

Phytochemical Composition, Nutritional Significance, and Pharmacological Potential of *Syzygium Cumini* (L.) Skeels Seed: A Comprehensive Review

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ABSTRACT

Syzygium cumini (L.) Skeels, commonly referred to as jamun, black plum, or Indian blackberry, is a tropical fruit native to the Indian subcontinent and belongs to the family Myrtaceae. It is both nutritionally and therapeutically valuable. In addition to its edible fruits, the seeds of jamun represent a significant by-product in agro-industrial processes, which is rich in bioactive plant compounds. Recent studies on the chemical composition of jamun seeds have identified the presence of various phytochemicals such as polyphenols, flavonoids, terpenoids, saponins, and other secondary metabolites. These compounds are associated with multiple biological activities, including antioxidant, antidiabetic, antimicrobial, and anti-inflammatory properties [1–3]. From a nutritional standpoint, jamun seeds are high in carbohydrates, dietary fiber, essential minerals, and vitamins, making them a promising candidate for use in functional foods and nutraceutical products [4,7]. This review compiles recent developments from 2018 to 2024 regarding the nutritional content, phytochemical makeup, methods of extraction, and pharmacological applications of *S. cumini* seeds. It also addresses existing research gaps, industrial opportunities, and future research directions for the application of jamun seed bioactives as natural therapeutic agents and sustainable ingredients in the nutraceutical industry.

Keywords: *Syzygium cumini*, jamun seed, phytochemicals, antioxidant, antidiabetic, nutraceuticals

INTRODUCTION

Medicinal plants have long been regarded as essential sources of therapeutic agents, supplying natural compounds that play crucial roles in health maintenance and disease prevention [1]. Among these, *Syzygium cumini* (L.) Skeels—commonly known as jamun, Indian blackberry, or Java plum—has received substantial attention for its multifaceted nutritional and pharmacological properties [2,3]. Belonging to the family Myrtaceae, this evergreen tropical species has been extensively utilized in Ayurvedic, Unani, and traditional folk medicine for managing diabetes, inflammation, digestive disorders, and cardiovascular ailments [4]. *Syzygium cumini* thrives in tropical and subtropical regions and is widely cultivated across India, Southeast Asia, Latin America, and parts of Africa [5,6]. The fruits are small, oval, and purple-black with a distinct astringent-sweet flavor. Due to their high perishability, fruits are often processed into jams,

juices, and fermented products such as vinegar and wine, leading to substantial seed waste generation [7]. The seeds constitute approximately 10–47% of the total fruit weight [8]. Despite their rich biochemical composition, these seeds are often discarded, posing environmental challenges while simultaneously representing an underutilized source of valuable bioactives. Several studies have reported that jamun seeds are abundant in carbohydrates, dietary fiber, minerals, and vitamin C, along with diverse classes of secondary metabolites such as tannins, flavonoids, phenolic acids, terpenoids, and saponins [9–11]. These phytochemicals collectively impart numerous biological properties, including antioxidant, antidiabetic, antimicrobial, and hepatoprotective effects [12,13]. Consequently, *S. cumini* seeds hold significant promise as a natural, cost-effective source of bioactive compounds for pharmaceutical and nutraceutical industries.

2. Botanical Description and Distribution

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Syzygium cumini (L.) Skeels, commonly known as Indian blackberry, black plum, or Java plum, is a member of the family Myrtaceae and the genus *Syzygium*, which encompasses over 1,100 tropical and subtropical species [6]. The species is indigenous to the Indian subcontinent but has become widely naturalized across Asia, Africa, and South America due to its adaptability to diverse ecological conditions [7].

2.1 Botanical Characteristics

Jamun is an evergreen, medium- to large-sized tree that can attain a height of 25–30 m, forming a dense canopy of glossy green foliage. The bark is greyish-brown and exfoliates in irregular patches. Leaves are opposite, leathery, elliptic-oblong, and rich in aromatic oil glands, which impart a characteristic fragrance. The tree blooms from March to April, producing small, fragrant, white flowers arranged in terminal or axillary panicles. The fruits are oblong to ovoid drupes that mature from green to deep purple or black on ripening, each enclosing a single, large, ovoid seed with a hard testa and a pale brown kernel [8].

