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Nutritive, therapeutic and processing aspects of Jamun, *Syzygium cuminii* (L.)Skeels- An overview

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Jamun (*Syzygium cuminii* (L.) Skeels is a seasonal perishable berry, grows mainly in tropical and sub-tropical parts of the world. It is rich in minerals, phytochemicals and shows high antioxidant potential heading towards its therapeutic effects. From ancient era, jamun is being cherished and used for controlling diabetes mellitus. Its seeds are popular among alternative medicine systems to control different ailments such as diabetes, cardio-vascular and gastro-intestinal disorders. Owing to such attributes, the powdered jamun seeds have been commercialized to meet these purposes. Recently, pharmacological effect of this fruit has been systematically evaluated by many researchers. This review is an attempt to present the compendious information on nutritive, therapeutic and processing aspects of jamun available hitherto.

Keywords: *Syzygium cuminii,* Jamun, Black Plum, Nutritive composition, Antioxidant, Antidiabetic.

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Introduction

Phytochemicals, the biologically active compounds, occur naturally in plants and protect them from various diseases. Recently, it has been demonstrated that these chemicals also protect human against diseases. According to World Health Organization (WHO), to avoid chronic diseases such as heart disease, cancer, diabetes and obesity, there must be consumption of at least 400 g of fruits and vegetables (excluding potatoes and starchy tubers) on a daily basis[1].

Among fruits, berries including *Syzygium cuminii* (L.)Skeels (Fam.-Myrtaceae) possess sufficient nutritional and potential bioactive compounds having several health benefits. In addition to fruit, the leaves and bark are used for controlling blood pressure and gingivitis[2]. The fruit is a drupe with dicotyledonous seed. It is oblong, ovoid, and green in the initial days, but turns into crimson black as it arrive maturity. Reports on its medicinal importance dates back to vedic literature[3]. Also, the fruit is very attractive for its purple colour with good taste that combines sweetness, mildly sour and astringent flavour. This review emphasizes on the nutritional aspect of jamun, its health benefits supported by epidemiological studies and processing thereof nurtured in academic as well as on market shelf.

Nutrients and phytochemicals

Almost 75% of the fruit weight is from pulp (including skin) and the rest 25% is contributed by seed, both having good nutritive value and phytochemicals *vis-a-vis* medicinal potential[4].

Nutrients

Table 1 presents the nutritional composition of fresh pulp of jamun cultivars from different locations. The effect of agro-climatic conditions appears to be evident in mineral profile rather than the vitamin content and proximate composition in general including moisture, carbohydrates, fats, proteins and ash content[5-7]. If compared on dry basis, proximate composition of pulp (Table 1) is observed to be in same order as that of fresh jamun seed (Table 2). Detailed mineral profiling of seed powder of an indigenous variety of jamun from Pakistan by Shahnawaz *et al* reported potassium, sodium, calcium and magnesium in amounts of 12.39, 2.40, 0.21 and 0.10 g/kg, whereas copper, manganese, iron, zinc and chromium as 22.43, 13.31, 8.53, 5.67 and 5.157 mg/kg, respectively[8]. Thus, sodium, potassium, magnesium, and calcium are the major minerals of jamun pulp as well as seed. Sodium and potassium are

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Table 1—Proximate composition of jamun pulp (*contd.*)

Nutrient	Amount (% wet basis of pulp)	Location of sample	References
Moisture	81.2	India	9
	85.9 ± 1.4	North Bangladesh	7
	83.7 – 85.8		10
	85.0 ± 4.0	Kerala, India	6
Carbohydrates	14.0 - 19.0	India	9
	16.6 ± 1.2	North Bangladesh	7
	14.0		10
	soluble carbohydrates (80% ethanol) -40* and Starch - 35*	Kerala, India	6
Proteins	0.7	India	9,22
	1.4 ± 0.7	North Bangladesh	7
	0.7- 1.29		10
	0.72	Sindh, Pakistan	5
	6.6*	Kerala, India	6
Crude fibre	0.9	India	9, 22
	0.6 ± 0.06	North Bangladesh	7
	0.3 – 0.9		10
	0.22	Sindh, Pakistan	5
	0.7*	Kerala, India	6
Fat	0.1	India	9, 22
	0.6 ± 0.2	North Bangladesh	7
	0.15 -0.3		10
	0.27	Sindh, Pakistan	5
	1.6*	Kerala, India	6
Ash	0.4	India	9, 22
	0.32 -0.4		10
	0.32	Sindh, Pakistan	5
	4.5*	Kerala, India	6
Potassium	55 mg/100 g		10
	1791.029 mg/100 g	Sindh, Pakistan	5
Magnesium	49.8 ± 1.2 mg/100 g	North Bangladesh	7
	35 mg/100 g		10
	9.14 mg/100 g	Sindh, Pakistan	8
Sodium	3.5 ± 0.8 mg/100 g	North Bangladesh	7
	26.2 mg/100 g		10
	141.73 mg/100 g	Sindh, Pakistan	8
Calcium	0.02 mg/100 g	India	9, 22
	21.5 ± 1.5 mg/100 g	North Bangladesh	7
	8.3- 15 mg/100 g		10
	62.09 mg/100 g	Sindh, Pakistan	8
Phosphorous	0.01 mg/100 g	India	9, 22
	18.5 ± 2.8 mg/100 g	North Bangladesh	7
	15 - 16.2 mg/100 g		10
Iron	0.1 mg/100 g	India	9, 22
	0.15 ± 0.01 mg/100 g	North Bangladesh	7
	1.2-1.62 mg/100 g		10
	2.008 mg/100 g	Sindh, Pakistan	8
Zinc	0.28 ± 0.03 mg/100 g	North Bangladesh	7
	2.11 mg/100 g	Sindh, Pakistan	8

