

Review Paper

Alibertia patinoi (Cuatrec.) Delprete & C.H.Perss. (Borojó): food safety, phytochemicals, and aphrodisiac potential

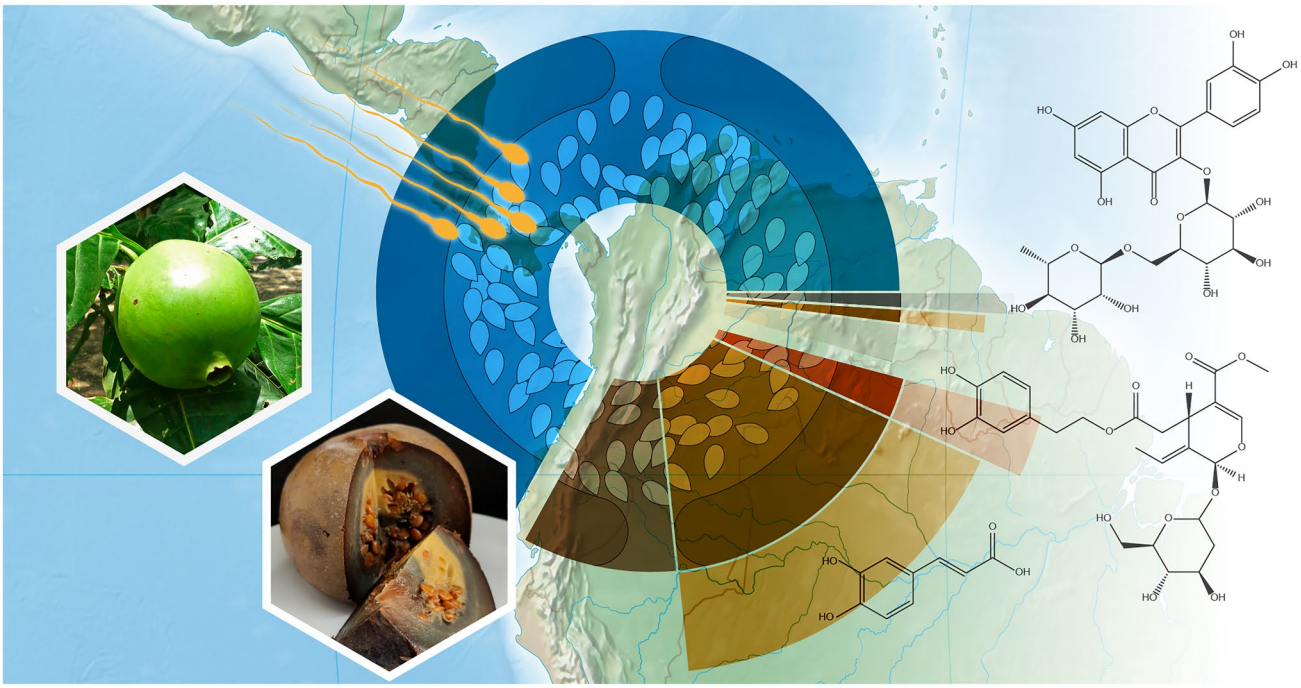
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Abstract
Although the western discovery of borojó [*Alibertia patinoi* Cuatrec. (Delprete & C.H.Perss.)] is as recent as 1948, its several traditional uses in gastronomy and medicine, and its fame as an aphrodisiac are long standing and strong: the "love juice" extracted from it is very appreciated in Colombia, Ecuador, and Panama. Its medicinal potential, though, is far wider. This literature review aims to summarize the knowledge about the fruit, its ethnomedical uses, its biological activity and phytochemical composition, to validate ethnomedical claims and to help envision future lines of research. Borojó extracts have confirmed antimicrobial and antioxidant, and potential anticancer activities, which can be at least partially explained by its phytochemical composition -compounds isolated and identified through Gas Chromatography, High Performance Liquid Chromatography and spectroscopic and spectrometric techniques- rich in phenolic compounds, some of which, for example oleuropein, chlorogenic acid and rutin, possess proven biological activity. There is potential for borojó products as a source of bioactive natural products, which have not been exhaustively identified despite phytochemical screenings that show the presence of unstudied compound families: terpenoids, alkaloids, steroids; and functional alimentary products. Although its aphrodisiac properties have not been confirmed, several compounds with confirmed aphrodisiac activity in other species, mainly flavonoids, are also found in borojó. These, coupled with its nutritional profile and perhaps compounds yet unidentified, could validate the claim.

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Graphical abstract



Keywords Tropical fruit · Ethnopharmacology · *Alibertia patinoi* (Cuatrec.) Delprete & C.H.Perss · Phytochemical screening · Aphrodisiacs · *Rubiaceae*

1 Introduction

Fruit is an integral part of human nutrition and wellbeing due to its fiber, mineral and phytochemical content [1]. Fruit production is a high-volume operation, with a worldwide production of more than 800 million tons in 2019 [2]. Tropical fruits represent more than 10% of this volume [3], and are a valued source of food and feed and also a prized ethnomedicinal resource [4] which has been validated by formal research. Also, fruit byproducts are a valuable market segment that provides materials for the pharmaceutical, cosmetic and other industries [5].

Erectile dysfunction (ED), also referred to as "impotence," is "the consistent or recurrent inability to attain and/or maintain penile erection sufficient for sexual satisfaction" [6]. ED has a high prevalence, is not well quantified and represents a significant quality of life (QoL) burden on affected men and their partners. Besides, it is a risk marker for cardiovascular disease and all-cause mortality [7]. ED is commonly managed with the help of aphrodisiacs since at least the third millennium BC, when an Akkadian incantation pleaded "Let my penis be taut as a harp string!" [8]. Plant aphrodisiacs are present throughout history in most cultures [9], with abundant folklore and traditions to guide and control their use, for example, Mandrake (*Mandragora officinarum* L.) [10].

The global aphrodisiac market volume in 2020 was 4 billion dollars and is expected to keep growing [11]. Several of these aphrodisiacs are of plant origin, and abundant new ED drugs are expected to be found in plants [12]. There are numerous phytochemicals associated with plant aphrodisiac activity: flavonoids and other phenolic



Fig. 1 Roadside sign that reads: "Natural juices, raise the dead, borojó shakes" Portoviejo, Ecuador

compounds, terpenoids, alkaloids, amino acids, fatty acids, etc. [13], which exert their effect in several mechanisms that affect erection. Not all plants considered aphrodisiac have been validated as such [14].

Among traditional aphrodisiacs, *Alibertia patinoi* Cuatrec (Delprete & C.H. Perss.) or *borojó* is a locally valued South American tropical fruit in the *Rubiaceae* family, grown mainly in the Pacific coast of northern South America, in the Chocó bioregion. It is mostly known for its purported revitalizing and aphrodisiac properties (Fig. 1), and it is prominent in food safety, ethnomedicine and social practices in southern Colombia and northern Ecuador. It is consumed fresh, as pulp, and has been made into several processed food products [15], such as wine, jams, energy bars, etc., and its cultivation has expanded to the Ecuadorian Amazon and Central America. Other species of the family, notably *Alibertia edulis* (Rich.) A.Rich. ex DC and *Alibertia sorbilis* Ducke are also cultivated for food and have ethnomedicinal uses [16, 17].

