**BIOACTIVE COMPOUNDS IN JAMUN (*Syzygium cumini* L.) ENSURING NUTRITIONAL SECURITY**

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**Abstract**

Jambolan is rich in bioactive phenolic compounds, which may have positive effects on health. The jambolan plant contains the phenolic compounds phenolic acids, flavonoids (mostly anthocyanins, flavonols, flavanols, and flavanonols), and tannins in its many different parts. It is mostly utilised for timber production and fruit orchards. Anti-diabetic, anti-hyperlipidemic, anti-oxidant, anti-ulcer, hepatoprotective, anti-allergic, anti-arthritic, anti-microbial, anti-inflammatory, anti-fertility, anti-pyretic, anti-plaque, radioprotective, neuropsychopharmacological, nephroprotective, and anti-diarrheal properties are among those attributed to the fruit. Anthocyanins (such as delphinidin, petunidin, and malvidin in glycosylated forms) (mainly ellagitannins) are concentrated in the jambolan fruit skin, whereas phenolic acids (such as gallic acid and ellagic acid) and tannins make up the bulk of the fruit pulp. In addition, the jambolan fruit is claimed to include numerous additional compounds. Flavonoids like quercetin, myricetin, and flavonol glycosides can be found in the leaves of the jambolan tree in addition to the skin and pulp of the fruit. Jambolan contains phenolic chemicals that have been linked to numerous health benefits, including those related to inflammation, allergies, blood sugar, cancer, heart health, radiation therapy, bacteria, chemotherapy, and more. The medicinal, nutritional, and physiological benefits of jamun, as well as the many bioactive compounds contained in it, are discussed in this chapter. Both the alkaloid jambosine and the glycoside jambolin (also known as antimellin) can be found in jamun seeds.

**Keywords:** Jamun, antioxidants, nutritional security, bioactive compounds

**Introduction:**

Phytochemicals are a type of food additive that has been shown to provide health benefits (such as a reduced risk of developing chronic diseases) despite not being a nutrient in and of itself. One family of these chemicals present in plants is called phenolic compounds, and it has grabbed the interest of researchers due to its potential antioxidant effects (Ignat et al., 2011; Singh et al., 2016). Some classes of these substances (such as tannins) have negative properties, and hence these chemicals and other secondary metabolites in plants were once thought to be antinutrients (Treutter, 2010). This long-held belief has been finally laid to rest by the plethora of epidemiological research that have demonstrated the importance of phenolic compounds in bestowing health benefits in humans. This shift in thinking has piqued the interest of scientists in food technology and related fields in characterising and measuring phenolic compounds found in food. A large evergreen tree found across the tropics and subtropics, jambolan (Syzygium cumini Skeels. ), is also known as jamun, jambul, black plum, or Indian blackberry. It is a member of the Myrtaceae family and is rich in phenolic compounds (Tavares et al., 2016). Its edible fruits led to its introduction to Southern Africa (Baliga et al., 2011; Oliveira et al., 2016), however it is originally from India and much of South-East Asia. In addition to its native range in South America and Eastern Africa, jambolan can be sourced from Bangladesh, Pakistan, Nepal, Sri Lanka, Indonesia, Malaysia, Burma, and the rest of Indonesia. To wit: (Li et al., 2009; Ayyanar & Subash-Babu, 2012). The state of Florida is just one of several in the United States that has access to jambolan. This plant has been used for centuries in Indian medicine and cuisine (Syama et al., 2017), and its fruits, seeds, leaves, and bark are all edible. These plant parts come from a wide variety of plants, and they all contain phytochemicals that may have some sort of bioactive effect (Ayyanar & Subash-Babu, 2012).

