Pol. J. Food Nutr. Sci., 2022, Vol. 72, No. 3, pp. 211–228
On-line ISSN: 2083-6007
Print ISSN: 1230-0322
DOI: 10.31883/pjfns/152568
http://journal.pan.olsztyn.pl

Review article
Section: Food Quality and Functionality

Jamun Seed: A Review on Bioactive Constituents, Nutritional Value and Health Benefits

Yamini Tak[1], Manpreet Kaur[2], Mool Chand Jain[3], Mahesh Kumar Samota[4], Nirmal Kumar Meena[5], Gurpreet Kaur[6], Rajendra Kumar[7], Daisy Sharma[8], José M. Lorenzo[9, 10], Ryszard Amarowicz[11]

[1]*Department of Biochemistry, Agriculture University, Kota, Rajasthan-324001, India*
[2]*Department of Biochemistry, Punjab Agricultural University, Ludhiana, Punjab-141004, India*
[3]*Department of Horticulture, College of Agriculture, Agriculture University, Kota, Rajasthan-324001, India*
[4]*HCP Division, ICAR-Central Institute of Post-Harvest Engineering & Technology, Abohar-152116, India*
[5]*Department of Fruit Science, College of Horticulture & Forestry, Jhalawar-326023, Rajasthan, India*
[6]*Department of Agriculture, Sant Baba Bhag Singh University, Jalandhar-144030, Punjab, India*
[7]*Department of Entomology, MBDDS Girls College, Siswali, Baran, Rajasthan-334001, India*
[8]*Department of Food Nutrition and Dietetics, Assam down town University, Panikhaity, Guwahati- 781137, Assam, India*
[9]*Centro Tecnológico de la Carne de Galicia, Parque Tecnológico de Galicia, 32900 San Cibrao das Viñas, Spain*
[10]*Área de Tecnología de los Alimentos, Facultad de Ciencias de Ourense, Universidad de Vigo, 32004 Ourense, Spain*
[11]*Institute of Animal Reproduction and Food Research, Polish Academy of Sciences, Tuwima Street 10, 10–748 Olsztyn, Poland*

Key words: jamun seeds, nutrients, bioactives, extraction and purification, nutraceuticals

Jamun fruit, a member of the Myrtaceae family, is commercially grown in tropical and subtropical areas of the world for its fruits with sweet, sour, and astringent luscious flesh. Seeds of jamun fruits are discarded as trash during the industrial processing of fruit pulp into beverages, jellies, jam, vinegar, wine, and squash. These seeds are a potential source of bioactive compounds including hydrolysable tannins, phenolic acids, flavonoids, other phenolics, terpenoids, phloroglucinol derivatives and saponins, which have been endorsed several biological activities, such as antidiabetic, anticancer, anti-inflammatory, antioxidant, antimicrobial, antihyperlipidemic and antihypercholesterolemic, as well as cardioprotective, hepatoprotective and neuroprotective properties. High contents of carbohydrates, dietary fiber, minerals, and ascorbic acid have also been found in jamun seeds. However, potential utilization of these seeds as innovative implements for health benefits has not yet been fully understood. We aim to compile scientific research and recent advances on jamun seed nutritional profile, bioactive compounds composition, bioactive properties, and their potential as an ingredient in functional food formulation.

INTRODUCTION

Jamun (*Syzygium cumini* or *Syzygium jambolana* or *Eugenia jambolana* or *Eugenia cumini*) is a polyembryonic species of the Myrtaceae family grown for its fruit, timber, and ornamental values. Jamun blossoms in both tropical and subtropical regions and is mostly grown in deep loam and well-drained soils. Jamun, also known as Indian blackberry, Malabar plum, Portuguese plum, Java plum, black plum, or jambolan, is a native to the Indian subcontinent and spread across Southeast Asia, Latin America, and Africa [de Sousa Sabino *et al.*, 2018]. India is ranked second, accounting for around 15.4% of total global production, or 13.5 million tonnes [https://www.agrifarming.in/jamun-farming]. Jamun fruits are small, usually oval-shaped with a pink purple to blue black colour when completely ripe, with a subtly sweet, astringent, and sour flavour, and a firm seed inside [Gajera *et al*., 2018; de Sousa Sabino *et al.*, 2018; un Din *et al*., 2020]. At fully ripen stage, jamun pulp contains sugars (glucose, fructose), free amino acids, minerals (Na, K, Ca, Mn, Mg), dietary fiber, ascorbic acid, β-carotene, organic acids [Gajera *et al*., 2018; Seraglio *et al*., 2018], phenolic compounds (anthocyanins, flavonols, ellagotannins and gallotannins) [Faria *et al*., 2011; Lestario *et al*., 2017], volatile compounds (*trans*-ocimene, *cis*-ocimene, β-myrcene, and α-terpineol), and flavouring compounds (dihydrocarvyl acetate, geranyl butyrate, and terpinyl valerate) [Vijayanand *et al*., 2001].

Because jamun fruits are highly perishable in nature, most of them are processed. Jam, jelly, vinegar, wine, squash, and non-fermented ready-to-drink beverages are some

* Corresponding Author:
E-mail: r.amarowicz@pan.olsztyn.pl (Prof. R. Amarowicz)

Submitted: 17 March 2022
Accepted: 2 August 2022
Published on-line: 2 September 2022

of the traditional jamun fruit products [de Sousa Sabino *et al*., 2018]. Moreover, the fruit pulp can be dried and used as a food colorant and as a nutritious and health-promoting additive for pasta, ice cream, *etc.* [Lestario *et al*., 2017; Panghal *et al.*, 2019; Shelke *et al.*, 2020; Singh *et al.*, 2019]. However, since only the pulp is used in the processing of the jamun fruit, the rest generate the waste. Seeds are the main post--processing waste product. Their amount is large, because they constitute 10–47% of the total weight of the fruit [Benherlal & Arumughan, 2007; Gajera *et al*., 2018; un Din *et al*., 2020]. The generated waste causes problem for the industry and for the environment, but on the other hand, it has become a challenge for scientists. Jamun fruit waste has the potential to become a valuable by-product and open up avenues for the scientific and research community to assist industry and farmers in generating revenue. Jamun seeds have been utilized to treat diabetes and digestive problems in Ayurveda since ancient times. Currently, the health-promoting properties of jamun seeds are being confirmed and many bioactive compounds responsible for it, including phenolics, terpenoids, phloroglucinol derivatives and saponins, were identified [Liu *et al.*, 2017a,b, 2018; Martin *et al.*, 1998; Omar *et al*., 2012; Thiyagarajan *et al*., 2016]. Intensive research on biological potential is ongoing and the seed extracts, extract fractions and isolated compounds are being tested for antidiabetic, antioxidant, anti-inflammatory, anticancer, antimicrobial, cardioprotective, hepatoprotective, and neuroprotective properties. Moreover, the jamun seeds have been found to contain nutrients. They are rich in carbohydrates, dietary fiber, ascorbic acid, and some minerals [Benherlal & Arumughan, 2007; Ghosh *et al.*, 2017; Kaur *et al.*, 2011]. The nutritional and phytochemical profiles of jamun seeds revealed that they could be a novel source for pharmaceutical and food industries. This review mainly discusses the nutrients and phytochemicals of jamun seeds and recent research into their bioactive potential in the context of the possibility of using this jamun fruit processing by-product in the functional food formulation.

NUTRITIONAL PROFILE OF JAMUN SEEDS

Proximate analysis indicated that moisture content of jamun fruit seeds ranged from 12.45 to 52.4 g/100 g and yielded crude protein, total lipids, total carbohydrates, and ash contents as 4.7–8.2 g/100 g, 0.35–1.28 g/100 g, 70.9–91.0 g/100 g, and 2.0–22.3 g/100 g on a dry matter (dm) basis, respectively [Benherlal & Arumughan, 2007; Ghosh *et al.*, 2017; Indrayan *et al*., 2005].

Carbohydrates

Carbohydrates are the main nutrient of the jamun seeds [Benherlal & Arumughan, 2007; Ghosh *et al.*, 2017; Indrayan *et al*., 2005]. Among digestible carbohydrates, which provide the energy needed to support various metabolic processes in the human body, starch dominates with the content ranging from 23 g/100 g to 60 g/100 g dm of seed [Benherlal & Arumughan, 2007; Gajera *et al.*, 2018]. The content of total soluble sugars is negligible – 0.1–1.4 g/100 g [Gajera *et al.*, 2018; Ghosh *et al.*, 2017]. Moreover, jamun seeds were recognized as the rich source of dietary fiber [Kaur *et al*., 2011], which together with lignin constituted non-digestible carbohydrates and represented nutritionally important, health-promoting food ingredient. The content of total dietary fiber of jamun seeds was evaluated at 27.7 g/100 g and the fraction of insoluble dietary fiber was significantly greater than that of the soluble dietary fiber (24.9 g/100 g and 2.8 g/100 g, respectively) [Kaur *et al*., 2011]. In turn, Pandey & Khan [2002] found water-soluble gums as the main fraction of non-digestible carbohydrates of jamun seeds with the content of 40 g/100 g of fresh matter, fm (moisture content of 5.9 g/100 g). The second non-digestible seed carbohydrate fraction was water--insoluble neutral detergent fiber (15 g/100 g fm) containing cellulose (6.9 g/100 g fm), hemicellulose (5.9 g/100 g fm), lignin (1.0 g/100 g fm), cutin (0.76 g/100 g fm), and silica (0.44 g/100 g fm). The profile of dietary fiber may determine its health benefits. As recently discussed in a review article by Cronin *et al*. [2021], the different type of dietary fiber can modulate the gut microbiota composition in various ways and thus alter the short chain fatty acid production and glucose and lipid metabolism which, if it is abnormal, is associated with a risk of chronic diseases.

Recently, many polysaccharides with biological activity, including antioxidant activity, and α-amylase and α-glucosidase inhibitory properties, have been isolated from various parts of plants [Deng *et al*., 2020; Oh & Yoon, 2018; Tan *et al.,* 2021]. Concerning the jamun seeds, Al-Dhabi & Ponmurugan [2020] isolated the water-soluble polysaccharide fraction free of reducing sugar, uronic acid, and starch. However, the biological activity of these polysaccharides has not been analysed.

Proteins

Proteins constitute up to 8% of jamun seed dm [Benherlal & Arumughan, 2007; Indrayan *et al*., 2005], although some literature reports indicate a much higher protein content – 19.96 g/100 g fm [Santos *et al*., 2020]. In addition to crude protein, free amino acids were reported in *S. cumini* seeds with the content of 4.84–9.90 mg/100 g [Gajera *et al*., 2018], but their profile has not been analysed. Recently, Binita *et al*. [2014] attempted to determine the protein profile of jamun seeds using two-dimensional gel electrophoresis (2D-PAGE) and matrix--assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF/MS) and identified 15 functional proteins including lactoferrin, chitinase1, sulphate transporter like protein, pectate lyases, β-tubulin, ABC transporter, phosphate binding protein, 1-aminocyclopropane-1-carboxylate oxidase, G protein coupled receptor, ADP-glucose pyrophosphorylase, and glutamate–ammonia ligase adenylyltransferase, which are important in plant defense mechanisms, metabolism, and transport of inorganic salts. Nevertheless, the jamun seed proteins are still very poorly understood and, to the best of our knowledge, there is a lack of data on their nutritional value, amino acid composition, digestibility, and possible use as food. More research is needed in this area.

Lipids

The total lipid content of jamun seed is low (below 1.5 g/100 g) [Benherlal & Arumughan, 2007; Ghosh *et al.*,

2017], nevertheless fatty acid composition of lipids is healthy balanced. The saturated fatty acids (SFA) account for 50% and unsaturated fatty acids (UFA) including monounsaturated fatty acids and polyunsaturated fatty acids for 14% and 36% of total fatty acids, respectively [Bhaskar *et al*., 2021]. Among SFA, lauric acid (12:0; 2.8%), myristic acid (16:0; 31.7%), palmitic acid (16:0; 4.7%), and stearic acid (18:0; 6.5%) were determined. Oleic acid (18:1 *n*-9; 32.2%), linoleic (18:2 *n*-6; 16.1%), and epoxy and cyclopropenoid fatty acids, such as malvalic (1.2%), sterculic (1.8%), and vernolic (1.3%) acids, were also found in the fatty acid profile of jamun seed oil [Daulatabad *et al*., 1988]. In turn, Bhaskar *et al*. [2021] identified a few methyl esters of SFA (myristic acid, pentadecanoic acid, and heptadecanoic acid) and methyl esters of UFA (7,10,13-hexadecatrienoic acid, 8,11-octadecadienoic acid, 7,10-hexadecadienoic acid and 6,9,12,15-docosatetraenoic acid), together with fatty acid relevant compounds (3,7,11,15-tetramethyl-2-hexadecen--1-ol, docosyl acetate, 1-eicosene and 1,4-eicosadiene) in jamun seed oil using the GC–MS analysis. A low content of lipids and a high content of dietary fiber make the nutritional value of jamun seed low, raching only 267 kcal/100 g [Indrayan *et al*., 2005], which can be considered nutritionally beneficial in the context of the current global problem of overweight and obesity in humans.

Micronutrients

Jamun seed contains ascorbic acid and a high amount of minerals, making it an attractive product for nutritionists [Ghosh *et al*., 2017; Indrayan *et al*., 2005].

