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Antioxidant and Antidiabetic Potential of Syzygium cumini (L.) Skeels: A Comparative In Vitro Assessment of Fruit Pulp and Seed Extracts

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Abstract

This study was undertaken to comparatively evaluate the in vitro antioxidant and antidiabetic activity of fruit pulp and seed extracts of Syzygium cumini (L.) Skeels, commonly known as Jamun or Indian blackberry, collected from the Gangetic plains region of Bihar. Aqueous, methanolic, and ethyl acetate extracts were prepared from both plant parts. Total phenolic content (TPC), total flavonoid content (TFC), anthocyanins, and tannins were quantified using standard spectrophotometric methods. Antioxidant activity was assessed through six assays: DPPH, ABTS, hydroxyl radical, nitric oxide, and hydrogen peroxide scavenging along with FRAP. Antidiabetic activity was evaluated by measuring inhibition of four carbohydrate-digesting enzymes: pancreatic alpha-amylase, intestinal alpha-glucosidase, sucrase, and maltase, using acarbose as the positive control. Seed methanolic extract showed significantly higher TPC (511.3 ± 19.7 mg GAE/100g DW) and TFC (231.8 ± 13.1 mg QE/100g DW) compared to fruit pulp (298.6 ± 12.4 and 114.2 ± 7.9 respectively). Fruit pulp was richer in anthocyanins (171.3 ± 10.2 mg CGE/100g FW). In antioxidant assays, seed extract consistently outperformed fruit pulp; DPPH IC50 was 29.7 ± 1.8 µg/mL for seeds against 51.3 ± 2.6 µg/mL for fruit pulp. For alpha-glucosidase inhibition, seed extract gave IC50 of 27.3 ± 1.6 µg/mL, compared to 67.4 ± 4.1 µg/mL for fruit pulp and 16.9 ± 0.8 µg/mL for acarbose. Lineweaver-Burk kinetic analysis confirmed competitive inhibition. One-way ANOVA revealed highly significant differences between all fractions ($p < 0.001$). Pearson correlation showed strong negative relationships between TPC and DPPH IC50 ($r = -0.951$, $p < 0.001$) and TFC and alpha-glucosidase IC50 ($r = -0.928$, $p < 0.001$). These results provide a quantitative scientific basis for the traditional Ayurvedic use of Jamun seed powder in managing hyperglycemia.

Keywords: Syzygium cumini; Jamun; antioxidant; alpha-glucosidase inhibition; DPPH; polyphenols; enzyme kinetics; ANOVA; Pearson correlation

1. Introduction

At the outset of my investigation into Jamun as a subject of botanical research, a consistent trend in the existing literature became apparent**.** Study after study examined the fruit pulp, its anthocyanin pigments, its commercial potential as a functional food ingredient, while the seeds were either ignored or mentioned briefly as a secondary material. Yet in every village market across Bihar during the summer months, it is the seed that the elderly diabetic patient takes home, dries, grinds, and consumes with water each morning. This disconnect between what traditional medicine does and what modern research prioritizes motivated the design of this study. Diabetes mellitus type 2 is a metabolic disorder characterized by progressive insulin resistance and impaired beta-cell function, resulting in chronic elevation of blood glucose that causes cumulative damage to vascular, renal, retinal, and neural tissues (DeFronzo et al., 2015). The disease burden in India

is particularly severe. The most recent national-level data from the ICMR-INDIAB study estimated approximately 101 million people with confirmed diabetes and a further 136 million with prediabetes in India as of 2019 (Anjana et al., 2023). Bihar, with its predominantly rural population and limited access to specialized healthcare, carries a disproportionate burden of undiagnosed and untreated cases. In this context, locally available plant-based interventions that are affordable and culturally familiar have a legitimate role to play alongside pharmaceutical management.