2.2 Distribution and Ecology

Syzygium cumini thrives in tropical and subtropical environments, preferring deep, fertile, and well-drained loamy soils. It is widely distributed across India, Bangladesh, Sri Lanka, Thailand, Malaysia, the Philippines, and several regions of Africa and South America [9]. In India, the species occurs abundantly in states such as Uttar Pradesh, Maharashtra, Tamil

Nadu, and West Bengal. It grows under an annual rainfall range of 500–2500 mm and tolerates elevations from sea level up to about 1,800 m [10]. Because of its ecological resilience, high fruit yield, and medicinal value, *S. cumini* is cultivated not only for its edible fruits but also for its leaves, bark, and seeds, which serve as valuable raw materials for pharmacological and nutraceutical applications.

3. Nutritional Profile of Jamun Seeds

Jamun (*Syzygium cumini*) seeds are an important by product of fruit processing industries and possess significant nutritional and functional attributes that contribute to their therapeutic relevance. These seeds are rich in macronutrients and micronutrients, including carbohydrates, proteins, dietary fiber, vitamins, and minerals, all of which play vital roles in maintaining human health and reducing the risk of metabolic disorders [11].

3.1 Proximate Composition

The proximate composition of *S. cumini* seeds indicates a high carbohydrate and fiber content, moderate protein levels, and low lipid concentration. Reports suggest that the seeds contain approximately 70–90% carbohydrates, 4–8% protein, 0.3–1.5% lipids, and 2–22% ash on a dry-weight basis [12]. The starch and non-digestible fiber fractions dominate the carbohydrate profile, with insoluble fiber accounting for nearly 90% of total fiber. This high fiber content aids digestive function and supports glucose metabolism [15].

Table 1. Proximate composition of *Syzygium cumini* seeds (per 100 g dry weight)

Nutritional Component	Reported Range
Carbohydrates	70–91 g
Protein	4.7–8.2 g
Lipid	0.35–1.28 g
Ash	2.0–22.3 g
Moisture	12–52%

3.2 Proteins and Amino Acids

Jamun seeds contain several biologically active proteins with enzymatic and defense-related functions. Proteomic studies have identified the presence of chitinases, pectate lyases, transport proteins, and lactoferrin-like proteins [13]. However,

research on amino acid composition, bioavailability, and protein digestibility remains limited and warrants further exploration.

3.3 Lipid Composition



Although the total lipid fraction is low, *S. cumini* seed oil contains a nutritionally balanced mix of saturated and unsaturated fatty acids. Major constituents include lauric, myristic, palmitic, oleic, and linoleic acids, with minor amounts of epoxy and cyclopropenoid fatty acids [14]. This lipid profile supports cardiovascular health and contributes to the overall antioxidant activity of the seed oil.

The seeds are rich in essential micronutrients, particularly potassium, calcium, magnesium, iron, zinc, and manganese, which play critical roles in enzymatic and metabolic regulation [15]. Additionally, the ascorbic acid (vitamin C) content ranges between 50–137 mg/100 g, reinforcing the antioxidant capacity and immune-supporting potential of the seeds.

3.4 Vitamins and Minerals

Table 2. Mineral composition of *Syzygium cumini* seeds (mg/100 g dry weight)

Mineral Element	Reported Content
Potassium (K)	606
Calcium (Ca)	136
Magnesium (Mg)	112
Iron (Fe)	4.2
Copper (Cu)	2.1
Chromium (Cr)	1.4
Zinc (Zn)	0.46

4. Bioactive Phytoconstituents of Jamun Seeds

The seed of *Syzygium cumini* (L.) Skeels is a rich repository of bioactive phytochemicals responsible for its diverse therapeutic and pharmacological effects. These secondary metabolites include phenolic compounds, flavonoids, terpenoids, alkaloids, saponins, and glycosides, which collectively contribute to its antioxidant, anti-inflammatory, antidiabetic, and antimicrobial activities [16,17]. Recent advances in analytical techniques such as HPLC, LC–MS/MS, and GC–MS have facilitated comprehensive profiling of these compounds, revealing several bioactives of nutraceutical relevance [18,19].