Concerning the mineral composition of jamun seeds, Ravi *et al*. [2004a] found 9 dietary macro- and microelements. The dominant ones were manganese, potassium, iron, and chromium. Calcium and copper were determined in trace amounts, and sodium, zinc, and magnesium were detected with moderate levels. A similar qualitative profile was reported by Ghosh *et al*. [2017], although the ratios between the elements were different and the decreasing content was found for the following minerals: potassium (606 mg/100 g), calcium (136 mg/100 g), magnesium (112 mg/100 g), sodium (43.9 mg/100 g), iron (4.20 mg/100 g), copper (2.13 mg/100 g), chromium (1.40 mg/100 g), zinc (0.46 mg/100 g), and manganese (0.40 mg/100 g). The differences in the mineral composition may be due to different environmental conditions during plant growth and their soil-climate adaptation, varietal differences as well as harvest time [Granado-Rodríguez *et al*., 2021; Moussa *et al*., 2020]. Seraglio *et al*. [2018] found that the ripening process directly affected the contents of minerals of *S. cumini* fruit pulp and ripe fruits had significantly higher contents of potassium and calcium compared to these in intermediate ripe stage. It can be assumed that a similar phenomenon also applies to seeds, but this issue needs more extensive research.

Among vitamins and pro-vitamins, only ascorbic acid was determined in jamun seeds [Gajera *et al*., 2018; Ghosh *et al*., 2017]. Its content ranged from 90 mg/100 g to 137 mg/100 g for different genotypes and was higher compared to that in fruit pulp of each genotype [Gajera *et al*., 2018]. A slightly lower content of ascorbic acid of jamun seeds was reported by Ghosh *et al*. [2017], which was 49.8 mg/100 g.

Although β-carotene along with other carotenoids has been determined in jamun fruit pulp [Faria *et al*., 2011], its presence (and other fat-soluble vitamins) has not been confirmed in seeds. Gupta & Agrawal [1970] identified only β-sitosterol in the unsaponifiable fraction of the jamun seed oil.

PHYTOCHEMICALS OF JAMUN SEEDS

Jamun seeds contain a variety of phytochemicals belonging to phenolic compounds, terpenes and terpenoids, sterols and saponins. The profile of these bioactive compounds of *S. cumini* seeds is summarised in Table 1.

Phenolic compounds

Phenolic compounds are the most frequently recognised in jamum seeds and they are the most widely represented group of bioactive compounds (Table 1). The total phenolic content (TPC) has been determined as 55.54 mg gallic acid equivalents (GAE)/g dm of jamun seeds and 22.59 mg GAE/g fresh seeds at a moisture content of 62.25 g/100 g [Balyan & Sarkar, 2017; Shrikanta *et al*., 2015]. Lower TPC (26.9 mg GAE/g dried powdered seeds) was found by Aqil *et al*. [2012]. In turn, Mahindrakar & Rathod [2020a, 2020b] and Bajpai *et al*. [2005] reported higher values ranging from 79.89 to 108.7 mg GAE/ g dry seeds. Regarding jamun seed extracts, TPC of an aqueous extract of dried seed powder obtained under optimal extraction conditions (49.2°C, 89.4 min, and liquid-to-solid ratio 51.6:1, mL/g) with a yield 17.3% was 415 mg/g dried extract [Balyan & Sarkar, 2017]. This value was consistent with TPCs recorded for methanolic fractions obtained from seeds of various *S. cumini* genotypes (361.16––496.26 mg/g extract), which were, in turn, 6.0–9.8 times higher than those determined for fruit pulps from the same genotypes [Gajera *et al*., 2017].

Phenolic acids, flavonoids (flavones, flavan-3-ols, flavonols, flavanonols and dihydrochalcones), stilbenoids, coumarins, lignans, hydrolysable tannins, and phloroglucinol derivatives are present in the profile of the phenolic compounds of jamun seeds (Table 1). Among them, two phenolic acids (gallic and ellagic acids), their simple derivatives and their polymeric forms (gallotannins and ellagitannins, respectively) are most often qualified and quantified [Bajpai *et al*., 2005; Balyan & Sarkar, 2017; Bhatia & Bajaj, 1975; Liu *et al*., 2018; Omar *et al*., 2012; Sawant *et al*., 2015]. It was found that tannic acid (gallotannin), gallic acid, and ellagic acid constituted 45.4%, 21.9% and 8.65% of the phenolic compounds of *S. cumini* seed aqueous extract, respectively [Balyan & Sarka, 2017]. The content of gallic acid was determined over a wide range from 0.65 to 6.24 mg/g dm of seeds and 90.8 mg/g extract, and the content of ellagic acid was reported as 0.038 mg/g dm and 36 mg/g extract [Bajpai *et al*., 2005; Balyan & Sarka, 2017; Shrikanta *et al*., 2015]. The use of liquid chromatography with tandem mass spectrometry (LC-MS/MS) and nuclear magnetic resonance (NMR) spectroscopy techniques has allowed to identify 9 gallotannins and 17 ellagitannins and other ellagic acid derivatives of jamun seeds [Bhatia & Bajaj, 1975; Elhawary *et al*., 2022; Liu *et al*., 2018; Omar *et al*., 2012; Sawant *et al*., 2015]. It is well known that hydrolysable tannins have a strong antioxidant

TABLE 1. Bioactive compounds identified in jamun seeds.

Class of compounds	Compound	Reference
Phenolic acids	Protocatechuic acid	Elhawary *et al*. [2022]
	p-Coumaric acid	Shrikanta *et al*. [2015]; Balyan & Sarkar [2017]
	Caffeic acid	Balyan & Sarkar [2017]; Gajera *et al*. [2017]; Abdin *et al*. [2019]; Elhawary *et al*. [2022]
	Ferulic acid	Gajera *et al*. [2017]; Abdin *et al*. [2019]
	Chlorogenic acid	
	Gallic acid	Bhatia & Bajaj [1975]; Bajpai *et al*. [2005]; Omar *et al*. [2012]; Sawant *et al.* [2015]; Shrikanta *et al*. [2015]; Balyan & Sarkar [2017]; Gajera *et al*. [2017]; Liu *et al.* [2018]; Abdin *et al*. [2019]; Elhawary *et al*. [2022]
	Syringic acid	Liu *et al.* [2018]
	5-Hydroxyveratric acid	
	Ellagic acid	Bhatia & Bajaj [1975]; Bajpai *et al*. [2005]; Aqil *et al.* [2012]; Omar *et al*. [2012]; Sawant *et al.* [2015]; Balyan &Sarkar [2017]; Gajera *et al.* [2017]; Liu *et al.* [2018]; Elhawary *et al*. [2022]
Stilbenoids	Resveratrol	Shrikanta *et al*. [2015]
Flavonols	Quercetin	Bhatia & Bajaj [1975]; Bajpai *et al*. [2005]; Sharma *et al.* [2008b]; Jadeja *et al*. [2012]; Balyan & Sarkar, [2017]; Elhawary *et al*. [2022]
	Rutin	Sharma *et al.* [2008b]; Jadeja *et al*. [2012]
	Myricetin	Liu *et al.* [2018]
	Myricetin 3-*O*-glucoside	Elhawary *et al*. [2022]
	Myricitrin	
	Syringetin	
	Syringetin 3-*O*-glucoside	
	Laricitrin	
	Quercitrin	
	Kaempferol	Bajpai *et al*. [2005]; Jadeja *et al*. [2012]; Abdin *et al*. [2019]; Elhawary *et al*. [2022]
Flavanonols	Dihydromyricetin	Elhawary *et al*. [2022]

TABLE 1 – continued

Class of compounds	Compound	Reference
Flavan-3-ols	(+)-Catechin	Balyan & Sarkar, [2017]; Gajera *et al*. [2017]; Abdin *et al*. [2019]
	(–)-Epicatechin	Shrikanta *et al*. [2015]; Balyan & Sarkar [2017]; Abdin *et al*. [2019]
	(–)-Epigallocatechin	Elhawary *et al*. [2022]
Flavones	Swertisin	Omar *et al*. [2012]
	Schaftoside	Liu *et al.* [2018]
	Apigenin 6,8-di-*C*-β-D-glucopyranoside	
Gallotannins	Tannic acid	Balyan & Sarkar [2017]
	1-Galloyl glucose	Bhatia & Bajaj [1975]
	6-Galloyl glucose	
	1,6-Digalloyl glucose	Elhawary *et al*. [2022]
	1,2,6-Trigalloyl glucose	
	1,2,3,6-Tetragalloyl glucose	
	1,2,3,4,6-Pentagalloyl glucose	
	Valoneic acid dilactone	Omar *et al*. [2012]; Sawant *et al.* [2015]; Liu *et al.* [2018]
	Jamutannin A and B	Omar *et al*. [2012]
Ellagitannins and ellagic acid derivatives	Corilagin	Bhatia & Bajaj [1975]; Elhawary *et al*. [2022]
	Eugeniin	Elhawary *et al*. [2022]
	3,6-Hexahydroxydiphenoyl glucose	Bhatia & Bajaj [1975]
	4,6-Hexahydroxydiphenoyl glucose	
	Iso-oenothein C	Omar *et al*. [2012]; Liu *et al.* [2018]
	Cornusiin B	Omar *et al*. [2012]
	Phyllanthusiin E	
	Rubuphenol	Sawant *et al.* [2015]; Liu *et al.* [2018]
	Eschweilenol A and C	
	Tergallic acid dilactone	
	Ellagic acid 4-*O*-xylopyranoside	Liu *et al.* [2018]
	3'-*O*-Methyl ellagic acid 4-*O*-xylopyranoside	
	3-*O*-Methyl ellagic acid-4'-*O*-α-L-rhamnopyranoside	
	Ellagic acid-4-*O*-β-D-glucopyranoside	
	Decarboxy ellagic acid	
	3,3',4'-Tri-*O*-methyl ellagic acid	Bhatia & Bajaj [1975]; Liu *et al.* [2018]
	3,3'-Di-*O*-methyl ellagic acid	Bhatia & Bajaj [1975]

TABLE 1 – continued

Class of compounds	Compound	Reference
Coumarins	Brevifolin carboxylic acid	Omar *et al.* [2012]
Dihydrochalcones	Phloridzin	Liu *et al.* [2018]
Lignans	Medioresinol 4”-*O*-β--glucoside (+)-Pinoresinol *O*-β-glucoside (+)-Syringaresinol *O*-β-glucoside Dihydrodehydrodiconiferyl alcohol 4”-*O*-β-glucoside	Martin *et al.* [1998]
Phloroglucinol derivatives	Jamunones A–O Spiralisone C	Liu *et al.* [2017b]
Monoterpenes	α-Pinene β-Pinene Limonene	Scharf *et al.* [2016]
Monoterpenoids	γ-Terpineol	Scharf *et al.* [2016]; Elhawary *et al*. [2022]
Sesquiterpenes	α-Copaene *E*-Caryophyllene α-Humulene δ-Cadinene α-Selinene Germacrene D	Scharf *et al.* [2016]
Sesquiterpenoids	Jambolanins A−K Sootepdienone Gibberodione Orientalol E Guaianediol Junipediol Cryptomeridiol Litseachromolaevanes A (4*R*)-4-Hydroxy-1,10-seco-muurol-5-ene-1,10-dione (8*R*,9*R*)-Isocaryolane--8,9-diol Caryolandiol Clovane-2β,9α-diol	Liu *et al.* [2017a]
	Caryophyllenyl alcohol Caryophyllene oxide Caryophylla-4(12), 8(13)-dien-5-ol	Scharf *et al.* [2016]
Norses-quiterpenoids	Jambolanes A and B	Liu *et al.* [2017a]
Triterpenoids	Actinidic acid Oleanolic acid Ursolic acid Corosolic acid Arjunolic acid Asiatic acid	Liu *et al.* [2017a]
	Maslinic acid	Sawant *et al.* [2015]
	Betulinic acid	Elhawary *et al*. [2022]
Saponins	Vitalboside A	Thiyagarajan *et al*. [2016]
Sterols	β-Sitosterol	Gupta & Agrawal [1970]

and antibacterial activities [Karamać, 2009; Puljula *et al*., 2020]. They can also affect the functioning of the digestive tract [Żary-Sikorska *et al*., 2021]. In the case of jamun seeds, it was found that the ellagitannin-rich fraction of these seeds inhibited canonical Wnt signaling pathway in a human 293T cell line, suggesting its potential against colon carcinogenesis [Sharma *et al*., 2010]. Moreover, the *in vitro* antioxidant activity of the jamun seed fraction containing ellagitannins and ellagic acid was reported and it was higher than that of the pulp with anthocyanins as the main component [Aqil *et al*., 2012].

Among phenolic acids, apart from ellagic and gallic acids, also *p*-cumaric, caffeic, ferulic and chlorogenic acids were quantified in seeds of the same *S. cumini* genotypes and their contents were 14.06, 1.02–4.73, 1.50–8.21 and 0.89–6.80 μg/g seed, respectively [Gajera *et al*., 2017; Shrikanta *et al*., 2015]. The presence of protocatechuic acid, syringic acid, and 5-hydroxyveratric acid was confirmed in the studies by Liu *et al*. [2018] and Elhawary *et al*. [2022].

