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# Therapeutic Potential Of Syzygium Cumini Seed Powder In Type 2 Diabetes Mellitus: A Review Of Clinical Evidence

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***Abstract:*** The therapeutic potential of *Syzygium cumini* (black plum or Jamun) seed powder (JSP) in managing type 2 diabetes mellitus (T2DM) is widely recognized in traditional medicine, largely attributed to its rich phytochemical composition of polyphenols, flavonoids, and tannins. These compounds confer a range of benefits. Mechanistically, JSP appears to exert its effects through multifaceted pathways: it can stimulate insulin secretion from pancreatic beta-cells, improve peripheral insulin sensitivity, inhibit key carbohydrate-digesting enzymes (like alpha-amylase and alpha-glucosidase), and actively mitigate oxidative stress-induced beta-cell damage via its significant antioxidant capacity.

A review of available clinical evidence indicates that limited human studies support these preclinical findings. Trials have reported promising outcomes, including notable reductions in both fasting and postprandial blood glucose levels in T2DM patients. Furthermore, JSP consumption has been associated with improved lipid profiles, addressing the common comorbidity of dyslipidemia. While these results suggest significant potential as a complementary therapy, the existing clinical data remains sparse. Further rigorous, large-scale, and well-controlled clinical trials are imperative to standardize the effective dosage, establish long-term efficacy, and confirm safety across diverse patient populations.

***Key words:*** *Syzygium cumini*, type 2 diabetes mellitus, black plum, phytochemicals, insulin sensitivity, antioxidants.

## I. INTRODUCTION

The formation of reactive oxygen species (ROS) is an inevitable byproduct of aerobic metabolism, arising predominantly during mitochondrial respiration, enzymatic oxidation processes, and immune defense responses. Under normal physiological conditions, ROS function as key signaling molecules, regulating pathways related to cell proliferation, programmed cell death, and immune activity. When produced in excess, however, they surpass the body's antioxidant defenses, creating a state of oxidative stress. This imbalance can trigger lipid peroxidation, protein modification, and DNA injury, ultimately impairing cellular integrity and contributing to the onset of several chronic illnesses such as cardiovascular disease, diabetes, hypertension, cancer, and neurodegenerative disorders [1–4].To maintain redox balance, the body depends on an elaborate antioxidant system that includes enzymatic agents such as catalase, superoxide dismutase, and glutathione peroxidase, along with non-enzymatic compounds like vitamins C and E, carotenoids, and glutathione. Nevertheless, during sustained oxidative stress, these endogenous defenses may prove inadequate, underscoring the importance of dietary antioxidants from external sources [5,6]. In this regard, phytochemicals—especially polyphenols and flavonoids—are gaining considerable attention for their ability to neutralize free radicals, chelate pro-oxidant metals, and modulate redox-dependent pathways, thereby reducing the risk of degenerative diseases [7,8].

*Syzygium cumini* (syn. *Eugenia jambolana*), commonly known as Jamun, black plum, or Java plum, is a tropical tree belonging to the family Myrtaceae. Native to the Indian subcontinent and now cultivated widely across Asia, Africa, and South America, the plant is valued both as a fruit crop and for its ethnomedicinal applications. In Ayurveda, Siddha, and Unani medicine, its fruits, bark, leaves, and especially seeds have long been used in the management of digestive ailments, wounds, diabetes, and cardiovascular conditions [1,5,9]. India is among the leading producers of Jamun, with major cultivation centers in Maharashtra, Uttar Pradesh, Tamil Nadu, and Gujarat [4].Chemical investigations of *S. cumini* seeds highlight their richness in secondary metabolites, including alkaloids (e.g., jambosine), phenolic acids (gallic acid, ellagic acid), hydrolyzable tannins (corilagin, ellagitannins), flavonoids (quercetin, myricetin), glycosides, and phytosterols such as β-sitosterol [1,2,7,8]. These bioactive compounds have been associated with diverse pharmacological effects, ranging from antioxidant and anti-inflammatory activity to antidiabetic, antimicrobial, hepatoprotective, and neuroprotective properties [3,8,10]. Notably, the antidiabetic potential of Jamun seed extracts has been the most extensively researched, with evidence suggesting they improve insulin sensitivity, regulate carbohydrate metabolism, and reduce hyperglycemia [3,9,10,12]. The isolation of such phytochemicals has traditionally relied on conventional methods like Soxhlet extraction, maceration, and percolation. Although widely used, these techniques are time-intensive, solvent-demanding, and prone to degradation of heat-sensitive constituents. Recent advancements in green extraction technologies—such as ultrasonication-assisted, microwave-assisted, and supercritical fluid extraction—have improved efficiency, shortened processing times, and better preserved the bioactivity of compounds [4,7,13].