4.1 Phenolic Compounds

Phenolic compounds are among the most abundant and biologically active components of *S. cumini* seeds. They exhibit potent antioxidant and free-radical scavenging properties due to their ability to donate hydrogen atoms and chelate transition metals [16]. The total phenolic content (TPC) in jamun seed extracts has been reported to range between 40–85 mg gallic acid equivalents (GAE)/g of dry extract [17]. Major phenolic acids identified include gallic acid, ellagic acid, ferulic acid, chlorogenic acid, syringic acid, and caffeic acid, all of which contribute to the

seed's hypoglycemic and hepatoprotective potential [18]. These phenolic constituents act synergistically to protect against oxidative stress and modulate glucose metabolism through inhibition of α -amylase and α -glucosidase enzymes [20].

4.2 Flavonoids

Flavonoids represent another important group of polyphenolic compounds in jamun seeds, known for their antioxidative, anti-inflammatory, and cytoprotective roles [18]. LC–MS/MS analysis has confirmed the presence of quercetin, kaempferol, myricetin, rutin, and catechin as dominant flavonoids in methanolic and ethanolic extracts [19]. The concentration of total flavonoids is estimated to range between 25–65 mg quercetin equivalents (QE)/g of extract, depending on solvent polarity and extraction conditions. These compounds stabilize reactive oxygen species (ROS), regulate lipid peroxidation, and enhance pancreatic β -cell function, thereby contributing to the antidiabetic potential of jamun seed formulations [17].

4.3 Terpenoids and Saponins

Terpenoids and saponins are abundant in *S. cumini* seeds and are largely responsible for their bitter taste and pharmacological versatility [17]. Terpenoids such

as **lupeol, betulinic acid, and oleanolic acid** have been identified and are known to exert anti-inflammatory, antimicrobial, and hypolipidemic effects [18]. Saponins, on the other hand, contribute to membrane-stabilizing activity and cholesterol regulation by forming insoluble complexes with bile acids [19]. Their amphiphilic nature also enhances the solubility and bioavailability of hydrophobic phenolic compounds, thus improving overall pharmacological efficiency [20].

4.4 Alkaloids and Other Constituents

In addition to phenolics, flavonoids, and terpenoids, jamun seeds also contain a wide spectrum of alkaloids, glycosides, and tannins [17]. Alkaloids such as jambosine, jamboline, and gallicin have been reported to exhibit antidiabetic and hypoglycemic activities by modulating carbohydrate metabolism and insulin secretion [16,18]. Other constituents include ellagitannins and lignans, which possess

antioxidant and hepatoprotective properties [19]. The diversity of these phytoconstituents provides a biochemical rationale for the traditional use of *S. cumini* seeds in treating diabetes, inflammation, and oxidative stress-related disorders [20].

5. Pharmacological Activities of *Syzygium cumini* Seeds

The pharmacological efficacy of *Syzygium cumini* seeds has been extensively studied owing to their rich phytochemical composition. Bioactive constituents such as phenolics, flavonoids, terpenoids, saponins, and alkaloids contribute to a wide spectrum of biological activities, including antioxidant, antidiabetic, antimicrobial, hepatoprotective, and anti-inflammatory effects [20–25]. The pharmacological potential of jamun seeds supports their application in pharmaceutical formulations, functional foods.