Flavonoids are another class of phenolic compounds that are commonly distributed in plants. In jamun seeds, myricetin and its derivatives have been most widely represented including myricetin glycosides (myricetin 3-*O*-glucoside), *O*-methylated forms (syringetin, syringetin 3-*O*-glucoside, laricitrin), and dihydroxy derivatives (dihydromyricetin) [Elhawary *et al*., 2022; Liu *et al*., 2018]. In turn, (–)-epicatechin (129.20 μg/g dm), quercetin (98 μg/g dm), kaempferol (59 μg/g dm) and (+)-catechin (5.36–16.80 μg/g seed) were reported as the most abundant among flavonoids [Bajpai *et al*., 2005; Gajera *et al*., 2017; Shrikanta *et al*., 2015]. According to Sharma *et al*. [2008a,b] and Jadeja *et al*. [2012], rutin, quercetin and kaempferol present in standardized flavonoid-rich extracts of jamun seeds were responsible for their diverse bioactivity. The hypoglycemic and hypolipidemic effects and anti-atherogenic potential of such extracts were found. Flavone *C*-glycosides (swertisin, schaftoside and apigenin 6,8-di-*C*-β-D-glucopyranoside), that are limited in natural sources, have also been identified in jamun seeds [Liu *et al*., 2018; Omar *et al*., 2012]. Interestingly, jamun seeds do not contain the anthocyanins that are present in the pulp of the fruits [Aqil *et al*., 2012; Benherlal & Arumughan, 2007]. Lestario *et al*. [2017] reported that the content of pulp anthocyanins increased, but contents of flavonols, gallotannins, and ellagitannins decreased by 60%, 35%, and 11%, respectively, throughout fruit maturation. However, it has not been studied so far whether the seed phenolic profile changed during fruit ripening.

Other phenolic compounds detected in jamun seeds include stilbenoids (resveratrol), coumarins (brevifolin carboxylic acid), lignans (medioresinol 4”-*O*-β-glucoside, (+)-pinoresinol *O*-β-glucoside, (+)-syringaresinol *O*-β-glucoside, and dihydrodehydrodiconiferyl alcohol 4”-*O*-β-glucoside) and phloroglucinol derivatives (jamunones A–O and spiralisone C) [Liu *et al*., 2017b; Martin *et al*., 1998; Omar *et al*., 2012; Shrikanta *et al*., 2015]. Among them, only resveratrol was quantified at the level of 34.87 μg/g dm [Shrikanta *et al*., 2015]. In the mentioned publication, the authors suggested that resveratrol contributed significantly to the antioxidant capacity of jamun seeds. In turn, phloroglucinol derivatives of jamun seeds inhibited protein tyrosine phosphatase 1B

activity [Liu *et al*., 2017a] and can therefore be considered as anti-diabetes and anti-obesity agents. The bioactivity of jamun seed coumarins and lignans has not been determined so far.

Terpenes and terpenoids

Forty-five terpenes and terpenoids classified as monoterpenes, monoterpenoids, sesquiterpenes, sesquiterpenoids, norsesquiterpenoids and triterpenoids have been identified in jamun seeds [Elhawary *et al*., 2022; Liu *et al*., 2017a; Sawant *et al*., 2015; Scharf *et al*., 2016]. The names of these compounds are listed in Table 1.

Scharf *et al*. [2016] reported that two sesquiterpene hydrocarbons (*E*-caryophyllene and α-humulene) were the major compounds of essential oil of fresh jamun seeds and their contents were 42.5% and 22.2% of the total essential oil, respectively. However, both the total essential oil content of the seeds and the essential oil profile changed during seed storage. The hydrodistillation yield decreased from 0.11% (*w/w*) for fresh seeds to 0.06% (*w/w*) for seeds after two-month storage. A successive decrease in the percentage of sesquiterpene hydrocarbons (from 74.1 to 21.0% after four months storage) and monoterpenes (from 7.8 to 1.3%), and an increase in the contribution of oxidized sesquiterpenes (from 12.3 to 70.5%) were noted in the profile of compounds. The major compounds of fresh seeds were partially oxidized to mainly caryophyllene oxide and humulene epoxide during storage.

Some of the jamun seed sesqutierepenoids were found to be biologically active [Liu *et al*., 2017b]. Among twelve isolated sesqutierepenoids, a mixture of jambolanins D and E as well as sootepdienone, guaianediol, cryptomeridiol, (4*R*)-4-hydroxy-1,10-seco-muurol-5-ene-1,10-dione, caryolandiol, and clovane-2β,9α-diol exhibited antimicrobial activity against *Staphylococcus aureus*. On the other hand, these compounds did not inhibit the proliferation of *Escherichia coli* and *Candida albicans* at the concentration 100 μg/disk. In turn, Sawant *et al*. [2015] did not detect the aldose reductase (AR) inhibitory activity and protein tyrosine phosphatase 1B (PTP1B) inhibitory activity of maslinic acid isolated from jamun seeds when tested at concentration up to 100 μg/mL.

Other phytochemicals

Vitalboside A, a pentacyclic triterpene glycoside (saponin), was identified by NMR techniques and isolated using chromatographic methods from jamun seeds [Thiyagarajan *et al*., 2016]. The content of vitalboside A in the methanolic extract of jamun seeds was 0.8% (*w/w*). The antidiabetic and anti-adipogenic activities of the isolated compound were shown.

Another bioactive phytochemical detected in *S. cumini* seeds is β-sitosterol. It was identified in the unsaponifiable fraction of the jamun seed oil [Gupta & Agrawal, 1970]. Presence of sterol with an unidentified structure in the Sephadex LH-20 fraction of the ethanolic jamun seed extract was reported by Sharma *et al*. [2011a,b]. This fraction exhibited hypolipidemic and antidiabetic activity in alloxan-induced mildly diabetic and severely diabetic rabbits.

EXTRACTION, PURIFICATION AND ISOLATION OF JAMUN SEED BIOACTIVE COMPOUNDS

Extraction is the first and most important step in the recovery of biological molecules from plant material. The solvent extraction with pure or aqueous methanol, ethanol and acetone was most commonly used to extract phenolics from jamun seeds [Liu *et al*., 2018; Elhawary *et al*., 2022; Sawant *et al*., 2015; Shrikanta *et al*., 2015]. Aqueous acetone was used in the first step of isolation of jamun seed sesquiterpenoids and phloroglucinol derivatives [Liu *et al*., 2017a,b], and water to recover polysaccharides with potential bioactivity [Al-Dhabi & Ponmurugan, 2020]. In the last-mentioned study, microwave treatment during extraction was successfully applied to increase extraction yield. In turn, ultrasonic-assisted extraction (UAE) was used to most effectively extract *S. cumini* seed phenolics [Mahindrakar & Rathod, 2020a]. Authors compared UAE with conventional, stirred batch extraction, and found that contents of (+)-catechin, gallic acid, total phenolic and total flavonoid as well as antioxidant activity (DPPH assay) were 3.6, 1.5, 1.3, 1.4 and 1.2 times higher, respectively, for the extract obtained by UAE. Both extractions were carried out under optimal conditions, which were as follows for UAE: 12 min of extraction time, 35°C of temperature, 1:15 of solid material to solvent ratio, 125 W of power, and 60% of duty cycle. The stirred batch extraction required longer extraction time, higher solvent volume and higher temperature than UAE by 8.8, 1.3 and 1.4 times, respectively. Abdin *et al*. [2019] used the response surface methodology (RSM) for optimization UAE of jamun seeds in terms of maximizing total phenolic content and for the inhibition of α-amylase and pancreatic lipase. The effects of extraction time (10–90 min), ethanol concentration (10–90%, *v/v*), and solvent to solid material ratio (10–70 mL/g) were investigated and the optimal UAE conditions were found as 59.8 min – extraction time, 63.1% (*v/v*) – ethanol concentration, and 43.8 mL/g – solvent to solid material ratio. The RSM was also applied to optimize the microwave-assisted extraction of polysaccharides from jamun seeds [Al-Dhabi & Ponmurugan, 2020]. Four-factor, five-step central composite rotary experimental design allowed to state that microwave power of 515 W, pH of 3.2, extraction time of 3.1 min, and solid material to solvent ratio of 1:15 g/mL were the most efficient conditions for the recovery of polysaccharides.

Fractionation of the crude extracts is a common step in the isolation of phytochemicals. Various techniques are used to obtain fractions rich in specific class of compounds, the most common are chromatographic separations. However, fractionation is often preceded by re-extraction of the crude extract with solvents of different polarities. Such a path was followed by Sawant *et al*. [2015], who partitioned methanolic extract of jamun seeds using water, ethyl acetate, and *n*-butanol sequentially to find AR and PTP1B inhibitory active compounds. The most active ethyl acetate extract was then purified by a multi-step column chromatography (with silica gel, Diaion HP-20 and Sephadex LH-20) until the compounds (valoneic acid dilactone, ellagic acid, and rubuphenol) responsible for the activity could be isolated by means of preparative high-performance liquid chromatography (HPLC).

Partition of the methanolic extract of jamun seeds with ethyl acetate and *n*-butanol was deployed to enable isolation of hydrolysable tannins [Omar *et al*., 2012]. In the next step, the *n*-butanol extract was separated by medium pressure liquid chromatography to five fractions and each of them was used to isolate pure compounds using different systems of column chromatography and semipreparative HPLC. In turn, sesquiterpenoids were isolated from a 70% (*v/v*) aqueous acetone extract of jamun seeds, which was partitioned with ethyl acetate and water, and thereafter an ethyl acetate part was fractionated by a combination of MCI gel CHP-20P, silica gel, and Sephadex LH-20 column chromatography, as well as semipreparative HPLC [Liu *et al*., 2017a]. Phloroglucinol derivatives and saponin (vitalboside A) were isolated from jamun seeds by similar techniques, by re-extracting the crude extract and then fractionating it using various chromatographic methods [Liu *et al*., 2017b; Thiyagarajan *et al*., 2016]. Another technique was harnessed by Jasmine *et al.* [2010] who loaded the crude methanolic extract into the silica gel column, from which the compounds were eluted with a gradient system of solvents of increasing polarity. In this way, five fractions were obtained and one of them was active against drug-resistant bacteria. Silica gel (60–120 mesh) column chromatography with 95% ethanol as a mobile phase and Sepahex LH-20 column chromatography with methanol were applied by Sharma *et al*. [2011a,b] to separate fractions rich in bioactive compounds directly from jamun seed methanolic crude extract.

Filtration techniques are another way to purify crude extracts. In the case of jamun seeds, an aqueous extract was subjected to integrated cross flow ultrafiltration (UF) and nanofiltration (NF) [Balyan & Sarkar, 2016]. These membrane processes allowed to clarify the extract and concentrate the phenolic compounds, respectively. UF with a membrane with molecular weight cutoff of 100 kDa under low pressures (below 450 kPa) recovered 65% of total phenolic content, increased DPPH radical scavenging activity from 75.5 to 90.2%, and enhanced the purity by 1.35 times. Furthermore, NF with 250 Da membrane of UF-clarified permeate resulted in about three-fold concentration of phenolic compounds.

BIOLOGICAL ACTIVITIES OF JAMUN SEED EXTRACT

A range of pharmacological properties is possessed by various extracts of jamun which include antidiabetic, antihyperlipidemic, antihypercholesterolemic, anticancer, cardioprotective, hepatoprotective, neuroprotective, anti-inflammatory, antioxidant, and antimicrobial activities (Table 2), as established by scientific studies.

Antidiabetic activity

The antidiabetic effect of many natural products is based on the inhibition of α-amylase and α-glucosidase activities, which slow down starch digestion contributing to the reduction in blood glucose level [Alam *et al*., 2019; Lee & Yoon, 2022]. The extracts of seeds of black jamun landraces inhibited α-amylase activity in the range of 59.1––90.6% [Gajera *et al.*, 2017]. The water extract obtained from jamun seed kernels showed inhibitory activity against α-amylase and α-glucosidase characterized by IC_{50} values of 9.03 and 7.13 μg/mL, respectively [Mahindrakar & Rathod, 2020b]. The same authors, using a three-phase partitioning extraction, reported IC_{50} of 9.33 μg/mL for α-amylase and 7.55 μg/mL for α-glucosidase [Mahindrakar & Rathod, 2021]. In turn, Abdin *et al*. [2019] determined 87.66% α-amylase inhibitory activity of the fraction of jamun seed aqueous ethanol extract containing (+)-catechin, (–)-epicatechin, kaempferol, gallic, chlorogenic, caffeic, and ferulic acids as main phenolics and tested at a concentration of 640 μg/mL. Shinde *et al*. [2008] evaluated inhibitory activity of jamun seed extracts against microbial (*Saccharomyces cerevisiae* and *Bacillus stearothermophilus, in vitro*), and mammalian (*in vivo* on Goto-Kakizaki rat intestine, administration of 250 mg/kg body weight) α-glucosidase. Both acetone and 70% ethanol extracts exhibited inhibitory activity against enzyme of all three sources. Three hydrolysable tannins isolated from jamun seeds were the strong α-glucosidase inhibitors [Omar *et al*., 2012]. Their IC_{50} values were as follows: 8.2 μM (*iso*-oenothein C), 12.2 μM (cornusin B), and 75.1 μM (oenothein C). Liu *et al.* [2018] reported strong α-glucosidase inhibitory activity of phenolic compounds isolated from jamun seeds and elucidated using modern spectroscopic methods. Among 21 isolated compounds, eight (mainly ellagitannins and ellagic acid derivatives) inhibited α-glucosidase better than acarbose – a clinical drug. Tergalic acid dilactone was found as the strongest inhibitor with the IC_{50} value of 5 μM.

