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**Received** 22 October 2025
**Revised** 28 October 2025
**Accepted** 25 January 2026
**Available Online** 30 June 2026

Edited by Kannan RR Rengasamy

**KEYWORDS**:
Antioxidants
Phytochemicals
Medicinal properties
Biomolecules
Pomarrosa
Immunomodulators

https://doi.org/10.53365/nrfhh/217345
eISSN: 2583-1194


# *Syzygium jambos* (L.) Alston (Rose Apple): A Review of its Phytochemistry and Pharmacology

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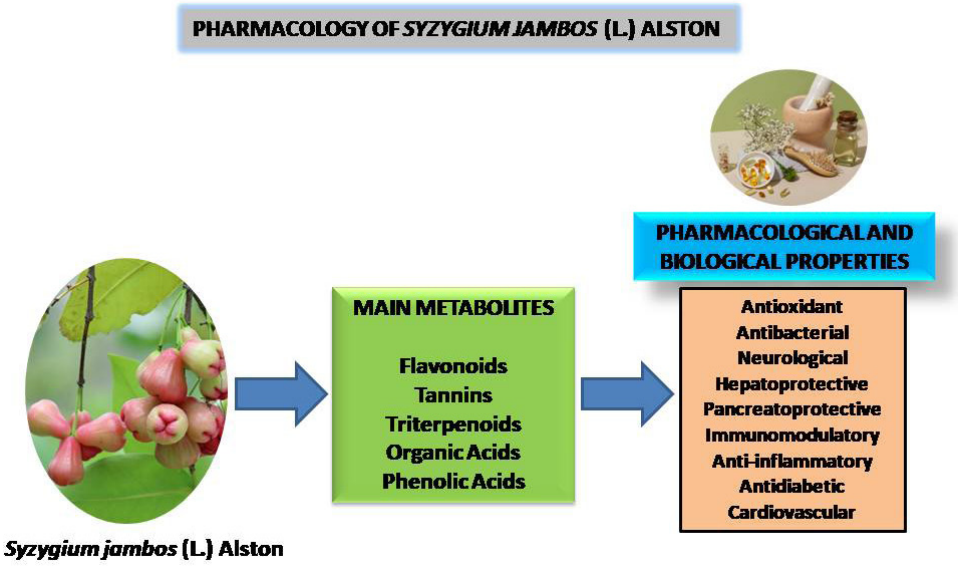
## GRAPHICAL ABSTRACT




**ABSTRACT:** *Syzygium jambos* L. Alston (Myrtaceae), commonly known as "pomarrosa", "jambolero", "rose apple", "yambo", among others, is a wild species found in Asia and America. It grows on the western slopes of northern Peru in rocky or stony and moderately sub-xerophytic environments at altitudes ranging from 1,500 to 2,200 meters above sea level. The objective of this review is to compile scientific information on *S. jambos*, focusing on its phytochemistry as a potential source of novel bioactive compounds and its therapeutic applications. The literature search was conducted using electronic databases such as Scopus, ScienceDirect, PubMed Central, and the Google Scholar search engine. A total of 33 documents in English and Spanish were selected. A bibliographic review of *S. jambos* reveals that this plant species is rarely utilized in traditional medicine. However, further research is required to explore its phytochemistry as a potential source

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of novel bioactive compounds, as well as its pharmacological properties, contemporary applications, and toxicological profile with scientific validation. The collected data indicate its efficacy in various in vitro and *in vivo* pharmacological activities, including antimicrobial, antiviral, anti-inflammatory, antimutagenic, antinociceptive, antipyretic, antispasmodic, antithrombotic, apoptotic, cardiovascular, chemomodulatory, antitumor, hepatoprotective, hypoglycemic, hypolipidemic, and memory-enhancing effects. Despite the diversity of pharmacological activities of *S. jambos*, further studies on clinical assays and the development of formulations must be carried out. Hence, *S. jambos* has emerged as a valuable source in traditional medicine and provides a significant foundation in pharmaceutical biology for the development and formulation of new drugs and future clinical applications.

## 1. INTRODUCTION

*Syzygium jambos* (L.) Alston, also referred to as *Jambosa jambos*(L.) Mill sp.,*Eugenia jambos*, *Myrtus jambos*(L.) Kunth, *Plinia jambos*(L.), *Myrtus jambos*(L.) Kunth, *Eugenia malaccensis*Lour., *Eugenia monantha*Merr., and *Eugenia malaccensis*Blanco, belongs to the Myrtaceae family and is mainly known as "pomarrosa", "jambolero", "rose apple", "yambo", "jambo", among others (Growables, 2021). It is a tall tree, reaching approximately 20 meters in height, with a highly branched structure. The species produces large flowers with numerous stamens measuring 3 to 4 cm in length, exhibiting a white coloration. The fruits are bright red, pear-shaped, sweet, and edible, emitting a fragrance reminiscent of rose petals. This species is native to Southeast Asia and is also found in America, adapted to different biomes. In Peru, for example, *S. jambos* is found thriving on the western slopes of the northern region in rocky or stony environments with semi-xerophytic characteristics, at altitudes ranging from 1,500 to 2,200 meters above sea level (López-Vergara and Ortega, 2022). In turn, this species is found in Brazil in the Atlantic Forest, between sea level and 1,000 meters above. Although native to tropical Asia, *S. jambos*is also cultivated in tropical America for its ornamental value, attributed to its striking red and fuchsia flowers, dense foliage that provides ample shade, and palatable fruit. It is also commonly found in Central America, including Costa Rica, El Salvador, and Belize, as well as in Venezuela and Ecuador (Filian Murrieta and Velásquez, 2017).

