



Review Article

Jamun (*Syzygium cumini*): An Underutilized Potential Fruit Crop in Asia

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ABSTRACT

Jamun [*Syzygium cumini* (L.)] is a tropical evergreen tree and its scrumptious fruit is consumed as fresh and processed. It is famous for its delicious taste and aroma, use for medicinal purposes. It is a rich source of antioxidants, vitamins, phenolic contents, minerals, and edible oils that are helpful for consumers' health. There is negligible information about cultivars due to the lack of genetic analysis of available clones. The tree can withstand water scarcity, the fruit is highly perishable with a limited shelf life of 3 days under ambient conditions and its marketing is confined to the local markets. Cold storage has been used to enhance its marketing window after pre-treatments by anti-ripening chemicals, edible coating, and non-chemical processing. In addition, modified atmosphere packaging (MAP) has also been found effective to increase its shelf life by 30 days. Nevertheless, limited research has been conducted to increase its postharvest life. This review includes preharvest factors affecting postharvest physiology, biochemical changes during fruit ripening, harvest maturity and postharvest techniques to extend shelf life and postharvest storability. This article provides the way forward for further R&D work concerning shelf-life extension and strengthens the Jamun industry with sustainable solutions for better returns to stakeholders.

Keywords: Antioxidants, anti-ripening, biochemical changes, perishable, Jamun industry.

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INTRODUCTION

Jamun [*Syzygium cumini* (L.)] is a tropical fruit with an evergreen large tree belonging to *Myrtaceae* family. It is alternatively known as *Eugenia jambolana* in literature while jambolan, jamboo, doowet, Indian blackberry, faux pistachier, black plum, jamun, jambul and java plum are its common names. It is native to Himalayas, India, Australia, Malaysia, and Sri Lanka (Ayyanar and Subash-Babu, 2012). It is currently grown in China, India, Pakistan, Bangladesh, Sri Lanka, Israel, Eastern Australia, West Indies, Algeria, and USA (Oliveira et al., 2016). China is the largest producer followed by India and total production is about 13.5 m tonnes (Kishore, 2019). It has been adapted to wide environmental conditions and can tolerate water shortage and extensive flooding. Tropical climate with rocky and shallow soils are favourable for its cultivation (Sarvade et al., 2016). The most common way of propagation is through seeds and maiden bearing starts after 10 years of plantation although maiden bearing could be possible after 5-6 years if propagated vegetatively (Singh et al., 2018).

It is a rich source of phytonutrients including vitamins (thiamine, riboflavin, niacin, ascorbic acid), minerals (sodium, potassium, manganese, copper, calcium, iron, magnesium, zinc), free amino acids (cysteine, glutamine, tyrosine, asparagine, alanine), carbohydrates (mannose, galactose, fructose, sucrose, glucose) and proteins (Benherlal and Arumughan, 2007) (Fig. 1). Cis-ocimene, myrcene, β -pinene, camphene and α -pinene are essential oils obtained from jamun (Ayyanar and Subash-Babu, 2012). Different parts of Jamun tree have been used traditionally in folk medicines for curing several diseases including dysentery, diarrhoea, diabetes, and allergic issues due to their antibacterial, antiemetic, antipyretic, and anti-inflammatory properties (Dagadkhair et al., 2017). Fruit colour at immature stage is due to chlorophyll and carotenoids while there is higher anthocyanin biosynthesis with the fruit development (Singh et al., 2018). It contains higher number of antioxidants, phenolic contents and flavonoids making imperative for human consumption (Brito et al., 2007). Jamun shows astringency in its taste that may be either due to condensed tannins with higher molecular weight or these may be hydrolysed tannins with low molecular weight substances (Table 1).

According to Patel and Rao (2014), jamun fruit exhibits significant rise in endogenous ethylene and respiration peaks representing behaviour like climacteric fruits. Fruit harvest and handling require a very careful practices as fruit is very delicate and perishable with 2-3 days shelf life at room temperature. Mechanical damage and physical bruising make fruit prone to