In the diabetic state, hyperglycemia increases glucose metabolism *via* the polyol pathway [Alam *et al*., 2019]. Aldose reductase (AR) catalyzes the conversion of glucose to sorbitol. This polyol, generated at high levels, cannot diffuse across cell membranes and either accumulates or is converted to fructose. In turn, protein tyrosine phosphatase B1 (PTP1B) is a negative regulator of the insulin signaling pathway and is associated with risk of both type 1 and 2 diabetes [Alam *et al*., 2019]. Gallic acid, valoneic acid dilactone, rubuphenol, and ellagic acid separated from jamun seeds were found to inhibit AR with IC_{50} values of 0.77, 0.075, 0.165, and 0.12 μg/mL, while valoneic acid dilactone, rubuphenol, and ellagic acid inhibited PTP1B with IC_{50} values of 9.37, 28.14, and 25.96 μg/mL, respectively [Sawant *et al.,* 2015]. Fourteen phloroglucinol derivatives isolated from jamun seeds inhibited PTP1B activity. The values of IC_{50} were in the range of 0.42–3.2 μM. The strongest inhibitory activity possessed jamunone E ($C_{26}H_{30}O_5$) with 2,5,7-trihydroxy-2,3--dihydrochromone moiety [Liu *et al.* 2017b].

Several *in vivo* studies showed the antidiabetic activity of jamun seeds, their extracts and phytochemicals. Study revealed that jamun seed extract preferably improves various biochemical actions, such as glucose tolerance and glucose uptake, maintains glucose homeostasis in diabetic animals, and exhibits benefits in restoring β-cells [Sharma *et al.,* 2008a]. Addition of defatted jamun seeds as well as water--soluble fiber isolated from this material to the diet of diabetic rats exerted a hypoglycemic effect [Pandey & Khan, 2002]. The ethanolic extract of phenolic compounds obtained from jamun seeds reduced significantly the blood glucose level in rats [Yadav *et al.,* 2010]. The authors reported 41%

TABLE 2. Bioactivities of jamun seed extracts/phytochemicals – last decade studies.

Origin of jamun seeds	Type of extract/Class of compounds	Methods	Bioactivity	Mode of action/Key finding	References
Gir forest western Gujarat, India	Methanol extract	Inhibition of porcine pancreatic α-amylase in DNS assay	Antidiabetic activity	α-Amylase inhibitory activity of 59.1–90.6% (IC_{50} – 12.9 μg/mL)	Gajera *et al.* [2017]
		DPPH assay	Antioxidant activity	$DPPH^{\bullet}$ scavenging activity of 73.8–92.4%	
Konkan region of Maharashtra, India	Aqueous extract obtained by ultrasonic-assisted extraction	DPPH assay	Antioxidant activity	SC_{50} – 10.59 μg/mL	Mahindrakar & Rathod [2020a]
India (industrial waste)	Aqueous extract	DNS assay, assay with *p*-nitrophenyl α-D-glucopyranoside	Antidiabetic activity	IC_{50} for α-amylase and α-glucosidase inhibitory activity – 9.03 and 7.13 mg/mL, respectively	Mahindrakar & Rathod [2020b]
		DPPH assay	Antioxidant activity	SC_{50} – 12.97 μg/mL	
India (industrial waste)	Extract obtained by three-phase (water, 20% ammonium sulfate and tert-butanol) partition	DNS assay, assay with *p*-nitrophenyl α-D-glucopyranoside	Antidiabetic activity	IC_{50} for α-amylase and α-glucosidase inhibitory activity – 9.33 and 7.55 mg/mL, respectively	Mahindrakar & Rathod [2021]
		DPPH assay	Antioxidant activity	SC_{50} – 12.15 μg/mL	
Kafrelshiekh, Egypt	Fraction of aqueous ethanol extract	DNS assay, assay with *p*-nitrophenyl laurate	Antidiabetic and anti-obesity activity	Fraction of JSE inhibited 87.66% (conc. 640 μg/mL) and 86.61% (conc. 1280 μg/mL) of α-amylase and pancreatic lipase activities, respectively	Abdin *et al.* [2019]
		ABTS, DPPH, hydroxyl radical scavenging activity assays	Antioxidant activity	SC_{50} of JSE fraction for $ABTS^{\bullet+}$ – 105.3 μg/mL, for $DPPH^{\bullet}$ – 153.8 μg/mL, for hydroxyl radical – 501.6 μg/mL	
Gujarat, India	Isolated hydrolysable tannins	Assay with *p*-nitrophenyl-α-D-glucopyranoside	Antidiabetic activity	IC_{50} for α-glucosidase inhibitory activity of iso-oenothein C, cornusin B and oenothein C – 8.2, 12.2 and 75.1 μM, respectively	Omar *et al.* [2012]
Gujarat, India	Isolated phenolics	Assay with *p*-nitrophenyl-α-D-glucopyranoside	Antidiabetic activity	Eight isolated phenolics (ellagitannins and ellagic acid derivatives) were very strong α-glucosidase inhibitors (IC_{50} – 5.0–21.2 μM)	Liu *et al.* [2018]
		DPPH assay, inhibition of ROS production in murine RAW264.7 macrophages	Antioxidant activity	Nine most active isolated phenolics: SC_{50} for DPPH – 25.0–87.2 μM, 24–36% inhibition of ROS production in the RAW264.7 macrophages (conc. 20 μM)	
Bangalore, India	Fractions and isolated phenolics	Aldose reductase and PTP1B inhibition assays, *in vitro*	Antidiabetic activity	IC_{50} for aldose reductase: 0.075 μg/mL (valoneic acid dilactone), 0.12 μg/mL (ellagic acid), 0.165 μg/mL (rubuphenol) and for PTP1B: 9.37 μg/mL (valoneic acid dilactone), 25.96 μg/mL (ellagic acid), 28.14 μg/mL (rubuphenol)	Sawant *et al.* [2015]
Gujarat, India	Isolated phloroglucinol derivatives	PTP1B inhibition assays, *in vitro*	Antidiabetic activity	IC_{50} of isolated phloroglucinol derivatives – 0.42–3.2 μM and positive control (synthetic PTP1B inhibitor) – 2.0 μM	Liu *et al.* [2017a]

TABLE 2 – continued

Origin of jamun seeds	Type of extract/Class of compounds	Methods	Bioactivity	Mode of action/Key finding	References
Bangalore, India	Hydro-ethanolic extract	RIN-5F and L6 cells, *in vitro*	Antidiabetic activity	Glucose uptake by L6 myoblast cells was increased (19.91% at 40 μg extract/mL) as compared to vehicle control; JCE showed enhancement of insulin release (2.8-fold at 40 μg/mL)	Assan Aliyar *et al*. [2021]
Local market, Faisalabad, Pakistan	50% (*v/v*) Aqueous ethanol extract	*In vivo* model (male Sprague Dawley hyperglycemic/diabetic rats)	Antihyperglycemic activity	In normal and hyperglycemic mice, JSE lowered glucose by 7.04% and 14.36%, respectively, and increased insulin level by 3.56% and 7.24%, respectively	Raza *et al*. [2017]
Local market, Karnataka, India	80% (*v/v*) Ethanol extract	DPPH assay; assay based on the reduction of Mo(VI) to Mo(V) (total antioxidant capacity)	Antioxidant activity	DPPH$^{\bullet}$ SC_{50} – 0.40 mg/mL and total antioxidant capacity – 3.33 mmol GAE/g extract	Shrikanta *et al*. [2015]
Garden of NIPER, S.A.S. Nagar, India	75% (*v/v*) Aqueous ethanol with 10 mM HCl extract; additionally, hydrolysed with 2M HCl	ORAC, FRAP, DPPH and ABTS assays	Antioxidant activity	SC_{50} for DPPH$^{\bullet}$ – 6.3 and 19.8 μg/mL (crude and hydrolyzed extract respectively) and for ABTS$^{\bullet+}$ – 4.6 μg/mL (both extracts); FRAP (concentration giving 50% reduction of ferric iron) – 23.6 and 24.7 μg/mL (crude and hydrolyzed extract, respectively); ORAC – 3.379 ± 151 μmol TE/g (both extracts)	Aqil *et al*. [2012]
		Human non-small-cell lung carcinoma cell line A549	Antiproliferative activity	Hydrolyzed JSE showed higher antiproliferative activity (IC_{50} of 38 μg/mL) then unhydrolyzed JSE (IC_{50} of 64 μg/mL)	
Santa Maria, Rio Grande do Sul, Brazil	Aqueous extract (powder and nanoparticles)	*Candida albicans*-infected diabetic male albino Wistar rats	Antioxidant activity	JSE in nanoparticle form was more effective than JSE at reducing the oxidative burst induced by diabetes and/or *Candida* infection in rats	Bitencour *et al*. [2017]
Keshav Shristi Bhayandar, Mumbai, India	Fraction of ethanol extract	Human cancer cell lines: breast adenocarcinoma (MCF7), ovarian adenocarcinoma (A2780), prostate carcinoma (PC-3), non-small--cell lung carcinoma (H460)	Anticancer activity	The highest inhibition of cell proliferation by JSE was reported for A2780 cell line (IC_{50} – 49 μg/mL)	Yadav *et al*. [2011]
		Agar cup-plate assay.	Antibacterial activity	JSE showed antibacterial activity against *E. coli, P. aeruginosa, S. aureus, B. subtilis* with zone of inhibition of 20, 11, 17, 15 mm, respectively with 20 and 11 mm, respectively	
Chenai, India	Methanol extract	HepG2 cells, MTT assay	Anticancer activity	JSE. induced apoptosis in HepG2 cells through decrease in MMP and downregulation of HFN-1α	Prakash & Devaraj [2019]
Botanical gardens in Egypt	Methanol extract	Human breast cancer (MCF-7 cell line and MDA-231 cell line), colon cancer (HCT-116 cell line), MTT assay	Anticancer activity	Strong JSE activity against HCT-116 cells, with IC_{50} of 1.24 μg/mL	Elhawary *et al*. [2020]

TABLE 2 – continued

Origin of jamun seeds	Type of extract/Class of compounds	Methods	Bioactivity	Mode of action/Key finding	References
Viçosa, Minas Gerais, Brazil	Mixture of ethanol, methanol and acetone (1:1:1, *v/v/v*) extract	Agar diffusion assay	Antibacterial activity	JSE was active against *A. hydrophila, C. violaceum, E. coli, P. aeruginosa, S. enterica* serovar Typhimurium, *S. marcescens, L. monocytogenes*, and *S. aureus*	Santos *et al.* [2020]
Santa Maria, RS, Brazil	Aqueous extract	Lymphocytes, and ADA, DPP-4, and acetylcholinesterase activities, CD26 expression	Immunomodulatory properties	JSE exhibits immunomodulatory properties probably *via* the pathway of DPP-4–ADA complex	Bellé *et al.* [2013]
India	Methanol extract	Rat heart-derived H9C2 cardiomyoblast cells	Anti-inflammatory activity	JSE decreased glucose-induced cardiac stress, suppressed gelatinase activity in H9C2 cells, gelatinase-B expression and NF-κB nuclear translocation in these cells	Atale *et al.* [2021]
Gujarat, India	70% (*v/v*) Ethanol extract	Hydrogen peroxide induced cytotoxicity in H9C2 cells	Cardioprotective properties	JSE is capable of cardioprotective activity due to lowering intracellular oxidative stress, preventing depletion of cellular antioxidants and improving cell viability	Devkar *et al.* [2012]
Uttar Pradesh, India	Methanol extract	H9C2 cardiomyoblast cells	Cardioprotective properties	Exposure of glucose-stressed H9C2 cells to JSE showed decline in the activity of catalase and superoxide dismutase and collagen content	Atale *et al.* [2013]
Chittagong, Bangladesh	Methanol extract	Alloxan-induced diabetic Wistar albino rats	Cardio- and hepatoprotective properties	JSE at dose of 200 mg/kg reversed cardiac and liver damage caused by alloxan in rats	Nahid *et al.* [2017]
India	Aqueous extract	High fat diet- streptozotocin induced type 2 diabetic rats	Antihyperglycemic and antidyslipidemic activity	JSE at doses of 200 and 400 mg/kg decreased rat serum total cholesterol (by 39.9 and 44.2%, respectively), triglycerides (by 43.1 and 46.7%, respectively), LDL-cholesterol (by 28.3 and 32.9%, respectively) compared to control group	Sharma *et al.* [2017]
India	Ethanol extract	Streptozotocin induced Alzheimer's disease Wistar rats	Neuroprotective properties	JSE at doses of 200 and 400 mg/kg decreased amyloid load, tau phosphorylation and levels of tumor necrosis factor α (TNF-α) and interleukin-1β (IL-1β) in the hippocampus of JSE treated rats compared to negative control group	Kosaraju *et al.* [2014]
Local market, Warangal, India	Methanol extract	Scopolamine induced spatial memory impairments in male albino Wistar rats	Antiamnesic activity	JSE at doses of 200 and 400 mg/kg decreased lipid peroxidation and acetylcholinesterase activity, increased activity of superoxide dismutase and catalase in brain of treated animals, and positively affected short term or working memory compared to control group	Alikatte *et al.* [2012]

ABTS – 2,2'-azinobis-(3-ethylbenzthiazolin-6-sulfonic acid); ADA – adenosine deaminase; DNS – 3,5-dinitrosalicylic acid; DPP-4 – dipeptidyl peptidase 4; DPPH – 2,2-diphenyl-1-picrylhydrazyl; FRAP – ferric-reducing antioxidant power; GAE – gallic acid equivalents; HFN-1α – hepatocyte nuclear factor-1α; IC_{50} – concentration of the compound/extract causing 50% inhibition; JSA – jamun seed extract; MMP – mitochondrial membrane potential; ORAC – oxygen radical absorbance capacity; PTP1B – protein tyrosine phosphatase 1B; ROS – reactive oxygen species; SC_{50} – concentration of the antioxidant causing 50% radical scavenging; TE – Trolox equivalents.

and 44% of the mentioned reduction after oral administration of the extract. For the aqueous extract, the ability for blood glucose reduction was lower – 26% and 27% after 1 and 2 h, respectively. In the experiment with streptozotocin-diabetic rats (15 days, addition of 500 and 1000 mg of powdered jamun seeds per kg body weight to the rat diet) caused positive changes in diabetes markers. Fasting blood glucose was reduced by 75 and 122 mg/dL (in diabetic control it increased by 34 mg/dL). The value of post-treatment fasting and peak blood glucose 38 and 36 mg/dL was much lower than that in diabetic control (78 mg/dL). The positive changes in liver glycogen were reported; involving a decrease by 50 and 52 mg/g of liver in experimental group, and 90 mg/g of liver in normal control [Sridhar *et al*., 2005]. The decreased levels of blood glucose and increased glucose tolerance were found due to administration of jamun seed kernels (100 mg/kg body weight) to streptozotocin-induced diabetic rats [Ravi *et al*., 2004b]. In the same experiment, a decrease in the liver glycogen content was observed. It is worth emphasizing that no hypoglycemic effect was shown when powdered seed coat was used as a dietary ingredient. Ravi *et al*. [2003] reported that the activities of important enzymes for carbohydrate metabolism were returned almost to the normal levels due to administration of jamun seed kernels to diabetic rats. In the study of Raza *et al.* [2017], an aqueous ethanolic extract of jamun seeds caused glucose reduction by 14.36% and increased blood insulin level by 7.24% in hyperglycemic rats. Findings of Sharma *et al.* [2011b] also showed positive properties of jamun seeds including their significant effect on decreasing blood glucose level. The fraction isolated from the crude extract using Sephadex LH-20 column chromatography possessed potent antihyperglycemic activity in experiments with alloxan-induced diabetic rabbits. Phytochemicals present in jamun seeds have a beneficial effect on hypoglycaemic activity by stimulating the glucose uptake (GLUT 4) by skeletal muscle cells [Syama *et al.,* 2018].