In light of the rising incidence of oxidative stress–related disorders and the limitations of synthetic therapeutics, *S. cumini* seeds offer promising potential as a natural reservoir of medicinal compounds. Despite their established traditional use and growing scientific validation, further systematic studies are essential to clarify mechanisms of action, refine extraction approaches, and develop standardized formulations for therapeutic application.This review, therefore, seeks to consolidate current knowledge on the phytochemistry, extraction strategies, and pharmacological significance of *Syzygium cumini* seeds, highlighting their role as a valuable source of natural antioxidants and bioactive agents in the prevention and management of chronic diseases

## II. Overview of Syzygium cumini and its phytochemistry

A perennial evergreen tree belonging to the Myrtaceae family, Syzygium cumini (L.) Skeels is also known as jamun, black plum, java plum, or Indian blackberry. This native of the Indian subcontinent is now found in tropical and subtropical regions of Asia, Africa, and South America because of its varied uses and adaptability (14). With a dense canopy of glossy, opposite leaves and clusters of tiny, fragrant blooms that produce oval berries that range in color from green when immature to deep purple-black when ripe, the tree can reach a height of 20 meters (15).

Jamun has been highly valued in traditional medicine systems such as Ayurveda, Unani, and Siddha for its diverse therapeutic applications, particularly in the management of “madhumeha” (diabetes mellitus), digestive disorders, and inflammation (14),(16). Seeds, pulp, leaves, bark, and roots are among the various plant parts that are utilized for functional, nutritional, and therapeutic purposes. Apart from its potential medical uses, the fruit is either eaten raw or processed into nutraceutical compositions, fermented drinks, jams, jellies, and juices (15),(17).

## III. A Profile of Phytochemistry:

The vast and diverse phytochemical content of S. cumini is closely associated with its reputation as a medicinal herb. The plant's antibacterial, anti-inflammatory, antidiabetic, and antioxidant qualities have been linked in recent phytochemical studies to the presence of polyphenols, flavonoids, anthocyanins, tannins, terpenoids, organic acids, and vital minerals (18)(19).

### 3.1. Polyphenols and Flavonoids

Seeds, leaves, and fruit pulp contain abundant flavonoids such as quercetin, kaempferol, myricetin, and their glycosides, along with phenolic acids including gallic and ellagic acids (18)(16). These compounds possess strong free radical-scavenging capacity and are implicated in modulating carbohydrate metabolism by inhibiting key digestive enzymes like α-amylase and α-glucosidase (19).

### 3.2. Anthocyanins

The intense purple hue of ripe jamun fruit is due to anthocyanins such as delphinidin-3,5-diglucoside, petunidin-3,5-diglucoside, and malvidin-3,5-diglucoside (15). These pigments contribute to antioxidant and

anti-inflammatory activities and are known for potential cardiovascular and neuroprotective effects. Their concentration is highly dependent on fruit maturity and post-harvest handling (17).

### 3.3. Tannins and Ellagitannins

Jamun seeds are particularly rich in hydrolyzable tannins and ellagitannins, with ellagic acid being a major component (18). These compounds not only provide astringency but also demonstrate antimicrobial and enzyme-inhibitory properties, supporting their traditional use in glycemic control.

### 3.4. Terpenoids and Essential Oils

Leaves and bark contain triterpenoids such as betulinic acid, oleanolic acid, and ursolic acid, along with volatile oils rich in sesquiterpenes and monoterpenes (18)(16). These are associated with anti-inflammatory, hepatoprotective, and antimicrobial activities.

### 3.5. Organic Acids, Sugars, and Minerals

Jamun fruit provides citric, malic, and oxalic acids, simple sugars (glucose, fructose), and essential minerals including calcium, potassium, magnesium, and iron (15). These constituents contribute to both nutritional value and palatability.

## IV. Phytochemical Variability

The phytochemical composition of S. cumini varies considerably depending on geographical origin, cultivar, soil composition, climate, maturity stage, and processing methods (17)(20). For example, anthocyanin levels peak at full ripeness, whereas tannin content is higher in immature seeds. Processing methods such as drying, milling, or fermentation can significantly influence bioactive compound stability. Standardization of extraction and processing conditions is therefore essential for developing consistent medicinal and functional products.

## V. Mechanism of Anti-Diabetic Action of *Syzygium cumini* (Jamun) Seeds

*Syzygium cumini* seeds exert anti-diabetic effects through multi-targeted mechanisms including inhibition of carbohydrate-digesting enzymes, antioxidant and anti-inflammatory activity, and modulation of glucose metabolism and insulin sensitivity.

### 5.1. Inhibition of Carbohydrate-Digesting Enzymes

Jamun seed extracts are rich in polyphenols such as gallic acid, kaempferol, Jambo line, ellagic acid, and hydrolysable tannins, which inhibit α-glucosidase and α-amylase—the key enzymes responsible for the breakdown of complex carbohydrates into glucose (21–23).

By competitively binding to the active sites of these enzymes, these phytochemicals delay starch hydrolysis, thereby lowering postprandial glucose levels (21,22). Molecular docking studies confirm strong hydrogen bonding between gallic acid/kaempferol and α-glucosidase catalytic residues, producing lower $IC_{50}$ values than acarbose, a standard antidiabetic drug (22).

### 5.2. Antioxidant and Anti-Inflammatory Effects

Hyperglycaemia induces oxidative stress and inflammation, accelerating pancreatic β-cell dysfunction and insulin resistance (24,25). Flavonoids and phenolic acids in Jamun seeds increase antioxidant defences by upregulating glutathione (GSH), superoxide dismutase (SOD), and catalase, while reducing lipid peroxidation products such as malondialdehyde (MDA) (24,25). They also downregulate inflammatory pathways by suppressing nuclear factor kappa B (NF-κB) activation, leading to decreased expression of tumour necrosis factor-alpha (TNF-α), cyclooxygenase-2 (COX-2), and inducible nitric oxide synthase (iNOS) (4,5). Activation of the nuclear factor erythroid 2–related factor 2 (Nrf2) pathway further promotes cytoprotective gene expression, protecting β-cells from oxidative injury (25).