It has been used for centuries in alternative medical practises as a stomachic, diuretic, anti-diabetic, and diarrheic remedy. Despite widespread consensus regarding the therapeutic potential of this herb, solid scientific evidence is lacking. Despite this, there have been claims that jambolan has been incorporated into a variety of processed foods, including wine, juice, frozen yoghurt, and muffins (Singh et al., 2015; Tavares et al., 2016) for human consumption. Jambolan contains phenolic compounds like phenolic acids, flavonoids, and tannins. These substances are renowned for their ability to neutralise harmful free radicals. The anthocyanins found in jambolan fruit have been shown to have potent antioxidant properties (Lestario et al., 2017). Since anthocyanins are soluble in water, they can be used to colour foods and nonfood components that include a lot of liquid (Veigas et al., 2007). In addition to anthocyanins (mainly cyanidin, petunidin, malvidin, and their glucosides), jambolan includes a wide variety of secondary compounds. These include ellagic acid, gallic acid, quercetin, myricetin, kaempferol, condensed tannins, and hydrolysable tannins. The plant's pharmacological value comes from the presence of bioactive compounds with a variety of health benefits (Afify et al., 2011). Jambolan acts as an antioxidant, antibacterial, chemopreventive, anti-inflammatory, anti-allergic, anti-hyperglycemic, anti-cancer, cardioprotective, radioprotective, and radioprotective agent (Afify et al., 2011).

There are phenolic compounds in jambolan. Bioactive secondary phytochemicals called phenolic compounds are produced mostly via the shikimic acid or phenylpropanoid pathways in all higher plants. They are highly concentrated in the outer layers of plant tissues and in seeds, where they can serve as a defence mechanism. These compounds (broadly classed as phenolic acids, flavonoids, and tannins) can be separated from one another based on the number of connected phenolic hydroxyl groups and the structural components linking benzene rings (Singh et al., 2016). Chemicals derived from hydroxycinnamic acid (such as caffeic acid and coumaric acid) and hydroxybenzoic acid (such as gallic acid and ellagic acid) are referred to as phenolic acids. Flavonoids are phenolic chemicals having a C6-C3-C6 structure, consisting of two aromatic rings joined by a heterocyclic ring consisting of three carbon atoms. Some examples of these compounds are flavonols, flavanols, flavones, flavanones, isoflavones, and anthocyanins. Tannins have a bitter and astringent flavour and have molecular weights (often between 500 and 3000) that make them water-soluble phenolic compounds. Phenolic chemicals are used in the food industry as preservatives, flavour enhancers, and colourants (especially anthocyanins, a family of flavonoids). Methods for detecting total phenolic content vary, but the most common use the Folin-Ciocalteu reagent, which involves reducing phosphomolybdic or phosphotungstic acid in an alkaline solution to form a blue-colored complex. In addition, mass spectrometry can verify the presence of phenolic compounds. In HPLC analysis, only reversed phase C18 columns are employed. In most cases, polar solvents are used in a binary solvent system. Fresh samples are required for extracting phenolic components from fruits like jambolan. However, freeze drying or other techniques are typically required because to the high perishability of these fruits. The amount of phenolic compounds in an extract can vary widely depending on how it was made. Many methods described in the literature are time-consuming and difficult to replicate (Aqil et al., 2014). However, numerous methods have been reported to be highly efficient, producing a high yield of phenolic compounds when preparing jambolan extract from fruits and seeds (Veigas et al., 2007; Aqil et al., 2012). Jambolan pulp and seed extracts were concentrated using column chromatography with Amberlite XAD-761 and Diaion HP-20 resin. Hydrolysis with 2N HCl (converting ellagitannins to ellagic acid and anthocyanins to anthocyanins) was used to improve the extracts prepared with acidified 75% ethanol, XAD-761, and HP-20 resins. The method produced an extract with a relatively high concentration of anthocyanin (0.54%). Veigas et al. (2007) conducted research into the extraction of anthocyanins from jambolan pulp using a different resin, Amberlite XAD-7. Similar to pomegranate juice, jambolan juice has a lot of phenolic compounds, however there isn't much known about them. Recent research by Tavares et al. (2017) demonstrated that the anthocyanins present in jambolan juice degrade more noticeably than the flavonols, making it easier to extract the hydrolysable tannins. In addition, the anthocyanin concentration in the juice was shown to be lower at higher dehydration temperatures (during foam mat drying of juice), whereas hydrolyzable tannins and flavonols were more vulnerable to oxidation and heating duration. They found that beneficial components such anthocyanins in jambolan juice were significantly degraded at processing temperatures above 70 °C.