Oxidative stress is closely intertwined with the pathophysiology of diabetes. Persistent hyperglycemia promotes the formation of advanced glycation end products and activates polyol and hexosamine pathways, all of which generate reactive oxygen species that outpace the body's antioxidant defenses (Lobo et al., 2010). This is why antioxidant activity is not merely an incidental feature of a plant extract to be reported alongside enzyme inhibition data; it is mechanistically relevant. Oxidative damage to pancreatic beta cells accelerates their functional decline in established diabetes, and vascular oxidative damage is the primary driver of diabetic complications. A plant material that simultaneously inhibits postprandial glucose absorption and provides meaningful antioxidant protection addresses two aspects of the diabetic milieu at once.

Syzygium cumini (L.) Skeels, family Myrtaceae, is a large evergreen tree native to the Indian subcontinent and widely distributed across South and Southeast Asia. In the traditional Ayurvedic system, the plant is known as Jambu and has been documented in the Charaka Samhita specifically in the context of treating prameha, a broad syndrome that encompasses various forms of polyuria and metabolic dysfunction including what we now recognize as diabetes mellitus (Warrier et al., 1995). The seed, called Jambu beej, was the preferred preparation. It was dried, powdered, and taken with water or buttermilk in doses of three to five grams daily, and this practice continues in rural Bihar to this day.

Phytochemically, Jamun fruit pulp is dominated by anthocyanins, particularly delphinidin and malvidin glycosides, which contribute both to its deep purple color and to its antioxidant capacity (Veigas et al., 2007). The seeds, by contrast, accumulate high concentrations of condensed and hydrolyzable tannins including gallic acid, ellagic acid, and the alkaloid jambosine (Srivastava and Singh, 1999). These differences in composition between fruit pulp and seed raise an important scientific question: do these chemically distinct parts of the same plant differ significantly in their antioxidant and antidiabetic potency, and if so, which part is superior for the intended medicinal application? This is the central question this study set out to answer.

The carbohydrate-digesting enzymes alpha-amylase and alpha-glucosidase are well-validated in vitro targets for antidiabetic screening. Alpha-amylase breaks down starch into oligosaccharides in the small intestine, and alpha-glucosidase at the intestinal brush border then releases free glucose from these fragments. Inhibiting these enzymes slows glucose entry into the bloodstream after a carbohydrate meal, reducing the postprandial spike that is particularly damaging to vascular endothelium (Van de Laar et al., 2005). Acarbose, the clinical reference drug for this mechanism, is effective but causes gastrointestinal distress in many patients. A plant-derived inhibitor with a selective, competitive, and reversible mechanism could offer clinical utility with better tolerability.

2. Materials and Methods

2.1 Collection and Authentication of Plant Material

Ripe Jamun fruits were collected in July 2023 from naturally growing trees in Rajgir, Nalanda district, Bihar (25.0319 N, 85.4189 E). Fruits were selected at full maturity, recognized by uniform deep purple-black skin and characteristic aromatic odour. Botanical identity was authenticated by comparison with herbarium specimens at the Patliputra University Botany Department herbarium. A voucher specimen has been deposited under accession number PPU-BOT-SC-2023-09. Fruits were brought to the laboratory in sterile polythene bags packed over ice within five hours of harvest and processed on the same day.

2.2 Preparation of Extracts

Fruit pulp was separated from seeds manually using clean stainless steel implements. Both fractions were washed three times with sterile distilled water. Pulp was dried at 40 degrees Celsius in a hot-air oven for 48 hours; seeds were shade-dried for 12 days followed by 24 hours at 45 degrees Celsius. Dried material was ground to a fine powder (60-mesh sieve) using a laboratory analytical mill and stored at minus 20 degrees Celsius in sealed amber containers.

For extraction, five grams of powder was macerated in 100 mL of each solvent: distilled water, ethanol (HPLC grade, Merck), and ethyl acetate (AR grade, Merck), separately in conical flasks sealed with aluminium foil. Maceration proceeded for 72 hours at 25 degrees Celsius with continuous stirring at 120 rpm. Extracts were filtered through Whatman No. 1 paper, concentrated under reduced pressure at 40 degrees Celsius using a rotary evaporator, and stored as 100 mg/mL stock solutions in DMSO at 4 degrees Celsius. For assays, working solutions were prepared in distilled water ensuring DMSO did not exceed 0.5% in any reaction mixture.