The species exhibits rapid growth and can attain heights of 12 to 18 meters, developing a pyramidal crown. Its leaves are evergreen, opposite, and have short petioles, with an elliptic-lanceolate to oblanceolate shape and a glossy, dark green adaxial surface. Initially, the flowers display a deep red hue, transitioning to pinkish tones over time. These flowers are highly abundant and nearly scentless, emerging from the upper trunk and the most mature branches. The fruit is oval-shaped, measuring between 5 and 10 cm in length and 2.5 to 7.5 cm in width. It possesses thin, waxy, pink-colored skin. The edible pulp is white, slightly crisp, spongy, and highly succulent, characterized by a mild and slightly sweet flavor. The fruit typically contains a single oval seed; however, in some cases, it may contain up to two nearly round or hemispherical seeds, measuring approximately 2 cm in diameter. The seeds exhibit a brown exterior and a green, fleshy interior (Mayhuasque Hernández, 2015).

According to León Lincango (2015), this fruit originates from the species known as "Jambeiro," belonging to the genus *Syzygium*, within the Myrtaceae family, which includes fruit-bearing plants such as cherries, eucalyptus, and guavas. Among the most well-known species within this genus are the red jambo (*Syzygium malaccense*), which is sweet with a slightly acidic taste; the white jambo (*Syzygium*), characterized by its mild flavor; and the rose jambo (*Syzygium jambolana*), which produces pink-colored fruits (León Lincango, 2015).

Ávila-Peña et al. (2007) state that the levels of phenolic compounds in medicinal plants can be influenced by environmental factors such as soil composition, precipitation, temperature, and humidity (Ávila-Peña et al., 2007). The tannin content in the plant may vary throughout its growth in response to changing environmental conditions. Studies have investigated the environmental influence on secondary metabolites and the chemical variability in certain species of the Myrtaceae family (Borges et al., 2013).

In species of *S. jambos*, research has also been conducted on chemical variability and environmental factors that may affect essential oil composition (Rezende et al., 2013). Environmental parameters such as soil composition, rainfall, temperature, and humidity are known to influence the concentration of phenolic compounds in medicinal plants. According to Rezende et al. (2015), variations in these factors markedly affect the synthesis of phenolic metabolites in the leaves of *Syzygium jambos*. Their study identified that the main determinants of phenolic content in this species include foliar nutrients (Fe, Mo, P, Ca, K, Na, and Co), soil elements (Mn, S, K, Na, and Al), and climatic conditions, particularly temperature and precipitation.

## 2. METHODOLOGY

The systematic compilation of scientific information was conducted using the databases Science Direct, PubMed Central®, Scielo, Scopus, Alicia, and the Google Scholar

search engine. The search employed combinations of the following keywords: (*Syzygium jambos*) AND (Antioxidant OR Endogenous Antioxidants OR Antioxidant Activity OR Antioxidant Effects) AND (Immunomodulations OR Immunomodulatory Therapies), (*Syzygium jambos*) AND "pharmacological effect", and (*Syzygium jambos*) AND (ethnomedicine OR phytochemistry OR "pharmacological effect"). This exploration led to the identification of 110 documents, from which 38 articles were selected (34 original research papers, 2 systematic reviews, and 2 theses), covering the period from 1983 to 2025, in English and Spanish.

## 3. LITERATURE REVIEW

### 3.1. Botanic Taxonomy

| Category | Name |
|---|---|
| Kingdom | Plantae |
| Division | Tracheophyta |
| Subdivision | Spermatophyta |
| Infradivision | Angiospermae |
| Class | Magnoliopsida |
| Superorder | Rosanae |
| Order | Myrtales |
| Family | Myrtaceae |
| Genus | *Syzygium* |
| Species | *Syzygium jambos* |

### 3.2. Phytochemical Composition

#### *3.2.1. Leaves*

Chemical characterization of *Syzygium jambos* leaf extracts revealed the presence of numerous secondary metabolites, including flavones, flavonol glycosides, flavonol diglycosides, phenolic acids, and ellagitannins, as determined by HPLC-PDA-MS/MS analysis. The isolation and structural elucidation of individual compounds were carried out using spectroscopic methods, particularly one-dimensional NMR techniques ($^{1}$H-NMR and $^{13}$C-NMR) (Slowing et al., 1994; Sobeh et al., 2018; Wong et al., 2024; Bonfanti-Azzolin et al., 2019) (Table 1).