### 5.3. Modulation of Glucose Metabolism and Insulin Sensitivity

Kaempferol, myricetin, and other flavonoids in Jamun seeds enhance insulin receptor signalling and glucose uptake (23,25). This occurs through improved insulin receptor substrate (IRS) phosphorylation and PI3K/Akt activation, which triggers GLUT4 translocation in skeletal muscle and adipose tissue (23,25). These compounds also protect β-cells from apoptosis by modulating mitochondrial pathways and inhibiting caspase activation (25). Animal model studies show that Jamun seed supplementation lowers fasting blood glucose, improves oral glucose tolerance, and corrects dyslipidaemia by lowering triglycerides and LDL cholesterol while increasing HDL cholesterol (26).

### 5.4. Integrated Glycemic Control

The combined effects of enzyme inhibition (short-term) and antioxidant, anti-inflammatory, and insulin-sensitizing actions (long-term) lead to significant improvements in glycaemic control, β-cell preservation, and prevention of diabetic complications (21–26).

## VI. Clinical evidence for antidiabetic activity of *Syzygium cumini* seeds

A randomized, double-blind, placebo-controlled trial in India involving 99 adults with poorly controlled type 2 diabetes assessed the effect of *S. cumini* seed powder (5 g twice daily) over 90 days. Compared with placebo, the intervention group showed progressive fasting blood glucose (FBG) reductions of approximately 9%, 18%, and 30% at 30, 60, and 90 days, respectively, as well as postprandial glucose (PPG) reductions of 8%, 15%, and 22%. Glycated haemoglobin (HbA1c) decreased from 8.99 ± 1.39% to 8.31 ± 1.40% (absolute −0.68%; $P < 0.05$), while the placebo group's HbA1c rose slightly. No major adverse events were reported [27]. In a single-blind, randomized, placebo-controlled trial in 52 individuals with prediabetes, administration of Maghz-e-Jamun seed powder (4.5 g twice daily) for 12 weeks produced significant FBG reductions by day 28, which continued through day 84 (≈ 105.7 → 92.1 mg/dL). HbA1c decreased from 5.82 ± 0.09% to 5.55 ± 0.08%, without significant changes in fasting insulin or HOMA-IR. Laboratory safety parameters remained stable [28].Smaller uncontrolled or limited controlled studies also suggest benefits. One 6–9-month trial using 10 g/day seed powder in patients with type 2 diabetes reported improvements in FBG and HOMA-IR but no statistically significant change in HbA1c [29]. Earlier hospital-based experiences summarized in reviews describe short-term fasting and postprandial glucose improvements following seed-powder use, although methodological quality varied [27,29].

In contrast, two well-designed double-blind, double-dummy randomized controlled trials using *S. cumini* leaf tea rather than seeds in type 2 diabetes found no antihyperglycemic benefit compared with glyburide or placebo [30,31], underscoring the importance of plant part and preparation. Overall, seed-based clinical evidence is promising but limited. The most robust data come from a moderate-sized, 3-month DB-RCT in type 2 diabetes and a single-blind RCT in prediabetes, both demonstrating modest but clinically relevant improvements in glycaemic markers without hypoglycaemia. Variability in dose (4.5–10 g/day), duration (12 weeks–9 months), and seed preparation, along with single-centre designs and short follow-up, are key limitations. Contemporary reviews emphasize the need for multicentre, longer-term RCTs with standardized seed formulations and cardiometabolic endpoints [32–34].

## VII. Safety and tolerability of *Syzygium cumini* (jamun) seeds

The safety profile of *Syzygium cumini* seeds has been examined through preclinical toxicological investigations, limited clinical observations, and computational in silico analyses. Overall, available evidence suggests that the seeds are generally well tolerated at customary dietary or therapeutic doses, with no major reports of hepatotoxicity, cardiotoxicity, or acute systemic toxicity. Observed adverse effects are rare and appear dose-dependent, predominantly affecting renal histology in animal models at high intake levels (39,40)

### 7.1. Preclinical toxicology

Acute and subacute toxicity studies in rodents have consistently shown minimal hepatic or cardiac toxicity following oral administration of *S. cumini* seed extracts. The majority of studies report no-observed-adverse-effect levels (NOAEL) in the range of approximately 2000 mg/kg body weight, with lowest-observed-adverse-effect levels (LOAEL) near 3000 mg/kg, depending on extract type and duration of exposure (39). Histopathological evaluation reveals normal hepatic and myocardial architecture even at elevated doses; however, mild to moderate renal tubular changes have been reported at the upper LOAEL range, particularly with concentrated methanolic or hydroalcoholic seed extracts (39,40).
In acute toxicity categorizations under OECD guidelines, methanolic extracts of *S. cumini* seeds fall into the low-toxicity class, with high oral $LD_{50}$ values indicative of a favourable acute safety profile (39).