2.3 Quantitative Phytochemical Analysis

Total phenolic content was measured by the Folin-Ciocalteu method (Singleton and Rossi, 1965). One hundred microliters of extract (1 mg/mL) was reacted with diluted Folin-Ciocalteu reagent and 20% sodium carbonate, incubated 90 minutes in darkness, and absorbance read at 765 nm. Gallic acid standard curve: R2 = 0.9982. Results expressed as mg GAE/100g DW.

Total flavonoid content was measured by the AlCl3 complexation method (Zhishen et al., 1999). Extract was reacted with NaNO2, AlCl3, and NaOH sequentially, absorbance at 510 nm after 15 minutes. Quercetin standard curve: R2 = 0.9971. Results expressed as mg QE/100g DW.

Anthocyanin content in fruit pulp was quantified by the pH differential method using McIlvaine buffers at pH 1.0 and pH 4.5 (Giusti and Wrolstad, 2001), absorbance at 520 nm and 700 nm, and expressed as mg cyanidin-3-glucoside equivalents per 100g FW. Tannin content was estimated by the vanillin-HCl method (Price et al., 1978) with tannic acid standard, expressed as mg TAE/100g DW.

2.4 Antioxidant Assays

DPPH radical scavenging was performed by the method of Blois (1958) as modified by Brand-Williams et al. (1995). Serial concentrations (10 to 200 µg/mL) of each extract were reacted with 0.1 mM DPPH in ethanol for 30 minutes in darkness, absorbance at 517 nm. Percent scavenging = 100 × [(A blank minus A sample) / A blank]. IC50 by four-parameter logistic regression.

ABTS radical cation scavenging was performed according to Re et al. (1999). The radical was generated by reaction of 7 mM ABTS with 2.45 mM potassium persulfate for 16 hours in darkness, diluted in ethanol to absorbance 0.700 ± 0.010 at 734 nm. Reaction time with extract: 6 minutes at room temperature.

Hydroxyl radical scavenging used the Fenton system (Fe2+-H2O2-deoxyribose) of Kunchandy and Rao (1990), quantifying deoxyribose degradation products via thiobarbituric acid reaction at 532 nm. Nitric oxide scavenging used sodium nitroprusside as donor with Griess reagent at 546 nm after 150 minutes (Sreejayan and Rao, 1996). Hydrogen peroxide scavenging measured residual H2O2 at 230 nm after 10 minutes (Ruch et al., 1989). FRAP assay followed Benzie and Strain (1996) with FeSO4 standard curve, absorbance at 593 nm. All assays run in triplicate with ascorbic acid as reference standard.

2.5 Antidiabetic Enzyme Inhibition Assays

Alpha-amylase inhibition used porcine pancreatic alpha-amylase (Sigma-Aldrich A6255, 5 U/mg) at 0.5 U/mL in 20 mM sodium phosphate buffer (pH 6.9, 6.7 mM NaCl). Extract at test concentration was pre-incubated with enzyme for 10 minutes at 37 degrees Celsius, then 1% soluble starch substrate was added and incubated 30 minutes. Reaction stopped with DNS reagent, boiled 10 minutes, absorbance at 540 nm. Acarbose was positive control.

Alpha-glucosidase inhibition used rat intestinal acetone powder (Sigma-Aldrich) as enzyme source (10 mg/mL in 100 mM phosphate buffer pH 6.9, centrifuged 12,000 g, supernatant used). p-Nitrophenyl-alpha-D-glucopyranoside (pNPG, 5 mM) as substrate; reaction stopped with 0.1 M Na2CO3, absorbance at 405 nm (Kim et al., 2000). Sucrase and maltase inhibition were measured from the same enzyme system using sucrose and maltose as substrates respectively, with released glucose quantified by GOD-POD kit. Lineweaver-Burk double reciprocal plots (1/V vs 1/[S]) at fixed seed extract concentration (40 µg/mL) and varying substrate concentrations were used to determine mode of inhibition and Ki.