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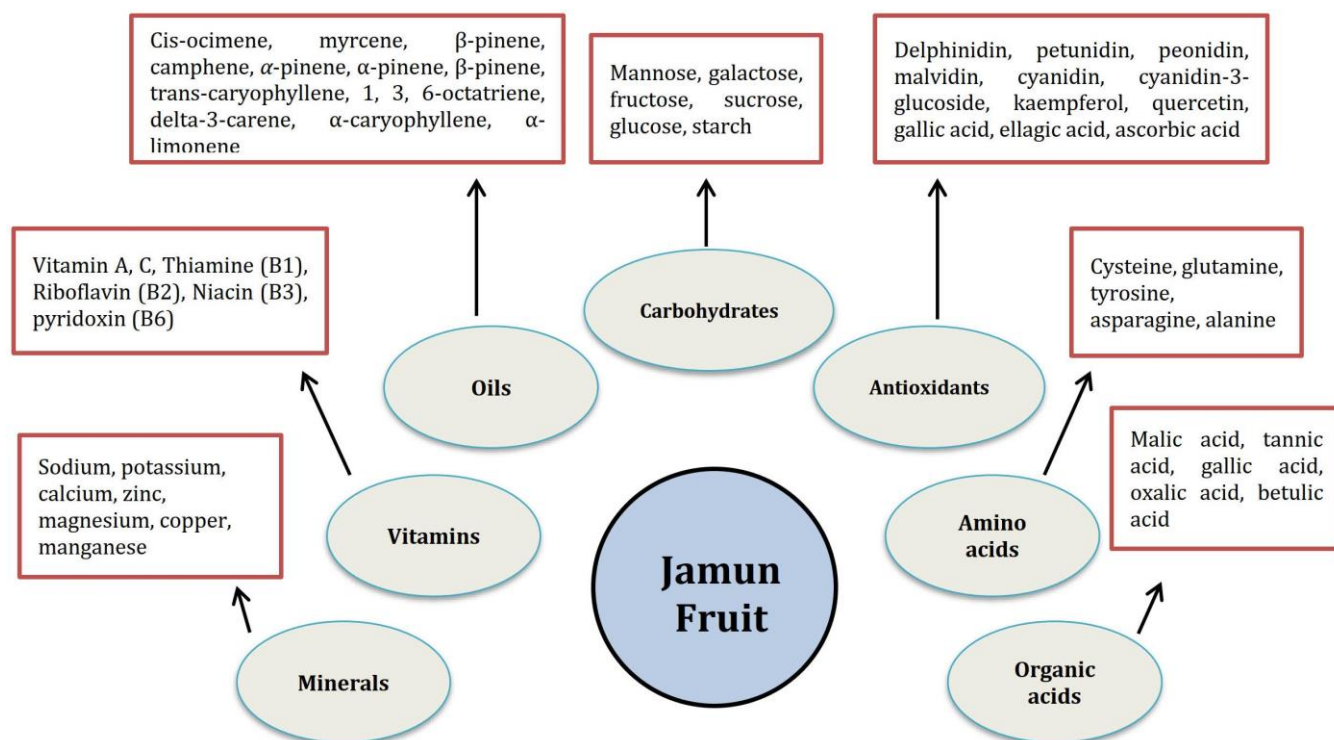


Figure 1: The chemical composition / active ingredients showing the nutritional quality of jamun fruit (Baliga et al., 2011; Ayyanar and Subash-Babu, 2012; Singh et al., 2018).

the infestation of pests, pathogens, microbes, and sap flow provides host for quick fungal growth (Jain and Babbar, 2000). To extend its shelf life, the cold storage (8-10 °C) has widely been used which has improved its storability up to 3 weeks; however, some cultivars are susceptible to chilling injury when stored below 9 °C (Joshi, 2011). Many other alternatives like edible coatings, modified atmosphere packaging, heat treatment and chemical dipping treatments have been tested to increase its

shelf life and maintain quality (Rai et al., 2011; Khaliq et al., 2020; Pattar et al., 2021b). Nevertheless, most of the work have been reported on value added products and juice instead of whole fruit storage. Postharvest diseases incidence is also limiting factor in its supply chain (Pattar et al., 2021a). Jamun fruit is being used by various processing industries and developing multiple products such as juice, drinks (ready to serve), squashes, wine, jam, cheese, toffee, and jelly etc (Dagadkhair et al., 2017).

Table 1: Nutritive value of jamun fruit.

Constituent	Per 100 g fresh weight
Energy	60 K Cal
Carbohydrates	15.56 g
Fat	0.23 g
Protein	0.72 g
Vitamin A	3 IU
Thiamine	0.006 mg
Riboflavin	0.012 mg
Niacin	0.260 mg
Vitamin C	14.3 mg
Calcium	19 mg
Iron	0.19 mg
Phosphorous	17 mg
Magnesium	15 mg
Anthocyanin	1.23 g
Flavanonol	2.8 mg
Flavanol	6.1 mg
Hydrolyzed tannins	202.1 mg
Water	83.13 g

(Baliga et al., 2011; Ayyanar and Subash-Babu, 2012; Singh et al., 2018)

To best of our knowledge, there is no published review article on production and postharvest technology of jamun fruit. Considering the gap, this article covers all aspects including preharvest factors affecting plant growth and fruit quality *i.e.*, biochemical, and physiological changes during fruit ripening, harvest maturity indices, and postharvest physiology as well as processing technologies of jamun fruit.