There is a dearth of published research on the species: most of the research output is in Spanish and thus not readily available to the international scientific community. Of the published research the focus is on food products, and there is less emphasis on the bioactivity of the fruit and its phytochemicals. There appears to be no published research on the most famous property -that of an aphrodisiac- of the species.

This work summarizes current knowledge about the ethnomedical and ethnopharmacological properties of borojó, its phytochemical composition, and the research concerning its chemical and biological activity with the objective of identifying trends and detecting gaps in the current knowledge to guide studies and suggest applications that could add value to the species as a source of natural products for pharmaceuticals, nutraceuticals, cosmetics, and others; with emphasis on the claims of aphrodisiac activity, which despite being the species most renowned property outside its native range, seems not to have garnered the same research interest.

2 Methods

A literature search was performed in the following scientific databases: Scopus, Web of Science, *Red de Revistas Científicas de América Latina y el Caribe, España y Portugal* (Redalyc) [18], and the Google Scholar search engine, through web interfaces (search engines, Dimensions app, Research rabbit) and desktop software [19], with no time range, to get all possible results. The keywords used were: borojó, *Borojoa patinoi*, *Alibertia patinoi* with inverted commas for exact matches, and logical connectors, e.g., Alibertia AND patinoi. Documents dealing with biological activity, ethnopharmacology, ethnomedicine, phytochemistry, and foodways were included. English, Portuguese, and Spanish language results were screened for relevancy. When available, more recent documents were preferred over older ones, and indexed publications were used; when necessary, non-peer reviewed documents such as theses, technical reports and other documents were used. There is a comparatively small number of documents in Scopus (22) and WoS (13), but in Redalyc, a database that reflects the research—and language—of countries closer to the distribution area of *A. patinoi*, 82 results were found, of which 33 were within the scope of this review.

A potential limitation of the study is the scope of the research concerning Borojó: a sizable part of it -mostly devoted to food products- is found as preliminary research in undergraduate and master's theses, rather than as published articles.

3 Taxonomy, description, and traditional uses

Originally one of the eleven species in the *Borojoa* genus, *Alibertia patinoi* Cuatrec. (Delprete & C.H.Perss.) was reclassified in the genus *Alibertia* A.Rich. ex DC. in the *Rubiaceae* Juss. Family in 2011 [20], which consists of 15 or 25 accepted species, according to the source [21, 22].

Alibertia patinoi is an evergreen, 3 to 5 m tall tree, characterized "by its large stipules ([19-]25–35[-45] mm long), glabrous leaves with (9 to) 12 to 17 pairs of secondary veins, 5- or 6(7)-merous male flowers, 7- to 9-merous female flowers, stout corollas, and large fruits with a thick, fleshy mesocarp." [20]. The fruit is 7–12 cm in diameter with an average weight of 740 g, changing from green to brown when ripe [23]. Figure 2 shows the unripe borojó fruit. This large, globous fruit gives the species its vernacular name: borojó means "head-fruit" in emberá, a Chocoan language [24].



Fig. 2 Borojó leaves and unripe fruit. Image by Jean-Luc Crucifix, CC BY 3.0



Fig. 3 Distribution of *A. patinoi* by country. Dark green: [26]; Orange: [27]. The Tumbes-Chocó-Magdalena biodiversity hotspot is highlighted in blue in the map on the left

Table 1 Records of wild *A. patinoi* in the literature

Country (Region)	Year	Article title	References
Colombia (Chocó)	1948	*Borojoa*, un nuevo género de Rubiáceas	[25]
Honduras	1975	Enumeración de las plantas de Honduras	[27]
Colombia	1986	A Survey of the Gardenieae and Related Tribes *Rubiaceae*	[33]
Colombia (Chocó)	1999	A nomenclator of Mexican and Central American Rubiaceae	[34]
Colombia (Antioquia)	2011	Listado de las Plantas Vasculares del departamento de Antioquia	[35]
Panamá	1987	Flora of Panama. Checklist and Index. Part 1: The introduction and checklist	[36]
Panamá (Darién)	2004	Catálogo de las Plantas Vasculares de Panamá	[37]
Costa Rica (Puntarenas)	2012	Phytogeography of the trees of the Osa Peninsula, Costa Rica	[38]

3.1 Origin and distribution

Alibertia patinoi was first described by Colombian botanist and pharmacologist José Cuatrecasas Arumí in 1948, from a specimen collected near the Colombian city of Buenaventura, in the Tumbes–Chocó–Magdalena diversity hotspot. [25]. *A. patinoi* is found from Costa Rica to Ecuador [26] with an altitude range of 0–700 m above sea level. It has also been reported in Honduras [27]. It shares part of its distribution range with closely related species *Alibertia sorbilis* Huber ex Ducke; and *Alibertia edulis* (Rich.) A.Rich. ex DC., and although it shares the common name of "Borojó" with other species, notably the Amazonian Borojó (*Duroia maguirei* Steyerm.) the species are not related [28]. Figure 3 shows the geographical distribution of *A. patinoi*.

Table 1 summarizes the location mentions for wild *A. patinoi* in the literature.

The species has spread through cultivation from the Chocó region to the Amazon and can now be found in Ecuadorian and Brazilian Amazon regions as a crop [29–31], and is also being introduced in other tropical countries, such as Australia, Ghana, and India [32]

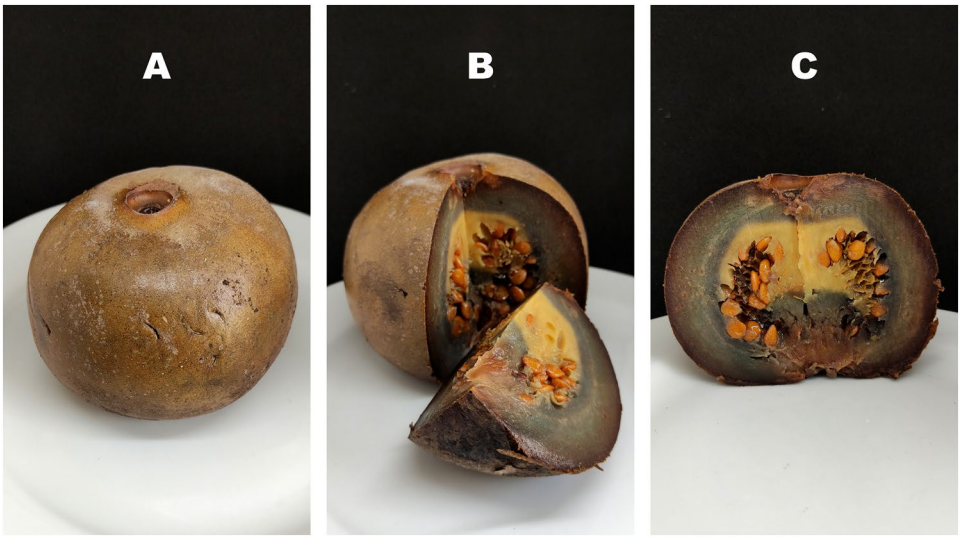


Fig. 4 Ripe Borojó fruit, A: whole, B: quartered, and C: halved. Purchased at the Central Market, Portoviejo, Ecuador. Weight: 817 g; equatorial diameter: 10.5 cm; height: 9.6 cm

3.2 Borojó fruit

The most important Plant organ of *A. patinoi* is its fruit, which is used as both food and medicine, and is included as traditional fare in food security and nutrition planning in Colombia [39]. As it is a dioecious species where only the female trees bear fruit, it is important to optimize the male to female tree ratio to maximize production, which is 10% of male trees, uniformly distributed in the plantation [40]. Traditionally, it is only at the time of flowering when the sex of the tree is recognized; and now this ratio can be better controlled either by early sex determination or by explant production [41, 42]. The fruit is a non-climacteric berry that requires careful post-harvest handling. Around 85% of the weight of the fruit corresponds to a fleshy, sour and aromatic pulp, chocolate brown in color when ripe [23]. Figure 4 shows the fruit exterior and interior with the thin epicarp, and undivided mesocarp and endocarp. [43].