2.6 Statistical Analysis

All experiments were conducted in triplicate on three separate days (n = 3 biological replicates, each measured in triplicate). Results are expressed as Mean ± Standard Deviation. One-way Analysis of Variance (ANOVA) was used to compare means between groups, followed by Tukey's HSD post-hoc test for pairwise comparisons, with significance threshold at $p < 0.05$. Pearson's bivariate correlation coefficient (r) was computed between phytochemical content and IC50 values across all six extract fractions. Normality was confirmed by Shapiro-Wilk test before

parametric analysis. Statistical analysis was carried out using SPSS Version 26.0 (IBM Corp., USA). IC50 was calculated by four-parameter logistic regression in GraphPad Prism 9.5.

3. Results

3.1 Extract Yield

Ethanolic extraction gave the highest yields from both plant parts: 18.4% from seeds and 14.7% from fruit pulp (w/w of starting dry powder). Aqueous extracts yielded 12.1% from seeds and 10.8% from fruit pulp. Ethyl acetate fractions were lowest: 7.2% and 5.9% from seeds and fruit pulp respectively. The yield pattern confirms that the dominant extractable constituents in both fractions are polar in nature.

3.2 Phytochemical Composition

Table 1 presents the quantitative phytochemical profile of fruit pulp and seed fractions measured in this study.

Table 1. Quantitative phytochemical composition of Syzygium cumini fruit pulp and seed.

Phytochemical Constituent	Fruit Pulp (mg/100g FW)	Seed Kernel (mg/100g DW)
Total Phenolics (mg GAE/100g)	298.6 ± 12.4	511.3 ± 19.7
Total Flavonoids (mg QE/100g)	114.2 ± 7.9	231.8 ± 13.1
Tannins (mg TAE/100g)	79.4 ± 4.6	368.2 ± 22.5
Anthocyanins (mg CGE/100g)	171.3 ± 10.2	8.1 ± 1.4
Ascorbic Acid (mg/100g)	16.8 ± 1.1	5.2 ± 0.6
Alkaloids (qualitative)	Absent	Present
Saponins (qualitative)	Present	Present

FW = fresh weight; DW = dry weight; GAE = gallic acid equivalents; QE = quercetin equivalents; CGE = cyanidin-3-glucoside equivalents; TAE = tannic acid equivalents. Values are Mean ± SD (n = 3). All differences between fruit pulp and seeds are significant at $p < 0.001$ by Tukey HSD.

Seeds were markedly richer in total phenolics (511.3 ± 19.7 vs 298.6 ± 12.4 mg GAE/100g), flavonoids (231.8 ± 13.1 vs 114.2 ± 7.9 mg QE/100g), and tannins (368.2 ± 22.5 vs 79.4 ± 4.6 mg TAE/100g). The tannin difference is particularly large: seeds contain nearly 4.6 times the tannin content of fruit pulp. Fruit pulp, however, was far superior in anthocyanin concentration: 171.3 ± 10.2 mg CGE/100g FW in pulp versus only 8.1 ± 1.4 mg CGE/100g DW in seeds. Alkaloids were detected qualitatively in seeds but absent in fruit pulp. Both fractions contained saponins.

3.3 Antioxidant Activity

Table 2 shows IC50 values from five radical scavenging assays and FRAP reducing power for the ethanolic fractions of both plant parts. Across every parameter, seed extract outperformed fruit pulp, though neither reached the potency of pure ascorbic acid.

Table 2. In vitro antioxidant activity of Syzygium cumini fruit pulp and seed ethanolic extracts. Lower IC50 values indicate stronger scavenging activity.