#### *3.2.2. Bark*

The study by Mahmoud et al. (2021) revealed the following secondary metabolites: HHDP-hexoside, bis-HHDP-hexoside, phyllanthuslin g, castalagin, vescalagin, ellagic acid pentoside, methyl ellagic sulfate, and ellagic acid (Mahmoud et al., 2021) (Table 1).

**Table 1.**
Phytochemical compounds from*Syzygium jambos* leaves.

| Metabolites | Extraction Method | Reference |
|---|---|---|
| **Flavonoids** | | |
| Hexahydroxydiphenoyl-hexoside<br>Galloyl-HHDP-DHHDP-hexoside<br>Bis-HHDP-hexoside<br>Galloyl-bis-HHDP-hexoside<br>Ellagic acid pentoside<br>Ellagic acid rhamnoside<br>Myricetin rhamnoside<br>Myricetin 3-O-xylosyl-rhamnoside<br>Rosmarinic acid rhamnoside<br>Quercetin 3-O-xylosyl-hamnoside | LC-MS/MS | (Sobeh et al., 2018) |
| Catechin<br>Rutin<br>Epicatechin<br>Isoquercitrin<br>Quercitrin<br>Kaempferol | HPLC | (Bonfanti-Azzolin et al. 2019) |
| Myricetin derivative<br>Kaempferol derivative<br>Myrigalone G | NMR | (Wong et al., 2024) |
| Quercetin glucuronide<br>Myricetin glucoside<br>Quercetin xyloside<br>Quercetin galloylglucoside<br>Myricetin robinoside<br>Myricetin xylosyl-rhamnoside<br>Jaceidin rhamnoside<br>Quercetin arabinoside<br>Quercetin rhamnoside<br>Quercetin xylosyl-rhamnoside<br>Kaempferol rhamnoside-xyloside | UPLC-MS/MS | (Wong et al., 2024) |
| **Tannins** | | |
| Castalagin<br>Casuarinin<br>Vescalagin<br>Vescalin<br>di-Hexahydroxydiphenoyl (HHDP) glucose<br>Galloyl castalagin<br>Trigalloyl glucose<br>Tellimagrandin II<br>Coriariin A<br>Coriariin B<br>Praecoxin A<br>Praecoxin B | NMR | (Wong et al., 2024) |
| Strictinin<br>Pterocarinin A<br>Tellimagrandin I<br>(-)-Epigallocatechin | UPLC-MS/MS | (Wong et al., 2024) |
| **Triterpenoids** | | |
| Stigmasterol<br>Lupeol<br>β-amyrin<br>Pomolic acid<br>Friedelin | NMR | (Wong et al., 2024) |

(Continued)

**Table 1:** (Continued)

| Metabolites | Extraction Method | Reference |
|---|---|---|
| Madecassic acid<br>Asiatic acid<br>Maslinic acid<br>Oleanolic acid | UPLC-MS/MS | (Wong et al., 2024) |
| **Organic Acids** | | |
| Malic acid<br>Citric acid<br>Ellagic acid<br>Ellagic acid hexoside | LC-MS/MS | (Sobeh et al., 2018) |
| **Phenolic Acids** | | |
| Caffeic acid<br>Gallic acid<br>Chlorogenic acid<br>Syringic acid<br>Gallic acid coumaroyl hexose | HPLC | (Bonfanti Azzolin et al., 2019) |
| **Sugars** | | |
| α-glucose<br>β-glucose<br>Fructose | NMR | (Wong et al., 2024) |
| Raffinose | UPLC-MS/MS | (Wong et al., 2024) |
| **Fatty acids** | | |
| Trihydroxy octadecadienoic acid<br>Trihydroxy octadecenoic acid<br>Hydroxy-docosanoic acid | UPLC-MS/MS | (Wong et al., 2024) |
| **Other metabolites** | | |
| Valine<br>Alanine<br>Choline<br>Formic acid | NMR | (Wong et al., 2024) |
| Stigmasterol glucoside<br>Pheophorbide A<br>Methyl hydroxydocosanoate | UPLC-MS/MS | (Wong et al., 2024) |

LC-MS/MS: Liquid Chromatography–Mass Spectrometry
HPLC: High-Performance Liquid Chromatography
MS: Mass Spectrometry

#### *3.2.3. Fruit*

The total phenolic content in *S. jambos*fruit was 127.61 mg GAE/100 g, while the seed contained 217.34 mg GAE/100 g. Additionally, the flavonoid content in the fruit was measured at 8.64 mg QE/100 g (Dutta et al., 2023). Moreover, the rose apple fruit is rich in carbohydrates, calcium, phosphorus, vitamin C, β-carotene, and iron (León Lincango, 2015) (Table 1).