(*contd.*)

Table 1—Proximate composition of jamun pulp

Nutrient	Amount (% wet basis of pulp)	Location of sample	References
Copper	0.07 - 0.32 mg/100 g	North Bangladesh	7
	0.23 mg/100 g		10
	6.8 mg/100 g	Sindh, Pakistan	8
Manganese	1.33mg/100 g	Sindh, Pakistan	8
Chromium	0.35 mg/100 g	Sindh, Pakistan	8
Sulphur	13 mg/100 g		10
Chlorine	8 mg/100 g		10
Thiamine	0.03 mg/100 g	India	9, 22
	0.12 ± 0.06 mg/100 g	North Bangladesh	7
	0.008-0.03 mg/100 g		10
Riboflavin	0.01 mg/100 g	India	9, 20
	0.06 ± 0.02 mg/100 g	North Bangladesh	7
	0.009-0.01 mg/100 g		10
Niacin	0.2 mg/100 g	India	9
	0.2-0.29 mg/100 g		10
Ascorbic Acid	18 mg/100 g	India	9
	30 ± 6.9 mg/100 g	North Bangladesh	7
	5.7-18 mg/100 g		10
	19.4 mg/100 g	Sindh, Pakistan	5
Choline	7 mg/100 g		10
Folic Acid	3 mcg/100 g	India	9
	3 mcg/100 g		10
Vitamin A	80 I.U.		10

*% dry basis of pulp

Table 2—Proximate composition of fresh jamun seed[#!]

Nutrients	Content (g/100 g of seed dry basis)
Moisture	47.0**
Carbohydrate	72.0
Protein	6.8
Fat	0.35
Crude fibre	2.9
Ash	2.0

[#] Data compiled from Benherlal and Arumughan[6]
[!] Removal of seed coat was not mentioned
** g/ 100 g of seed wet basis

electrolyte of human body thus regulating blood pressure, and magnesium and calcium are responsible for cellular metabolism and bone strengthening. Along with remarkable mineral profile, jamun is also embraced with appreciable protein quality. Noomrio *et al* reported oven dried pulp of jamun procured from Pakistan as a source of free amino acids like alanine, tyrosine, cysteine, glutamine and asparagine[11]. Presence of reducing sugars like fructose, galactose, glucose, maltose and mannose with maltose being the highest one was also reported by them.

Phytochemicals

The purple colour of pulp and peel is attributed to the presence of anthocyanins whereas its astringent taste relates to high tannin content of 386-428 mg/100 g[9]. In addition to anthocyanins the pulp and peel contain phenolic acid, flavonols, flavanonol, carotenoids and terpenes. Among the class of anthocyanins, glucose, glucosides of delphinidin, petunidin and malvidin have been identified by Veigas *et al* and Li *et al*[12,13]. Faria *et al* further identified the non-anthocyanin bioactive compounds as carotenoids (15-Cis β-carotene, 13-Cis β-carotene, 9-Cis β-carotene, all trans β-carotene, all trans α-carotene, all trans β-cryptoxanthin, phytofluene, phytoene, all trans-zeaxanthin, all trans-lutein, cis-lutein and cis-neoxanthin), phenolic acid (galloyl-glucose ester and gallic acid), flavonols (myricetin, myricetin acetyl rhamnoside, myricetin rhamnoside, myricetin pentoside and myricetin glucoside) and flavanonol (dimethyl-dihydromyricetin diglucoside, methyl dihydromyricetin, dihydroquercetin diglucoside and dihydromyricetin diglucoside)[14].