Assay	Fruit Pulp IC50 (µg/mL)	Seed Extract IC50 (µg/mL)	Ascorbic Acid IC50 (µg/mL)
DPPH Radical Scavenging	51.3 ± 2.6	29.7 ± 1.8	13.4 ± 0.8
ABTS Radical Scavenging	58.7 ± 3.1	26.4 ± 1.5	11.9 ± 0.6
Hydroxyl Radical Scavenging	71.2 ± 4.3	44.8 ± 2.9	22.7 ± 1.2
Nitric Oxide Scavenging	66.4 ± 3.8	39.1 ± 2.4	19.3 ± 1.0
H2O2 Scavenging	57.9 ± 3.4	38.6 ± 2.1	17.8 ± 0.9
FRAP (mM Fe2+/g extract)	5.14 ± 0.28	8.43 ± 0.37	— (N/A)

Values are Mean ± SD (n = 3). For FRAP, higher values indicate stronger reducing power (mM Fe2+ equivalents per gram of extract, so IC50 is not applicable). All differences between fruit pulp and seed extract: $p < 0.001$ by one-way ANOVA with Tukey HSD.

DPPH IC50 for seed extract was 29.7 ± 1.8 µg/mL, compared to 51.3 ± 2.6 µg/mL for fruit pulp, a 1.73-fold difference. ABTS IC50 was 26.4 ± 1.5 for seeds versus 58.7 ± 3.1 µg/mL for fruit pulp, a 2.22-fold difference. Hydroxyl radical scavenging, physiologically the most damaging radical species, showed seed IC50 of 44.8 ± 2.9 versus 71.2 ± 4.3 µg/mL for pulp. FRAP values confirmed superior electron-donating capacity of seeds (8.43 ± 0.37 vs 5.14 ± 0.28 mM Fe2+/g). Among solvents, ethanolic extracts outperformed aqueous and ethyl acetate fractions from both plant parts in all assays, with ethyl acetate consistently weakest, indicating that the active antioxidant constituents are predominantly of intermediate to high polarity.

3.4 Antidiabetic Enzyme Inhibitory Activity

Inhibitory activity against four carbohydrate-digesting enzymes is presented in Table 3. Seed extract was significantly more potent than fruit pulp for all four enzymes, and for alpha-glucosidase it approached the activity of acarbose to a remarkable degree.

Table 3. Inhibitory activity (IC50, µg/mL) of Syzygium cumini fruit pulp and seed ethanolic extracts against carbohydrate-digesting enzymes. Acarbose used as standard.

Enzyme	Fruit Pulp IC50 (µg/mL)	Seed Extract IC50 (µg/mL)	Acarbose IC50 (µg/mL)
Pancreatic alpha-amylase	82.6 ± 5.3	41.2 ± 2.7	26.8 ± 1.4
Intestinal alpha-glucosidase	67.4 ± 4.1	27.3 ± 1.6	16.9 ± 0.8
Sucrase	89.1 ± 5.8	54.7 ± 3.4	29.4 ± 1.7
Maltase	94.3 ± 6.2	61.8 ± 3.9	33.2 ± 2.1

Values are Mean ± SD (n = 3). All differences between fruit pulp and seed extract statistically significant ($p < 0.001$, Tukey HSD). Ki for alpha-glucosidase competitive inhibition by seed extract = 18.4 ± 2.1 µg/mL (Lineweaver-Burk analysis).

The IC50 for alpha-glucosidase inhibition by seed extract was 27.3 ± 1.6 µg/mL, placing it at approximately 62% of the potency of acarbose (16.9 ± 0.8 µg/mL). Fruit pulp IC50 for this enzyme was 67.4 ± 4.1 µg/mL, nearly four times weaker than the seed extract. For alpha-amylase, seed extract gave IC50 of 41.2 ± 2.7 µg/mL versus acarbose at 26.8 ± 1.4 and fruit pulp at 82.6 ± 5.3 µg/mL. Notably, the ratio of alpha-glucosidase to alpha-amylase IC50 for seed extract was 1:1.51, indicating modest but real selectivity toward alpha-glucosidase inhibition, which is the pharmacologically preferred target. Lineweaver-Burk plots at fixed seed extract concentration (40 µg/mL) and varying pNPG concentrations showed convergence on the y-axis, confirming competitive inhibition with same Vmax and increased Km. The inhibition constant Ki was calculated as 18.4 ± 2.1 µg/mL.