### 3.3. Pharmacological and Biological Properties

#### *3.3.1. Antimicrobial activity*

Leaves

Rajkumari et al. (2018a) reported that ethanolic leaf extracts of *Syzygium jambos* were fractionated and analyzed through activity-guided HPLC profiling. Two major bioactive compounds, 5-hydroxymethyl-2-furfural and betulin, were identified as key contributors to the plant's anti-quorum sensing (anti-QS) properties. This activity interfered with quorum sensing (QS)-regulated virulence mechanisms in *Pseudomonas aeruginosa*. At concentrations below the minimum inhibitory level (sub-MIC), the extract notably disrupted QS signaling, resulting in decreased production of virulence factors and inhibition of biofilm development. Molecular docking studies further demonstrated that these phytochemicals displayed high binding affinities toward the QS transcriptional regulators LasR and RhlR, surpassing those of the native signaling molecules 3-oxo-C12-HSL and C4-HSL.These findings underscore the potential of *S. jambos* and its bioactive compounds as quorum sensing antagonists, offering a promising therapeutic approach for treating chronic infections caused by *P. aeruginosa* (Rajkumari et al., 2018a) (Table 2).

Bark

The *in vitro* antibacterial activity of acetone and aqueous extracts of *S. jambos* bark was analyzed using the agar dilution method in Petri plates. These extracts demonstrated notable efficacy against *Yersinia enterocolitica*, *Staphylococcus aureus*, and several coagulase-negative *Staphylococcus* strains, including *Staphylococcus hominis*, *Staphylococcus cohnii*, and *Staphylococcus warneri*. Furthermore, the research conducted by Djadjo Djipa et al. (2002) suggests that the high tannin concentration in *S. jambos* bark extracts, as measured by the European Pharmacopoeia method (77% in aqueous extracts and 83% in acetone extracts), is directly associated with antimicrobial properties. Comparatively, extracts from *Hamamelis virginiana*,*Alchemilla vulgaris*, *Krameria triandra*, and *Rubus fruticosus* exhibited lower tannin levels, at 48%, 46%, 44%, and 28%, respectively. Notably, complete tannin removal resulted in a total loss of antimicrobial activity, confirming their essential role in the bioactivity of *S. jambos* (Djadjo Djipa et al., 2000) (Table 2).

#### *3.3.2. Antioxidant activity*

Seeds

Phenolic compounds, such as flavonoids, are natural pigments widely found in nature. They possess a chemical structure that enables them to function as antioxidants by scavenging free radicals and neutralizing reactive oxygen species (ROS) and metal ions. Due to their reactivity, they are often combined with organic acids, sugars, or polymerized with each other (Cartaya et al., 2001). Furthermore, phenolic compounds play a fundamental role in plant development and, in their interaction with humans, protect the body from oxidative damage. Additionally, they are used in the treatment of cardiovascular disorders and in the prevention of certain types of cancer (Škerget et al., 2005).

**Table 2.**
Pharmacological and biological properties of *S. jambos.*

| Pharmacological Properties | Sample | Experimental Assay | Bioactive Compounds | Authors |
|---|---|---|---|---|
| **Antioxidant** | 50% ethanolic seed extract | *In vitro* models: ABTS and DPPH | Phenols, proanthocyanidins, flavones and flavonols | (Škerget et al., 2005) |
| | Aqueous pulp extract | *In vivo*: diabetic rats | NI | (Pandita et al., 2022) |
| | Leaf extract | *In vivo*: *Caenorhabditis elegans* | Polyphenols | (Sobeh et al., 2018) |
| **Antibacterial** | Ethanol leaf extract | *Pseudomonas aeruginosa* | 5-hydroxymethyl-2-furfural and betulin | (Dutta et al., 2023) |
| **Neurological** | Ethyl acetate and hexane fractions | Strongest anti-AChE potential | Anacardic acid derivatives 4 and 5 | (Amir Rawa et al., 2022) |
| **Hepatoprotective and pancreatoprotective** | Methanolic leaf extract | *In vivo*: $CCl_4$-intoxicated rats; *In vitro*: human liver cells | Phenolic compounds | (Sobeh et al., 2018) |
| | | *In vivo*: paracetamol intoxicated Wistar albino rats | NI | (Selvam et al., 2013) |
| | Aqueous bark extract | *In vivo:* streptozotocin-induced diabetes in rats | HHDP-hexoside, bis-HHDP-hexoside, phyllanthuslin g, castalagin, vescalagin, ellagic acid pentoside, methyl ellagic sulfate and ellagic acid | (Mahmoud et al., 2021) |
| **Immunomodulatory** | Hydroethanolic leaf extract | *In vitro*: rat spleen lymphocytes | Gallic, chlorogenic, and ellagic acids, catechin, epicatechin, rutin, quercetin, isoquercitrin, quercetin, and kaempferol | (Bonfanti Azzolin et al., 2019) |
| **Anti-inflammatory** | Methanolic and ethyl acetate leaf extract | *In vivo*: rats in acute and chronic inflammation model (carrageenan) | NI | (Slowing et al., 1994) |
| **Antidiabetic** | Hydroalcoholic seed extract | *In vivo*: hyperglycemic rats fed high-caloric diets | Vitamin C, Glutathione | (González Blas, 2022) |
| **Cardiovascular** | Ethyl acetate fraction from aqueous naïve leaf extract (boiled) | In vitro: isolated hind limb from dog | NI | (Romero, 1995) |
| | Lyophilized leaf extract | *In vivo*: human polymorphonuclear and mononuclear cells | Gallic acid, Rutin | (Inostroza-Nieves et al., 2022) |