Flavour characterization of jamun pulp carried out by Vijayanad *et al* indicated the presence of 30 compounds including several phytochemicals[15].

Among these, monoterpenes and their oxygenated compounds (constituting-79.14 %), sesquiterpenes and their oxygenated products (constituting-17.67 %), hexylene glycol, γ-decalactone and hexadecanoic acid were identified. They opined, probably, dihydrocarvyl acetate, geranyl butyrate and terpinyl valerate along with alcohols and ketones are crediting towards typical flavour of jamun.

Phytochemicals in jamun seeds have been reported on qualitative basis only. The seed has been reported to contain jambosine, gallic acid, ellagic acid, corilagin, 3,6-hexahydroxydiphenoyl glucose, 4,6-hexahydroxydiphenoyl glucose, quercetin, and β-sitoterol[16-20]. In separate studies, Modi *et al* and Kumar *et al* asserted presence of alkaloids, flavonoids, glycosides, phytosterol, saponins, tannins and triterpenoids in alcoholic extract of the seed[16,21].

Therapeutic effects of jamun

Entire plant of *S. cuminii* (seeds, fruit pulp, leaves, flower and bark) is renowned for its medicinal value[4, 22,23]. Jamun encompasses its use in various traditional medicinal systems like Ayurveda, Unani, Siddha and Homeopathic and in Sri Lankan and Tibetan medicinal system of alternative and complementary medicines[24]. History of medicinal usage of jamun is marked by its prescribed usance by Charkha and Sushruta for curing many diseases like diarrhoea, obesity, vaginal discharge, menstrual disorders, haemorrhage, etc[25]. Recent studies have demonstrated its several pharmacological effects like antibacterial[26-29], antifungal[26,30], antiviral[31], antioxidant potential[32-34], anti-inflammatory[35], hepatoprotective[36,37], anti-diabetic[38-40], hypolipidemic[41], cardioprotective[42], anti-diarrhoeal[43], anti-allergic[44], anti-fertility[45], anti-pyretic[46], neuro-psychopharmacological[47,48], anti-neoplastic[49], chemopreventive[50,51], radioprotective[52,53], anti-clastogenic[54] and larvicidal activity[55]. Among all these therapeutic properties, antidiabetic effect is most vividly studied.

Therapeutic effects of jamun seeds

Phytochemicals of jamun seeds are successively leading its usage in various diseases curing applications[56]. The therapeutic effects are substantiated by pharmacological work as discussed below.

Antimicrobial

Effectiveness of jamun seed extract as antibacterial agent was reported by Bhuiyan *et al* against *Bacillus cereus, B. subtilis, B. megateriun, Steptococcus betahaemolyticus, Staphylococcus aureus, Shigella dysenteriae, Sh. shiga, Sh. boydii, Sh. flexneriae, Sh. sonnei, Escherichia coli, Salmonella typhi B, Sal. typhi* B-56 and *Klebsiella* species[57]. Bagchi *et al* reported antibacterial property against several Gram positive and Gram negative bacteria[58]. According to Jadhav *et al*, the methanolic extract of the seeds possesses broad antibacterial spectrum against *Vibrio cholera, Aeromonas hydrophila* and *B. subtilis* with minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) ranging from 1.5-12.0 and 1.5-16.0 mg/mL[56]. Such extract is also detrimental on *Proteus vulgaris* and *Pseudomonas aeruginosa*[59]. Banerjee and Narendhirakannan reported antibacterial effect of ethanolic extract against two Gram positive (*S. aureus* and *E. faecalis*) and three Gram negative bacteria (*E. coli, K. pneumonia* and *P. aeruginosa*)[60]. Comparing with standard antibiotics, they concluded the MIC against *E. coli, P. aeruginosa* and *E. faecalis* to be 6.25 mg/mL whereas against *S. aureus* and *K. pneumonia*, the value was 3.13 mg/mL. Although the alcoholic extract of the seed is effective in inhibiting the growth of *E. coli,* it does not possess the bactericidal effect[61,62].

Chandrasekaran and Venkatesalu reported that the aqueous and methanolic extracts of jamun seeds possess antifungal activity against dermatophytic fungi, i.e., *Candida albicans, Tricophyton rubrum, T. mentagrophytes* and *Microsporum gypseum*[63]. The methanolic extract is also reported to possess antifungal activity against *Aspergillus niger*[59].