3.3 Traditional uses

The reported uses of *A. patinoi* are food, medicine material in embalming, and social, in the preparation of *chicha* (fermented beverage) for coming of age rituals when boys turn into men [44]. The use of borojó reportedly passed from the aborigines to the Afro-American Chocoans, who have made this fruit part of their culture [45].

Traditionally, the pulp is consumed as a nutritious food rich in energy and minerals in southern Colombia and northern and central Ecuadorian coast and is thus used to combat malnourishment. Borojó-based products include juice, fermented beverages, jams, jellies, compotes, candy, energy bars, and sauces [46, 47]. From an ethnomedical perspective, the pulp is used for wound-healing, dermatological and respiratory conditions, blood pressure control, diuretic and anti-tumor [41, 43, 48] in the communities of southern Colombia (Emberá and Afrocolombian). The fruit is also touted as an energizer and aphrodisiac, and borojó juice (love juice) and shakes are popular under the double

Table 2 Physicochemical and nutritional composition of *Alibertia patinoi* pulps produced in Ecuador and Colombia

Parameter	Unit	C1	C2	C3	E1	E2	E3	E4
Water content	%	66	62.81 ± 3.46	64	69.41 ± 0.26	65.98	69.5 ± 0.25	65.45
Protein	%	0.69	0.88 ± 0.14	3	0.78 ± 0.02	1.18	NS	1.01
Fat	%	0.15	0.09 ± 0.01	0.6	0.06 ± 0.01	0.05	NS	NS
Ash	%	0.76	0.75 ± 0.07	1.8	0.73 ± 0.01	1.07	0.74 ± 0.03	0.76
Total carbohydrate	%	NS	31.00 ± 2.37	30.5	29.03 ± 3.40	29.40	NS	28.94
pH	–	3.03	2.75 ± 0.25	NS	2.93 ± 0.09	3.35	2.91 ± 0.22	2.92
TSS	°Brix	27.3	24.91 ± 2.33	NS	32.00 ± 0.96	NS	32 ± 0.1	24.36
References		[56]	[52]	[50]	[57]	[51]	[58]	[59]

Percentages are in g/100 g fresh pulp. C1: Chocó, Colombia; C2: Chocó, Colombia; C3: Chocó, Colombia; E1: Los Ríos, Ecuador; E2: Chical, Carchi province, Ecuador; E3: Cascales, Sucumbíos province, Ecuador; E4: Amazonia, Ecuador. NS: Not Stated; TSS: Total Soluble Solids

entendre "raisers of the dead" in Colombia, Ecuador, and Panama.

4 Composition and nutritional value

Borojó fruit has a water content of between 60 and 66%, which is less than average (85%) in tropical fruit [49]. The fruit is a source of energy, with around 130 kcal/100 g fresh pulp [50, 51]. The pH of the pulp is about 3.0, which together with its antimicrobial compound content makes it suitable for room temperature or refrigerated storage for up to six months [15], which is relevant for a non-climacteric fruit. The fruit is rich in iron (167.7 mg/100 g) and a source of phosphorus (851 mg/100 g), calcium (51 mg/100 g), sodium (8 mg/100 g), potassium (464 mg/100 g), magnesium (38 mg/100 g) and zinc (1.5 mg/100 g) [50, 52]; and also a source of vitamins B2, B3 and C [50, 53]. The nutritional and phytochemical profile depends on the variety, ripeness, rainfall and sunlight [54]. Table 2 shows the average composition of borojó pulp. No information was found about the composition of Panamanian, Costa Rican, or Honduran cultivar composition. In Panama, the species is considered an orphan fruit [55]. Figure 5 summarizes the composition of the fruit.

The composition of the pulp is fairly consistent despite the geographical differences; the only outliers are protein and ash [50]. All Colombian samples come from the Chocó department, where the fruit originates; Ecuadorian samples come from the Chocó biogeographical region (Carchi and Los Ríos provinces) and from the Amazon (Sucumbíos province and not specified), where *A. patinoi* is an introduced species.

4.1 Food products

The main traditional and industrial use for borojó is its pulp, either consumed directly or processed in jam, gummies, wine, vinaigrettes, energy bars and others, [60]; and although there have been studies and trials for the characterization and use of its seeds and peel as coproducts [61, 62], no seed or peel products seem to have been marketed yet. Most of the borojó consumption takes place in Colombia and Ecuador, and the presence of the fruit in other markets is mostly as a "superfood" in the form of creams, capsules, powder, and seeds for planting.

5 Biological activity

Several ethnopharmacological uses have been tested for validation. Most studies have to do with anticancer activity: immunomodulation [63], antitumor [64], and cytotoxicity [65], showing the importance of natural products in the prevention and treatment of cancer [66]. Other studies validate the antioxidant, antimicrobial, and skin care activity of borojó extracts. In the case of food products, the antioxidant activity will depend on storage conditions, [67]. Table 3 lists the studies. Several ethnopharmacological uses have been tested for validation. Most studies have to do with anticancer activity: immunomodulation [63], antitumor [64], and cytotoxicity [65], showing the importance of natural products in the prevention and treatment of cancer [66]. Other studies validate the antioxidant, antimicrobial, and skin care activity of borojó extracts. In the case of food products, the antioxidant activity will depend on storage conditions, [67]. Table 3 lists the studies.

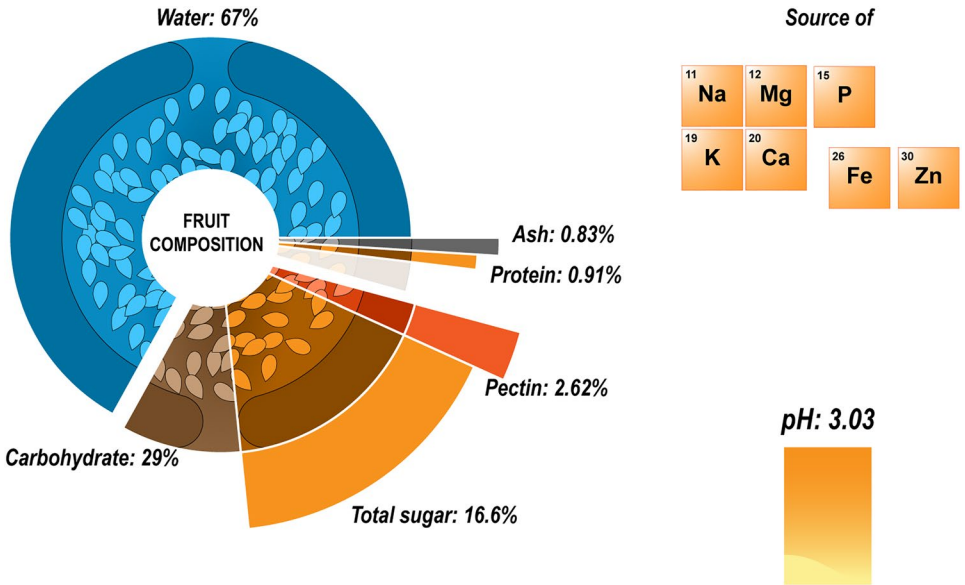


Fig. 5 Borojó pulp composition and mineral content, from the averaged values in Table 2