NI = Not Informed

Various laboratory studies have shown the antioxidant effects of alcoholic extracts from seeds. These extracts exert their effects through different mechanisms, such as chelation of transition metal catalysts like ferric ions and scavenging of free radicals, including 2,2-diphenyl-1-picrylhydrazyl (DPPH), hydroxyl, superoxide, nitric oxide, and lipid peroxide. The antioxidant capacity of the seed extract has been observed to vary with concentration, exhibiting a potency six times higher than that of Trolox against the superoxide radical (Vasi and Austin, 2009). Animal studies on skin cancer formation indicated that oral administration of the seed extract could significantly increase levels of both non-enzymatic antioxidants (such as glutathione and vitamin C) and antioxidant enzymes (such as catalase and superoxide dismutase), while simultaneously reducing lipid peroxidation (Parmar et al., 2011). Several researchers have investigated the antioxidant potential of the pulp through in vitro assays, including hydroxyl radical scavenging, lipid peroxidation, superoxide radical scavenging, and DPPH assays (Khan et al., 2015). Another study reported that *S. jambos*seeds contain flavonoids with potent antioxidant and free radical scavenging activity, as demonstrated in DPPH assays, which could contribute, at least in part, to their traditionally recognized therapeutic benefits (Zheng et al., 2011). Additional research has confirmed the presence of alkaloids, flavonoids, glycosides, phytosterols, saponins, triterpenoids, and tannins in the alcoholic extract of the seed (Khan et al., 2015).

In a recent study, Liu et al. (2022) identified a key factor for assessing how different variables influence the extraction of triterpenoids from *S. jambos*seeds, using yield as the primary reference measure. Additionally, the antioxidant activity of triterpenoids from the seeds was evaluated by determining their free radical scavenging capacity through DPPH and ABTS assays. The results indicated that the most efficient

extraction conditions included a methanol concentration of 44.30%, a solid-to-liquid ratio of 1:47.18 g/mL, and an extraction time of 101.07 minutes (rounded to 101 minutes). The IC50 values obtained were 24.93 µg/mL for DPPH radical scavenging and 12.16 µg/mL for ABTS radical scavenging. A dose-dependent relationship was observed between antioxidant activity and sample concentration, demonstrating an effective and feasible optimization process. The triterpenoids extracted from *S. jambos*exhibited in vitro antioxidant activity, providing complementary insights into the potential use of seeds in food and medicinal applications (Liu et al., 2022). In another study, Duttas et al. (2023) also reported the high antioxidant capacity of the seed extract, indicating that it can be considered a potential resource for the prevention and treatment of oxidative stress-related diseases, including gout, arthritis, diabetes, cardiovascular diseases, neurodegenerative diseases, cancer, and respiratory tract infections (Duttas et al., 2023) (Table 2).

Leaves

The fruit of *Syzygium jambos* contains numerous phytochemicals with potent antioxidant properties capable of scavenging free radicals. These compounds contribute to both the prevention and mitigation of oxidative stress, a condition arising when the generation of reactive oxygen species (ROS) surpasses the cell's antioxidant defense capacity (Duttas et al., 2023).

*In vitro* evaluations of total phenolic content (TPC), DPPH radical scavenging, nitric oxide (NO•) scavenging, and inhibition of α-amylase and α-glucosidase activities revealed that the 70% ethanolic leaf extract exhibited the strongest bioactive potential across all assays. Metabolite profiling by ultra-high-performance liquid chromatography–electrospray ionization quadrupole-Orbitrap tandem mass spectrometry (UHPLC/ESI Q-Orbitrap MS/MS) and nuclear magnetic resonance (NMR) spectroscopy led to the tentative identification of 59 and 30 metabolites, respectively. Based on this chemical profile, tannins, flavonoids, and triterpenes were identified as the predominant bioactive classes, supporting the antioxidant and antihyperglycemic activities of the *S. jambos* leaf extract (Wong et al., 2024).

The pathogenesis of chronic diseases such as atherosclerosis, cancer, arthritis, and neurodegenerative disorders is closely associated with the excessive production and insufficient clearance of reactive oxygen species, including superoxide anion ($O_2^{\cdot-}$), hydroxyl radical (·OH), and hydrogen peroxide ($H_2O_2$).