Antioxidant

Antioxidants control free-radicals which lead to several diseases and accelerate ageing. Several *in vitro* studies have demonstrated such potentiality using alcoholic extracts of the seed. The extracts could act in various ways by trapping free radical like superoxide, hydroxyl, lipid-peroxide and 2,2-diphenyl-1-picrylhydrazyl (DPPH) and nitric oxide and by chelating transition metal catalyst like ferric ions[6,64]. In support of trapping mechanism, inhibition of auto-oxidation in β-carotene and linoleic acid has been reported by Bhajpai *et al*[65]. It was revealed that the antioxidant potential of the seed extract against superoxide radical is six times higher than trolox[6] and is concentration dependent[64].

Regarding *in vivo* studies in relation to skin carcinogenesis, it was reported that oral administration of the seed extract could significantly lower lipid

peroxidation and increase the level of antioxidants both enzymatic (catalase and superoxide dismutase) and nonenzymatic (glutathione and vit-C)[66].

Gastro-protective

Chaturvedi *et al* reported effect of ethanolic extract of jamun seeds against gastric ulcers induced by cold restraint stress, aspirin, 95 % ethanol and pylorus ligation in rats[67]. The mechanism of action was ascertained by decreased acid-pepsin secretion, cell shedding, lipid peroxidation and enhanced mucin and mucosal glycoprotein. The beneficial effects of the extract in diabetic rats with co-occurring gastric ulcer could be due to its antidiabetic and direct promoting effect on the gastric mucosal defense, as recommended by them[68].

Antidiabetic

A large stratum of population dwelling with lifestyle diseases like diabetes is inkling towards alternative medicine systems like Unani, Ayurvedic and others. Jamun seeds are prescribed widely in such medicine systems for controlling diabetes[69]. Anti-diabetic effect of jamun seed has also been substantiated by many pharmacological studies. The studies carried out by Helmstadter and Kumar *et al* revealed considerable reduction in blood glucose level of induced diabetic animals when treated with jamun seed[70,71]. Effectiveness of the extracts using different solvents has been explored by different scientists on different animal models. Rat studies have been successfully carried on alloxan induced diabetes[39,40,72-74], streptozotocin induced diabetes[41,71,75-79] and fructose induced model[80]. Sharma *et al* studied diabetes ameliorative effect of ethanolic extract of jamun seeds on alloxan induced diabetes on rabbits[81]. Study has also been extended to clinical trials on human subjects[82-84]. Pharmacological studies revealed that the administration of powder form of jamun seeds[79,82], its ethnolic[72,73,85], methanolic[86], ethyl acetate[71,75], and aqueous[40,80,87,88] extracts either orally[71,86] or injected intraperitoneally[85,88] are capable of ameliorating diabetes.

When used in the above mentioned alternative medicine systems, the seeds offer no toxicity on subjects. This has been evidenced from the toxicological studies performed on rats using aqueous extract and ethyl acetate and methanol extracts[71,87], which rallied no mortality with sub acute and acute oral toxicities. In clinical studies on human subjects with diabetes Type-1(Ref.83,84) and Type-2(Ref. 82), successful results with no side effects have been reported on oral administration of jamun seed powder. However, Srivastava *et al* accounted five patients with adverse reactions like nausea, diarrhoea and epigastric pain, possibly arising from high dose of consumption[84].

Regarding the probable mechanism towards anti-diabetic action of jamun seeds, Sharma *et al* attributed to its direct insulinotropic action[78]. This delineation has also been supported by many studies concluding the effect as increased plasma insulin level after dose administration[77,79,89-92]. Singh and Gupta and Gohil *et al* speculated the increment in serum insulin level towards its effect on repairing of β-cells of pancreas, the later in damaged state reduces the insulin secretion[40,93]. In support of β-cells regeneration, Dusane and Joshi reported potentiality of chloroform extract to induce islet neogenesis in *in vivo* as well as *in vitro* studies[94]. The antidiabetic effect of seed extracts has also been observed in regard with lowering efficacy of starch hydrolysing enzymes including α-amylase, pancreatic amylase and α-glucoamylase[62,95,96]. Sharma *et al* ascribed the mechanism towards maintaining carbohydrate homeostasis by increasing and decreasing the activity of key enzymes for glycolysis and gluconeogenesis[78,97]. The extract also activates glucose transport in a phosphatidylinositol 3'kinase-dependent fashion in cell culture manner[98]. Kumar *et al* identified mycaminose, a deoxyaminosugar, in the alcoholic extract of seed powder[71]. They reported hypoglycaemic effect of this aminosugar at dosage level of 50 mg/kg body weight in streptozotocin induced diabetic rats.