Table 3 Chemical and biological activity of borojó extracts

Plant organ	Material	Biological model	Activity	Mechanism	Result	References
Homogenized Pulp	MeOH, EtOH:acetone and aqueous extracts	-	Antioxidant	DPPH	EtOH:acetone: 55.55 ± 0.6 µmol TE/100 g	[24]
				FRAP	EtOH:acetone: 426.58 ± 7.26 µmol TE/100 g	
				FIC	EtOH: acetone: 1.63 ± 0.01 µmol EDTAE/100 g	
Homogenized Pulp	Aqueous extract	*S. enteriditis* SE4406	Antimicrobial	Inhibition halo	pH: 2.9: 22.4 ± 0.9 mm pH 6.0: 16.7 ± 0.8 mm	[24]
Pulp	Aqueous extract	*Pseudomonas aeruginosa* (R001- R006), *Staphylococcus aureus*, *Candida* spp	Antimicrobial	Inhibition halo	Activity against *P. aeruginosa* at concentrations > 1.45 µg mL^{-1} Control: Chloramphenicol. Activity: NS	[69]
Pulp	Commercial extract, AgNP	*Candida albicans*	Antimicrobial	Filamentation inhibition	Inhibition at 50 and 100 ng/mL of spherical NPs	[65]
Whole fruit	Treated aqueous extract, spray dried	K-562 cells	Antitumor activity regulation	Just isolated PBMCs, Vγ9Vδ2-T cells treated with 10, 50 y 100 µg/mL pulverized Borojó	Non-cytotoxic to PBCM, promotes its proliferation Vγ9Vδ2-T at 100 µg/mL improve antitumor activity. > secretion of INF-γ, TNF-α	[63]
Culture from leaf cells (callus)	Biomass extract with different solvents	Jurkat and MCF-7 cells	Antitumor activity	Cell viability reduction	AcOEt extract: 60% Jurkat cell viability reduction Hexane extract 52% MCF-7 cell viability reduction	[64]
Pulp	Commercial extract, AgNP	MES-OV	Cytotoxicity	Viability exposure to 50, 100 ng/mL of each AgNPs	Cytotoxicity at 50 and 100 ng/mL of spherical NPs	[65]
Pulp	Cosmetic matrix with pulp powder	SPF grade KM mice, Guinea pigs	Skin care	Skin hydration, anti-aging, anti-UV, anti-anaphylaxis, whitening	Significant effect compared with the cosmetic matrix in all properties Tyrosinase inhibition: 48.18%. Melanogenesis inhibition: 37.21% Optimum concentration: 5%	[70, 71]

Table 3 (continued)

Plant organ	Material	Biological model	Activity	Mechanism	Result	References
Dried fruit	Aqueous extract	Human sperm	Sperm motility	Sperm immobilization Spermicidal activity	Activity increase at 10 min at 20 mg/mL Control: nonoxynol-9. Activity NS	[72]
Dried fruit	Aqueous extract, EtOH extract	HeLa cells	Cytotoxic	Cell viability (MTS)	Aq: 30% viability/24 h EtOH: 38% viability/24 h	[72]

MS:. MeOH: methanol. EtOH: ethanol. AcOEt: ethyl acetate. DPPH: diphenyl picrylhydrazyl assay. FRAP: ferric reducing activity power assay. FIC: ferrous iron chelating assay. TE: Trolox equivalent. EDTAE: EDTA (ethylenediaminetetraacetate) equivalent. K-562: myeloid leukemia bone marrow cell line. PMBC: peripheral blood mononuclear cell. Vγ9Vδ2-T: T-lymphocytes predominant in peripheric human blood. Jurkat: Immortalized T-lymphocyte cell line. MCF-7: breast cancer cell line. Caco-2 human colorectal adenocarcinoma cell line. MES-OV: human ovarian cancer cell line. WKD: Wong-Kilbourne cell line. KM mice: Chinese Kun Ming breed. AgNP: Silver Nanoparticles. SPF: specific pathogen free. Aq: aqueous. NS: Not Specified

Even though aphrodisiac is the most popular non-food use for Borojó, we managed to find only one study related to this property, in which aqueous and ethanolic dried fruit extracts were evaluated on human sperm motility by Medina et al. [68]: the aqueous extract was found to slightly increase sperm motility at 10 min, and both extracts resulted in total sperm immobilization at 60 min, attributed to the presence of spermicidal alkaloids. The same study found *A. patinoi* extracts to be cytotoxic against HeLa cells.

The biological activity tests were performed using pulp (70%), pulp and seeds (10%), leaves (10%) and whole fruit (10%). Aqueous extract (70%), ethanol-acetone extract (10%) and ethyl acetate extract (10%) were used, along with pulp powder (10%). The activity studied was cancer-related (40%), antimicrobial (30%); and antioxidant, spermicidal, and skin care (10% each) (Fig. 6).

The biological activity studies validate some of the ethnopharmacological claims: wound-healing and respiratory use can be related to antibacterial activity; skin care, anti UV and similar activity are associated to antioxidant capacity. The anti-tumor use has been validated in several of the cited studies. There is promise in the activity of the aqueous extract against drug-resistant nosocomial infections [69]. There is correspondence between biological activity and phytochemicals identified in the species, which is mentioned in the next section.

6 Phytochemical composition

The determination of the phytochemical composition of Borojó is not exhaustive yet. Studies have found triterpenes and sesquiterpene lactones and attributed part of the antibacterial activity of the fruit to them, possibly through active phytocomplexes, more active than compounds on their own [73], but so far the only identified terpenoid is limonene. Iridoids are active compounds found in species of the tribe *Gardenieae* to which borojó belongs [74], and could partly account for the biological activity of the fruit. Also alkaloids have been found in phytochemical screenings [43], but no alkaloids have been identified or isolated. Phytochemical screening results are shown in Table 4.

The pulp is the most studied structure of *A. patinoi*. It contains a wide variety of phytochemicals identified through spectroscopic techniques. The compounds are listed in Table 5; phenolic compounds are shown in Fig. 7; and other compounds in Fig. 8. The phenolic and flavonoid compounds present in the fruit give it its antimicrobial and other useful properties [75]; and there are several compounds of interest, such as flavonoids, oleuropein and chlorogenic acid, which exhibit several beneficial effects [76, 77].