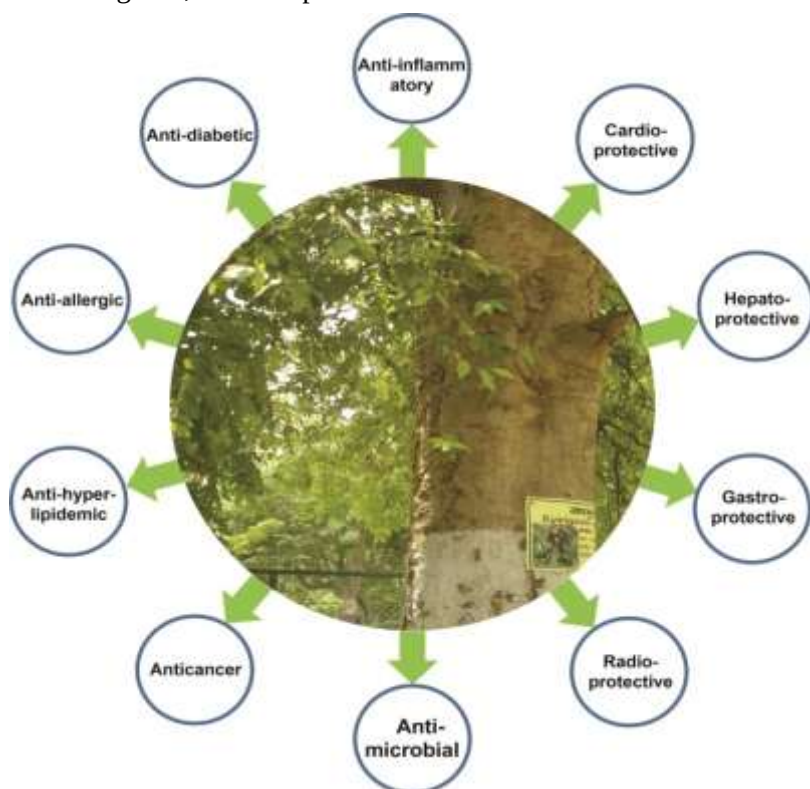


Fig. 1 Different activities of various parts of Jamun, *Syzygium cumini*.

5.1 Antioxidant Activity

The antioxidant potential of *S. cumini* seeds has been attributed to their high polyphenolic and flavonoid content [16,17]. Studies have reported strong radical-scavenging activity in both aqueous and alcoholic extracts using DPPH, ABTS, and FRAP assays [20].

Polyphenols such as gallic acid, ellagic acid, and quercetin are primarily responsible for neutralizing reactive oxygen species (ROS) and inhibiting lipid peroxidation. In vitro analyses by Raut et al. [20] demonstrated that methanolic extracts of jamun seeds exhibited IC₅₀ values ranging from 40–55 µg/mL against DPPH radicals, indicating superior

antioxidant efficacy compared to standard ascorbic acid. The antioxidant capacity contributes to the protective effect of jamun seed extracts against oxidative stress-mediated tissue damage, supporting their potential use as natural antioxidant agents in therapeutic formulations.

5.2 Antidiabetic Activity

The seeds of *S. cumini* are traditionally used in the management of diabetes mellitus due to their hypoglycemic properties [3,10]. Active constituents such as jambosine, jamboline, ellagic acid, and gallic acid modulate glucose homeostasis by inhibiting α -amylase and α -glucosidase enzymes, reducing postprandial hyperglycemia [21]. Singh et al. [21] reported that phenolic-rich fractions of jamun seed significantly reduced fasting blood glucose levels in diabetic rats while enhancing glycogen synthesis in hepatic tissues. The mechanism of action involves both enzyme inhibition and enhancement of insulin secretion, with flavonoids contributing to improved β -cell regeneration. These findings validate the traditional use of jamun seeds as a natural antidiabetic agent and encourage their integration into modern nutraceutical therapies [20,21].

5.3 Antimicrobial Activity

The antimicrobial potential of *S. cumini* seeds has been widely investigated against bacterial and fungal pathogens. Extracts containing polyphenols and terpenoids exhibit strong bactericidal and fungicidal effects through membrane disruption and inhibition of microbial enzymes [22,25]. Kaushik et al. [22] demonstrated that ethanolic seed extracts inhibited the growth of *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans* with minimum inhibitory concentrations (MICs) ranging from **1.25–2.50 mg/mL**. Moreover, Gupta et al. [25] showed that incorporating jamun seed powder into food systems effectively suppressed spoilage microorganisms, highlighting its application as a **natural preservative and food-grade antimicrobial**.