Studies have shown that jamun seeds also prevent diabetic induced secondary pathogenesis like kidney damage[86,87,99-101], neuropathy[100], gastropathy[100], diabetic cataract[102], peptic ulcer[68] and weight loss[91]. The seed also reduces hyperglycaemia induced oxidative stress by restoring levels of glutathione, increasing activities of superoxide dismutase, catalase and consequently decreasing the levels of lipid peroxidises[88,103]. Thus, jamun seed could be considered as novel therapeutic armamentarium for treatment of diabetes.

Hypolipidemic

Alteration in lipid profile is one of the most common complications in diabetic mellitus and in that context hypolipidemic effect of jamun seed has been thoroughly studied on both alloxan and streptozotocin induced diabetic rats. Ethanolic extract of seeds is able to reduce the level of total serum cholesterol/high density lipoprotein cholesterol ratio, low density lipoproteins (LDL) and triglycerides[4,77,78,81,103,104].

Ravi *et al* reported that elevated levels of cholesterol, phospholipids, triglycerides and free fatty acids in the plasma, liver and kidney tissues of streptozotocin induced diabetic rats were reverted back to normalcy on oral administration of ethanolic extract of jamun kernel[41]. According to them, the lowering effect was comparable to that of the treatment with standard drug (glibenclamide). It has been hypothesised by Modi *et al* that anti-hyperlipidemic effect of jamun seeds may be due to presence of alkaloids, tannins, saponins, phenols, flavanoids and triterpenes[104].

Cardioprotective

Mastan *et al* reported beneficial effects of methanolic extract of jamun seeds on cardioprotection against isoproterenol-induced myocardial infarction in albino rats[42]. The effect was probably related to strengthening of the myocardial membrane, induced by the phytochemicals like alkaloids, amino acids, flavonoids, glycosides, phytosterols, saponins, steroids, tannins and triterpenoids in the extract.

Immunomodulatory

The term immunomodulatory means regulation of the immune system by suppression and stimulation of cells and organs of the immune system. It is now being recognized that immunomodulatory therapy could be practiced as an alternative to conventional chemotherapy towards variety of diseased conditions. Mastan *et al* suggested that the methanolic extract of jamun seeds possesses promising immunomodulatory activity[105]. While working on humoral and cellular immunity in mice by injecting carbon ink suspension and hemagglutination reaction and delayed type hypersensitivity response in rats induced by Sheep Red Blood Cell, they reported a significant increase in total white blood cell, neutrophils and lymphocytes count in dose-dependent manner[105].

Neuropsychopharmacological

Neuropsyschopharmacology is an approach to study the effect of functional component on the central nervous system (CNS) with respect to biochemical and behavioural changes in subject. Depressants for CNS are often prescribed by doctors for people suffering from anxiety. Chakraborty *et al* studied neuropsychopharmacological effect with chloroform extract of jamun seed on rats[47]. The study observed alteration in general behaviour pattern, reduction in spontaneous motility, hypothermia, potentiation of pentobaritone hypnosis, analgesia, reduction in exploratory behaviour pattern, muscle relaxation and suppression of aggressive behaviour, suggesting that organic extract of jamun seed possesses CNS depressant action[47]. The study was supported by Kumar *et al* with ethyl acetate and methanolic extracts[48]. The extract also caused suppression of conditioned avoidance response and exhibited antagonism to amphetamine group toxicity[106]. Oral treatment with hydroalcoholic extract showed an anticonvulsant activity in pentylenetetrazol- and maximal electroshock-induced convulsions, besides a hypothermic effect[107]. The results suggested that some active principles of jamun with central depressant properties exhibit an anticonvulsant action, although the polyphenols do not seem to be the main constituents responsible for this effect.

Radioprotective

Radiotherapy is widely used for cancer treatment. Its advantages are countervailed by cytotoxic effects on normal tissues during usage. As a solution, incorporation of chemical compounds termed as radioprotectors, which selectively protect the normal cells from deleterious effect, is practised. Studies have supported radioprotective effect of jamun seed extract. Jagetia *et al* studied intraperitoneal administration of hydroalcoholic extract on mice; they observed survival of mice on administration with 80 mg extract /kg body weight before exposure of 6 to 11 Gy of γ radiation in comparison to its counterparts without dosage[52].

Anticlastogenic

Anticlastogenic effect refers to protection against mutagenesis at chromosomal level. Recently, Arun *et al* have concluded that oral administration of aqueous extract to mice can enhance antioxidant defense leading to protective mechanism against genomic damage induced by the carcinogens 7, 12-dimethyl benz(a)anthrancene (DMBA) and urethane[54].