Plants possess a natural ability to produce a diverse range of enzymatic and non-enzymatic antioxidants, which can mitigate oxidative damage caused by reactive oxygen species (ROS). The ethanolic leaf extracts from *Syzygium jambos* and *Terminalia citrina* Roxb. demonstrated significant in vitro antioxidant activity compared to the natural antioxidant ascorbic acid. Rajkumari et al. (2018b) reported that, during their study, these extracts exhibited a strong protective effect against oxidative stress-induced damage in hydrogen peroxide ($H_2O_2$)-treated *Saccharomyces cerevisiae* mutant strains (tsa1Δ and sod1Δ). Identification of the leaf extracts by gas chromatography-mass spectrometry (GC-MS) revealed the presence of plant-derived compounds, predominantly terpenes, fatty acids, and vitamins, which contribute to their antioxidant properties. These plant extracts could serve as a valuable source of exogenous antioxidants to counteract the detrimental effects of oxidative stress (Rajkumari et al., 2018b) (Table 2).

Fruit

The antioxidant potential of *Syzygium jambos* pulp was further validated using carotene bleaching, ferric reducing antioxidant power (FRAP), and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assays (Rufino et al., 2010). Additionally, the in vivo antioxidant activity of the aqueous pulp extract was assessed in streptozotocin-induced diabetic rats. The treatment significantly enhanced hepatic antioxidant enzyme levels, including catalase, glutathione peroxidase, glutathione-S-transferase, reduced glutathione (GSH), and superoxide dismutase (SOD), indicating a protective effect against oxidative stress and highlighting the pulp as a promising source of antioxidants in the body (Pandita et al., 2022) (Table 2).

#### *3.3.3. Neurological activity*

Leaves

*Macaranga tanarius* (MT) and *Syzygium jambos* (SJ) have been recognized for their antioxidant, anti-inflammatory, and antidiabetic activities, with growing evidence supporting their potential neuroprotective roles. In the study conducted by Amir Rawa et al. (2022), leaf extracts of both species demonstrated substantial inhibition of acetylcholinesterase (AChE) activity—76.32% for MT and 93.81% for SJ—at a concentration of 50 µg/mL in their respective ethyl acetate and hexane fractions. The investigation aimed to identify the bioactive constituents responsible for this effect and to elucidate the molecular mechanisms underlying AChE inhibition. Through bioassay-guided fractionation, prenylated flavonoids (1–3) were isolated from MT, while anacardic acid derivatives (4 and 5) were obtained from SJ, as confirmed by NMR and mass spectrometric analyses. Among these compounds, derivative 5 exhibited the strongest AChE inhibitory activity ($IC_{50}$ = 0.54 µM), followed by compounds 1, 4, 3, and 2 ($IC_{50}$ = 1.0, 2.4, 6.8, and 33 µM, respectively). Molecular

docking simulations indicated that compound 5 established stronger binding interactions, including three hydrogen bonds, than compound 4—an effect attributed to its saturated alkyl chains. Additionally, the presence of a five-carbon prenyl moiety in compound 1 enhanced its interaction with the enzyme's active site, explaining its superior inhibitory potency compared to derivatives 2 and 3. This study constitutes the first identification of AChE inhibitors from these two plant species, emphasizing their potential as novel neuroprotective candidates (Amir Rawa et al., 2022) (Table 2).

#### 3.3.4. Hepatoprotective and pancreatoprotective activities

Leaves

Sobeh et al. (2018) demonstrated that treatment with *Syzygium jambos* leaf extract in rats subjected to acute $CCl_4$-induced hepatotoxicity led to a marked decrease in hepatic injury biomarkers, including ALT, AST, total bilirubin (TB), total cholesterol (TC), triglycerides (TG), and malondialdehyde (MDA), while simultaneously elevating glutathione (GSH) and superoxide dismutase (SOD) levels. These hepatoprotective effects were comparable to those produced by silymarin. In cultured hepatocytes, pretreatment with *S. jambos* extract significantly attenuated the generation of reactive oxygen species (ROS) triggered by sodium arsenite exposure and increased GSH content, without altering the phosphorylation of p38 MAPK or its downstream target MAPKAPK-2. These results suggest that *S. jambos* exerts its hepatoprotective action primarily through free radical scavenging and inhibition of ROS formation (Sobeh et al., 2018).

Similarly, Selvam et al. (2013) found that pre-administration of methanolic extracts from *S. jambos* leaves (100 and 200 mg/kg) mitigated paracetamol-induced hepatic injury in rats, resulting in reduced serum levels of bilirubin, SGOT, SGPT, and ALP, thereby improving overall liver function markers. Histopathological examination confirmed that the higher dose preserved hepatic cytoarchitecture and reduced cellular degeneration. These findings reinforce the hepatoprotective potential of *S. jambos* leaf extracts and their ability to restore hepatic integrity following toxic insult (Selvam et al., 2013) (Table 2).