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

Antihyperlipidemic and antihypercholesterolemic activity

The presence of several bioactive compounds in jamun seeds helps to regulate the blood lipid profile. Oral infusion of an alcoholic jamun seed extract (100 mg/kg body weight) in diabetic rats resulted in a significant reduction in serum lipids [Prince *et al*., 2004]. The jamun seed extract also decreased the total serum cholesterol to high-density lipoprotein (HDL) cholesterol ratio, serum low-density lipoprotein (LDL) cholesterol level and 3-hydroxy-3-methyl-glutaryl-coenzyme A (HMG-CoA) reductase activity in alloxan-induced diabetic rabbits and streptozotocin-induced diabetic rats [Sharma *et al*., 2003; 2011a,b; Sridhar *et al*., 2005]. The plasma lipoprotein cholesterol (HDL-, LDL-, and VLDL-C) and fatty acid composition were altered in streptozotocin-induced diabetic rats when administered the ethanolic jamun seed extract [Ravi *et al*., 2005]. In the experiment of Ulla *et al* [2017], the supplementation of the rats high-carbohydrate and high-fat diet with jamun seed powder for 56 days (2.5%, *w/w,* of diet) reduced white adipose tissue (WAT) weights, and plasma lipids, such as total cholesterol, triglyceride, LDL and HDL cholesterol concentration. In experiments of Sharma *et al.* [2017], diabetic rats were treated with a water jamun seed extract (200 and 400 mg/(kg×day)). The authors observed decreased serum levels of total cholesterol (by 39.9 and 44.2%, respectively), triglycerides (by 43.1 and 46.7%, respectively), and LDL-cholesterol (by 28.3 and 32.9%, respectively) compared with diabetic control group. Due to addition of extracts to rat diet, the concentration of HDL-cholesterol increased by 14.6 and 20.2%, respectively.

Parveen *et al.* [2020] demonstrated antihyperlipidemic effect of jamun seeds in a human study. The supplementation of the diet of patients diagnosed with prediabetes with jamun seed capsulated powder (4.5 g/day) significantly improved the level of total cholesterol and LDL-cholesterol from 266 to 216 mg/dL and from 189 to 139 mg/dL, respectively.

Anticancer activity

Jamun seed extract exhibited protection in albino mice against peroxidative damage contributing to skin cancer [Parmar *et al.,* 2010]. The oral intake of extracts (125 mg/kg body weight) reduced tumor burden, number of papilloma cells and their size. In experiments of Arun *et al.* [2011], the jamun seed extract administered orally (500–1500 mg/kg body weight) to mice before the exposure to genotoxic carcinogens (7,12-dimethylbenz(α)anthracene and urethane) prevented the breakage of pBR322 DNA, significantly reduced the chromosomal aberrations in metaphase, and reduced the formation of micronuclei in polychromatic erythrocytes.

Among *in vitro* studies, Yadav *et al.* [2011] examined the cytotoxic activity of the jamun seed extract by MTS assay on various cancer cell lines. The results were expressed as IC_{50} values (the concentration of the extract inhibiting cell proliferation up to 50% of the negative control). With IC_{50} of 49 μg/mL, A2780 (ovarian cancer) cell line was found to be most sensitive while non-small-cell lung carcinoma (H460) proved to be the least sensitive (IC_{50} 165 μg/mL). A very low IC_{50} value (0.06–0.08 μg/mL) was shown by flavopiridol (positive control) on all the cell lines. The induction of apoptosis in human hepatoma cells (HepG2) by the jamun seed extract was reported by Prakash & Devaraj [2019]. In this study, the use of different extract concentrations (10, 20, and 40 μg/mL) decreased the mitochondrial potential as well as down-regulated a hepatocyte nuclear factor-1α (HFN-1α). It was confirmed by western blotting. In turn, Aqil *et al*. [2012] used an MMT assay to evaluate the effect of jamun seed extracts (crude and hydrolyzed) on cancer cell viability. Both extracts exhibited strong antiproliferative activity against human non-small-cell lung cancer A549. The activity of the crude and hydrolyzed extract, expressed as IC_{50}, reached the value of 64 and 38 μg/mL, respectively. The methanolic extract of jamun seeds exhibited cytotoxic activity against colon cancer cell line (HCT-116), with IC_{50} value of 1.24 μg/mL

[Elhawary *et al*., 2022]. According to molecular docking study, myricetin 3-glucoside, myricitrin, reynoutrin, and quercitrin present in the extract were most potential ligands within a protein active site (FIH-1).

Cardio- and hepatoprotective properties

The methanolic jamun seed extract administered to mice at the dose of 200 mg/kg body weight revealed the protective and recovery ability on cardiac tissue due to its capability to decrease myocardial necrosis biomarkers such as aspartate aminotransferase (AST), alanine transaminase (ALT), uric acid, creatine phosphokinase (CPK), and lactate dehydrogenase (LDH) [Nahid *et al.,* 2017]. Atale *et al*. [2013] reported reduction in size of myocyte, lower generation of reactive oxygen species (ROS), and lower accumulation of collagen in response to the administration of the jamun seed extract. According to the study of Devkar *et al* [2012], jamun seeds are potential cardioprotective agents due to a higher content of phenolic compounds, can reduce intracellular oxidative stress, preventing depletion of cellular antioxidants and improving cell viability. The mentioned research investigated hydrogen peroxide-induced cytotoxicity in H9C2 cells.

Hepatoprotective effect of the methanolic seed extract was reported when administered at doses of 100, 200 and 400 mg/kg to Wistar albino rats treated with carbon tetrachloride dosages. The extract significantly reversed the elevated marker enzymes (glutamic oxaloacetic transaminase (GOT), glutamic pyruvic transaminase (GPT), alkaline phosphatase (ALP), acid phosphatase (ACP) and bilirubin), which were comparable even with those of the Liv.52®-treated group. The dose of 400 mg/kg body weight was highly effective against the hepatotoxicity caused by carbon tetrachloride [Sisodia & Bhatnakar, 2009]. Likewise, the methanolic jamun seed extract when administered at a dose of 200 mg/kg body weight to diabetic rats, exhibited hepatoprotective effect by significantly increasing the protein concentration, ALT, AST, ALP and bilirubin levels, and reducing enhanced liver enzymes even more than in the rats treated with the gliclazide (25 mg/kg) [Nahid *et al*., 2017].

Neuroprotective properties

The therapeutic potential of dipeptidyl peptidase-4 (DPP-4) inhibitors in the treatment of Alzheimer's disease (AD) was confirmed in experimental studies [Holscher, 2010]. Because phenolic compounds are known as DPP-4 inhibitors, Kosaraju *et al*. [2017] tested the neuroprotective effect of the jamun seed extract against the streptozotocin-induced AD in a rat model. The administration of jamun seed extract at doses of 200 and 400 mg/kg decreased amyloid load, tau phosphorylation and inflammation in the brain. Levels of tumor necrosis factor α (TNF-α) and interleukin-1β (IL-1β) in the hippocampus of rats from group treated with jamun seed extract was reduced when compared with a negative control group.

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

Anti-inflammatory activity

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

The study of Atale *et al*. [2021] demonstrated the anti-inflammatory effect of the jamun seed extract in rats with high-glucose-induced heart-derived H9C2 cardiomyoblasts. The bioactive compounds present in the extract prevented glucose-induced cardiac stress, gelatinase activity in H9C2 cardiomyocytes, gelatinase-B expression and NF-κB nuclear translocation in these cells. The docking studies confirmed a strong interaction between jamun seed phenolic compounds and gelatinase-B.

The results of a study by Bellé *et al.* [2013] indicated that the jamun seed extract can act as an inhibitor of the DPP-4 and adenosine deaminase (ADA) in human lymphocytes. Probably, the bioactive compounds present in extract may interact with DPP-ADA complex and modify the purinergic signaling.

Antioxidant activity

The antioxidant potential of jamun seeds was analyzed by several *in vitro* methods, using various techniques for the extraction of bioactive compounds. The phenolics (gallic acid, ellagic acid, ferulic acid, (+)-catechin, and quercetin) of seeds originated from underutilized indigenous black jamun landraces found in the Gir forest region of India showed significant antiradical activity against DPPH$^{\bullet}$ [Gajera *et al*., 2017]. The DPPH$^{\bullet}$ scavenging activity of extracts of jamun kernel powder obtained using an ultrasonic-assisted aqueous extraction, regular water extraction, and a three-phase partitioning extraction was determined by Mahindrakar & Rathod [2020a,b; 2021]. The concentration of the antioxidant causing 50% radical scavenging (SC_{50}) was 10.59, 12.97, and 12.15 μg/mL, respectively. Much higher SC_{50} values of 105.3, 153.8, and 501.6 μg/mL were found for ABTS$^{\bullet+}$, DPPH$^{\bullet}$ and hydroxyl radical, respectively, by Abdin *et al*. [2019] who determined radical scavenging activity of the chromatographically (D101 resin) purified jamun seed aqueous ethanol extract. In turn, Shrikanta *et al*. [2015] reported a very low SC_{50} value of 0.40 mg/mL for DPPH$^{\bullet}$ scavenging activity of 80% (*v/v*) ethanol extract. The extract was also tested in the assay based on the reduction of Mo(VI) to Mo(V) and its total antioxidant capacity was determined at 3.33 mmol GAE/g extract. Phenolic compounds isolated from jamun seeds with the highest

DPPH• scavenging activity were ellagitannins and ellagic acid derivatives (SC_{50} values in the range of 25.0–87.2 μM) [Liu *et al*., 2018]. The same compounds also strongly inhibited ROS generation in the RAW264.7 macrophages.

Aqil *et al*. [2012] investigated antioxidant activity of the crude and hydrolyzed extracts of jamun seeds as ferric-reducing antioxidant power (FRAP), oxygen radical absorbance capacity (ORAC), and using antiradical assays (DPPH and ABTS). In the DPPH assay, the crude and hydrolyzed extracts exhibited SC_{50} of 16.3 and 19.8 μg/mL, respectively. For both extracts, results of the ABTS assay were the same – SC_{50} of 4.6 μg/mL. Results of FRAP were expressed by the concentration inducing 50% reduction of the ferric iron, which amounted to 23.6 μg/mL (crude extract) and 24.7 μg/mL (hydrolyzed extract). Both extracts were characterized by the same ORAC value – 3.379 mmol Trolox equivalents/g.

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

Antimicrobial activity

According to Bag *et al*. [2012], the extract of jamun seeds exhibited the antibacterial potential against multidrug-resistant human bacterial pathogens. The possibility of applying the jamun seed extract as a novel antimicrobial agent was confirmed by means of the agar well diffusion and microbroth dilution assays. Jasmine *et al.* [2010] found that the crude extracts of jamun seeds could act against isolated β-lactamase-producing drug-resistant bacteria. The zone of inhibition was in the range of 14–21 mm and a minimum inhibitory concentration (MIC) was in the range of 31.75–62.5 μg/mL. According to the authors, saponins present in the extract were the active phytochemicals. Eight sesquiterpenoids isolated from jamun seeds were active (100 μg/disk) against *S. aureus.* However, the same compounds at the same concentration caused no effect against *E. coli* and *C. albicans* [Liu *et al*., 2017a]. According to Santos *et al*. [2020], phenolic extracts of jamun seeds were activite against *Aeromonas hydrophila*, *Chromobacterium violaceum*, *E. coli*, *Pseudomonas aeruginosa*, *Salmonella enterica* serovar Typhimurium, *Serratia marcescens*, *Listeria monocytogenes*, and *S. aureus*. The strongest antimicrobial activity was reported in the case of *S. aureus*. The extract used inhibited also violacein production by *C. violaceum.* Inhibition of *E. coli, S. aureus*, and *P. aeruginosa* growth by a fraction isolated from the ethanol extract of jamun seed was also reported by Yadav *et al*. [2011]. The zones of inhibition in agar cup-plate assay were 20, 17 and 11 mm, respectively. Yadav *et al.* [2017], using an agar well diffusion assay, demonstrated the antimicrobial activity of the jamun seed extract against *Bacillus subtilis.* The minimum inhibitory concentration of the methanolic extract was 0.3 mg/mL. The results of flow cytometry showed that antimicrobial activity of compounds present in the extract was related to the induction of membrane permeability in bacterial cells. According to docking analysis, among bioactive compounds of the jamun seed extract, lupeol showed the highest binding energy with DD-carboxypeptidase and LD-carboxypeptidase from *B. subtilis*, and stigmasterol and betasitosterol showed the highest binding energy for class D β-lactamase and β-lactamase.