**Flavonoids**

Extracts of jambolan fruit (both pulp and peel) were found to contain a variety of flavonols and flavanonols (Faria et al., 2011). These included myricetin, myricetin pentoside, myricetin rhamnoside, myricetin glucoside, and myricetin acetylrhamnoside. In jambolan fruit pulp, flavanols myricetin 3-O-glucoside, syringetin 3-O-galactoside, myricetin 3-O-pentose, myricetin 3-O-rhamnose, syringetin 3-O-glucoside, myricetin 3-O-glucuronide, laricitrin 3-O-glucoside, laricitrin 3-O-galactoside and myricetin 3-O-galactoside were the identified and quantified as 30.31, 17.74, 11.55, 10.64, 8.92, 7.53, 5.82, 5.00 and 2.50 mg kg1 fresh weight (FW), respectively (Tavares et al., 2016). On the other hand, the flavanols observed in jambolan fruit peel were myricetin 3-O-glucoside, myricetin 3-O-rhamnose, myricetin 3-O-glucuronide, laricitrin 3-O-glucoside, myricetin 3-O-pentose, syringetin 3-O-glucoside, syringetin 3- O-galactoside, myricetin 3-O-galactoside and laricitrin 3-O-galactoside and their content was 64.4, 11.92, 8.0, 5.04, 3.21, 2.13, 1.91, 1.76 and 1.62 mg kg-1 FW, respectively (Tavares et al., 2016).

Jambolan fruit pulp contained 64.54 mg kg 1 fresh weight (FW) of flavanonol dihexosides, including dihydromyricetin, methyldihydromyricetin, methyl-dihydroquercetin, and dihydroquercetin (Tavares et al., 2016). Fruit peel contained flavanonol dihexosides at concentrations of 53.56 mg kg 1 FW (dihydromyricetin), 20.58 mg kg 1 FW (dimethyl-dihydromyricetin), 11.66 mg kg 1 FW (dihydroquercetin), and 6.67 mg kg 1 FW (dimethyl-dihydromyricetin) (Tavares et al., 2016). Myricetin 3-O-pentoside, myricetin 3-O-hexoside, and myricetin 3-O-rhamnoside were all identified in a recent study on freeze-dried jambolan fruit extract (Lestario et al., 2017).

Freeze-dried jambol was found to have five different anthocyanins, four of which are 3,5-O-diglucosides (petunidin 3,5-O-diglucoside, cyaniding 3,5-O-diglucoside, delphinidin 3,5-O-diglucoside, peonidin-3,5-O-diglucoside, and malvidin 3,5-O-diglucoside), and one of which is a 3-O-gluco Delphinidin, petunidin, malvidin, peonidin, and cyanidin all had concentrations of 256, 245, 166, 75, and 29 mg/100 g DW, respectively, in freeze-dried jambolan fruit extract (Brito et al., 2007). Delphinidin (20.2 mg mL 1) was found in freeze-dried jambolan fruit pulp extract by Singh et al. (2016). Minor amounts of delphinidin, petunidin, and malvidin (3,5-O-diglucosides; 40.39, 30.29, and 23.93 mg kg 1 FW, respectively) can be found in jambolan pulp (Tavares et al., 2016). Similar to how 3,5-O-diglucosides of delphinidin, petunidin, and malvidin were the most abundant in jambolan peel (37.61, 33.27, and 23.31 mg kg 1 FW), while 3-O-glucosides of delphinidin, cyanidin, and malvidin were present in much smaller amounts (1.59, 0.37, and 0.17 mg kg 1 FW, respectively; Tavares et al. Young jambolan fruit typically has a low anthocyanin concentration, which rises as the fruit ripens and matures.