PREHARVEST FACTORS AFFECTING GROWTH

Soil and climate

Jamun has variable adaptability in different climates and can be grown either in tropical or sub-tropical areas and can withstand water stress for a longer time (Chovatia and Singh, 2000). It is very hardy in nature and can bear very tough climatic conditions especially in semi-arid areas with poorly drained soils where other crops are unable to withstand and develop properly. Dry weather is required for optimum blooming and fruit set with subsequent rainfall that can increase fruit growth, improve fruit quality with better taste, maturity, colour, and size. Soil is the basic component for all types of vegetation and directly effects

fruit yield and quality. Jamun needs well drained loamy soils for best growth; however, they can tolerate degraded lands, ravines, saline, and sodic soils (Bhowmik et al., 2013). Although the tree is very hardy but still there should not be very light or heavy soil for new plantation. Soil and water pH (up to 10.5) is also very critical factor for best emergence of new seedlings after plantation (Joshi, 2011).

Plant propagation and varieties

There are two types of plant propagations i.e., sexual through seeds and asexual propagation via grafting and micropropagation. Most common way of propagation in different areas of the world is through a seed that is source of genetic variability, helpful for maintaining good characters in changing environment. However, clonal conservation with required characteristics is not possible through this way of propagation and there is ample chance for crop improvement (Devi et al., 2002). The bearing period for sexually propagated plants starts from 8-10 years after propagation and this duration can be reduced by using asexual method of orchard establishment. *Syzygium* species has preferably used as rootstock for jamun production that can be raised in nurseries for further use. True-to-type tree with desirable characters is the main benefit of vegetative propagation; although, rootstock has very influential role in determining tree vigour, health, yield, and quality. In jamun, dwarfing rootstocks are more valuable because they provide manageable canopy that can ease cultural practices for the labour, also harvesting can be done with more efficiency than in taller plants. Insect attack especially termites' resistance can be induced in jamun by using *Syzygium densiflore* as rootstock (Ayyanar and Subash-Babu, 2012). Rootstock nursery can be raised in polyethylene bags or soil for about 9-12 months to attain desirable plant height, health, and vigour. Sandy soil should be avoided as there is less than 10 % success rate. Grafting has higher success rate in jamun orchard development in contrast to other methods. Softwood should be used rather than hard wood for grafting, and veneer grafting is recommended in jamun on 9-12 months rootstock (Kishore, 2019). The other economical way to raise jamun is micropropagation that produces large scale plants in very short time and input. However, expertise is required for this method and there is chance of fungal infestation at propagated part of plant (Joshi, 2011). Jamun is referred as minor fruit without any varietal identification on genetic basis and every country has its own clones with traditional or local names. Typically, all varieties can be divided into two main types 1) kaatha or Desi jamun, 2) Ra or Ram jamun. Desi cultivars are blackish or dark purple in colour, slightly round and small sized fruit with acidic pulp, small stone and ripe in August, while Ram cultivars are sweet in taste with higher juice content and small size stone. Later one is more suitable for marketing in many areas of the world (Ghojage et al., 2011).

Irrigation and fertilizer management

Jamun is very hardy in nature that can tolerate severe drought as well as heavy rainfall and even flooding condition. However, young plants need regular irrigation after transplantation or emergence to cope with drought stress. As trees grow, there may be little or no need of irrigation for plant if there is adequate

rainfall in the area of growth (Hiwale, 2015). Fertilizer requirements are directly associated with the tree age and soil fertility. The optimal production with good quality is only possible when there is 20-80 kg manure application for mature trees. The other important aspect is the time of fertilizer application and pre-flowering fertilizer dosage ensures full bearing with better fruit quality. Generally, there is no need of phosphorous for jamun with 400-500 g potassium and 600 g nitrogen per mature bearing tree; however, it may be different depending upon soils. The method of application is also key point for tree, and it is applied under the canopy followed by mixing in soil and irrigation. Loamy soils with good nutrient status negatively work against fertilizer application so it should be avoided with regular dose (Reang and Das, 2010).