Chemopreventive

Parmar *et al* have reported that hydro-alcoholic extract of jamun seed possesses chemopreventive properties in the DMBA-induced and croton oil promoted skin carcinogenesis in Swiss albino mice[51]. According to them, feeding of 125 mg extract/kg body weight/day during phases of, either pre-initiation (i.e 7 days before and 7 days after application of DMBA) or post initiation (i.e. from the day of start of croton oil treatment and continued till the day of experiment), reduced the cumulative numbers of papillomas, the tumour incidence and increased the average latency period when compared with the

control group (carcinogen alone). In continuation to this study, Parmar *et al* concluded that jamun seed has the potential to modulate biochemical and histopathological status during skin carcinogenesis[66]. Researchers have identified antioxidant capacity of jamun seed as the probable mechanism of chemopreventive effect[51,54]. In addition, Goyal *et al* have observed that administration of the aqueous extract of jamun seed (25 mg/kg body weight/day) was effective in preventing benzo-a-pyrene (BaP)-induced forestomach carcinogenesis in Swiss albino mice, when applied as pre-, post-, and pre-post treatment; it reduced the tumour incidence, tumour burden and cumulative number of gastric carcinomas[50].

Anti-inflammatory

Several workers have reported anti-inflammatory effect of jamun seed extract on carrageenan induced odema[46,59,108,109]. Kumar *et al* have reported anti-inflammatory effect using ethyl acetate and methanol extracts against paw oedema in wistar rats[108]. When compared to untreated control group, Modi *et al* also reported that oral administration of the methanolic and aqueous extracts @ 250 mg/kg body weight reduced 48.29 % and 68.85 % of the oedema whereas diclofenac sodium, the standard drug, at 100 mg/kg body weight reduced by 75.08 %[109]. Besides this, significant reduction in the oedema paw volume was also noticed for lower dose (120 mg/kg body weight)[59]. Chloroform extract of jamun seed could reduce oedema induced not only by carrageenan but also by kaolin and other mediator[110].

Arthritis is a chronic variety of inflammatory disease in joints. Kumar *et al* have reported significant antiarthritis effect of methanolic extract of jamun seeds[111]. The study reported direct proportionality between inhibitions of Freund's complete adjuvant induced arthritis (a commonly used technique) and dose of extract when orally administered in rats. Methanolic extract has also been reported by Arya *et al* showing antiarthritic effect on adjuvant induced arthritis in rats[112].

Antipyretic

Antipyretic activity of jamun seeds has been reported by many scientists namely, Mahapatra *et al* with methanol extract and Chaudhari *et al* with chloroform extract as reviewed by Sah and Verma[4,46,110]. Mahapatra *et al* studied methanol extracts of dried seeds administered intraperitoneally to rats at doses of 50 mg/kg body weight were active against yeast induced pyrexia[110].

Therapeutic effect of jamun pulp and skin

Jamun pulp and skin hold significant therapeutic effectuates due to the presence of anthocyanins and other phytochemicals[12,17,49]. These phytochemicals possess several health benefits being antidiabetic[76], antioxidant[33], hepatoprotective[113], antibacterial[114] and anti-cancerous[115]. A brief account of the investigations is presented hereunder.

Antidiabetic

Hitherto, animal studies have been carried out to demonstrate antidiabetic property of jamun pulp. Achrekar *et al* first evidenced this pertaining property of aqueous extract on streptozotocin induced diabetic rats[90]. On persuasion of this rat study, Rekha *et al*[116] observed that oral administration of the aqueous extract caused significant dose dependent decrease in blood glucose level with concomitant improvement in body weight. Farhana and Swarnomoni reported ameliorative effect on blood glucose level with oral administration of ethanolic extract in alloxan induced diabetic rats[72].

Sharma *et al* studied the antidiabetic property of ethanolic and aqueous extract of jamun pulp on rabbits after induction of diabetes with streptozotocin[39], showing effective hypoglycaemic activity onwards 30 minutes of oral administration. They also reported that the extract with dosage of 300 and 200 mg/kg body weight shows comparable results against standard drug, tolbutamide with dosage of 100 mg/kg body weight. Further, aqueous extract of *S. cumini* pulp exhibited no toxic effects on liver and kidney of alloxan induced diabetic[39].

Achrekar *et al* and Sharma *et al* proposed insulinotropic action as the mechanism for hypoglycaemic effect as the extract stimulated secretion of insulin from the cultured Langerhans cells in *in vitro* system[39,90].