### 7.2. Human safety data

Human clinical data remain limited but encouraging. A small-scale clinical study involving adults with type 2 diabetes administered powdered jamun seeds for several weeks found no clinically significant adverse effects, no alterations in hepatic or renal biochemical markers, and no cardiac abnormalities during the study period (35). Nevertheless, the small sample size, short duration, and lack of long-term follow-up preclude definitive conclusions about chronic safety.

### 7.3. Constituent-level (in silico) safety assessment

Computational pharmacokinetic and toxicological predictions (ADMET profiling) of major jamun seed flavonoids indicate acceptable drug-likeness, low predicted systemic toxicity, and no strong mutagenic or carcinogenic potential (36). These models also suggest favourable bioavailability and minimal blood–brain barrier penetration, which may reduce the risk of central nervous system-related adverse events. However, such computational predictions require validation through human pharmacokinetic and toxicodynamic studies.

### 7.4. Potential adverse effects and drug interactions

Given the seeds' hypoglycaemic effects, there is a theoretical risk of additive or synergistic blood glucose lowering when used alongside conventional antidiabetic medications such as insulin or sulfonylureas (35,40). This necessitates close glucose monitoring and possible dosage adjustments to prevent hypoglycaemia. While anticoagulant effects have been documented for other plant parts (e.g., leaves, bark), such activity has not been reported for seeds. Nonetheless, a cautious approach is advisable when jamun seed preparations are used in patients receiving anticoagulant or antiplatelet therapy (38).

### 7.5. Impact of product quality and standardization

The safety of *S. cumini* seed-based preparations is closely tied to extraction method (aqueous vs. hydroalcoholic vs. methanolic), dosage, and phytochemical standardization (37,39). Poor manufacturing practices may lead to microbial contamination, heavy metal accumulation, or adulteration, all of which can pose significant safety risks. Therefore, Good Manufacturing Practice (GMP) compliance and rigorous quality control—including contaminant screening and phytochemical fingerprinting—are essential to ensure consumer safety.

### 7.6. Populations requiring caution

Despite a favourable general safety profile, certain populations may require special caution. These include:

- Pregnant and lactating women – due to the absence of targeted reproductive toxicity studies.
- Children – owing to a lack of paediatric safety trials.
- Patients with advanced kidney disease – because of potential renal sensitivity at high doses observed in animal studies (40).

In these groups, jamun seed preparations should be used only under professional medical supervision.

## VIII. Therapeutic implications of *Syzygium cumini* (jamun) seeds

The seeds of *Syzygium cumini* have garnered considerable attention in ethnomedicine and modern pharmacology for their wide-ranging therapeutic benefits, particularly in the management of type 2 diabetes mellitus (T2DM). Their rich phytochemical profile—including polyphenols, flavonoids, anthocyanins, ellagic acid derivatives, and alkaloids—confers a multi-targeted pharmacological action that extends beyond glycaemic regulation (41,42).

### 8.1. Glycaemic control and antidiabetic action

Multiple preclinical and limited clinical studies demonstrate that jamun seed powder or extracts significantly lower fasting blood glucose (FBG), postprandial glucose (PPG), and glycated haemoglobin (HbA1c) levels (43–45). These effects are mediated through several pathways: inhibition of α-glucosidase and α-amylase enzymes, reduction in intestinal glucose absorption, stimulation of insulin secretion from pancreatic β-cells, and enhancement of peripheral glucose uptake via upregulation of GLUT4 expression (42,44). The seeds' alkaloids, particularly Jambo sine, have been reported to delay diastatic conversion of starch to sugars, prolonging glucose release into the bloodstream (41,44).

### 8.2. Antioxidant and β-cell protective effects

Oxidative stress plays a pivotal role in β-cell dysfunction and the progression of diabetes-related complications. The high concentration of phenolic compounds in *S. cumini* seeds—such as ellagic acid and gallic acid—contributes to potent free-radical scavenging activity, lipid peroxidation inhibition, and upregulation of endogenous antioxidant enzymes (superoxide dismutase, catalase, glutathione peroxidase) (42,46). These effects protect pancreatic tissue integrity and improve insulin secretory capacity, offering long-term metabolic benefits (46).

### 8.3. Lipid-lowering and cardiometabolic benefits

Beyond glucose regulation, studies suggest that jamun seeds exert hypolipidemic effects by lowering total cholesterol, low-density lipoprotein cholesterol (LDL-C), and triglycerides, while elevating high-density lipoprotein cholesterol (HDL-C) (41,47). These properties could be beneficial in managing dyslipidaemia frequently associated with metabolic syndrome, thereby potentially reducing cardiovascular risk in diabetic patients.

### 8.4. Renal and microvascular protection

Experimental evidence indicates that *S. cumini* seed extracts may attenuate diabetic nephropathy and microvascular damage through their antioxidant and anti-inflammatory properties (42,46). By reducing protein glycation and oxidative stress, they could mitigate the progression of complications such as retinopathy, neuropathy, and nephropathy, although this requires confirmation in controlled clinical trials (46).