Insect pests and diseases

Jamun is susceptible to insects and diseases that can lower its production and marketing. Generally, the major insects are white fly (*Dialeurodes eugenia*), leaf roller (*Dudua aprobola* Meyrick) and leaf eating caterpillars (*Carea subtilis* Walker) while major diseases are anthracnose, fruit rot and die back (Hiwale, 2015). White fly is most dangerous for jamun as they suck the fruit sap and bruise the skin leading to sap flow that is main point of contamination for disease attack. The attack can be more severe for plant facing drought stress leading to damage of twig or whole plant. Leaf roller incidence is second major issues during fruit growth and can be observed by rolled leaves with subsequent drying. This insect cause distortion of twigs and causes low leaf flush rate in affected trees. Leaf eating caterpillars feed on leave and causes defoliation of whole tree. The systematic collection can be used to control these insects or spray of recommended chemicals available in area can be used (Jain and Babbar, 2000). Fruit rot is major disease caused by *Glomerella cingulata* (Stonem) with primary symptoms on leaves exhibiting light brown to reddish colour scattered spots. Affected fruits develop water-soaked lesions which produce a scar on affected area with dark colour. Humidity or rain splashes enhance pathogen growth, and it can be controlled by using traditional Bordeaux mixture or recommended chemicals (Bose et al., 2001). Anthracnose caused by *Colletotrichum* species is another major disease in fruits that is developed mainly due to contaminated soils and spores can also be transferred by wind. *Colletotrichum gloeosporioides* is the major pathogen of jamun and fungicidal spray can control its growth (Hiwale, 2015).

FRUIT RIPENING PHYSIOLOGY

Fruit shows pure sigmoidal curve growth that can be divided into three distinct phases 1) slow growth stage start from fruit set to 7 weeks 2) rapid growth from 7-8 week after fruit set and 3) maturation phase with ethylene biosynthesis and respiration increase (Kishore, 2019). There is very slow fruit development in start with rapid increase in fruit weight and size in middle of development followed by maturation with no increase in size and colour development (Shukla and Prasad, 1980). However, climatic conditions have direct role in fruit development time. There is series of biochemical changes during fruit development that involves the enzymatic activity that produces sweet, delicious, and soft fruits (Bajpai et al., 2012). Acidic contents of jamun are higher at green stage and there is characteristic

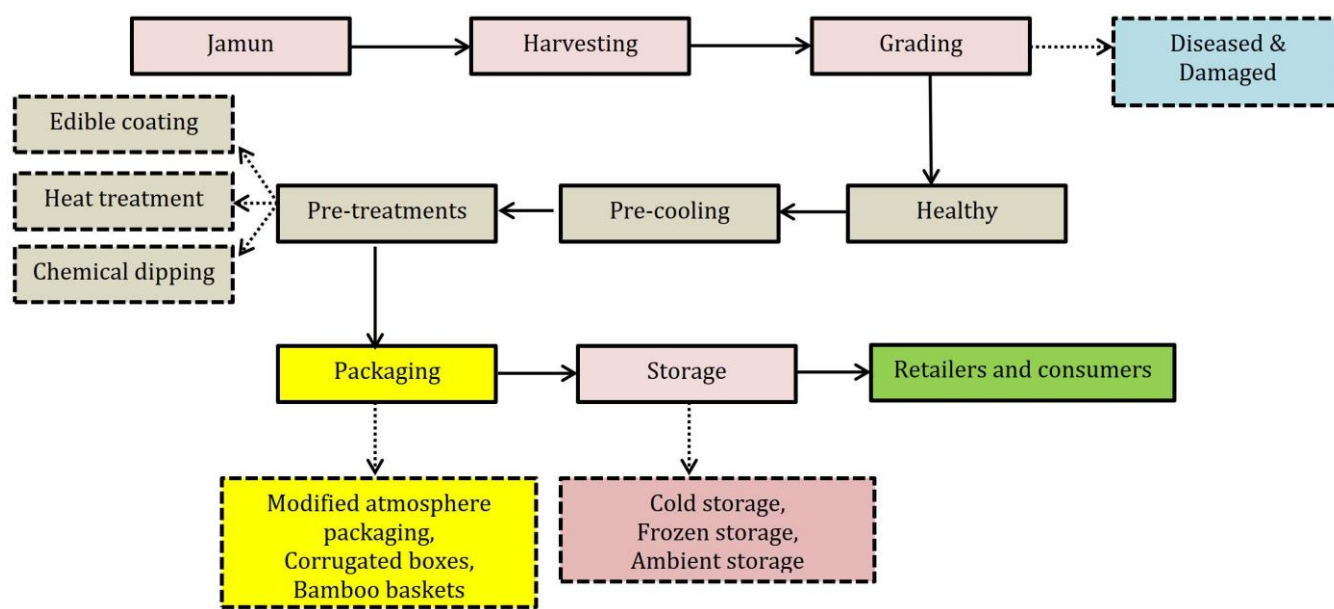


Figure 2: Flow chart for postharvest handling and processing techniques of jamun fruit as per available published literature.