Antioxidant

The antioxidant potential of jamun pulp has been studied by several researchers through *in vitro* assays like DPPH, superoxide radical, hydroxyl radical and lipid peroxidation. These include studies canvassed by Banerjee *et al*, Rufino *et al*, Benherlal and Arumughan and Reynertson *et al* using aqueous extract of skin, and aqueous-methanolic, ethanolic, and methanolic extract of pulp, respectively[6, 117-119]. However, Rufino *et al* further confirmed the antioxidant potential of pulp through 2, 2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS), ferric reducing antioxidant power (FRAP) and

β-carotene bleaching assays[118]. *In vitro* study using thiobarbituric acid assay was performed by Veigas *et al* to test the efficacy of isolated anthocyanins from pulp for inhibiting iron sulphate induced lipid peroxidation in rat brain, liver, liver mitochondria, testes and human erythrocytes ghost cells[12].

Rekha *et al* studied *in vivo* antioxidant potential of aqueous jamun pulp extract in streptozotocin induced diabetic rats[116]. The study reported significant increase in the level of superoxide dismutase, catalase, glutathione peroxidase, glutathione-S-transferase and reduced glutathione in liver tissue, professing jamun pulp as novel source for antioxidant in biological system.

Hepatoprotective

Effectuality of jamun peel extract as hepatoprotective agent against carbon tetrachloride (CCl_4) induced oxidative damage on rat hepatocytes was reported by Veigas *et al*[120]. The study also reported decrease in CCl_4 induced LDL release and lipid peroxidation and normalization of cellular glutathione level. *In vivo* studies by Das and Sarma on paracetamol induced toxicity in rats has also supported the hepatoprotective effect[113]. Based on oral administration of ethanolic extract of pulp in dose dependent manner, they reported decrement in rise of serum enzymes, level of total protein and albumin owing towards hepatoprotection. The study also asserted no acute oral toxicity and intact histological structure of liver.

Antibacterial

Recently, Patel and Rao reported antibacterial action of jamun pulp[114]. The study was performed with extracts using different solvent systems (ethyl acetate, acetone, methanol, aqueous and diethyl ether) and different maturity index of the fruit pulp (young, premature, mature, preripened and ripened). The extracts asserted more effectiveness on Gram positive bacteria than Gram negative. Among different stages of maturity and the solvents used, the diethyl ether extract from preripened pulp was the most potential antimicrobial agent.

Anticancerous

Anticancerous effect of jamun pulp has been successfully studied on human cervical carcinoma cell lines i.e. HeLa and SiHa using crude methanolic extract[115] and breast cancer cells using hexane: acetone: methanolic extract[49]. The study revealed that the extracts induced apoptosis in tumorous cells, and the antiproliferative effect was proportional to dose and exposure time. Li *et al* also opined that the extract exerted no apoptotic effect on non-tumorous breast cells[49]. These *in vitro* oncological studies profess the potentiality of jamun pulp extracts towards inhibition and death of cancerous cells.

Food potential of jamun

Jamun is luscious when consumed fresh with salt. However, its seasonal availability with high perishability have raised the need for preservation of jamun either as such or as processed food and beverage prepared thereof. Recent conceptual enlightenments on functional food i.e., health benefits driven from the food itself, are triggering various scientific investigation. Some products of jamun have already been made available commercially (Table 3) as obtained from the global new product database (GNPD)[121]. Brief account on hitherto status covering scientific investigations and commercial outlets is presented below.

Fresh jamun

Very recently, Rai *et al* attempted to extend the shelf life of fresh jamun by differential modified atmosphere storage (MAP) using polypropylene film (35 μm thickness) with 1 and 2 perforations (0.3 mm diam.) made on film surface, followed by storing at 5°C and 75% RH[122]. Most of subjective and objective qualitative parameters were retained satisfactorily under such storage, with 64% retention of anthocyanins in film with 1 perforation in comparison to fresh sample. Also, acceptable microbiological quality of fruits stored in this film for 23 days under pertaining conditions surmised its use for long term storage. One product is available on Chinese market shelf presenting fresh jamun to be relished as a snack. The product enlists use of salt, citric acid, white sugar, and preservatives on pack label.

Jamun powder

Few food companies in India have launched health claim powders where jamun was incorporated as one of the ingredient. Recently, Shahnawaz and Sheikh have reported scientific investigation on preservation of jamun in powder form[123]. The powder was packed in glass containers and stored at 25±2°C and 90% RH. The parameters monitored were moisture content, colour and stickiness. The predicted shelf-life was more than 300 days. One product on dried whole black plum, marketed as Bom Preco by Wal-Mart, Brazil, has been published in 2011 in GNPD.

Jamun juice

Companies have brought up jamun juice as pure as well as in combination with other juices to serve its

health benefits. Know-how (Fig. 1) was developed by enzymatic treatment for the production of clarified jamun juice that could be stored with no turbidity or sedimentation till 6 months at ambient storage[124]. Shahnawaz and Sheikh reported that 4 months stored (at 32°C) jamun juice had deflection of colour from original purple red to muddy-red, probably, as a result of anthocyanins degradation[125]. Later, these researchers investigated rheology for scale-up and quoted a viscosity of 25226 poise for a juice with *p*H 3.77, total soluble solids (TSS) 18.1°Brix and 94.5% moisture content[126].