5.4 Hepatoprotective and Cardioprotective Activities

Polyphenolic and flavonoid compounds in jamun seeds exert protective effects on hepatic and cardiac

tissues by attenuating oxidative stress and enhancing antioxidant enzyme levels [24]. Experimental studies by Jain et al. [24] revealed that administration of ethanolic seed extract significantly restored serum biochemical markers (ALT, AST, ALP) and improved histopathological parameters in carbon tetrachloride (CCl_4)-induced hepatotoxic rats. Furthermore, phenolic-rich extracts modulate lipid metabolism and prevent atherogenesis by reducing LDL oxidation and enhancing HDL cholesterol levels [23,24]. These findings suggest that *S. cumini* seed bioactives could serve as hepatoprotective and cardioprotective nutraceuticals in oxidative stress-related disorders.

5.5 Anti-inflammatory Activity

Jamun seed extracts exhibit notable anti-inflammatory effects through the inhibition of pro-inflammatory mediators such as nitric oxide (NO), prostaglandin E_2 , and tumor necrosis factor- α (TNF- α) [22]. The mechanism involves downregulation of the **NF- κ B and COX-2 pathways**, as reported by Kaushik et al. [22]. In vitro and in vivo assays have confirmed that phenolic and flavonoid constituents mitigate inflammation in models of edema and arthritis by reducing oxidative and cytokine-mediated tissue damage. This multifaceted anti-inflammatory activity complements the antioxidant and antidiabetic properties of *S. cumini*, supporting its therapeutic relevance in managing chronic metabolic and inflammatory disorders [20–22].

6. Extraction Techniques and Processing of Jamun Seeds

The extraction and processing of *Syzygium cumini* seeds play a vital role in determining the yield, purity, and bioactivity of their phytochemical constituents. Various extraction methodologies have been employed to obtain phenolic-rich and pharmacologically active fractions from jamun seeds, with solvent type, extraction temperature, and particle size being key influencing parameters [26]. The selection of an appropriate extraction technique depends on the target compounds, desired yield, and potential application in pharmaceutical or nutraceutical formulations.

6.1 Conventional Extraction Methods



Traditional solvent extraction remains the most widely used method for obtaining bioactive compounds from jamun seeds. Techniques such as **maceration, Soxhlet extraction, and refluxing** have been extensively used to extract phenolics, flavonoids, and alkaloids [26]. Maceration involves soaking powdered seed material in solvents such as methanol, ethanol, or water for extended durations under controlled temperature, facilitating diffusion of soluble compounds into the solvent phase [27]. Soxhlet extraction provides continuous solvent percolation through the seed matrix, improving efficiency and ensuring exhaustive extraction. While these methods are simple and cost-effective, they are often associated with long processing times, high solvent consumption, and possible thermal degradation of heat-sensitive compounds [26,27].

6.2 Advanced Extraction Techniques

To overcome the limitations of conventional methods, several modern and eco-friendly extraction approaches have been developed. Ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), and supercritical fluid extraction (SFE) have gained prominence due to their higher extraction efficiency, shorter processing time, and lower solvent usage [27,28]. UAE enhances cell wall disruption through cavitation, improving solvent penetration and release of intracellular compounds. MAE utilizes electromagnetic radiation to heat polar solvents and plant matrices rapidly, significantly enhancing extraction yield of thermolabile phytochemicals [28]. In comparison, **supercritical CO₂ extraction** has emerged as a solvent-free and green technology that efficiently extracts non-polar bioactives such as terpenoids and essential oils from jamun seeds [27]. The use of co-solvents like ethanol further enhances the recovery of phenolics and flavonoids under optimized pressure and temperature conditions.

6.3 Drying, Grinding, and Storage

Proper preprocessing and storage of jamun seeds are crucial to maintaining the stability of bioactive components. After seed collection, drying at 40–50°C helps reduce moisture content and prevent microbial growth, while grinding into fine powder increases the surface area for effective extraction [26]. Storage in airtight containers under low humidity and

absence of light minimizes oxidation and degradation of phenolics and flavonoids [27]. Additionally, encapsulation or lyophilization of seed extracts can improve stability, solubility, and bioavailability of phytoconstituents for pharmaceutical applications [28].