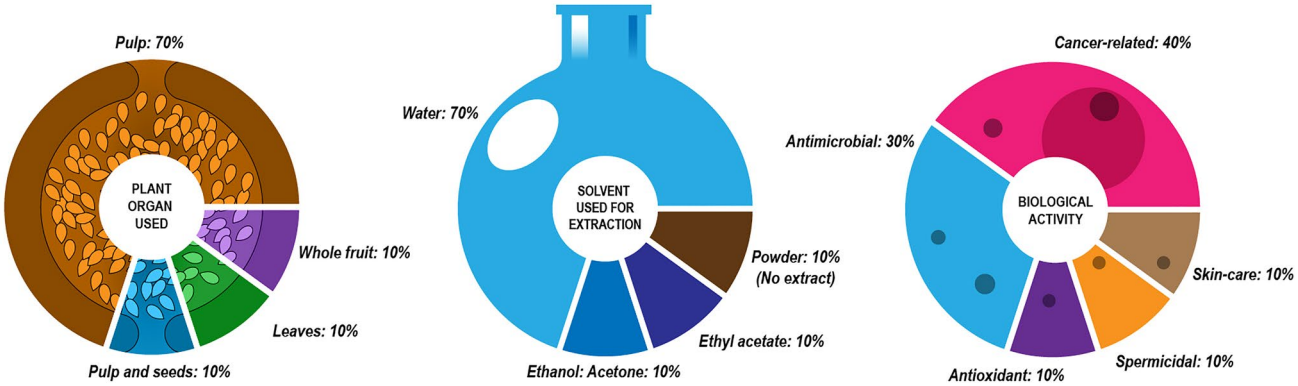


Fig. 6 Chemical and biological activity of borojó

Table 4 Phytochemical screening results for *A. patinoi*

Compound family	Plant organs	Extracts	Tests	References
Alkaloids	Whole fruit, peel	H_2O/EtOH	Dragendorff Mayer Wagner	[62, 68]
Cardiotonics	Whole fruit	EtOH	Kedde	[68]
Coumarins	Cell culture, whole fruit, peel	AcOEt, Hex, EtOH	Baljet	[62, 64, 68]
Flavonoids	Pulp		Shinoda NaOH	[43, 73]
Leucoanthocyanidins	Whole fruit	EtOH	HCl	[68]
Phenols	Peel, pulp	H_2O, EtOH	$FeCl_3$	[73]
Quinones	Peel	EtOH	Börntrager	[62]
Triterpenes/steroids	Whole fruit	EtOH	$CHCl_3$	[64, 68, 73]
Saponins	Peel	EtOH	Foam	[62]

NS: Not specified; EtOH: Ethanol, Hex: Hexane; AcOEt: Ethyl acetate

6.1 Phenolic compounds

Phenolic compounds garner much attention because of their chemical and biological activity and are used by several industries [78]. Antioxidant activity correlates with the phenolic compounds present in *A. patinoi* fruit, but should not be considered the only source of antioxidants [43]. Extraction from fruit can be a sustainable way to obtain phenolic compounds, and thus borojó is an interesting candidate. A breakdown of phenolic compounds present in *A. patinoi* follows.

Phenolic acids identified in *A. patinoi* **(1–4)** show considerable biological activity: anti-inflammatory, antimicrobial, antineoplastic and neuroprotective among others. Hydroxycinnamic acids identified in borojó are compounds **(5–13)**. Chlorogenic acid **(6)** is the most abundant hydroxycinnamic acid found in borojó and exhibits a wide range of biological effects. Chlorogenic acids are a group of compounds [79], and further study into the chlorogenic acid(s) content of borojó is warranted. Flavonoids **(14–24)** are compounds with ample biological activity and nutraceutical and pharmaceutical applications as antibacterial, antiviral, anticancer and protective, among others. One of their effects is diuresis [80], and their presence in the pulp and peel supports the ethnopharmacological use as a diuretic [43]. 2-heptanone has an analgesic-like behavior that may contribute to explain the use of borojó poultices in pain reduction [81].

Among the noteworthy compounds identified in *A. patinoi* are phenolic acids. Some examples of the variety of their bioactivity are presented. Gallic acid (**1**) is a powerful antioxidant, used as reference for antioxidant activity determination with an Antioxidant Activity Index (AAI) of 27 [116]. It also exhibits antineoplastic activity with an IC_{50} of 50.9 ± 1.5 µM against Jurkat cells [117]. Vanillic acid (**2**) exhibits protective effect against oxidative stress with IC_{50} = 250 µg/ml in the D. Mel-2 cell line [118]. *p*-hydroxybenzoic acid (**3**) exhibits hypoglycemic activity with an IC_{50} = 15.1 µM against α-glucosidase in Sprague Dawley rat muscle tissue [119]. Syringic acid (**4**) shows antimitogenic