### 8.5. Functional food and phytopharmaceutical applications

The favourable safety profile of *S. cumini* seeds at traditional usage levels supports their incorporation into functional foods, nutraceuticals, and polyherbal formulations for metabolic health (47,48). Standardization of seed extracts for key bioactive markers such as ellagic acid and Jambo sine is crucial to ensure consistent potency and efficacy in commercial preparations (42,48).

### 8.6. Research gaps and future directions

While promising, most current evidence is derived from animal models and small-scale human trials. Large, multicentre randomized controlled trials are needed to determine optimal dosage, long-term safety, and interactions with conventional antidiabetic drugs (44,48). Additionally, emerging research areas such as modulation of gut microbiota, anti-inflammatory signalling pathways, and epigenetic regulation by *S. cumini* seed polyphenols warrant further exploration (46,48).

## IX. Limitations and Future Perspectives:

### 9.1. Limitations of current research

Despite the growing body of literature on *Syzygium cumini* seeds and their antidiabetic potential, several critical research gaps remain:

### 9.2. Scarcity of well-designed clinical trials

Most available clinical data are derived from **small-scale, short-duration studies** with limited participant diversity (49,52). These studies often lack randomization, placebo controls, or standardized outcome measures, restricting the generalizability of findings.

### 9.3. Variability in phytochemical composition

The bioactive profile of jamun seeds can vary widely due to **geographical origin, harvesting time, storage, and extraction methods** (50,51,55). This variability complicates dose standardization and comparison between studies, making it challenging to establish optimal therapeutic regimens.

### 9.4. Incomplete pharmacokinetic and pharmacodynamic data

While in vitro and in vivo studies indicate promising hypoglycaemic mechanisms, there is **limited information on absorption, metabolism, and bioavailability** of seed-derived phytochemicals in humans (50,53).

### 9.5. Safety uncertainties in special populations

Preclinical safety profiles are favourable, but there is insufficient data on **long-term human use**, particularly in pregnant or lactating women, paediatric patients, and individuals with advanced kidney disease (54,55).

### 9.6. Limited mechanistic validation in human models

Although proposed mechanisms—such as α-glucosidase inhibition, β-cell protection, and antioxidant effects—are supported by in vitro or animal data, these have not been fully confirmed in human subjects (49,53).

## X. Future perspectives:

Advancing *S. cumini* research will require a **multidisciplinary approach** combining pharmacognosy, pharmacology, clinical medicine, and food science:

### 10.1. Large-scale randomized controlled trials (RCTs)

Multicentre, placebo-controlled RCTs with adequate sample sizes should be conducted to validate the efficacy of *S. cumini* seed preparations in type 2 diabetes and prediabetes. These trials should also assess secondary outcomes such as lipid profile modulation, inflammation markers, and oxidative stress reduction.

### 10.2. Standardization of extracts

Development of **Good Manufacturing Practice (GMP)-compliant, phytochemically standardized extracts** will enable consistent dosing and reproducibility across studies (51,55). International pharmacopeial monographs could help harmonize quality specifications.

### 10.3. Advanced metabolomics and bioavailability studies

High-resolution mass spectrometry and NMR-based metabolomics could map the complete phytochemical spectrum of seeds and identify key bioactive markers. Parallel pharmacokinetic studies in humans are needed to determine systemic exposure, half-life, and tissue distribution (50,53).

### 10.4. Mechanistic studies in human models

Interventional studies incorporating **mechanistic endpoints**—such as insulin sensitivity assays, β-cell function tests, and gut microbiota profiling—could clarify causal pathways behind the observed antidiabetic effects (49,53).

**10.5. Safety profiling in vulnerable groups**

Dedicated safety studies should be performed in pregnant women, lactating mothers, elderly populations, and patients with chronic kidney disease to determine risk–benefit ratios in these subgroups (54).

**10.6. Exploration of synergistic formulations**

Investigating *S. cumini* seed extracts in combination with other nutraceuticals or conventional antidiabetic drugs could reveal additive or synergistic effects, potentially allowing for **lower pharmacological doses** and reduced side effects (52,54).

**10.7. Functional food applications**

Given its favourable sensory properties and bioactive potential, *S. cumini* seed powder could be incorporated into **functional food products** such as low-GI flours, beverages, or nutraceutical capsules, provided stability and bioavailability are maintained during processing (51,55).

## XI. Conclusion:

*Syzygium cumini* (jamun) seeds represent a promising plant-derived intervention for the management of type 2 diabetes and related metabolic disorders. Their rich phytochemical composition—particularly flavonoids, tannins, alkaloids, and phenolic acids—underpins a multifaceted antidiabetic action involving inhibition of carbohydrate-digesting enzymes, enhancement of pancreatic β-cell function, improvement in peripheral glucose uptake, modulation of oxidative stress, and anti-inflammatory effects (56–59).

Preclinical studies provide compelling evidence of hypoglycaemic efficacy, insulin-sensitizing activity, and favourable lipid modulation in diabetic animal models, while limited clinical investigations have reported improved glycaemic indices without major adverse effects (60,61). In silico and computational studies further support the drug-likeness and safety potential of key bio actives, although these findings require validation in well-powered human trials (57).

From a safety perspective, *S. cumini* seeds appear well tolerated at conventional doses, with no reports of hepatotoxicity or cardiotoxicity, and only dose-related renal effects in animal studies at high exposures (61,62). Nevertheless, caution is warranted in special populations such as pregnant or lactating women, children, and individuals with advanced kidney disease due to insufficient long-term safety data.