**Tannins**

Complex and sophisticated methods are required for accurate structure elucidation of both condensed tannins (made from the condensation of flavans) and hydrolyzed tannins (tannins that, when hydrolyzed, release gallic or ellagic acids). The astringency of jambolan fruit comes from hydrolyzable tannins. The peel and pulp of jambolan fruit include hydrolyzable tannins (ellagitannins and gallotannins) and condensed tannins (proanthocyanidins; Gordon et al., 2011; Tavares et al., 2016). Hydrolyzable tannins, called ellagitannins, were discovered in jambolan fruit by Zhang and Lin (2009). These tannins have a glucose core surrounded by gallic acid and ellagic acid units. Gordon et al. (2011) isolated and characterised 12 gallotannins, 1 hexahydroxydiphenoyl (HHDP)-gallotannin, and 1 trisgalloyldiglucose as hydrolysable tannins from jambolan fruit (skin and pulp) extract. Gallic acid, nonahydroxytriphenolyl (NHTP), hydroxyhexyldiphenol (HHDP), trisgalloyl, and valoneic acids are the building blocks of hydrolysable tannins (Gordon et al., 2011; Tavares et al., 2016). Jambolan fruit contains a variety of hydrolyzable tannins, but gallotannins predominate (Tavares et al., 2016). In addition, the hydrolysable tannin content of jambolan fruit peel was found to be higher in gallotannin than that of the pulp. The most common gallotannin isomers in fruit pulp and peel were monogalloylglucose and tetragalloylglucose, respectively. In addition to monogalloyl to trigalloylglucose, trigalloylglucose, pentagalloylglucose, and hexagalloylglucose, the other isomers identified in gallotannins of fruit pulp ranged from digalloyl to hexagalloylglucose. Jambolan fruit extract gallotannins were shown to contain galloyl, trigalloyl to hexagalloyl glucose, and gallic acid by Lestario et al. (2017). Jambolan fruit skin ellagitannins had galloyl or trisgalloyl-HHDP substituents, while the pulp ellagitannins included HHDP and NHTP substituents (castalagin, vescalagin, trisgalloyl-HHDP-glucose, and diHHDP-glucose isomers) (Tavares et al., 2016).

Highly galloylated prodelphinidins, largely composed of oligomeric and polymeric flavan-3-ols including gallocatechin and epigallocatechin subunits, were found in the skin and pulp of jambolan fruit (Tavares et al., 2016). Jambolan fruit extract has been shown to have 453 g cyanidin chloride equivalent/g fresh weight (FW) of total proanthocyanidins. The work of Luximon-Ramma and coworkers (2003). Tavares et al. (2016) found that the jambolan fruit peel and pulp had a condensed tannin content (CTC) of 11.92 and 9.03 mg catechin equivalents [CE]/kg fresh weight, respectively. Brandao et al. (2011) and Lestario et al. (2017) report that as jambolan fruit ripens and matures, its tannin content drops.

**Degree of phenolic compounds**

Total phenolic content (TPC) was found for various jambolan plant parts in Table 1. Jambolan fruit peel had significantly more TPC than the pulp and seed combined (Ali et al., 2015). The crude extract of jambolan seeds includes ellagic acid (38 micrograms per gramme), gallic acid (646 micrograms per gramme), quercetin (98 micrograms per gramme), and kaempferol (59 micrograms per gramme), as reported by Bajpai et al. (2005). Jambolan pulp and seed powder have TPC concentrations of 1.15 and 2.69 percent, respectively (Aqil et al., 2012). Arun et al. (2011) reported TPC concentrations of 16 833 mg GAE/100 g in water, 47 167 mg GAE/100 g in ethanol, 23,000 mg GAE/100 g in acetone, and 37,500 mg GAE/100 g in ethyl acetate. Jambolan leaf methanolic and methylene chloride extracts were reported to contain 1403 and 655 mg GAE/100 g DW of TPC, respectively (Mohamed et al., 2013). Jambolan fruit had a higher quantity of phenolic components while they were unripe, but this decreased as the fruit ripened (Brandrao et al., 2011).