3.5 Statistical Analysis Summary

Table 4 summarizes the ANOVA results and Pearson correlation coefficients that quantify the relationship between phytochemical composition and biological activity across all extract fractions.

Table 4. One-way ANOVA F-statistics and Pearson correlation coefficients for phytochemical versus biological activity data.

Statistical Parameter	Value	p-value	Inference
ANOVA: TPC Fruit vs Seed	F = 91.47	< 0.001	Highly significant (***)
ANOVA: TFC Fruit vs Seed	F = 78.32	< 0.001	Highly significant (***)
ANOVA: DPPH IC50 Fruit vs Seed	F = 64.19	< 0.001	Highly significant (***)

ANOVA: alpha-glucosidase IC50	F = 96.73	< 0.001	Highly significant (***)
Pearson r: TPC vs DPPH IC50	r = -0.951	< 0.001	Strong negative correlation
Pearson r: TFC vs alpha-gluc IC50	r = -0.928	< 0.001	Strong negative correlation
Pearson r: Tannins vs amylase IC50	r = -0.884	< 0.001	Strong negative correlation

*** $p < 0.001$. Pearson r values computed across all six fractions (n = 6 data points per correlation, two-tailed significance test, null hypothesis r = 0). Negative r values indicate that higher phenolic content is associated with lower IC50 (stronger activity).

The correlation between TPC and DPPH IC50 across all six fractions was r = -0.951 ($p < 0.001$), indicating that over 90% of variance in antioxidant IC50 is statistically explained by total phenolic content. TFC correlated with alpha-glucosidase IC50 at r = -0.928, and tannin content with alpha-amylase IC50 at r = -0.884, both $p < 0.001$. These correlations, taken together, indicate that phenolic accumulation is not coincidentally associated with activity but is quantitatively predictive of it. ANOVA F-statistics ranged from 64.19 to 96.73 with $p < 0.001$ across all pairwise comparisons between fruit pulp and seed fractions, confirming that none of the observed differences between the two plant parts can be attributed to random experimental variation.

4. Discussion

The data from this experiment tell a coherent and consistent story. From phytochemical quantification through to enzyme kinetics, every measurement pointed in the same direction: the seed of Syzygium cumini is pharmacologically superior to the fruit pulp for both antioxidant protection and postprandial glycemic management. This is not a marginal difference. The seed extract required 1.73 to 2.22 times less concentration than fruit pulp to achieve 50% DPPH or ABTS scavenging, and approximately 2.5 times less to inhibit alpha-glucosidase by 50%. Against the traditional medicine background that informs this study, these numbers validate the folk selection of seeds over fruit pulp as the medicinal preparation of choice.

Understanding why seeds are superior requires thinking about the ecological function of tannins. The seed is the reproductive unit of the plant, and it must survive from fruit formation through dispersal, passage through animal digestive tracts, and germination in soil. Throughout this period it faces oxidative challenge from UV exposure, microbial attack, and the enzymatic environment of the animal gut. Tannins serve as chemical armor. They are potent antioxidants because of their multiple hydroxyl groups, and they resist enzymatic degradation because of their cross-linked polyphenolic structure (Cos et al., 2004). The consequence of this ecological pressure is that seeds accumulate a concentration of tannins (368.2 mg TAE/100g DW in our study) that is nearly five times greater than the fruit pulp (79.4 mg TAE/100g FW), and this chemical reality underlies the biological superiority observed in every assay.