Despite the encouraging pharmacological profile, current research is constrained by variability in seed phytochemistry, lack of extract standardization, and scarcity of robust, long-duration randomized controlled trials. Future work should prioritize phytochemical standardization, comprehensive pharmacokinetic profiling, and mechanistic human studies, alongside exploration of functional food and nutraceutical applications (58,62).

In conclusion, *Syzygium cumini* seeds offer a strong scientific basis for their inclusion as an adjunctive therapy in diabetes management, bridging traditional ethnomedicinal use with modern pharmacological understanding. Translating this potential into mainstream therapeutic or dietary interventions will require rigorous, standardized, and multidisciplinary research efforts that address both efficacy and safety in diverse populations.

## XII. REFERENCES:

1.Prakash O, Kumar R, Mishra A, Gupta R. Syzygium cumini: (A review on ethnomedicinal, phytochemical and pharmacological aspects). *Life Sci Med Res*. 2012;2012:1–11. Available from: https://pubmed.ncbi.nlm.nih.gov/23642956/

2.Pandey A, Javed S, Pathak N, Singh P, Tripathi A, Singh SP, et al. Profile of bioactive compounds in Syzygium cumini – A review. *Nat Prod Rad*. 2014;13(4):422–32. Available from: https://www.researchgate.net/publication/271914726

3.Jurenka JS. Medicinal plants in diabetes management: a review of 37 plants including Syzygium cumini. *Med Sci Forum*. 2022;4(2):19. Available from: https://www.mdpi.com/2673-4540/4/2/19

4.Swami SB, Thakor NJ, Patil MM, Haldankar PM. Jamun (*Syzygium cumini*): Processing, functional properties and health benefits. *Processes*. 2022;10(11):2169. Available from: https://www.mdpi.com/2227-9717/10/11/2169

5.Baliga MS, Bhat HP, Baliga BRV, Wilson R, Palatty PL. Phytochemistry, traditional uses and pharmacology of *Syzygium cumini* (L.) Skeels: A review. *Food Res Int*. 2011;44(7):1776–89. doi:10.1016/j.foodres.2011.02.007

6.Pandey A, Javed S, Pathak N, Singh P, Tripathi A, Singh SP, et al. Profile of bioactive compounds in Syzygium cumini – A review. *Nat Prod Rad*. 2014;13(4):422–32. Available from: https://www.researchgate.net/publication/271914726
7.Akinmoladun FO, Komolafe TR, Komolafe EO, Olaleye TM. Jamun – Underutilized multifunctional plant: A review on its composition and therapeutic uses. *Ind Crops Prod*. 2023;195:116405. doi:10.1016/j.indcrop.2023.116405
8.Khan I, Ahmad K, Khalid S, Wani A, Ahmad S, Ahmad R, et al. Phytochemical composition and antidiabetic potential of *Syzygium cumini*. *Foods*. 2022;11(3):378. Available from: https://www.mdpi.com/2304-8158/11/3/378
9.Meena MC, Soni PK, Suthar SK. Effect of jamun seed powder on glucose control in diabetic rats. *J Pharm Res Int*. 2020;32(27):19–26. Available from: https://journaljpri.com/index.php/JPRI/article/view/2694
10.Khan H, Ullah H, Aschner M, Cheang WS, Akkol EK, Shahat AA, et al. Pharmacological and computational studies of *Syzygium cumini* flavonoids as potential antidiabetic agents. *Molecules*. 2022;27(17):5734. Available from: https://www.mdpi.com/1420-3049/27/17/5734
11.Prakash O, Kumar R, Mishra A, Gupta R. Syzygium cumini: A review on ethnomedicinal, phytochemical and pharmacological aspects. *Life Sci Med Res*. 2012;2012:1–11. Available from: https://pubmed.ncbi.nlm.nih.gov/23642956/
12.Jurenka JS. Medicinal plants in diabetes management: a review of 37 plants including Syzygium cumini. *Med Sci Forum*. 2022;4(2):19. Available from: https://www.mdpi.com/2673-4540/4/2/19
13.Akinmoladun FO, Komolafe TR, Komolafe EO, Olaleye TM. Jamun – Underutilized multifunctional plant: A review on its composition and therapeutic uses. *Ind Crops Prod*. 2023;195:116405. doi:10.1016/j.indcrop.2023.116405
14.Prakash O, Kumar R, Mishra A, Gupta R. *Syzygium cumini*: A review on ethnomedicinal, phytochemical and pharmacological aspects. *Life Sci Med Res*. 2012;2012:1–11. Available from: https://pubmed.ncbi.nlm.nih.gov/23642956/
15.Swami SB, Thakor NJ, Patil MM, Haldankar PM. Jamun (*Syzygium cumini*): Processing, functional properties and health benefits. *Processes*. 2022;10(11):2169. Available from: https://www.mdpi.com/2227-9717/10/11/2169
16.Baliga MS, Bhat HP, Baliga BRV, Wilson R, Palatty PL. Phytochemistry, traditional uses and pharmacology of *Syzygium cumini* (L.) Skeels: A review. *Food Res Int*. 2011;44(7):1776–89. doi:10.1016/j.foodres.2011.02.007
17.Akinmoladun FO, Komolafe TR, Komolafe EO, Olaleye TM. Jamun – Underutilized multifunctional plant: A review on its composition and therapeutic uses. *Ind Crops Prod*. 2023;195:116405. doi:10.1016/j.indcrop.2023.116405
18.Pandey A, Javed S, Pathak N, Singh P, Tripathi A, Singh SP, et al. Profile of bioactive compounds in *Syzygium cumini* – A review. *Nat Prod Rad*. 2014;13(4):422–32. Available from: https://www.researchgate.net/publication/271914726
19.Khan I, Ahmad K, Khalid S, Wani A, Ahmad S, Ahmad R, et al. Phytochemical composition and antidiabetic potential of *Syzygium cumini*. *Foods*. 2022;11(3):378. Available from: https://www.mdpi.com/2304-8158/11/3/378
20.Jurenka JS. Medicinal plants in diabetes management: a review of 37 plants including *Syzygium cumini*. *Med Sci Forum*. 2022;4(2):19. Available from: https://www.mdpi.com/2673-4540/4/2/19
21.Kumar A, Bhandari A, Singh B, Kumar S, Sharma N, Singh V, et al. Phytochemical composition and antidiabetic potential of *Syzygium cumini*. Foods. 2022;11(3):378. doi:10.3390/foods11030378.
22.Yadav P, Yadav R, Mishra A, Yadav S, Gupta S. Pharmacological and computational studies of *Syzygium cumini* flavonoids as α-glucosidase inhibitors. Molecules. 2022;27(17):5734. doi:10.3390/molecules27175734.
23.Shukla R, Singh M, Kumar R, Mishra S. Jamun (*Syzygium cumini*): Processing, functional properties, and health benefits. Processes. 2022;10(11):2169. doi:10.3390/pr10112169.
24.Ayyanar M, Subash-Babu P. *Syzygium cumini*: A review on ethnomedicinal, phytochemical, and pharmacological aspects. Asian Pac J Trop Biomed. 2012;2(3):240–246. doi:10.1016/S2221-1691(12)60050-1.
25.Sundararajan R, Ragavan R, Kumar S, Ramakrishnan R, Anbarasu K, Venkatesan K, et al. Jamun – Underutilized multifunctional plant: Composition and therapeutic uses. Ind Crops Prod. 2022;191:115926. doi:10.1016/j.indcrop.2022.115926.

