclazide (25 mg/kg, p.o.).	[41]
Antidiabetic effect: There was a significant reduction in serum glucose, insulin, and HOMA-IR. The supplementation had a protective effect on-cells of diabetic rats, evidenced by an increased architecture of nuclei and mitochondria. The effect was dose dependent. Hypolipidemic effect: The levels of total cholesterol, triglyceride, and LDL-c were reduced significantly, and an increased level of HDL-c was observed. Antioxidant activity: The levels of superoxide dismutase, catalase, and glutathione peroxidase increased. The contents of Thio barbituric acid reactive	Male Wistar albino rats (150-200 g) 12-14 weeks old (STZ:40 mg/kg)	21 days; 5 groups (n = 10) (1) Control-saline (5.0 mL/kg, p.o.) (2) Positive Control-diabetic rats + saline. (3) Diabetic + <i>Syzygium cumini</i> (100mg/kg; 200 mg/kg; 400 mg/kg). (4) Diabetic + Aegle marmelos (500 mg/kg) + <i>Syzygium cumini</i> (200 mg/kg) (5) Diabetic + Metformin(100mg/kg).	[42]

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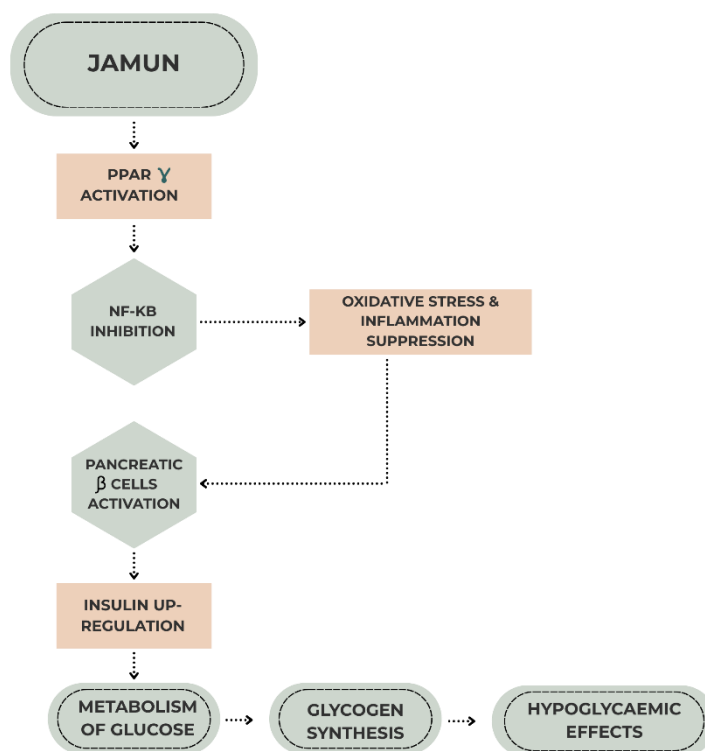


Figure 5: Mechanism action of *Syzygium cumini* in diabetic management

Syzygium cumini exerts its antidiabetic effects by activating PPAR- γ and inhibiting NF- κ B, thereby reducing oxidative stress and inflammation. This modulation supports the activation and functional improvement of pancreatic β -cells, leading to enhanced insulin secretion. The increased insulin availability facilitates glucose utilization and promotes glycogen synthesis, ultimately resulting in a hypoglycemic effect that aids in the regulation of blood glucose levels.

CONCLUSION

Syzygium cumini (L.) demonstrates significant potential as a natural therapeutic agent for the management of diabetes mellitus. Both seed and leaf extracts exhibit notable biological activities, largely attributed to their rich phytochemical composition, including flavonoids, alkaloids, tannins, and phenolic compounds. Among the various extracts, the methanolic seed extract appears particularly effective in controlling postprandial hyperglycemia, primarily through the inhibition of key carbohydrate-digesting enzymes such as α -amylase and α -glucosidase. This enhanced activity may be associated with a higher concentration of phenolic constituents, including gallic acid, ellagic acid, and quercetin derivatives.

Overall, the findings emphasize the importance of *Syzygium cumini* based phytopharmaceuticals and nutraceuticals as promising complementary approaches for diabetes management. However, further research is necessary to isolate and characterize the active compounds, elucidate their precise molecular mechanisms, and validate their safety and efficacy through comprehensive *in vivo* studies and clinical trials. Additionally, the cultivation and utilization of *Syzygium cumini* present a sustainable, plant-based strategy for addressing metabolic disorders, particularly diabetes and its associated complications.

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CONFLICT OF INTEREST

The authors confirm that there are no conflicts of interest associated with the creation or publishing of this work. The outcome of this review was not influenced by any financial, personal, or professional connections; the article was prepared and examined transparently.

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DATA AVAILABILITY STATEMENT

This published article and its accompanying sources contain all the data collected or analyzed during this investigation. The supporting data is derived from already published research and cited literature; no new datasets were created.

COMPLIANCE WITH ETHICAL STANDARDS

This article's contributors did not conduct any research on humans or animals. All information provided is based on previously published studies and secondary literature sources, which have been properly cited and recognized.

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