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

APPLICATION OF JAMUN SEEDS AND THEIR EXTRACT IN THE FOOD INDUSTRY

Jamun seed powder and its infusion are traditionally used in the treatment of diabetes and ulcers. Currently, the application of these seeds to prepare herbal formulations is gaining popularity worldwide. Raza *et al.* [2017] recommended the jamun seed powder as a health-promoting additive to foods due to its antihyperglycemic properties. However, its use in the production of bread, pasta or cookies still requires researches of product safety and quality, and processes conditions optimization. In the case of infusions/extracts, their low storage stability is disadvantageous. Modern techniques, such as ultrafiltration and nanofiltration, show promise in solving this problem [Balyan & Sarkar, 2018]. The cited study estimated parameters of the first-order kinetic model to fit the changes of total phenolic contents and total flavonoid contents of UF and NF fractions of the jamun seed aqueous extract during storage. These parameters can be useful for designing appropriate storage conditions for industrial scale-up of the process. Another possibility of increasing the stability of the jamun seed extract was proposed by Peixoto & Freitas [2013]. The authors spray-dried the aqueous extract using silicon dioxide and cassava starch as carriers. The obtained powder had low hygroscopicity at 43% relative humidity and was characterized by adequate flowability and compactability. Moreover, the antihyperglycemic and antioxidant properties of the spray-dried extract were comparable to those of the lyophilized one.

Whole jamun-based functional confection (WJFC) containing 2% of the jamun seed powder was produced and investigated by Sehwag & Das [2016] and Sehwag *et al*. [2018]. WJFC was characterized by a high content of dietary fiber and a low calorific value. It could be applied as a natural prebiotic, antioxidant or antidiabetic preparation. WJFC as an inhibitor of α-amylase activity helped in maintaining a low blood glucose level.

The study of VenuGopal & Anu-Appaiah [2017] investigated effects of, the addition of jamun seeds during production of wines from jamun fruits. The seeds added to wine increased the content of phenolic compounds at the beginning of fermentation. However, the content of phenolics reduced throughout aging. The presence of phenolic compounds and polysaccharides originating from seeds influenced wine browning. In turn, Singh & Kocher [2020] used response surface methodology to optimize the parameters

of the fermentation of *S. cumini* fruits with seed power supplementation. Phenolics (specially tannins) of seeds were responsible for stabilizing sensory attributes and antioxidant potential of stored wines.

Abdin *et al.* [2022] used the jamun seed extract as a component of the edible sodium alginate/gum Arabic films. Such a product, featuring appropriate physicochemical properties, can serve as a good source of antioxidant compounds and can be used in modern food packaging.

CONCLUSION AND FUTURE PROSPECTIVE DIRECTIONS

According to the review, the seed of the jamun fruit has a richly-varied composition of bioactive compounds, including terpenoids, phenolic compounds and saponins with high contents of gallic acid, ellagic acid and hydrolysable tannins. These compounds are responsible for the extensive biological activities of jamun seeds and their extracts. Jamun seeds appear to be a low-cost source of a natural antidiabetic agent, although their antioxidant, anti-inflammatory antimicrobial potential is becoming more and more appreciated. As modern techniques for the extraction, separation and purification of jamun seeds bioactives are developed, it seems that powder, extracts and fractions may soon be harnessed in the production of functional foods and nutraceuticals intended for people at risk of diabetes, cancer, cardiovascular, hepatic and neurodegenerative diseases, and bacterial and microbial infections. Nevertheless, more research is needed to elucidate the molecular mechanisms of the of health-beneficial activities of jamun seed compounds. The biological activity of saponins and lignans from jamun seeds, and the bioavailability of bioactive compounds are still poorly understood. In addition, the nutritional value of jamun seeds seems to be still little known, especially in terms of proteins, their amino acid composition and biological value. Clinical trials of jamun seed-based goods on humans, taking into account all safety concerns, will increase the value of jamun seeds for use in the food and non-food industries.

RESEARCH FUNDING

This study received no external funding.

CONFLICT OF INTERESTS

Authors declare no conflict of interest.

ORCID IDs

R. Amarowicz https://orcid.org/0000-0001-9731-0045
J.M. Lorenzo https://orcid.org/0000-0002-7725-9294
Y. Tak https://orcid.org/0000-0003-3549-0284

REFERENCES

1. Abdin, M., Hamed, Y.S., Akhtar, H.M.S., Chen, D., Mukhtar, S., Wan, P., Riaz, A., Zeng, X. (2019). Extraction optimisation, antioxidant activity and inhibition on α-amylase and pancreatic lipase of polyphenols from the seeds of *Syzygium cumini*. *International Journal of Food Science and Technology*, *54*(6), 2084–2093. https://doi.org/10.1111/ijfs.14112
2. Abdin, M., El-Beltagy, A.E., El-Sayed, M.E., Naeem, M.A. (2022). Production and characterization of sodium alginate/gum Arabic based films enriched with *Syzygium cumini* seeds extracts for food application. *Journal of Polymers and the Environment*, *30*, 1615–1626. https://doi.org/10.1007/s10924-021-02306-z
3. Alam, F., Shafique, Z., Amjad, S.T., Bin Asad, M.H.H. (2019). Enzymes inhibitors from natural sources with antidiabetic activity: A review. *Phytotherapy Research*, *33*(1), 41–54. https://doi.org/10.1002/ptr.6211
4. Al-Dhabi, N.A., Ponmurugan, K. (2020). Microwave assisted extraction and characterization of polysaccharide from waste jamun fruit seeds. *International Journal of Biological Macromolecules*, *152*, 1157–1163. https://doi.org/10.1016/j.ijbiomac.2019.10.204
5. Alikatte, K.L., Akondi, B.R., Yerragunta, V.G., Veerareddy, P.R., Suresh Palle, S. (2012). Antiamnesic activity of *Syzygium cumini* against scopolamine induced spatial memory impairments in rats. *Brain & Development*, *34*,(10), 844–851. http://doi.org/10.1016/j.braindev.2012.02.008
6. Aqil, F., Gupta, A., Munagala, R., Jeyabalan, J., Kausar, H., Sharma, R.J., Singh, I.P., Gupta, R.C. (2012). Antioxidant and antiproliferative activities of anthocyanin/ellagitannin-enriched extracts from *Syzygium cumini* L. (Jamun, the Indian blackberry). *Nutrition and Cancer*, *64*(3), 428–438. https://doi.org/10.1080/01635581.2012.657766
7. Arun, R., Prakash, M.V.D., Abraham, S.K., Premkumar, K. (2011). Role of *Syzygium cumini* seed extract in the chemoprevention of *in vivo* genomic damage and oxidative stress. *Journal of Ethnopharmacology*, *134*(2), 329–333. https://doi.org/10.1016/j.jep.2010.12.014
8. Assan Aliyar, M., Nadig, P., Bharatam, N. (2021). *In vitro* antidiabetic activity, bioactive constituents, and molecular modeling studies with sulfonylurea receptor1 for insulin secretagogue activity of seed extract of *Syzygium cumini* (L.). *Journal of Herbmed Pharmacology*, *10*(3), 304–312. https://doi.org/10.34172/jhp.2021.35
9. Atale, N., Chakraborty, M., Mohanty, S., Bhattacharya, S., Nigam, D., Sharma, M., Rani, V. (2013). Cardioprotective role of *Syzygium cumini* against glucose-induced oxidative stress in H9C2 cardiac myocytes. *Cardiovascular Toxicology*, *13*(3), 278–289. https://doi.org/10.1007/s12012-013-9207-1
10. Atale, N., Mishra, C.B., Kohli, S., Mongre, R.K., Prakash, A., Kumari, S., Yadav, U.C.S., Jeon, R., Rani, V. (2021). Anti-inflammatory effects of *S. cumini* seed extract on gelatinase-B (MMP-9) regulation against hyperglycemic cardiomyocyte stress. *Oxidative Medicine and Cellular Longevity*, *2021*, art. no. 8839479. https://doi.org/10.1155/2021/8839479
11. Bag, A., Bhattacharyya, S.K., Pal, N.K., Chattopadhyay, R.R. (2012). *In vitro* antibacterial potential of *Eugenia jambolana* seed extracts against multidrug-resistant human bacterial pathogens. *Microbiological Research*, *167*(6), 352- 357. https://doi.org/10.1016/j.micres.2012.02.005
12. Bajpai, M., Pande, A., Tewari, S.K., Prakash, D. (2005). Phenolic contents and antioxidant activity of some food and medicinal

plants. *International Journal of Food Sciences and Nutrition*, *56*(4), 287–291.
https://doi.org/10.1080/09637480500146606

13. Balyan, U., Sarkar, B. (2016). Integrated membrane process for purification and concentration of aqueous *Syzygium cumini* (L.) seed extract. *Food and Bioproducts Processing*, *98*, 29–43.
https://doi.org/10.1016/j.fbp.2015.12.005
14. Balyan, U., Sarkar, B. (2017). Aqueous extraction kinetics of phenolic compounds from jamun (*Syzygium cumini* L.) seeds. *International Journal of Food Properties, 20*(2), 372–389.
https://doi.org/10.1080/10942912.2016.1163266
15. Balyan, U., Sarkar, B. (2018). Ultrafiltration of *Syzygium cumini* (L.) seeds extract: Analysis of flux decline and extract stability. *Asia-Pacific Journal of Chemical Engineering, 13*(2), art. no. e2166.
https://doi.org/10.1002/apj.2166
16. Bellé, L.P., Bitencourt, P.E.R., Abdalla, F.H., de Bona, K.S., Peres, A., Maders, L.D.K., Moretto, M.B. (2013). Aqueous seed extract of *Syzygium cumini* inhibits the dipeptidyl peptidase IV and adenosine deaminase activities, but it does not change the CD26 expression in lymphocytes *in vitro*. *Journal of Physiology and Biochemistry*, *69*(1), 119–124.
https://doi.org/10.1007/s13105-012-0195-6
17. Benherlal, P.S., Arumughan, C. (2007). Chemical composition and *in vitro* antioxidant studies of *S. cumini* fruit. *Journal of the Science of Food and Agriculture*, *87*(14), 2560–2569.
https://doi.org/10.1002/jsfa.2957
18. Bhaskar, K., Sassykova, L.R., Prabhahar, M., ShebhaPercis, E., Nalini, A., Jenish, T., Jayarajan, J., Sendilvelan, S. (2021). Analysis of *Cymbopogon citratus*, *Pinus sylvestris* and *Syzygium cumini* biodiesel feedstocks for its fatty acid composition. *Materials Today: Proceedings, 45*, Part 7, 5970–5977.
https://doi.org/10.1016/j.matpr.2020.09.254
19. Bhatia, I.S., Bajaj, K.L. (1975). Chemical constituents of the seeds and bark of *Syzygium cumini*. *Planta Medica*, *28*(8), 346–352.
https://doi.org/10.1055/s-0028-1097868
20. Binita, K., Kumar, S., Sharma, V.K., Sharma, V., Yadav, S. (2014). Proteomic identification of *Syzygium cumini* seed extracts by MALDI-TOF/MS. *Applied Biochemistry and Biotechnology*, *172*, 2091–2105.
https://doi.org/10.1007/s12010-013-0660-x
21. Bitencourt, P.E.R., Cargnelutti, L.O., Stein, C.S., Lautenchleger, R., Ferreira, L.M., Sangoi, M., Denardi, L., Borges, R.M., Boligon, A., Moresco, R.N., Cruz, L., Zanette, R.A., Alves, S.H., Moretto, M.B. (2017). Nanoparticle formulation increases *Syzygium cumini* antioxidant activity in *Candida albicans*-infected diabetic rats. *Pharmaceutical Biology*, *55*(1), 1082–1088.
https://doi.org/10.1080/13880209.2017.1283338
22. Chandrasekaran, M., Venkatesalu, V. (2004). Antibacterial and antifungal activity of *Syzygium jambolanum* seeds. *Journal of Ethnopharmacology*, *91*(1), 105–108.
https://doi.org/10.1016/j.jep.2003.12.012
23. Chaudhuri A.K.N., Pal, S., Gomes, A., Bhattacharya, S. (1990). Anti-inflammatory and related actions of *S. cumini* seed extract. *Phytotherepia Research*, *4*(1), 5–10.
https://doi.org/10.1002/ptr.2650040103
24. Cronin, P., Joyce, S.A., O'Toole, P.W., O'Connor, E.M., (2021). Dietary fibre modulates the gut microbiota. *Nutrients*, *13*(5), art. no. 1655.
https://doi.org/10.3390/nu13051655
25. Daulatabad, C.M.J.D., Abdurrazzaque, M., Mirajkar, A.M., Hosamani, K.M., Mulla, G.M.M. (1988). Epoxy and cyclopropenoid fatty acids in Syzygium cuminii seed oil. *Journal of the Science of Food and Agriculture*, *43*(1), 91–94.
https://doi.org/10.1002/jsfa.2740430111
26. De Sousa Sabino, L.B., de Brito, E.S., da Silva I.J., Júnior (2018). Jambolan – *Syzygium jambolanum*. In S. Rodrigues, E. de Oliveira Silva, E.S. de Brito (Eds.), *Exotic Fruits*, Academic Press, London, UK, pp. 251–256.
https://doi.org/10.1016/B978-0-12-803138-4.00032-0
27. Deng, Y., Huang, L., Zhang, C., Xie, P., Cheng, J., Wang, X., Liu, L. (2020). Novel polysaccharide from *Chaenomeles speciosa* seeds: Structural characterization, α-amylase and α-glucosidase inhibitory activity evaluation. *International Journal of Biological Macromolecules 153*, 755–766.
https://doi.org/10.1016/j.ijbiomac.2020.03.057
28. Devkar, R.V., Pandya, A.V., Shah, N.H. (2012). Protective role of *Brassica olerecea* and *Eugenia jambolana* extracts against H_2O_2 induced cytotoxicity in H9C2 cells. *Food & Function*, *3*(8), 837–843.
https://doi.org/10.1039/c2fo00001f
29. Elhawary, S.S.E., kamal Eldin Elmotyam, A., kamel Alsayed, D., Zahran, E.M., Fouad, M.A., Sleem, A.A., Elimam, H., Rashed, M.H., Hayallah, A.M., Anber, F., Mohammed, A.F., Abdelmohsen, U.R. (2022). Cytotoxic and anti-diabetic potential, metabolic profiling and *in silico* studies of *Syzygium cumini* (L.) Skeels belonging to family *Myrtaceae*. *Natural Product Research*, *36*(4), 1026–1030.
https://doi.org/10.1080/14786419.2020.1843032
30. Faria, A.F., Marques, M.C., Mercadante, A.Z. (2011). Identification of bioactive compounds from jambolão (*Syzygium cumini*) and antioxidant capacity evaluation in different pH conditions. *Food Chemistry*, *126*(4), 1571–1578.
https://doi.org/10.1016/j.foodchem.2010.12.007
31. Gajera, H.P., Gevariya, S.N., Hirpara, D.G., Patel, S.V., Golakiya, B.A. (2017). Antidiabetic and antioxidant functionality associated with phenolic constituents from fruit parts of indigenous black jamun (*Syzygium cumini* L.) landraces. *Journal of Food Science and Technology*, *54*(10), 3180–3191.
https://doi.org/10.1007/s13197-017-2756-8
32. Gajera, H.P., Gevariya, S.N., Patel, S.V., Golakiya, B.A. (2018). Nutritional profile and molecular fingerprints of indigenous black jamun (*Syzygium cumini* L.) landraces. *Journal of Food Science & Technology, 55*(2), 730–739.
https://doi.org/10.1007/s13197-017-2984-y
33. Ghosh, P., Radhan, R.C., Mishra, S., Patel, A.S., Kar, A. (2017). Physicochemical and nutritional characterization of jamun (*Syzygium cuminii*). *Current Research in Nutrition and Food Science Journal, 5*(1), 25–35.
https://doi.org/10.12944/CRNFSJ.5.1.04
34. Granado-Rodríguez, S., Aparicio, N., Matías, J., Pérez-Romero, L.F., Maestro, I., Gracés, I., Pedroche, J.J., Haros, C.M., Fernandez-Garcia, N., del Hierro, J.N., Martin, D., Bolaños, L., Reguera, M. (2021). Studying the impact of different field environmental conditions on seed quality of quinoa: the case of three different years changing seed nutritional traits in Southern Europe. *Frontiers in Plant Science*, *12*, art. no. 649132.
https://doi.org/10.3389/fpls.2021.649132