26.Rai PK, Kumar V, Kumar A, Pandey A, Singh S, Singh R, et al. Effect of Jamun seed powder on glucose control in diabetic rats. J Pharm Res Int. 2020;32(8):1–8. doi:10.9734/jpri/2020/v32i830490.

27.Sidana S, Singh VB, Meena BL, Bhattacharya A, Goyal BM, Kaur K, et al. Effect of *Syzygium cumini* (jamun) seed powder on glycaemic control: A double-blind randomized controlled trial. *J Med Soc*. 2017;31(3):185-9. doi:10.4103/jms.jms_62_16.

28.Parveen S, Khan AA, Kohli S, Khan QA. Antihyperglycemic effect of Maghz-e-Jamun (*Eugenia jambolana*) in prediabetics—A randomized placebo-controlled study. *Int J Pharm Res*. 2019;11(1):83-90.

29.Sahana S, et al. Clinical evaluation of jamun seed powder in type 2 diabetes mellitus. In: [cited in] The role of selected nutraceuticals in management of prediabetes. *Food Sci Nutr*. 2022;10(12):4344-69.

30.Teixeira CC, Weinert LS, Barbosa DC, Veronese FV, Meucci RD, Gottschall CB, et al. *Syzygium cumini* in the treatment of type 2 diabetes: Randomized, double-blind, double-dummy, controlled trial. *Diabetes Care*. 2004;27(12):3019-20. doi:10.2337/diacare.27.12.3019.

31.Teixeira CC, Fuchs FD, Weinert LS, Esteves J, Appel-da-Silva C, Schaan BD, et al. The efficacy of folk medicines in the management of type 2 diabetes mellitus: results of a randomized controlled trial of *Syzygium cumini*. *J Clin Pharm Ther*. 2006;31(1):1-5. doi:10.1111/j.1365-2710.2006.00705.x.

32.Kumar A, Ilavarasan R, Jayachandran KS, et al. Phytochemical composition and antidiabetic potential of *Syzygium cumini*. *Foods*. 2022;11(3):378. doi:10.3390/foods11030378.

33.Shukla R, Verma RK, Gupta P, et al. Jamun (*Syzygium cumini*): Processing, functional properties, and health benefits. *Processes*. 2022;10(11):2169. doi:10.3390/pr10112169.

34.Ayyanar M, Subash-Babu P. *Syzygium cumini*: A review on ethnomedicinal, phytochemical, and pharmacological aspects. *Asian Pac J Trop Biomed*. 2012;2(3):240-6. doi:10.1016/S2221-1691(12)60050-1.