The competitive inhibition of alpha-glucosidase demonstrated by the Lineweaver-Burk analysis is an important mechanistic finding that goes beyond a simple IC50 number. Competitive inhibition means that the polyphenolic compounds in the seed extract occupy the active site of the enzyme in direct competition with the substrate pNPG, and that inhibition is reversible. This is pharmacologically significant for two reasons. First, reversibility means that the enzyme is not permanently inactivated, which would risk complete carbohydrate malabsorption if the inhibitor were present throughout the intestinal lumen. Second, and more importantly, competitive inhibition of alpha-glucosidase but relatively weaker inhibition of alpha-amylase creates a situation where oligosaccharides released by amylase are not further hydrolyzed to glucose at the brush border, slowing glucose absorption without preventing starch digestion entirely. This mechanistic selectivity may explain why folk practitioners using Jamun seed powder report acceptable gastrointestinal tolerance despite the high tannin load.

The alpha-glucosidase IC50 of 27.3 µg/mL for the crude seed extract is a number worth examining in the context of available literature. Tadera et al. (2006) reported IC50 values of around 30 to 60 µg/mL for purified flavonoids including quercetin and myricetin against alpha-glucosidase. Our crude extract, containing not just flavonoids but also tannins, gallic acid, and ellagic acid, achieved IC50 of 27.3 µg/mL. This is consistent with synergistic activity among multiple polyphenolic constituents, each contributing to occupying the enzyme active site at different affinity levels, their combined effect exceeding what any single component would achieve at the same concentration. Synergy among polyphenols in enzyme inhibition has been documented in other plant systems (Kim et al., 2000) and represents one of the practical advantages of using whole plant extracts over isolated compounds for functional food applications.

The Pearson correlations observed in this study are worth addressing directly because they are sometimes misunderstood. A correlation of r = -0.951 between TPC and DPPH IC50 does not prove that total phenolics cause antioxidant activity in a strict biochemical sense; what it shows is that across the six fractions tested, the fraction that is richest in phenolics is invariably the most potent antioxidant, and this relationship is linear and highly consistent. The practical implication is that phenolic content can serve as a surrogate marker for antioxidant potency when comparing fractions or preparations of Syzygium cumini, which is useful for quality control in any standardized extract development. Similarly, the correlation between TFC and alpha-glucosidase IC50 (r = -0.928) suggests that flavonoid content is a reasonable predictor of antidiabetic enzyme inhibitory potency for this plant material.

Two limitations of this study must be acknowledged. First, the findings are entirely from in vitro assays using purified or semi-purified enzyme preparations and chemical radical generators. The translation to in vivo or clinical efficacy is not guaranteed. Tannins in particular are known to have limited oral bioavailability when measured as intact molecules in the bloodstream, though their activity within the intestinal lumen, which is precisely where alpha-glucosidase inhibition is needed, may be relatively unaffected by this. Second, this study used crude extracts and did not attempt compound isolation. The identity of the specific molecules responsible for the strongest enzyme inhibitory activity remains to be established by bioassay-guided fractionation, which is planned as a continuation of this work.

5. Conclusion

This study provides a systematic, quantitatively rigorous comparison of Syzygium cumini fruit pulp and seeds across a comprehensive panel of antioxidant and antidiabetic in vitro assays. Seeds are significantly richer in total phenolics, flavonoids, and tannins, while fruit pulp contains more anthocyanins. This chemical difference translates directly into superior biological activity of seeds in every antioxidant assay and for every carbohydrate-digesting enzyme tested. The alpha-glucosidase inhibitory activity of seed extract at IC50 of 27.3 µg/mL is the most clinically relevant finding, as this enzyme is the primary target of approved antidiabetic drugs of the acarbose class, and seed extract approached acarbose potency at low concentrations. Competitive inhibition kinetics and strong Pearson correlations between polyphenol content and biological activity collectively establish a mechanistic basis for the observed effects. The data validate the centuries-old folk medical practice of using Jamun seed powder for glycemic management and identify Syzygium cumini seeds as a priority candidate for further phytochemical investigation, standardized extract development, and ultimately clinical evaluation in pre-diabetic and diabetic populations.

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