decline with the advancement in growth as mature fruits have lower acidic value. Among organic acids, there is highest value of malic acid in ripe fruit with lower amount of oxalic acid (Sharma et al., 2012). Starch is the main sugar in immature green fruits that undergo hydrolysis with fruit development. On the other hand, there is escalation in non-reducing sugars that contribute sweet taste and fruit softening (Venkitakrishnan et al., 1997). Decline in acidity and increase in sugar content improves sugar to acid ratio leading to sweetness of fruit that is characteristic of ripe jamun. Fruit softening is brought about with the pectin degradation enzyme pectin methyl esterase which increases with the increase in fruit size with sudden decline at the time of maturation. Other enzyme is polygalacturonase that also reduces fruit hardness (Gol et al., 2015). Furthermore, ethylene biosynthesis and higher respiration rate also causes fruit softening. The sharp rise in ethylene with respiration rate at the time of maturation is the main reason to classify jamun as climacteric fruit; while other researchers reported it as non-climacteric fruit because there is no ripening in fruit after harvest from tree (Singh et al., 2018). Volatiles are responsible for fruit aroma so there have been about 30 compounds identified in ripe fruit; terpineol, myrcene, cis-ocimene and trans-cimene are major components. In addition, terpinyl valerate, geranyl butyrate and dihydrocarvyl acetate were detected as major esters responsible for aroma of jamun (Mehta et al., 2018).

Phenolic contents are important biochemical compounds present in jamun fruit mainly at immature stage with subsequent reduction at the time of maturity (Brandão et al., 2011). Kaempferol, quercetin, gallic acid and ellagic acid are the main phenolic content in jamun that have ability to scavenge the free radicals and contribute towards total antioxidants level. This scavenging and antioxidant level is much higher in peel tissues than fruit flesh and seeds (Bajpai et al., 2012). Carotenoids and chlorophyll contents are main ingredients in immature fruit due to which yellowish green colour is shown by

fruit that undergo a decline with fruit development. Fruit colour of ripe jamun is due to lutein and total anthocyanin contents that produce dark purple colour at maturity (Veigas et al., 2007). Cyanide-3-glucoside, cyanidin, malvidin, peonidin, petunidine and delphinidin are major anthocyanins depending upon cultivars, climatic conditions, and analysis method (Benherlal and Arumughan, 2007). It is also dependent upon fruit development stage with minimum level at fruit set and highest at fully mature stage (Brito et al., 2007). There is direct correlation between ripening stage and anthocyanin accumulation rate and maximum increase is observable at fully mature stage (Lestario et al., 2017). Peonidin-3,5-O-diglucoside, malvidin-3,5-O-diglucoside, delphinidin-3,5-O-diglucoside and cyanidin-3,5-O-diglucoside were exhibited by pink, green stage jamun although there was no anthocyanin detection at green stage. Moreover, peonidin-3,5-O-diglucoside and delphinidin-3-O-glucoside contents were present at light pink stage, and also major anthocyanin contents in jamun fruit. Tannins are other important components of immature and ripe fruits with two major types including proanthocyanidins or condensed tannins with large molecular size and galloylation degree account for astringency of fruit and second type is ellagitannins or hydrolysable tannins (Pattar et al., 2021a). Later one is very complex molecule having complex constituents like valoneic acid or trisalloyl, nonahydroxytriphenolyl (NHTP), hexahydroxydiphenolyl (HHDP) and gallic acid. Tong et al. (2014) outlined that valoneic acid dilactone methyl ester, ellagic acid and gallic acid are major hydrolysable tannins, are the part of fruit pulp and peel. They show characteristic decline in ripe fruit as maximum are observed at immature green stage (Tavares et al., 2016).

FRUIT MATURITY AND HARVEST HANDLING

Fruit maturity can be assessed on different indicators like fruit colour, acidity, sugar contents, anthocyanin, and phenolic contents. However, the most common method is the fruit colour

Table 2: Effect of different treatments on the quality management of jamun fruit and products.