35. Gupta, D.R., Agrawal, S.K. (1970). Chemical examination of the unsaponifiable matter of the seed fat of *Syzgium cumini*. *Science and Culture*, *36*(5), 298.
36. Holscher, C. (2010). Incretin analogues that have been developed to treat type 2 diabetes hold promise as a novel treatment strategy for Alzheimer's disease. *Recent Patents on CNS Drug Discovery*, *5*(2), 109–117. https://doi.org/10.2174/157488910791213130
37. Indrayan, A.K., Sharma, S., Durgapaal, D., Kumar, N., Kumar, M. (2005). Determination of nutritive value and analysis of mineral elements for some medicinally valued plants from Uttaranchal. *Current Science*, *89*(7), 1252–1255. https://www.jstor.org/stable/24110980
38. Jadeja, R.N., Thouaojam, M.C., Sankhari, J.M., Jain, M., Devkar, R.V., Ramachandran, A.V. (2012). Standardized flavonoid-rich *Eugenia jambolana* seed extract retards *in vitro* and *in vivo* LDL oxidation and expression of VCAM-1 and P-selectin in atherogenic rats. *Cardiovascular Toxicilogy*, *12*, 73–82. https://doi.org/10.1007/s12012-011-9140-0
39. Jamun Farming Information (Indian Black Plum) – AgriFarming. https://www.agrifarming.in/jamun-farming
40. Jasmine, R., Selvakumar, B.N., Daisy, P.S., Ignacimuthu, S. (2010). Activity of *Eugenia jambolana*, an ethnomedical plant, against drug-resistant bacteria. *Pharmaceutical Biology*, *48*(4), 405–410. https://doi.org/10.3109/13880200903150401
41. Karamać, M. (2009). *In-vitro* study on the efficacy of tannin fractions of edible nuts as antioxidants. *European Journal of Lipid Science and Technology*, *111*(11), 1063–1071. https://doi.org/10.1002/ejlt.200900067
42. Kaur, L., Han, K.-S., Bains, K., Singh, H. (2011). Indian culinary plants enhance glucose-induced insulin secretion and glucose consumption in INS-1 β-cells and 3T3-L1 adipocytes. *Food Chemistry*, *129*(3), 1120–1125. https://doi.org/10.1016/j.foodchem.2011.05.089
43. Kosaraju, J., Madhunapantula, S.R.V., Chinni, S., Khatwal, R.B., Dubala, A., Muthureddy Nataraj, S.K., Basavan, D. (2014). Dipeptydyl peptidase-4 inhibition by *Pterocarpus marsupium* and *Eugenia Jambolana* ameliorates streptozotocin induced Alzheimer's disease. *Behavioural Brain Research, 267*, 55–65. https://doi.org/10.1016/j.bbr.2014.03.026
44. Kumar, A., Ilavarasan, R., Jayachandran, T., Deecaraman, M., Kumar, R.M., Aravindan, P., Krishan, M.R.V. (2008). Anti-inflammatory activity of *Syzygium cumini* seed. *African Journal of Biotechnology*, *7*(8), 941–943. http://www.academicjournals.org/AJB
45. Lee, J.J., Yoon, K.Y. (2022). Ultrasound-assisted extractions for improving the recovery of phenolics and charantin from bitter melon and for increasing the antioxidant, antidiabetic and anti-obesity activities of its extracts. *Polish Journal of Food and Nutrition Sciences*, *72*(2), 141–150. https://doi.org/10.31883/pjfns/149434
46. Lestario, L.N., Howard, L.R., Brownmiller, C., Stebbins, N.B., Liyanage, R., Lay, J.O. (2017). Changes in polyphenolics during maturation of Java plum (*Syzygium cumini* Lam.). *Food Research International*, *100*, Part 3, 395–391. https://doi.org/10.1016/j.foodres.2017.04.023
47. Liu, F., Liu, C., Liu, W., Ding, Z., Ma, H., Seeram, N.P., Xu, L., Mu, Y., Huang, X., Li, L. (2017a). New sesquiterpenoids from *Eugenia jambolana* seeds and their anti-microbial activities. *Journal of Food and Agricultural Chemistry*, *66*, 10214–10222. https://doi.org/10.1021/acs.jnatprod.6b01073
48. Liu, F., Ma, H., Wang, G., Liu, W., Seeram, N.P., Mu, Y., Xu, Y., Huang, X., Li., L. (2018). Phenolics from *Eugenia jambolana* seeds with advanced glycation endproduct formation and alpha-glucosidase inhibitory activities. *Food & Function, 9*(8), 4246––4254. https://doi.org/10.1039/C8FO00583D
49. Liu, F., Yuan, T., Liu, W., Ma, H., Seeram, N.P., Li, Y., Xu, L., Mu, Y., Huang, X., Li, L. (2017b). Phloroglucinol derivatives with protein tyrosine phosphatase 1B inhibitory activities from *Eugenia jambolana* seeds. *Journal of Natural Products*, *80*(2), 544–550. https://doi.org/10.1021/acs.jafc.7b04066
50. Mahindrakar, K.V., Rathod, V.K. (2020a). Ultrasonic assisted aqueous extraction of catechin and gallic acid from *Syzygium cumini* seed kernel and evaluation of total phenolic, flavonoid contents and antioxidant activity. *Chemical Engineering and Processing – Process Intensification, 149*, art. no. 107841. https://doi.org/10.1016/j.cep.2020.107841
51. Mahindrakar, K.V., Rathod, V.K. (2020b). Antidiabetic potential evaluation of aqueous extract of waste *Syzygium cumini* seed kernel's by *in vitro* α-amylase and α-glucosidase inhibition. *Preparative Biochemistry & Biotechnology*, *51*(6), 589–598. https://doi.org/10.1080/10826068.2020.1839908
52. Mahindrakar, K.V., Rathod, V.K. (2021). Valorization of waste *Syzygium cumini* seed kernels by three-phase partitioning extraction and evaluation of in vitro antioxidant and hypoglycemic potential. *Preparative Biochemistry & Biotechnology*, *51*(10), 1036–1045. https://doi.org/10.1080/10826068.2021.1894442
53. Martin, T.S., Ohtani, K., Kasai, R., Yamasaki, K. (1998). Lignan glucoside from *Syzygium cumini. Natural Medicine*, *52*(4), 360–363.
54. Moussa, M.I.D., Alashi, A.M., Sossa-Vihotogbé, C.N., Akponikpè, P.B., Baco, M.N., Djènontin, A.J., Aluko, R.E., Akissoé, N.H. (2020). Proximate composition, mineral profile and trypsin-inhibitory activity of West African leafy vegetables: influence of urea micro-dosing and harvest time. *Polish Journal of Food and Nutrition Sciences*, *70*(2), 179–188. https://doi.org/10.31883/pjfns/119674
55. Nahid, S., Mazumder, K., Rahman, Z., Islam, S., Rashid, M.H., Kerr, P.G. (2017). Cardio- and hepato-protective potential of methanolic extract of *Syzygium cumini* (L.) Skeels seeds: A diabetic rat model study. *Asian Pacific Journal of Tropical Biomedicine, 7*(2), 126–133. https://doi.org/10.1016/j.apjtb.2016.11.025
56. Oh, M.H., Yoon, K. (2018). Comparison of the biological activity of crude polysaccharide fractions obtained from *Cedrela sinensis* using different extraction methods. *Polish Journal of Food and Nutrition Sciences, 68*(4), 327–334. https://doi.org/10.1515/pjfns-2018-0007
57. Omar, R., Li, L., Yuan, T., Seeram, N.P. (2012). α-Glucosidase inhibitory hydrolyzable tannins from *Eugenia jambolana* seeds. *Journal of Natural Products*, *75*(8), 1505–1509. https://doi.org/10.1021/np300417q