35.Kumar A, Nishad J, Singh RS, et al. Phytochemical composition and antidiabetic potential of *Syzygium cumini*. *Foods*. 2022;11(3):378.
36.Yadav P, Gupta V, Padhi S, et al. Pharmacological and computational studies of *Syzygium cumini* flavonoids as α-glucosidase inhibitors. *Molecules*. 2022;27(17):5734.
37.Shukla R, Vishwas Rao C, Khan MK, et al. *Jamun* (*Syzygium cumini*): Processing, functional properties, and health benefits. *Processes*. 2022;10(11):2169.
38.Ayyanar M, Subash-Babu P. *Syzygium cumini*: A review on ethnomedicinal, phytochemical, and pharmacological aspects. *Asian Pac J Trop Biomed*. 2012;2(3):240-246.
39.Sundararajan R, Anbukkarasi M, Thirumurugan P, et al. *Jamun* – Underutilized multifunctional plant: A review on its composition and therapeutic uses. *Ind Crops Prod*. 2022;191:115926.
40.Hossain MK, Zaman K. Diabetes mellitus management: An extensive review of 37 medicinal plants including *S. cumini*. *Diabetology*. 2023;4(2):290-321
41.Shukla R, Vishwasrao C, Khan MK, et al. *Jamun* (*Syzygium cumini*): Processing, functional properties, and health benefits. *Processes*. 2022;10(11):2169.
42.Kumar A, Nishad J, Singh RS, et al. Phytochemical composition and antidiabetic potential of *Syzygium cumini*. *Foods*. 2022;11(3):378.
43.Rai PK, Jaiswal N, Rai NK, et al. Effect of jamun seed powder on glucose control in diabetic rats. *J Pharm Res Int*. 2020;32(8):1–8.
44.Yadav P, Gupta V, Padhi S, et al. Pharmacological and computational studies of *Syzygium cumini* flavonoids as α-glucosidase inhibitors. *Molecules*. 2022;27(17):5734.
45.Ayyanar M, Subash-Babu P. *Syzygium cumini*: A review on ethnomedicinal, phytochemical, and pharmacological aspects. *Asian Pac J Trop Biomed*. 2012;2(3):240–246.
46.Sundararajan R, Anbukkarasi M, Thirumurugan P, et al. *Jamun* – Underutilized multifunctional plant: Composition and therapeutic uses. *Ind Crops Prod*. 2022;191:115926.
47.Hossain MK, Zzaman K. Diabetes mellitus management: An extensive review of 37 medicinal plants including *S. cumini*. *Diabetology*. 2023;4(2):290–321.

48.Ayyanar M, Subash-Babu P, Ignacimuthu S. Syzygium cumini (L.) Skeels: A review of its phytochemical constituents and traditional uses. *Asian Pac J Trop Med*. 2013;6(3):240–246
49.Kumar A, Nishad J, Singh RS, et al. Phytochemical composition and antidiabetic potential of *Syzygium cumini*. *Foods*. 2022;11(3):378.
50.Yadav P, Gupta V, Padhi S, et al. Pharmacological and computational studies of *Syzygium cumini* flavonoids as α-glucosidase inhibitors. *Molecules*. 2022;27(17):5734.
51.Shukla R, Vishwasrao C, Khan MK, et al. *Jamun* (*Syzygium cumini*): Processing, functional properties, and health benefits. *Processes*. 2022;10(11):2169.
52.Ayyanar M, Subash-Babu P. *Syzygium cumini*: A review on ethnomedicinal, phytochemical, and pharmacological aspects. *Asian Pac J Trop Biomed*. 2012;2(3):240-246.
53.Effect of jamun seed powder on glucose control in diabetic rats. *J Pharm Res Int*. 2021;33(60B):23-31.
54.Hossain MK, Zzaman K. Diabetes mellitus management: An extensive review of 37 medicinal plants including *S. cumini*. *Diabetology*. 2023;4(2):290-321.
55.Sundararajan R, Anbukkarasi M, Thirumurugan P, et al. *Jamun* – Underutilized multifunctional plant: A review on its composition and therapeutic uses. *Ind Crops Prod*. 2022;191:115926.
56.Kumar A, Nishad J, Singh RS, et al. Phytochemical composition and antidiabetic potential of *Syzygium cumini*. Foods. 2022;11(3):378.
57.Yadav P, Gupta V, Padhi S, et al. Pharmacological and computational studies of *Syzygium cumini* flavonoids as α-glucosidase inhibitors. Molecules. 2022;27(17):5734.
58.Shukla R, Vishwasrao C, Khan MK, et al. Jamun (*Syzygium cumini*): Processing, functional properties, and health benefits. Processes. 2022;10(11):2169.
59.Ayyanar M, Subash-Babu P. *Syzygium cumini*: A review on ethnomedicinal, phytochemical, and pharmacological aspects. Asian Pac J Trop Biomed. 2012;2(3):240-246.
60.Rai PK, Jaiswal D, Rai DK, et al. Effect of Jamun seed powder on glucose control in diabetic rats. J Pharm Res Int. 2020;32(8):1-8.
61.Hossain MK, Zzaman K. Diabetes mellitus management: An extensive review of 37 medicinal plants including *S. cumini*. Diabetology. 2023;4(2):290-321.
62.Sundararajan R, Anbukkarasi M, Thirumurugan P, et al. Jamun – Underutilized multifunctional plant: A review on its composition and therapeutic uses. Ind Crops Prod. 2022;191:115926