Table 5 Phytochemical composition of *Alibertia patinoi* fruit

No	Compound	Formula	Plant organs	Isolation/identification	Activity	References
Phenolic acids						
1	Gallic acid	$C_7H_6O_5$	Peel and pulp	UHPLC-MS/MS	Antioxidant, anti-inflammatory, antineoplastic	[69, 82]
2	Vanillic acid	$C_8H_8O_4$	Peel and pulp	UHPLC-MS/MS	Anti-inflammatory, analgesic, antioxidant, neuroprotective	[69, 83]
3	*p*-Hydroxybenzoic acid	$C_7H_6O_3$	Peel and pulp	UHPLC-MS/MS	Antimicrobial, antimutagenic, hypoglycemic	[69, 84]
4	Syringic acid	$C_9H_{10}O_5$	Peel and pulp	UHPLC-MS/MS	Antimicrobial, anti-inflammatory, antidiabetic, antiangiogenic	[69, 85]
Hydroxycinnamic acids						
5	Caffeic acid	$C_9H_8O_4$	Peel and pulp	UHPLC-MS/MS	Antioxidant, anti-inflammatory, anticarcinogenic	[69, 86]
6	Chlorogenic acid (not specified)	$C_{16}H_{18}O_9$	Peel and pulp	UHPLC-MS/MS	Antioxidant, antibacterial, hepatoprotective, cardioprotective, anti-inflammatory, antipyretic, neuroprotective, anti-obesity, antiviral, anti-microbial, anti-hypertension, free radical scavenger, central nervous system stimulator	[69, 77]
7	Ferulic acid	$C_{10}H_{10}O_4$	Peel and pulp	UHPLC-MS/MS	anti-inflammatory, antimicrobial, anticancer, anti-arrhythmic, antithrombotic	[69, 87]
8	*p*-Coumaric acid	$C_9H_8O_3$	Peel and pulp	UHPLC-MS/MS	Antioxidant, anti-inflammatory, antimelanogenic	[69, 88]
9	*o*-Coumaric acid	$C_9H_8O_3$	Peel and pulp	UHPLC-MS/MS	Anticarcinogenic, antibacterial	[69, 89]
10	Sinapic acid	$C_{11}H_{12}O_5$	Peel and pulp	UHPLC-MS/MS	Antioxidant, antimicrobial, anti-inflammatory, anticancer, anti-anxiety	[69, 90]
11	Caftaric acid	$C_{13}H_{12}O_9$	Peel and pulp	UHPLC-MS/MS	Chemoprotective, antimutagenic antidiabetic	[69, 91, 92]
12	Chicoric acid	$C_{22}H_{18}O_{12}$	Peel and pulp	UHPLC-MS/MS	HIV-1 inhibitor, neuroprotective, antioxidant, antiobesity	[69, 93]
13	Rosmarinic acid	$C_{18}H_{16}O_8$	Peel and pulp	UHPLC-MS/MS	Antioxidant, antibacterial	[69, 94]
Flavonoids						
14	Catechin	$C_{15}H_{14}O_6$	Peel and pulp	UHPLC-MS/MS	Antioxidant, antimicrobial, anti UV	[69, 95]
15	Epicatechin	$C_{15}H_{14}O_6$	Peel and pulp	UHPLC-MS/MS	Antioxidant, antimicrobial, anti UV	[69, 95]
16	Quercetin	$C_{15}H_{10}O_7$	Peel and pulp	UHPLC-MS/MS	Antioxidant, anti-inflammatory, antibacterial, antiviral, radical scavenging, gastroprotective, and immunomodulatory	[69, 96, 97]
17	Kaempferol	$C_{15}H_{10}O_6$	Peel and pulp	UHPLC-MS/MS	Antioxidant, anti-inflammatory, antimicrobial, cardiovascular, neuroprotective	[69, 98, 99]
18	Myricetin	$C_{15}H_{10}O_8$	Peel and pulp	UHPLC-MS/MS	Antioxidant, anti-inflammatory	[69, 100]
19	Rutin	$C_{27}H_{30}O_{16}$	Peel and pulp	UHPLC-MS/MS	Antibacterial, antiprotozoal, antitumor, anti-inflammatory, antiallergic, antiviral, cytoprotective, vasoactive, hypolipidemic, antiplatelet, antispasmodic, antihypertensive	[69, 101, 102]
20	Isoquercetin	$C_{21}H_{20}O_{12}$	Peel and pulp	UHPLC-MS/MS	Neuroprotective, cytotoxic	[69, 103]
21	Hesperidin	$C_{28}H_{34}O_{15}$	Peel and pulp	UHPLC-MS/MS	Antioxidant, anti-inflammatory, anticancer	[69, 104]
22	Neohesperidin	$C_{28}H_{34}O_{15}$	Peel and pulp	UHPLC-MS/MS	Antioxidant, anti-aging	[69, 105]
23	Apigenin	$C_{15}H_{10}O_5$	Peel and pulp	UHPLC-MS/MS	Antiviral	[69, 106]
24	Luteolin	$C_{15}H_{10}O_6$	Peel and pulp	UHPLC-MS/MS	Antioxidant, nephroprotective	[69, 99]
Other phenolics						
25	Oleuropein		Peel and pulp	UHPLC-MS/MS	Antioxidant, anti-inflammatory, cardioprotective, neuroprotective, anticancer, hepatoprotective, gastroprotective, antidiabetic	[69, 76]

Table 5 (continued)

No	Compound	Formula	Plant organs	Isolation/identification	Activity	References
26	Phloridzin	$C_{21}H_{24}O_{10}$	Peel and pulp	UHPLC-MS/MS	Antioxidant, antidiabetic, bone loss prevention, memory enhancement, cancer cell inhibition, cardioprotective	[69, 107]
Alcohols						
27	Ethanol	C_2H_6O	Peel and pulp	HS-SPME-GC-MS		[24]
28	2-Pentanol	$C_5H_{12}O$	Peel and pulp	HS-SPME-GC-MS		[24]
29	1-Hexanol	$C_6H_{14}O$	Peel and pulp	HS-SPME-GC-MS		[24]
30	2-Heptanol	$C_7H_{16}O$	Peel and pulp	HS-SPME-GC-MS		[24]
31	1-Octanol	$C_8H_{18}O$	Peel and pulp	HS-SPME-GC-MS		[24]
32	2-Nonanol	$C_9H_{20}O$	Peel and pulp	HS-SPME-GC-MS		[24]
33	4-Decanol	$C_{10}H_{22}O$	Peel and pulp	HS-SPME-GC-MS		[24]
34	3-Nonen-1-ol	$C_9H_{18}O$	Peel and pulp	HS-SPME-GC-MS		[24]
Ketones						
35	2-Heptanone	$C_7H_{14}O$	Peel and pulp	HS-SPME-GC-MS	Analgesic, chemical communication	[24, 108]
36	2-Nonanone	$C_9H_{18}O$	Peel and pulp	HS-SPME-GC-MS	Bactericidal, nematocidal, insecticidal	[24, 109]
Esters						
37	Ethyl acetate	$C_4H_8O_2$	Peel and pulp	HS-SPME-GC-MS		[24]
38	Butyl acetate	$C_6H_{12}O_2$	Peel and pulp	HS-SPME-GC-MS		[24]
39	1-Methylethyl acetate	$C_5H_{10}O_2$	Peel and pulp	HS-SPME-GC-MS		[24]
40	Methyl hexanoate	$C_7H_{14}O_2$	Peel and pulp	HS-SPME-GC-MS		[24]
41	Ethyl hexanoate	$C_8H_{16}O_2$	Peel and pulp	HS-SPME-GC-MS	Antifungal	[24, 110]
42	Methyl octanoate	$C_9H_{18}O_2$	Peel and pulp	HS-SPME-GC-MS		[24]
43	Benzyl acetate	$C_9H_{10}O_2$	Peel and pulp	HS-SPME-GC-MS		[24]
44	Ethyl octanoate	$C_{10}H_{20}O_2$	Peel and pulp	HS-SPME-GC-MS		[24]
Carboxylic acids						
45	Acetic acid	$C_2H_4O_2$	Peel and pulp	HS-SPME-GC-MS		[24]
46	Oxalic acid	$C_2H_2O_4$	Peel and pulp	HPLC-Standards		[24]
47	Tartaric acid	$C_4H_6O_6$	Peel and pulp	HPLC-Standards		[24]
48	Malic acid	$C_4H_6O_5$	Peel and pulp	HPLC-Standards		[24]
49	Citric acid	$C_6H_8O_7$	Peel and pulp	HPLC-Standards		[24]
50	Hexanoic acid	$C_6H_{12}O_2$	Peel and pulp	HS-SPME-GC-MS		[24]
Other						
51	Maltose	$C_{12}H_{22}O_{11}$	Peel and pulp	HPLC-Standards		[24]
52	Sucrose	$C_{12}H_{22}O_{11}$	Peel and pulp	HPLC-Standards		[24]
53	Fructose	$C_6H_{12}O_6$	Peel and pulp	HPLC-Standards		[24]
54	Glucose	$C_6H_{12}O_6$	Peel and pulp	HPLC-Standards		[24]
55	Ascorbic acid	$C_6H_{12}O_6$	Peel and pulp	HPLC-Standards	Antioxidant	[24]
56	Limonene	$C_{10}H_{16}$	Peel and pulp	HS-SPME-GC-MS	Antioxidant, anticancer, antinociceptive, antidiabetic,	[24, 111]
57	Ixoside	$C_{16}H_{20}O_{11}$	Peel and pulp	HPLC-PDA HPLC-ESI-MS NMR	Analgesic, antipyretic, central nervous system depressant, antileishmanial and hypoglycemic	[112, 113]
58	4,8-dicarboxyl-8,9-iridoid-1-glycoside	$C_{16}H_{20}O_{11}$	Pulp	HPLC-MS/MS NMR, IR	Antioxidant Stimulates differentiation of embryonic neural stem cells	[114, 115]