Jamun jam

In the form of jam, Shahnawaz and Sheik have reported a viscosity of 47841 poise at 25°C having *p*H 3.11, TSS 68°Brix and moisture 37.44% [126].

Jamun wine

Shukla *et al* worked on standardization of wine making by using *Saccharomyces cerevisiae* and about 10.93 to 11.23% ethanol production was obtained depending on cultivar used[127]. They also reported better sensorial acceptability of wine when the pulp was pre-treated with pectic enzyme (0.25%) followed by 6 months ageing of the final product. The enzyme treatment slightly increased acidity and ethanolic content with simultaneous decrease in reducing sugar and tannin level in the finished wine. In another study by Chowdhury and Ray, jamun fruit was fermented using *S. cerevisiae* var *bayanus* to produce jamun wine with 6 % ethanol and good anthocyanin content (60 mg/100 mL)[128]. The method was conventional but with little modification including maintenance of TSS and *p*H using cane sugar and tartatric acid before culture addition. The product was accepted by the sensory panel but was inferior to market grape wine samples. Joshi *et al* studied the effect of concentration of jamun pulp in broth and subsequent ageing of the final product with respect to latter's physicochemical property and sensory quality[129]. According to them, wine prepared from 1:1 dilution of pulp had optimum TSS, ethanol content and acidity and highest overall sensorial acceptance. All these studies concede jamun as fermentable substrate and augment products development thereof. In 2011, Sapporo Breweries Ltd, Japan has launched Sapporo Black Plum Liqueur having 10% alcohol content.

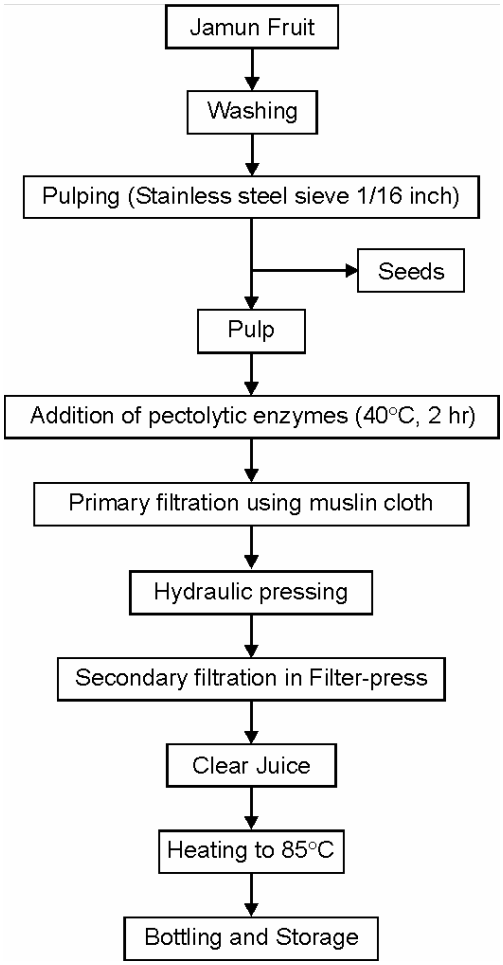

Fig. 1—Flowchart for jamun juice preparation[124]

Other products

Jamun chips and vinegar are processed and marketed by Indian food companies. Also, incorporation of jamun pulp in many other food products like yoghurt and cookies are brought forth on global food market sector. The joint effort of research and development at laboratory as well as industrial level may enable jamun to hold place in functional food market with upholding its health benefits.

Conclusion

Whole contour of jamun comprising peel, pulp and seed is a rich source of phytochemicals including phenolic as well as non-phenolic bioactives. Pharmacological studies relate the phytochemicals to provide diversified therapeutic effects like antioxidative, anticancerous, antidiabetic, antimicrobial, radioprotective and others, the most widely investigated one being the ameliorating action against Type 1 and Type 2 diabetes. Further studies are required to identify the principal functional component responsible for such functions. Jamun which possesses attractive colour, astringent taste and appreciable mineral and vitamin content is seasonal, perishable and underutilized fruit. Jamun carries a great potential to be taken up as a raw material for post harvest

processing and development of functional food carrying disease prevention ability besides the basic function of supplying nutrients. This review covering comprehensive information on the nutritional, therapeutic and processing aspects would help to append a silver lining to jamun based therapeutic and functional food sector.

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