6.4 Optimization and Standardization

Recent studies have emphasized the need for optimization of extraction parameters using statistical tools such as Response Surface Methodology (RSM) and Design of Experiments (DOE) to maximize yield and maintain consistency across batches [28]. Standardization of extracts based on marker compounds like gallic acid, ellagic acid, and quercetin ensures reproducibility and quality assurance in formulation development [26]. Such optimized extraction protocols are critical for the large-scale utilization of jamun seed bioactives in **functional foods, herbal supplements, and drug delivery systems** [27,28].

7. Pharmacokinetics and Bioavailability of Jamun Seed Constituents

The pharmacokinetic behavior and bioavailability of bioactive compounds from *Syzygium cumini* seeds determine their therapeutic efficacy and clinical potential. Despite the seeds being rich in phenolics, flavonoids, alkaloids, and terpenoids, their **oral bioavailability is often limited** due to poor solubility, instability in the gastrointestinal environment, and first-pass metabolism [29]. Understanding the absorption, distribution, metabolism, and excretion (ADME) of these phytochemicals is essential for developing effective formulations and delivery systems.

7.1 Absorption and Metabolic Transformation

After oral administration, jamun seed extracts undergo extensive metabolism in the intestine and liver, where polyphenolic compounds such as gallic acid, ellagic acid, and quercetin are conjugated into glucuronides and sulfates [29]. These metabolites retain biological activity and contribute to the antioxidant and antidiabetic effects observed in vivo. However, the low lipophilicity and large molecular weight of certain phenolics limit their passive

diffusion across biological membranes, resulting in reduced systemic absorption [30]. The presence of dietary lipids or natural co-factors such as saponins can enhance the solubility and absorption of hydrophobic compounds, improving bioavailability.

7.2 Distribution and Target Interaction

Once absorbed, bioactive constituents from jamun seeds distribute through the bloodstream to various target tissues, including the liver, pancreas, and kidneys — organs primarily involved in glucose and oxidative metabolism [30]. Studies have demonstrated that phenolic metabolites can cross cellular membranes and accumulate in tissues, where they exert **antioxidant and enzyme-modulating effects** [29,30]. The interaction of flavonoids and ellagitannins with cellular proteins further influences insulin secretion, hepatic enzyme regulation, and oxidative stress pathways, contributing to the observed pharmacological outcomes.

7.3 Strategies to Enhance Bioavailability

To overcome poor bioavailability, several formulation strategies have been explored. **Encapsulation, nanoemulsion, and liposomal delivery systems** have been successfully employed to protect jamun seed bioactives from degradation and enhance their intestinal absorption [31]. Nanoencapsulation not only improves solubility and permeability but also provides sustained release and targeted delivery, enhancing the overall pharmacokinetic profile [29]. Similarly, **phytosome and polymer-based nanoparticles** have been designed for improved transport across biological membranes and increased residence time in systemic circulation [31]. These advanced delivery approaches have paved the way for the development of **functional foods and nutraceutical formulations** incorporating jamun seed extracts.

7.4 Future Prospects

Although preclinical studies have established the pharmacological relevance of *S. cumini* seed constituents, further **in vivo pharmacokinetic and clinical studies** are needed to correlate plasma concentrations with pharmacodynamic effects [30]. Establishing standardized pharmacokinetic models

will be crucial for dosage optimization and therapeutic validation of jamun-based formulations [31].

8. Therapeutic and Nutraceutical Applications of Jamun Seed Extracts

The bioactive compounds present in *Syzygium cumini* (L.) Skeels seeds have demonstrated a wide range of pharmacological and nutraceutical applications owing to their antioxidant, antidiabetic, hepatoprotective, antimicrobial, and anti-inflammatory properties [30]. The seed extracts are incorporated into several traditional and modern formulations aimed at managing metabolic disorders and oxidative stress-related conditions. Recent developments in functional foods and nutraceutical technologies have further expanded the utilization of jamun seed extracts as natural therapeutic agents [31].