Treatment	*Experimental condition	Commodity form	Inference	Shelf life (days)	Reference
Heat treated fruits	Heat treatment at 50 °C with ambient storage after canned packing	Fruit pulp and RTS beverages	Total sugars, non-reducing sugars, pH, and ascorbic acid content were decreased while TSS, acidity and reducing sugars increased.	60	Kesharwani et al., 2015
Heat treatment followed by chemical dipping	Pasteurization at 75°C for 30 seconds and dipping in citric acid (0.05%) and sodium benzoate (0.07%) and storage on ambient temperature for 90 days	Fruit juice, squash	There was increase in reducing sugars, TSS, TA and pH with decline in non-reducing sugars, ascorbic acid, anthocyanin, and total sugar contents.	60	Joshi et al., 2014
Chemical application before ambient storage	2 mM oxalic acid treatment	Fruit	Fruit shrivelling, weight loss, TSS/TA ratio increased while vitamin C, antioxidant activity, SOD and CAT enzymes activities decreased.	4	Aslam et al., 2020
Chemical pre-treatment before cold storage	1% CaCl ₂ solution was used for dipping followed by storage at 13°C + 85% RH for 15 days	Fruit	Respiration and ethylene production was lowered with better firmness, TSS and TA.	14	Vandana et al., 2015
Pre-treatment in chemical	Iron powder sachet 1g/kg fruit with ambient storage	Fruit	Respiration and rotting were low with higher antioxidants, phenols, and acidity retention.	6	Pattar et al., 2021a
Pre-treatment with chemical and low temperature storage	The combination of 0.01% SA and 1% chitosan coating with cold storage at 7°C and ambient temperature	Fruit	Fruit firmness, flavonoids, anthocyanin, and phenolic contents were higher while respiration was lowered. Best results in cold temperature.	6 days at ambient and 30 at cold storage	Saurabh, 2018
Chemical treatment prior to storage	1000 ppm sodium benzoate application followed by ambient storage (28°C) and cold storage (12°C)	Fruit juice	The microbial activity was lowered in fruit juice and maintained sensory attributes.	120 days in cold storage	Bagkar et al., 2016
Pre-treatment with chemical	1 mM PUT dipping for 5 minutes and ambient storage for 4 days	Fruit	Fruit firmness was maintained. Higher TSS was recorded.	4	Archana et al., 2015
Pre-treatment with chemical followed by coating	1.5% SA dipping with 1.5% chitosan coating and ambient storage	Fruit	Higher radical scavenging, antioxidants, flavonoids, phenolics and anthocyanin with lower fruit decay, weight loss and MDA content.	3	Saurabh et al., 2019
Polysaccharide based edible coating	1.5% chitosan and 1.5% CMC for 2 minute and stored at 10±1°C for 16 days	Fruit	Lowered cellulase and PG enzymes activities with higher anthocyanin and less fruit decay.	16	Gol et al., 2015
Edible coatings	Zein-based coatings enriched with 0.2% AA, 0.2% cysteine and 0.2% JLE and stored at 10±2°C for 2 weeks	Fruit	Reduced fruit softening, fruit decay and fruit weight loss with higher antioxidants.	14	Baraiya et al., 2015
Edible coating and hot water treatment	45°C hot water dipping for 5 minutes followed by AV coating (15%) for 10 minutes	Fruit	Lowered respiration rate and maintained higher colour with better sensory attributes.	14	Kalagudi, 2014
Edible coating and essential oil treatment	15% guggul gum coating and 0.1% basil oil application with storage at 20°C for 12 days	Fruit	Delayed activities of cellulase and PG enzymes activities with higher TA, pH, AA content, phenolic and total antioxidants.	12	Khaliq et al., 2020

Drying techniques	MCD at 70°C	Fruit	Higher gallic acid equivalent activity, anthocyanin and BTH activity.	-	Paul and Das, 2018
MAP storage with MPPE	MPPE packaging (0.3 mm diameter) and storage at 5°C for 23 days	Fruit	Maintained higher anthocyanin, phenolic, flavonoid and AA contents with less disease incidence.	23	Rai et al., 2011
MAP storage with MPP and LDPE	Drying of fruit pulp at -40°C followed by packaging in MPP and LDPE at 4°C for 6 months	Fruit powder	Best nutritional components like phenols, anthocyanin and AA contents were maintained.	-	Jebitta et al., 2016
Chemical dipping with MAP storage	Ethephon dipping and MAP storage at 10°C in LDPE packaging	Fruit	Low ethylene production with less astringency of jamun fruit.	12	Mohammed and Wickham, 1999
MAP storage	PE packaging for 12 days	Fruit	Low rotting, respiration, and TA loss.	12	Pattar et al., 2021b

AA = ascorbic acid, AV = aloe vera, BTH = butylated hydroxyanisole, CAT = catalase, CMC = carboxymethyl cellulose, HDPE = high density polyethylene, LDPE = low density polyethylene, MAP = modified atmosphere packaging, MCD = microwave convective hot air drying, MDA = malondialdehyde, mM = milli mole, MPP = metalized polyester pouch, MPPE = macro perforated polyethylene, PG = polygalacturonase, ppm = parts per million, PUT = putrescine, RH = relative humidity, RTS = ready to serve, SA = salicylic acid, SOD = superoxide dismutase, TA = titratable acidity, TSS = total soluble solids.