**Quantity of flavonoids in total**

Total flavonoid content (TFC) data for several jambolan plant parts are shown in Table 1. Ali et al. (2015) discovered that the largest concentrations of TFC were in the fruit's skin, followed by its pulp and its seed. TFC concentrations were 6531, 11 488, 10 386, and 13 826 quercetin equivalents [QE] mg/100 g in water, ethanol, acetone, and ethyl acetate extracts, respectively (Arun et al., 2011). Flavonoids have been suggested to be extracted with methanol rather than methylene chloride. According to a 2013 study by Mohamed et al., TFC values in methanolic and methylene chloride extracts of jambolan leaf were 622 and 204 mg QE g 1 DW, respectively. Freeze-dried jambolan fruit pulp extract contained 573 mg QE/100 g of total phenolic compounds (TFC). In a 2016 study (Singh et al. The flavanonol content was 1676.8 mg/100 g FW and the naringin content was 63.7 mg/100 g FW, whereas the jambolan peel and pulp contained 701.9 and 43.1 mg myricetin 3-O-glucoside equivalents/100 g FW, respectively. In a 2016 study (Tavares et al.

**Absolute anthocyanin concentration**

Total anthocyanin content (TAC) data for several jambolan plant parts. Jambolan fruit's anthocyanin content shifts as it matures. There were 79 milligrammes of TAC per 100 grammes of fresh jambolan fruit. Researchers Brito and his team in 2007. Reynertson et al. (2008) showed that freeze-dried jambolan fruit extract contained TAC (663 mg cyanidin 3-O-glucoside [C3G] equivalents/100 g). According to a paper by Tavares et al. (2016), the total antioxidant capacity (TAC) of fruit extract (peel and pulp combined) is 31.55 mg/100 g FW (as malvidin 3,5-O-diglucoside equivalents). TAC is quite low in unripe jambolan fruits but rises dramatically during the ripening process. TAC levels in unripe jambolan fruits are extremely low but rise dramatically as the fruit ripens. The total phenolic content (TAC) was found to be 28.5 mg/100 g dry weight (DW) in green-yellow, green-pink, pink, red, light purple, dark purple, and fully mature black jambolan fruit, respectively (Lestario et al., 2017).

Having antioxidant qualities Many fruits include anthocyanins and flavonoids, which are more potent antioxidants than regular phenols. In addition to preventing free radicals from being produced, these compounds also prevent them from being scavenged or deactivated (Singh et al., 2016; 2017). Jambolan's antioxidant properties come from the high concentration of phenolic compounds it contains. The antioxidant activity of fruit peel is higher than that of the pulp and the seed because of the greater concentration of bioactive components in the peel. Jambolan fruit peel, pulp, and seed have been measured to have free radical scavenging activities of 90.6, 82.5, and 85.2%, respectively (Ali et al., 2015). Jambolan fruit is a rich source of antioxidants and natural colourants due to its high anthocyanin content when ripe (Lestario et al., 2017).

There were 970 lmol Trolox equivalents [TE]/g of jambolan fruit extract's TEAC at pH 7.0, and 1640 lmol TE/100 g of jambolan fruit extract's ORAC at pH 7.4. In a 2011 study (Faria et al. According to the results of this investigation, the antioxidant capacity of hemiacetals and/or chalcones, the colourless forms of anthocyanins that can be accessed in phosphate buffer (pH 7.0 or 7.4), is greater than that of flavylium cation. The ORAC values for jambolan pulp were 144.5 mM TE/100 g, while the values for jambolan seed hydrolysates were 337.9 mM TE/100 g (Aqil et al., 2012). Kaempferol's methyl ether is an effective free radical scavenger (Afify et al., 2011). Aqil et al. (2012) found that the radical scavenging capacity was due in part to the presence of cis-diols in ellagic acid/ellagitannins, catechol (orthodihydroxyl), and pyrogallol (vicinal trihydroxyl) groups in cyanidin and delphinidin-derived pigments.