UHPLC-MS/MS: Ultra High Performance Liquid Chromatography coupled to dual mass spectrometers. ACE Excel 2 C_{18}-PFP column. HS-SPME-GC-MS: Headspace solid phase micro-extraction, gas chromatography, mass spectrometry. TRACSIL Meta.X5 column. HPLC: High Performance Liquid Chromatography. PDA: photo diode array. ESI-MS: Electrospray ionization mass spectrometry. HPLC-MS/MS: High Performance Liquid Chromatography coupled to dual Mass Spectrometers. NMR: Nuclear magnetic resonance spectroscopy. IR: Infrared spectroscopy

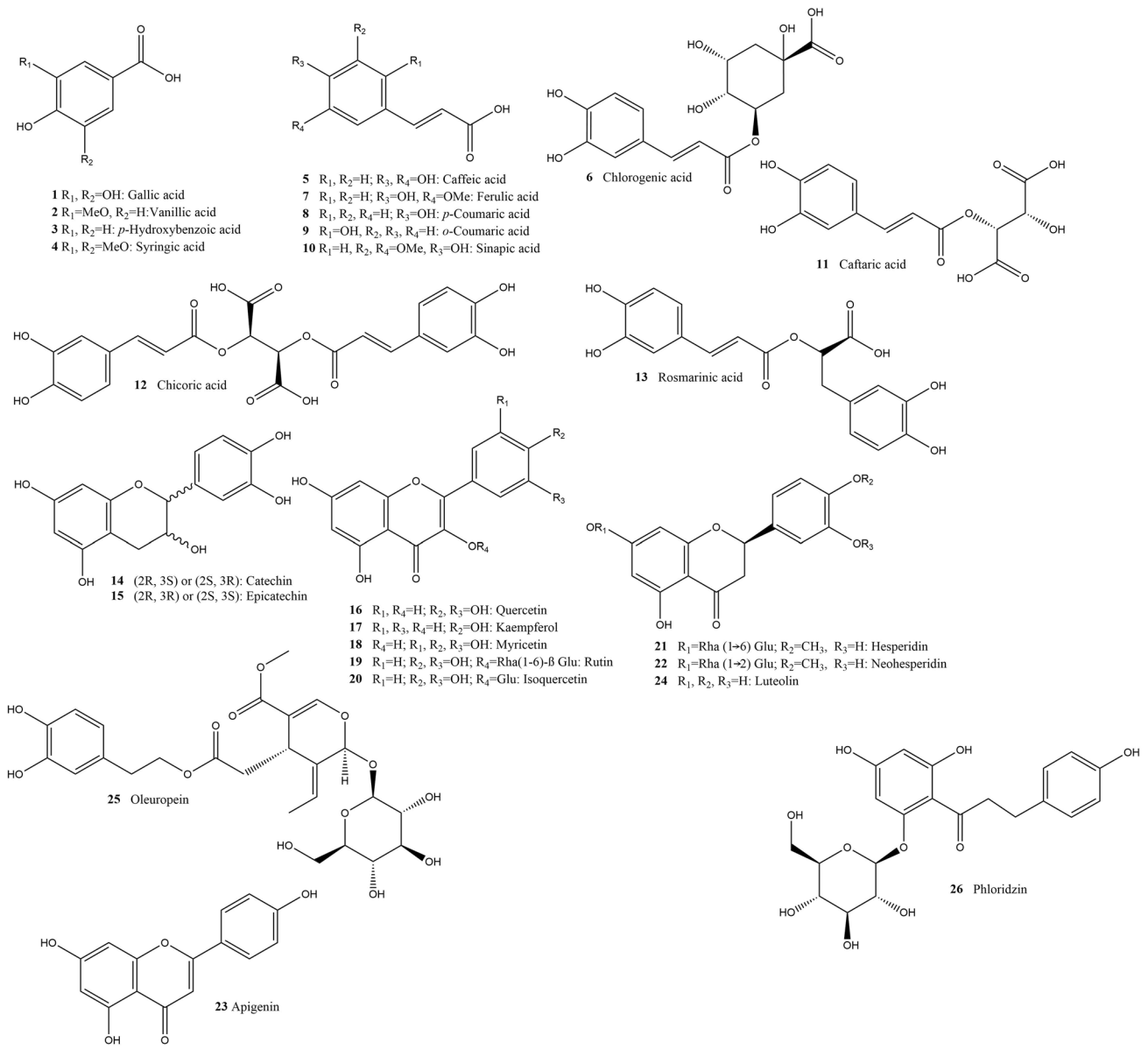


Fig. 7 Phenolic compounds identified in *A. patinoi*

(IC_{50} = 0.95–1.2 mg/mL) and chemosensitizing effect in human colorectal cancer cell lines (SW1116 and SW837) [120].

Among hydroxycinnamic acids, caffeic acid (**5**) inhibits enzymes associated with aging: collagenase IC_{50} = 74.42 µg/mL, elastase IC_{50} = 76.95 µg/mL, tyrosinase IC_{50} = 145.91 µg/mL), and hyaluronidase IC_{50} = 244.45 µg/mL [121]. Chlorogenic acid (**6**) shows hypolipemiant effect at 1–10 mg/kg body weight/day supplementation in rats [77]. Ferulic acid (**7**) shows cytotoxic effects on MCF-7 and HepG2 cell lines (IC_{50} = 75.4 and 81.38 µg/mL) [122]. *p*-Coumaric acid (**8**) inhibits human tyrosinase at IC_{50} = 3 µM, while *o*-Coumaric acid (**9**) does so at IC_{50} = 300 µM [88]. Sinapic acid (**10**) exhibits among others, antiproliferative activity, with an IC_{50} value of 7×10^{-11} M in human breast cancer T47D cell line [90]. Caftaric acid (**11**) shows hypoglycemic activity at IC_{50} 1.25–2.5 mg/mL [92]. Chicoric acid (**12**) is known for inhibiting HIV-1 integrase at an IC_{50} = 100 nM [123]. Rosmarinic acid (**13**) shows inhibitory activity against influenza virus neuraminidase with the IC_{50} of 0.40 µM [124].

Flavonoids are a family of biologically active compounds. Epicatechin (**15**) is a potent, stable antioxidant with IC_{50} ~ 1.5 µg/mL [125]. Compounds quercetin (**16**), kaempferol (**17**), rutin (**19**), apigenin (**23**) inhibit the angiotensin converting Enzyme (ACE) at IC_{50} = 43–73 µM [126].