*Optimal experimental condition

on the basis of which harvesting is done. There is discontinuous ripening of fruits in same inflorescence so there may be difference in maturity with multiple pickings. Fully dark purple colour stage is the indicator of harvesting stage (Venkitakrishnan et al., 1997). Ethylene biosynthesis and respiration increase can also be used as the maturity index. Fruit softening is another very important harvest maturity index that is actually due to pectin methyl esterase and polygalacturonase enzymes activities subjected to degradation of pectin content in cell wall (Gol et al., 2015). In India, fruit taste is also considered as the quality and maturity indicator, harvesting is done when fruit becomes sweet and non-astringent due to reduction in tannin contents (Patel and Rao, 2014). The most common method is shaking of branch and fruits drop on cloth underneath tree. Other way is hand picking that is very laborious work due to large tree size and delicate branches that can be broken down during labour climbing. Jamun fruit is very perishable and harvesting by shaking often causes fruit mechanical damage that is point of contamination for microbes on the sap flow. Packing is mostly done in the field however pre-cooling at 8 °C can enhance fruit postharvest shelf life (Shukla and Prasad, 1980). Fruits are sorted manually on the basis of fruit size, weight, colour, mechanical damage, and diseases. Harvesting is usually done on daily basis with immediate transport in local markets with corrugated boxes or bamboo baskets (Joshi, 2011). The proposed operations from harvest to marketing have been described in Fig. 2.

POSTHARVEST TECHNOLOGY OF JAMUN FRUIT

Cold storage

Jamun fruit is very perishable, and its shelf life is about 3 days on ambient temperature because it ripe only on tree and there is no change in fruit colour after harvesting; while it takes about 12 hours from harvest to local markets (Ali et al., 2015). Many techniques have been used to maintain its postharvest quality (Table 2). Cold storage is one of the techniques to enhance the shelf life of jamun fruit above 10 °C because fruit softening is carried out when stored below this temperature (Tong et al., 2014). Cold storage lowers respiration and ethylene production. Quality attributes and nutritional value is also retained during cold storage with less softening of fruit for 5 days (Shahnawaz et al., 2009). Similarly, sugar contents and acidity can be increased during cold storage with better sensory attributes (Priyanka et al., 2015). The use of jamun fruit is very limited and its juice is also prepared for marketing due to high nutritive value. The main issue in jamun fruit juice is quality deterioration and unpleasant smell due to microbial infestation. Cold storage with sodium benzoate application-maintained fruit juice quality in optimum range with less microbial infestation for 4 months (Bagkar et al., 2016). Moreover, heat treatment of juice followed by cold storage can enhance its shelf life for 60 days with decrease in anthocyanin content, total sugars and non-reducing sugars while reducing sugars, pH and TSS are increased. However, Kesharwani et al. (2015) observed decline in pH and ascorbic acid in jamun fruit juice when stored more than 15 days during cold storage.

Anti-ripening chemicals

Chemical application is one of the most widely used methods to

preserve the fruits and shelf-life extension. They not only maintained physico-chemical attributes but also enhance their shelf life and storage quality (Shah et al., 2017). Calcium chloride (CaCl_2) is very important chemical used for postharvest quality management of horticultural commodities. It can increase the shelf life of jamun fruit up to 14 days with best organoleptic attributes and decrease in microbial decay (Vandana et al., 2015). The combination of CaCl_2 with GA_3 significantly enhanced total antioxidant level and phenolic contents in jamun. The fruit rotting and fruit firmness decline was also controlled by this treatment during 6 days storage at ambient temperature (Pattar et al., 2021a). The combination of salicylic acid with chitosan followed by low temperature storage maintained higher antioxidant level, radical scavenging activity, flavonoids, and ascorbic acid contents with reduction in weight loss, anthocyanin degradation and firmness loss for 6 days at ambient; while similar results were achieved at 7 °C for 30 days without causing any chilling injury in fruits (Saurabh, 2018). Similar treatment in another study was effective in lowering microbial decay and anthocyanin degradation (Saurabh et al., 2019). Application of oxalic acid dip treatment was also effective to control fruit decay, anthocyanin degradation and fruit weight loss with higher phenolic and ascorbic acid contents (Aslam et al., 2020). Metabolic energy conservation is key factor in fruit quality conservation and higher energy status of fruit can effectively delay the senescence. Higher respiration rate catalyses fruit senescence and shelf life is ultimately reduced due to higher metabolic activity. Archana et al. (2015) reported that application of putrescine lowered respiration rate, fruit firmness loss and fruit weight loss after 4 days storage.