Bark

Mahmoud et al. (2021) evaluated the antidiabetic and pancreatic protective effects of *Syzygium jambos* bark extract in a streptozotocin (STZ)-induced diabetic rat model. The animals received daily oral doses of 100 or 200 mg/kg of the extract, while a control group was administered glibenclamide (0.5 mg/kg). STZ was injected two days before the start of treatment, which continued for 14 consecutive days. In diabetic rats, the induction of diabetes led to marked hyperglycemia, elevated fructosamine levels, positive glucosuria, and increased pancreatic concentrations of tumor necrosis factor-alpha (TNF-α), malondialdehyde (MDA), and caspase-3. Concurrently, reductions were observed in serum insulin, pancreatic interleukin-10 (IL-10), B-cell lymphoma 2 (BCL-2), reduced glutathione (GSH), as well as phosphorylated hepatic protein kinase B (p-AKT), glucose transporter 4 (GLUT4), and insulin receptor substrate 2 (IRS2) in hepatic tissue. On the other hand, all these values were mitigated in the treated groups, such that the higher dose displayed an effect comparable to the glibenclamide treatment. These findings demonstrate the significant oxidative and inflammatory disturbances associated with STZ-induced diabetes and suggest that *S. jambos* bark extract may offer protective and regulatory effects on glucose metabolism and pancreatic function (Mahmoud et al., 2021) (Table 2).

#### 3.3.5. Immunomodulatory activity

Leaves

Bonfanti-Azzolin et al. (2019) argue that *S. jambos* appears to exhibit immunomodulatory effects by enhancing mitochondrial activity in lymphocytes and inhibiting AChE activity. Some findings suggest potential adverse effects of these plant-derived products, which could be valuable for therapeutic decision-making and future toxicological research on these extracts when used as herbal medicines (Bonfanti-Azzolin et al., 2019). On the other hand, part of the immunomodulatory effect can be explained by the high myricetin content in *S. jambos* leaves. Myricitrin, a glycosylated flavonol, is a chemical marker for the *Syzygium* genus (Tian et al., 2011), being found in the myricetin-3-O-rhamnoside form in the ethanol extract from *S. jambos* (Sharma et al., 2013) and in the ethanol extract from *S. aqueum* leaves (Manaharan et al., 2012). This flavonol has antioxidant, anti-inflammatory, antinociceptive, and antigenotoxic actions (Xu et al., 2020). Myricetin can decrease the generation of nitric oxide, myeloperoxidase, and malondialdehyde and increase the activity of superoxide dismutase and glutathioneperoxidase, which could be linked to its antioxidant properties (Park et al., 2016). These findings indicate that the high contents of compounds with strong antioxidant capacity in *Syzygium* species can enable them to prevent the proliferation of cancer cells and mitigate the adverse effects induced by chemotherapy (Singh et al., 2018) (Table 2).

#### 3.3.6. Anti-inflammatory activity

Leaves

*S. jambos*is traditionally used to alleviate toothaches, oral ailments, cough, wound healing, and infectious diseases. Its anti-inflammatory activity has been reported for the leaf

extract, attributed to its isolated flavonoid glycosides, which are closely related to analgesic activity (Rezende et al., 2015). On the other hand, the fruit is rich in carbohydrates, vitamin C, beta-carotenes, calcium, phosphorus, and iron and exhibits antidiabetic, antiepileptic, and antiseptic properties (Bartra Vasquez, 2019).

Extracts from various *Syzygium* species contain a diverse range of phytochemicals with the potential to modulate different inflammatory processes (Cock and Cheesman, 2009). For instance, phytosterols, which are abundant in the *Syzygium*genus, influence prostacyclin (PGI2) release by smooth muscle cells and prostaglandin E2 (PGE2) release by macrophages, which may play a role in vasodilatory effects associated with inflammation. It was reported that two glycosylated flavonoids were identified in the $CH_2Cl_2$/MeOH fraction of *S. jambos*: quercetin-3-O-β-d-xylopyranosyl-(1→2)-α-l-rhamnopyranoside and myricetin-3-O-β-d-xylopyranosyl-(1→2)-α-l-rhamnopyranoside. Apaza Ticona et al. (2021) also examined the cytotoxic and anti-inflammatory activities of the isolated compounds. Toxicity was evaluated in *RAW 264.7* macrophage cells using the lactate dehydrogenase (LDH) assay, revealing that all compounds displayed markedly lower cytotoxicity than the reference compound, actinomycin D ($CC_{50}$ = 0.008 µM). The anti-inflammatory and anti-arthritic effects were further assessed through the modulation of inflammatory markers in murine models. Notably, the two glycosylated flavonoids suppressed tumor necrosis factor-alpha (TNF-α) production in *RAW 264.7* cells, exhibiting $IC_{50}$ values of 1.68 and 1.11 µM, respectively. Moreover, when administered at 5 mg/kg, all flavonoids significantly decreased TNF-α, C-reactive protein (CRP), and fibrinogen levels in mice, supporting their potential as anti-inflammatory agents (Apaza Ticona et al., 2021).