8.1 Antidiabetic Applications

Jamun seed powder and its standardized extracts are extensively used as **natural antidiabetic agents** in Ayurvedic and contemporary formulations [30]. Phenolic compounds such as **gallic acid, ellagic acid, and jamboline** modulate glucose metabolism through the inhibition of carbohydrate-hydrolyzing enzymes like α -amylase and α -glucosidase, thereby delaying glucose absorption [31]. Preclinical studies have confirmed that oral administration of jamun seed extract significantly reduces fasting blood glucose levels, enhances insulin secretion, and improves pancreatic β -cell regeneration [30,31]. These properties make jamun seed a potent adjunct in the management of type 2 diabetes mellitus and metabolic syndrome,

8.2 Antioxidant and Hepatoprotective Roles

The high concentration of polyphenols and flavonoids confers strong **antioxidant activity**, which helps neutralize free radicals and prevent oxidative damage to biomolecules [30]. Regular consumption of jamun seed formulations has been shown to improve hepatic antioxidant enzyme levels (SOD, CAT, GPx) and reduce lipid peroxidation [31]. Moreover, the hepatoprotective potential of jamun seed extract has been validated in experimental models where it demonstrated protection against toxin-induced liver

injury, indicating its role in maintaining hepatic integrity and detoxification processes [30].

8.3 Antimicrobial and Anti-inflammatory Properties

The phytochemicals in jamun seeds, particularly **flavonoids, terpenoids, and alkaloids**, exhibit broad-spectrum antimicrobial activity against both Gram-positive and Gram-negative bacteria [31]. These compounds disrupt microbial membranes, inhibit biofilm formation, and reduce microbial load, making them useful in natural food preservation and topical formulations [30]. Additionally, the anti-inflammatory effects of the seed extract are attributed to the suppression of pro-inflammatory mediators such as TNF- α , IL-6, and COX-2, thereby reducing inflammation and oxidative stress in chronic disease conditions [31].

8.4 Nutraceutical and Functional Food Applications

Due to its high nutritional value and bioactive content, jamun seed powder has been increasingly incorporated into functional foods, beverages, and nutraceutical supplements [30]. Formulations enriched with jamun seed extract enhance antioxidant intake, regulate postprandial glycemia, and support metabolic health [32]. Recent innovations in nutraceutical product development have focused on microencapsulation, nanoemulsions, and jamun seed-based dietary blends, ensuring better stability, bioavailability, and consumer acceptability [31,32]. The inclusion of jamun seed bioactives in daily diets has shown potential in promoting overall well-being and preventing lifestyle-related disorders.

8.5 Emerging Therapeutic Opportunities

Beyond conventional uses, ongoing research has revealed the potential of *S. cumini* seed bioactives in managing neurodegenerative, cardiovascular, and gastrointestinal disorders [32]. The antioxidant and enzyme-regulatory mechanisms contribute to neuroprotection, lipid regulation, and gastrointestinal health. These emerging insights indicate that jamun seed-based formulations may evolve as safe, multifunctional nutraceuticals for preventive and therapeutic health care [30–32].

CONCLUSION

Syzygium cumini (L.) Skeels, commonly known as jamun, represents a highly valuable medicinal and nutritional resource. Its seeds, long regarded as a by-product, have now emerged as a potent reservoir of bioactive compounds including phenolics, flavonoids, terpenoids, alkaloids, and saponins. These phytochemicals are responsible for the wide range of pharmacological effects such as **antioxidant, antidiabetic, hepatoprotective, antimicrobial, and anti-inflammatory activities**. Advanced extraction and formulation technologies have significantly enhanced the recovery and bioavailability of these constituents, making jamun seed extracts suitable for incorporation into **functional foods, nutraceuticals, and therapeutic formulations**.

Recent research underscores the importance of standardized extraction protocols, optimization of dosage, and in vivo pharmacokinetic evaluation to ensure reproducible efficacy and safety. Future prospects lie in the development of **novel nanoformulations and encapsulated delivery systems** that could improve the targeted delivery and therapeutic potential of jamun seed bioactives. Overall, *S. cumini* seeds offer an exceptional opportunity for developing cost-effective, natural, and sustainable health-promoting products.

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