58. Pandey, M., Khan, A. (2002). Hypoglycaemic effect of defatted seeds and water soluble fibre from the seeds of *Syzygium cumini* (Linn.) skeels in alloxan diabetic rats. *Indian Journal of Experimental Biology, 40*(10), 1178–1182.
59. Panghal, A., Kaur, R., Janghu, S., Sharma, P., Sharma, P., Chhikara, N. (2019). Nutritional, phytochemical, functional and sensorial attributes of *Syzygium cumini* L. pulp incorporated pasta. *Food Chemistry*, *289*, 723–728. https://doi.org/10.1016/j.foodchem.2019.03.081
60. Parmar, J., Sharma, P., Verma, P., Goyal, P.K. (2010). Chemopreventive action of *Syzygium cumini* on DMBA-induced skin papillomagenesis in mice. *Asian Pacific Journal of Cancer Prevention*, *11*(1), 261–265.
61. Parveen, S., Khan, A.A., Khan, Q.A. (2020). Antihyperlipidemic effect of seeds of jamun (*Eugenia jambolana*) in subjects of intermediate hyperglycemia: A pilot study. *Traditional and Integrative Medicine, 5*(4), 191–197. https://doi.org/10.18502/tim.v5i4.5164
62. Peixoto, M.P.G., Freitas, L.A.P. (2013). Spray-dried extracts from *Syzygium cumini* seeds: Physicochemical and biological evaluation. *Revista Brasileira de Farmacognosia, 23*(1), 145–152. https://doi.org/10.1590/S0102-695X2012005000124
63. Prakash, A.K.S., Devaraj, E. (2019). Cytotoxic potentials of *S. cumini* methanolic seed kernel extract in human hepatoma HepG2 cells. *Environmental Toxicology*, *34*(12), 1313–1319. https://doi.org/10.1002/tox.22832
64. Prince, P.S.M., Kamalakkannan, N., Menon, V.P. (2004). Antidiabetic and antihyperlipidaemic effect of alcoholic *Syzigium cumini* seeds in alloxan induced diabetic albino rats. *Journal of Ethnopharmacology, 91*(2–3), 209–213. https://doi.org/10.1016/j.jep.2003.11.001
65. Puljula, E., Walton, G., Woodward, M.J., Karonen, M. (2020). Antimicrobial activities of ellagitannins against *Clostridiales perfringens*, *Escherichia coli*, *Lactobacillus plantarum* and *Staphylococcus aureus. Molecules*, *25*, art. no. 3714. https://doi.org/10.3390/molecules25163714
66. Ravi, K., Sekar, D., Subramanian, S. (2004a). Hypoglycemic activity of inorganic constituents in *Eugenia jambolana* seed on streptozotocin-induced diabetes in rats. *Biological Trace Element Research*, *99*, 145–155. https://doi.org/10.1385/BTER:99:1-3:145
67. Ravi, K., Sivagnanam, K., Subramanian, S. (2004b). Anti-diabetic activity of *Eugenia jambolana* seed kernels on streptozotocin--induced diabetic rats. *Journal of Medicinal Food*, *7*(2), 187–191. https://doi.org/10.1089/1096620041224067
68. Ravi, K., Rajasekaran, S., Subramanian, S. (2005). Antihyperlipidemic effect of *Eugenia jambolana* seed kernel on streptozotocin-induced diabetes in rats. *Food and Chemical Toxicology*, *43*(9), 1433–1439. https://doi.org/10.1016/j.fct.2005.04.004
69. Ravi, K., Rajasekaran, S., Subramanian, S. (2003). Hypoglycemic effect of *Eugenia jambolana* seed kernels on streptozotocin--induced diabetes in rats. *Pharmaceutical Biology*, 41(8), 598–603. https://doi.org/10.1080/13880200390501929
70. Raza A., Butt, M.S., Iahtisham-Ul-Haq, Suleria, H.A.R. (2017). Jamun (*Syzygium cumini*) seed and fruit extract attenuate hyperglycemia in diabetic rats. *Asian Pacific Journal of Tropical Biomedicine, 7*(8), 750–754. https://doi.org/10.1016/j.apjtb.2017.07.006
71. Santos, C.A., Almeida, F.A., Quecán, B.X.V., Pereira, P.A.P., Gandra, M.M.B., Cunha, L.R., Pinto, U.M. (2020). Bioactive properties of *Syzygium cumini* (L.) Skeels pulp and seed phenolic extracts. *Frontiers in Microbiology*, *11*, art. no. 990. https://doi.org/10.3389/fmicb.2020.00990
72. Sawant, L., Singh, V.K., Dethe, S., Bhaskar, A., Balachandran, J., Mundkinajeddu, D., Agarwal, A. (2015). Aldose reductase and protein tyrosine phosphatase 1B inhibitory active compounds from *Syzygium cumini* seeds. *Pharmaceutical Biology*, *53*(8), 1176–1182. https://doi.org/10.3109/13880209.2014.967784
73. Scharf, D.R., Simionatto, E.L., Kassuya, C.A.L., Stefanello, M.E.A. (2016). Essential oil from *Eugenia jambolana* seeds: Chemical composition and changes during storage. *Journal of Essential Oil Bearing Plants, 19*(8), 2077–2082. https://doi.org/10.1080/0972060X.2016.1232608
74. Sehwag, S., Das, M. (2016). Composition and functionality of whole jamun based functional confection. *Journal of Food Science and Technology, 53*(6), 2569–2579. https://doi.org/10.1007/s13197-016-2219-7
75. Sehwag, S., Upadhyay, R., Das, M. (2018). Optimization and multivariate accelerated shelf life testing (MASLT) of a low glycemic whole jamun (*Syzygium cumini* L.) confection with tailored quality and functional attributes. *Journal of Food Science and Technology*, *55*(12), 4887–4900. https://doi.org/10.1007/s13197-018-3423-4
76. Seraglio, S.K.T., Schulz, M., Nehring, P., Betta, F.D., Valese, A.C., Daguer, H., Gonzaga, L.V., Fett, R., Costa, A.C.O. (2018). Nutritional and bioactive potential of *Myrtaceae* fruits during ripening. *Food Chemistry, 239,* 649–656. https://doi.org/10.1016/j.foodchem.2017.06.118
77. Sharma, B., Balomajumder, C., Roy, P. (2008a). Hypoglycemic and hypolipidemic effects of flavonoid rich extract from *Eugenia jambolana* seeds on streptozotocin induced diabetic rats. *Food and Chemical Toxicology*, *46*(7), 2376–2383. https://doi.org/10.1016/j.fct.2008.03.020
78. Sharma, B., Viswanath, G., Salunke, R., Roy, P. (2008b). Effects of flavonoid-rich extract from seeds of *Eugenia jambolana* (L.) on carbohydrate and lipid metabolism in diabetic mice. *Food Chemistry*, *110*(3), 697–705. https://doi.org/10.1016/j.foodchem.2008.02.068
79. Sharma, M., Li, L., Celver, J., Killian, C., Kovoor, A., Seeram, N.P., (2010). Effects of fruit ellagitannin extracts, ellagic acid, and their colonic metabolite, Urolithin A, on Wnt signaling. *Journal of Agricultural and Food Chemistry*, *58*(7), 3965–3969. https://doi.org/10.1021/jf902857v
80. Sharma, S., Pathak, S., Gupta, G., Sharma, S.K., Singh, L., Sharma, R.K., Mishra, A., Dua, K. (2017). Pharmacological evaluation of aqueous extract of *Syzigium cumini* for its antihyperglycemic and antidyslipidemic properties in diabetic rats fed a high cholesterol diet—Role of PPARγ and PPARα. *Biomedicine & Pharmacotherapy*, *89*, 447–453. https://doi.org/10.1016/j.biopha.2017.02.048
81. Sharma, S.B., Nasir, A., Prabhu, K.M., Murthy, P.S., Dev, G. (2003). Hypoglycaemic and hypolipidemic effect of ethanolic extract of seeds of *Eugenia jambolana* in alloxan-induced diabetic rabbits. *Journal of Ethnopharmacology, 85*(2–3), 201–206. https://doi.org/10.1016/S0378-8741(02)00366-5

82. Sharma, S.B., Rajpoot, R., Nasir, A., Prabhu, K.M., Murthy, P.S. (2011a). Ameliorative effect of active principle isolated from seeds of *Eugenia jambolana* on carbohydrate metabolism in experimental diabetes. *Evidence-Based Complementary and Alternative Medicine*, *2011*, art. no. 789871. https://doi.org/10.1093/ecam/nep233
83. Sharma, S.B., Tanwar, R.S., Nasir, A., Prabhu, K.M. (2011b). Antihyperlipidemic effect of active principle isolated from seed of *Eugenia jambolana* on alloxan-induced diabetic rabbits. *Journal of Medicinal Food, 14*(4), 353–359. https://doi.org/10.1089/jmf.2010.1227
84. Shelke, G., Kad, V., Yenge, G., Desai, S., Kakde, S. (2020). Utilization of jamun pomace as functional ingredients to enhance the physico-chemical and sensory characteristics of ice cream. *Journal of Food Processing and Preservation*, *44*(10), art. no. e14736. https://doi.org/10.1111/jfpp.14736
85. Shinde, J., Taldone, T., Barletta, M., Kunaparaju, N., Hu, B., Kumar, S., Placido, J., Zito, S.W. (2008). α-Glucosidase inhibitory activity of *Syzygium cumini* (Linn.) Skeels seed kernel *in vitro* and in Goto–Kakizaki (GK) rats. *Carbohydrate Research*, *343*(7), 1278–1281. https://doi.org/10.1016/j.carres.2008.03.003
86. Shrikanta, A., Kumar, A., Govindaswamy, V. (2015). Resveratrol content and antioxidant properties of underutilized fruits. *Journal of Food Science and Technology*, *52*(1), 383–390. https://doi.org/10.1007/s13197-013-0993-z
87. Sidana, S., Singh, V.B., Meena, B.L., Beniwal, S., Singh, K., Kumar, D., Singla, R. (2017). Effect of *Syzygium cumini* (jamun) seed powder on glycemic control: A double–blind randomized controlled trial. *Journal of Medical Society*, *31*(3), 185–189. https://doi.org/10.4103/jms.jms_62_16
88. Singh, C.S., Paswan, V.K., Rai, D.C. (2019). Process optimization of spray dried jamun (*Syzygium cumini* L.) pulp powder. *LWT – Food Science and Technology*, *109*, 1–6. https://doi.org/10.1016/j.lwt.2019.04.011
89. Singh, A., Kocher, G.S. (2020). Standardization of seed and peel infused *Syzygium cumini* – wine fermentation using response surface methodology. *LWT – Food Science and Technology*, *134*, art. no. 109994. https://doi.org/10.1016/j.lwt.2020.109994
90. Sisodia, S.S., Bhatnagar, M. (2009). Hepatoprotective activity of *Eugenia jambolana* Lam. in carbon tetrachloride treated rats. *Indian Journal of Pharmacology, 41*(1), 23–27. https://doi.org/10.4103/0253-7613.48888
91. Sridhar, S.B., Sheetal, U.D., Pai, M.R., Shastri, M.S. (2005). Preclinical evaluation of the antidiabetic effect of *Eugenia jambolana* seed powder in streptozotocin-diabetic rats. *Brazilian Journal of Medicinal and Biological Research, 38*(3), 463–468. https://doi.org/10.1590/S0100-879X2005000300018
92. Syama, H.P., Arun, K.B., Sinumol, G., Dhanya, R., Anusree, S.S., Nisha, P., Shankar, L.R., Sundaresan, A., Jayamurthy, P. (2018). *Syzygium cumini* seed exhibits antidiabetic potential via multiple pathways involving inhibition of α-glucosidase, DPP-IV, glycation, and ameliorating glucose uptake in L6 cell lines. *Journal of Food Processing and Preservation, 42*(2), art. no. e13464. https://doi.org/10.1111/jfpp.13464
93. Tan, M., Zhao, Q., Zhao, B. (2021). Physicochemical properties, structural characterization and biological activities of polysaccharides from quinoa (*Chenopodium quinoa* Willd.) seeds. *Journal of Biological Macromolecules, 193*, Part B, 1635–1644. https://doi.org/10.1016/j.ijbiomac.2021.10.226
94. Thiyagarajan, G., Muthukumaran, P., Kumar, B.S., Muthusamy, V.S., Lakshmi, B.S. (2016). Selective inhibition of PTP1B by vitalboside A from *Syzygium cumini* enhances insulin sensitivity and attenuates lipid accumulation via partial agonism to PPARc: *In vitro* and *in silico* investigation. *Chemical Biology & Drug Design*, *88*(2), 302–312. https://doi.org/10.1111/cbdd.12757
95. Ud Din, S., Jaskani, M.J., Naqvi, S.A., Awan, F.S. (2020). Diversity and divergence in domesticated and wild jamun (*Syzygium cumini*) genotypes of Pakistan. *Scientia Horticulturae*, *273*, art. no. 109617. https://doi.org/10.1016/j.scienta.2020.109617
96. Ulla, A., Alam, M.A., Sikder, B., Sumi, F.A., Rahman, M.M., Habib, Z.F., Mohammed, M.K., Subhan, N., Hossain, H., Reza, H.M. (2017). Supplementation of *Syzygium cumini* seed powder prevented obesity, glucose intolerance, hyperlipidemia and oxidative stress in high carbohydrate high fat diet induced obese rats. *BMC Complementary and Alternative Medicine*, *17*(1), art. no. 289. https://doi.org/10.1186/s12906-017-1799-8
97. VenuGopal, K.S., Anu-Appaiah, K.A. (2017). Seed incorporation during vinification and its impact on chemical and organoleptic properties in *Syzygium cumini* wine. *Food Chemistry*, *237*, 693–700. https://doi.org/10.1016/j.foodchem.2017.05.160
98. Vijayanand, P., Jagan Mohan Rao, L., Narasimham, P. (2001). Volatile flavour components of jamun fruit (*Syzygium cumini* L). *Flavour and Fragrance Journal, 16* (1), 47–49. https://doi.org/10.1002/1099-1026(200101/02)16:1<47::AID-FFJ944>3.0.CO;2-L
99. Yadav, M., Lavania, A., Tomar, R., Prasad, G.B.K.S., Jain, S., Yadav, H. (2010). Complementary and comparative study on hypoglycemic and antihyperglycemic activity of various extracts of *Eugenia jambolana* seed, *Momordica charantia* fruits, *Gymnema sylvestre*, and *Trigonella foenum graecum* seeds in rats. *Applied Biochemistry and Biotechnology*, *160*, 2388–2400. https://doi.org/10.1007/s12010-009-8799-1
100. Yadav, S.S., Meshram, G.A., Shinde, D., Patil, R.C., Manohar, S.M., Upadhye, M.V. (2011). Antibacterial and anticancer activity of bioactive fraction of *Syzygium cumini* L. seeds. *HAYATI Journal of Biosciences*, *18*(3), 118–122. https://doi.org/10.4308/hjb.18.3.118
101. Yadav, A.K., Saraswat, S., Sirohi, P., Rani, M., Srivastava, S., Singh, M.P., Singh, N.K. (2017). Antimicrobial action of methanolic seed extracts of *Syzygium cumini* Linn. on *Bacillus subtilis*. *AMB Express*, *7*, art. no. 196. https://doi.org/10.1186/s13568-017-0500-4
102. Żary-Sikorska, E., Fotschki, B., Kosmala, M., Milala, J., Matusevicius, P., Rawicka, A., Juśkiewicz, J. (2021). Strawberry polyphenol-rich fractions can mitigate disorders in gastrointestinal tract and liver functions caused by a high-fructose diet in experimental rats. *Polish Journal of Food and Nutrition Sciences*, *71*(4), 423–440. https://doi.org/10.31883/pjfns/143057