Jambolan leaf extracts in methanol had a FRAP value of 1314 mg ascorbic acid equivalents (AAE)/100 g dry weight (DW) and in methylene chloride had a value of 122 mg AAE/100 g DW (Mohamed et al., 2013). The antioxidant activity of jambolan leaves can be attributed in part to the high levels of TPC and TFC detected in polar extracts (methanolic). Jambolan ethanol extract contains tannins that significantly lower free radical levels. Chemicals in jambolan with antioxidant properties have been demonstrated to prevent gastrointestinal ulcers in rats when administered at a dose of 20 g/kg body weight (Ramirez & Roa, 2003). Extracts from many other medicinal plants have exhibited scavenging effect, but jambolan bark extract has been particularly helpful in reducing peroxidation (Sultana et al., 2007). Jambolan fruit peel extract was found to have high free radical-scavenging activity (78.2% DPPH scavenging activity) at an extremely low concentration (2.5 ppm) (Veigas et al., 2007), suggesting that it may be a source of natural antioxidant compounds.

Jambolan fruit and seed contain phenolic acids, which have been shown to have antioxidant, anti-diabetic, anti-cancer, anti-inflammatory, antibacterial, anti-allergic, and free radical scavenging activities (Aqil et al., 2016; Singh et al., 2016; Ghosh et al., 2017; Seraglio et al., 2018). Jambolan fruits and seeds were traditionally used to treat a wide range of ailments, including diarrhoea, colds, coughs, fevers, skin conditions, and gastrointestinal issues (Ayyanar & Subash-Babu, 2012). Some studies have shown that using jambolan fruit extracts can help reduce the risk of developing cancer (Li et al., 2009) or diabetes (Grover et al., 2000; Ravi et al., 2005; Sharma et al., 2006; Helmst€adter, 2008). Hydrochloric acid-hydrolyzed extracts of jambolan pulp and seed suppressed the growth of human lung cancer A549 cells (Aqil et al., 2012). Jambolan pulp powder had 30% extractability (down to 4% after enrichment), while enriched seed powder had 3% extractability. In addition, eating jambolan fruit has a soothing effect on the digestive system. Possessing anti-allergy qualities The anti-allergic properties of jambolan leaf extract were studied by Brito et al. (2007), who discovered that it prevented the development of oedema, the production of histamine and serotonin, the degranulation of mast cells, and the accumulation of eosinophils in mice. Inhibiting enzymes involved in cell activation and the generation of inflammatory mediators, the flavonoid glycosides contained in jambolan leaf extract have been related to anti-inflammatory and anti-oedematogenic properties. Safety from radiation Radiation-induced DNA damage can be prevented thanks to the bioactive compounds found in jambolan (Jagetia et al., 2008). They neutralise harmful oxygen radicals like superoxides and protect cell membranes from damage. Jambolan seeds extract (prepared with dichloromethane and methanol) was shown to have radioprotective effects in mice exposed to varied doses of c-radiation (Jagetia et al., 2005).

Mice pretreated with jambolan seed extract (80 mg kg1 body weight) were protected against sickness and death brought on by c-radiation. Bioactive components including flavonoids and ellagic acid in jambolan seed extract scavenge free radicals, which contributes to the extract's radioprotective action. Jambolan leaf extract protected against radiation-induced DNA damage in human peripheral cells cultured in vitro and subjected to 3 Gy of gamma radiation (Jagetia et al., 2008).

In conclusion, and looking ahead

Jambolan's phenolic compounds and antioxidant qualities make it a useful ingredient in the creation of healthful, purposeful foods. However, a thorough investigation into the health benefits of these compounds requires knowledge of their bioavailability. There are still numerous unanswered questions, and most of what is known about the safety of these medications comes from in vitro and animal model trials. Numerous opportunities exist for additional study in this field. Jambolan contains phenolic compounds, the roles of which need to be better explored through clinical trials and epidemiological investigations. There is also a need for additional study into the ways in which jambolan fruits are processed to minimise the loss of their beneficial compounds. There is no well-established market for jambolan and its derivatives in poor countries, and the substance has been underutilised in developed nations. Medical and pharmaceutical recognition for this plant can be increased with the use of findings from clinical investigations and phytochemical analysis.

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**Declaration of Conflict of Interest**

The authors declare that they have no conflict of interest.

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