Edible coatings

The edible coating works on the principle of modifications in the internal metabolism of the commodity when applied externally. The thin layer of edible coating develops a modified atmosphere inside the subjected fresh produce which restricts gaseous exchange thereby delaying the postharvest ripening and senescence during the storage period (Hasan et al., 2021). Due to chemical residual effects, there was increase in use of edible coatings that have no harmful effects on consumer health due to their organic nature (Xing et al., 2019). It provides protection against pathogens and minimizes the fruit quality losses by improving physico-chemical attributes. Chitosan application was helpful in lowering fruit damage in jamun for 30 days during cold storage and there was increase in non-reducing sugars as storage progressed (Saurabh, 2018). Meanwhile, there was less malondialdehyde (MDA) production due to suppression of lipid peroxidation by chitosan and salicylic acid (Saurabh et al., 2019). The combination of chitosan with carboxymethyl cellulose and alginate reduced oxidative stress by maintaining higher radical scavenging activity for 16 days at ambient temperature (Gol et al., 2015). These beneficial effects can be increased by applying exogenous antioxidants along with edible coating. The exogenous application along with internal antioxidant biosynthesis can alleviate the senescence of fruit with better biochemical profile. Baraiya et al. (2015) reported higher antioxidant level with alleviated fruit softening when zein based coating was incorporated with jamun leave extract, ascorbic acid, and cysteine. However, decay was observed after 6 days in both treated and untreated fruits. Aloe vera gel is most reported

plant-based coating for shelf life and quality management of fruits. It improves fruit quality and shelf life with no harmful effects on consumer health. The fruit colour (L^* , a^* , b^* , C^* , h°) and TSS was maintained in aloe vera gel coated, neem leaf extract and CaCl_2 treated fruits with extended shelf life for up to 15 days without any fruit decay incidence (Kalagudi, 2014). Guggal gum coating in jamun maintained fruit firmness by lowering polygalacturonase and cellulose enzymes activities for 12 days ambient temperature storage; however, there was no difference in fruit sensory attributes in untreated and treated fruits (Khaliq et al., 2020).

Heat treatments

Heat treatments either by hot air or hot water treatment have been investigated for increase in shelf and postharvest quality of horticultural commodities (Jin et al., 2016). Jamun is very perishable fruit, and its shelf life is about 3 days after harvest so different products have been formed by drying either through vacuum drying, hot air or freeze drying. The level of phenolic contents and ascorbic acid was more in dried than fresh fruit samples. Moreover, hot air drying is most successful method to maintain dried jamun fruit products than vacuum or freeze drying (Paul and Das, 2018). The colour variation (ΔE^*) in hot air dried jamun is also less than sun drying (Paul and Das, 2019). However, the anthocyanin content is reduced due to hot air application and ultrasonic pasteurization was found better than heat treatment. There was about 21.9% anthocyanin degradation in ultrasonic pasteurized jamun while this reduction was about 34.5% in hot air treated fruits. The other disadvantage of heat application on jamun is loss of enzymatic activity that may deteriorate fruit quality when stored as dried (Shaheer et al., 2014).

Modified atmosphere packaging (MAP)

Marketing of jamun is usually done in corrugated boxes and bamboo stick baskets. Proper packaging can increase fruit shelf life, maintain quality, avoid mechanical bruising, and increase marketing time (Pattar et al., 2021b). Modified atmosphere packaging is very important marketing technique that enhance fruit marketing window with minimum losses of jamun. Rai et al. (2011) evaluated the effectiveness of MAP by using non-perforated and perforated polyethylene packaging for jamun shelf life. They outlined that storage capacity can be increased for 23 days by using macro-perforated polyethylene packaging for jamun fruit subjected to 70-80 % relative humidity and 5 °C storage temperature. The microbial infestation was lowered by using polyethylene with 1 μm perforation. The comparison analysis indicated that better phenolic, anthocyanin and ascorbic acid contents were retained by using low density packaging than high density polyethylene (Jebitta et al., 2016). The astringency of jamun fruit was reduced by using ethephon treatment followed by low density polyethylene packing and improved consumer demand and acceptability (Mohammed and Wickham, 1999). Fruit rotting, ethylene biosynthesis and respiration rate was delayed by polyethylene perforated packaging (Pattar et al., 2021b).

CONCLUSION AND FUTURE PROSPECTS

Jamun is prime fruit growing around the globe, though

considered as minor and underutilized crop due to several constraints such as lower production, limited shelf life, no postharvest technology protocol, and unsustainable marketing system during supply chain. It has low shelf life of about 3 days but pre-treatments like edible coating, heat treatments and chemical dipping in combination with polyethylene packaging can increase its marketing window. However, there is limited material available on enzymatic activities to modulate ethylene production and respiration rate. It has been noted that the jamun crop has great potential to be studied for various aspects including molecular characterization of gene pool, the release of commercial varieties for cultivation with better yield, genetic modulation for reducing pit size with increased flesh proportion, preharvest factors affecting quality, postharvest quality preservation and processing to develop new value-added products. Moreover, additional research is required to improve processing techniques and standardization of pre-treatments on jamun fruit. The cultivar identification using genetic markers may also be done to domesticate the wild cultivars.

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Conflict of interest

The authors claim no conflict of interest whether financial or another aspect.

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