In a complementary study, Slowing et al. (1994) assessed the anti-inflammatory activity of four organic extracts obtained from *Syzygium jambos* leaves—hexane, dichloromethane, ethyl acetate, and methanol—in both acute and chronic inflammation models in rats. The extracts were orally administered at doses equivalent to 12.5 g/kg of dried plant material. All extracts demonstrated significant inhibition of both inflammatory phases, with ethyl acetate and methanol extracts exhibiting the strongest effects, comparable to or surpassing those of phenylbutazone (80 mg/kg). The methanolic extract, in particular, showed the greatest efficacy during the chronic inflammatory phase. Additionally, a 10% aqueous infusion tested under the same conditions proved to be more effective than the organic extracts, highlighting the potential therapeutic value of water-based preparations of *S. jambos* (Slowing et al., 1994). In addition, the leaf extract of *Syzygium jambos* was demonstrated to reduce the levels of the pro-inflammatory cytokines interleukin-8 (IL-8) and tumor necrosis factor-alpha (TNF-α). This finding is consistent with previous studies on *S. samarangense* leaf extracts, which exhibit strong anti-inflammatory capacity, as evidenced by a paw edema test in mice. The anti-inflammatory effect is likely attributed to aurentiacine chalcone from *S. samarangense*, which induces downregulation of nitric oxide synthase (NOS) levels and cytokine mRNA expression (Sobeh et al., 2018) (Table 2).

#### 3.3.7. Antidiabetic activity

Seeds

A recent study conducted by González-Blas et al. (2022) found that *S. jambos*seed extract exhibits hypoglycemic properties in rats. Additionally, the study identified the presence of triterpenes, steroids, phenols, flavonoids, lactones, alkaloids, tannins, leucoanthocyanidins, reducing sugars, and amino acids in the extract (González-Blas et al., 2022). This fruit-bearing plant has been traditionally used as a dietary supplement, particularly for the treatment of diabetes and other diseases. A separate study investigated the correlation between *S. jambos* leaf metabolites and bioactivities using a metabolomics approach based on proton nuclear magnetic resonance ($^1$H-NMR). This metabolomics approach provides reliable insights into the potential antioxidant and antihyperglycemic compounds present in *S. jambos* (Wong et al., 2024) (Table 2).

#### 3.3.8. Cardiovascular activity

Leaves

Romero (1995) reported that the aqueous extract of *Syzygium jambos* leaves exerts hypotensive and bradycardic effects comparable to those produced by veratridine and capsaicin. More recently, Inostroza-Nieves et al. (2022) demonstrated that the same extract inhibits secreted protein disulfide isomerase (PDI) activity and downregulates interleukin-6 (IL-6) expression, contributing to its antioxidant and anti-inflammatory effects in activated human endothelial and immune cells. Their findings indicated that *S. jambos* polyphenols modulate endothelin-1 (ET-1)-mediated pathways in a dose-dependent manner, thereby preventing ET-1-induced migration of human polymorphonuclear and mononuclear cells and the subsequent increase in reactive oxygen species (ROS) production. Collectively, these results reinforce the pharmacological potential of *S. jambos* phytochemicals in managing endothelial dysfunction and inflammatory disorders. This study highlights the extract's capacity to regulate endothelial activation, cytokine signaling, and immune responses, positioning it as a promising therapeutic candidate for cardiovascular protection (Inostroza-Nieves et al., 2022) (Table 2).

### 3.4. Toxicity

The toxicity of leaf extract of *S. jambos* was evaluated through *Artemia salina* assays and cytotoxicity evaluations in rat spleen lymphocytes. Several methods were employed, including methyl tetrazolium (MTT) assay, neutral red uptake (NRU) assay, trypan blue exclusion test, and lactate dehydrogenase (LDH) leakage assays. Additionally, the in vitro effect of the extract on acetylcholinesterase (AChE) activity was assessed. According to Bonfanti-Azzolin et al. (2019), the LC50 derived from the *Artemia salina* bioassay was 362.70 ppm, which suggested a low potential for toxic effects of the extract, and it also appears to present immunomodulatory effects by enhancing lymphocyte mitochondrial activity and decreasing AChE activity (Bonfanti-Azzolin et al., 2019).

## CONCLUSION

*Syzygium jambos*is a potential source of bioactive compounds, including flavonoids such as catechin, rutin, epicatechin, isoquercitrin, quercitrin, kaempferol, and quercetin, as well as acids such as malic, citric, ellagic, chlorogenic, caffeic, and gallic acids, among others. Moreover, quercetin is highlighted as the most abundant compound. The aerial parts of *S. jambos* exhibit pharmacological properties with therapeutic applications, including antioxidant, antibacterial, neurological, hepatoprotective, immunomodulatory, anti-inflammatory, antidiabetic, and hypotensive activities.

## AUTHOR CONTRIBUTIONS

All authors have read and agreed to the published version of the manuscript.

## ACKNOWLEDGMENTS

This article was drafted by C.S-C. in fulfillment of the requirements to obtain the degree of Doctor in Pharmacy and Biochemistry offered by the Universidad Nacional de Trujillo, Trujillo, Peru.

## COMPETING INTERESTS

The authors declare no conflicts of interest.

## AUTHORSHIP CONTRIBUTION STATEMENT

CESC was responsible for idealization, conceptualization, supervision and wrote the article. ADGS reviewed the pharmacological aspects and approved the article. MVGS reviewed the chemical aspects. KACG, NNCG and MLSC selected the article. GDGG structured the article. RDDGA wrote and made the overall revision.

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