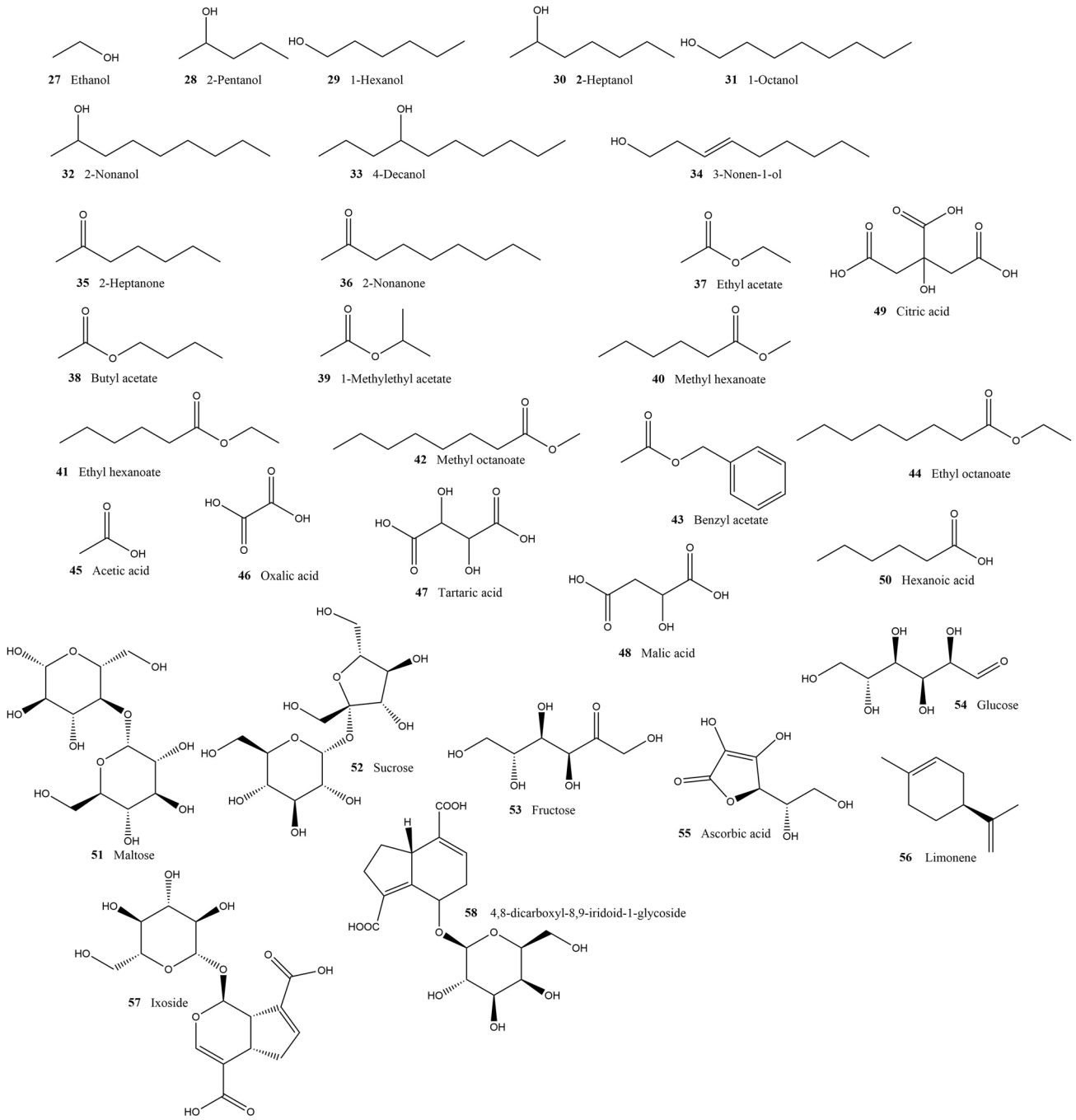


Fig. 8 Other compounds identified in *A. patinoi*

17 is active against enterovirus EV-A71 at 35 μM [127]. Myricetin (**18**) shows hypoglycemic effect on human intestinal α-glucosidase (IC_{50} = 0.38 mM) [128]. **19** exhibits, among others, antiaging activity comparable to **5** [121]. Luteolin (**24**) has activity against Coxsackieviruses (CA-16), EC_{50} = 10.52 μM [127].

Oleuropein (**25**), a secoiridoid, exhibits among others an antiproliferative effect: IC_{50} = 247.4 μM for MG63 osteosarcoma cells [129]. Ixoside (**57**) is a weak antioxidant (IC_{50} = 109.2 μM) and exhibits weak antimicrobial activity at 13 μg/mL with 17% inhibition against *C. albicans* [130]. 4,8-dicarboxyl-8,9-iridoid-1-glycoside (**58**) at 50 μg/ml stimulates differentiation of embryonic neural stem cells in Sprague–Dawley rats [115].

Other activities are shown in Table 6.

Table 6 Compounds present in borojó with aphrodisiac and fertility activity

Nº	Compound	Aphrodisiac Activity /Fertility stimulator	Model	Values	References
1	Gallic acid	Improved blood flow, decrease of blood viscosity, stimulation of internal peristalsis and improved sexual behavior	Male rats	NS	[135]
5	Caffeic acid	Preincubation of spermatozoa with protects against oxidative DNA damage in vitro	Human Sperm	10–100 µmol/L	[143]
6	Chlorogenic acid	↑ Number of sperm in epididymis ↓ Testosterone degradation ↑ Sperm protection against oxidative stress	Sprague–Dawley albino male rats Human semen	Rats:5 mg/kg bw Human semen: 100 µM	[144, 145]
7	Ferulic acid	↑ Sperm count	Sprague–Dawley albino male rats	5 mg/kg bw	[145]
12	Chicoric acid	↓ Activity of Phosphodiesterase 5	Docking	NS	[146]
13	Rosmarinic acid	↑ Protect Sperm quality (sperm motility, plasma membrane integrity, and acrosome integrity) to storage ↑ AMPK phosphorylation ↑ T-AOC and SOD activity increased ↓ MDA content ↑ Sperm-zona pellucida binding capacity during liquid storage at 17 °C	Boar sperm	40 µM	[147]
		↑ Protection against sertoli cell apoptosis caused by electromagnetic fields ↑ Testosterone serum level vs EMF	Male Wistar rats	5 mg/kg bw	[148]
14	Catechin	↑Improves sexual behavior, low toxicity	Male rats	50 mg/kg bw Control: Sildenafil citrate 4 mg/kg bw	[149]
16	Quercetin	↑ Vasorelaxing effects on the corpus cavernosum strips	Guinea pig	0.075 mg/ml	[150]
24	Luteolin	↑ Protective against testicular damage caused by EMF-induced oxidative stress: testis size and testosterone levels	Wistar albino rats	20 µg/kg/day	[151]
25	Oleuropein	↑ Plasma LH level increased dose dependently ↑ Testicular testosterone level	Rats	1 g/kg diet	[152]
27	Phloridzin	↑ Erectile function Suppress the decrease in Erectile function due to testicular toxicity in diabetic rats	Diabetic Sprague–Dawley rats	100 mg/kg, twice daily	[153]

↑: Increase, ↓: Decrease, AMPK: AMP-activated protein kinase, T-AOC: Total Antioxidant Capacity-Colorimetric, SOD: superoxide dismutase, MDA: Malondialdehyde, LH: Luteinizing hormone, EMF: electromagnetic field

The activity reported for some of the compounds identified in Borojó pulp partially explain the biological activity of extracts and validate some ethnopharmacological uses of the fruit: the most frequent activities of the listed compounds are antioxidant (13%), anti-inflammatory (9%), and antimicrobial, antiviral and neuroprotective (7% each). These account for the traditional uses of wound-healing, dermatological and respiratory conditions; blood pressure control can be related to the presence of chlorogenic acid and flavonoids; and anti-tumor use can be related to limonene, caffeic acid and other compounds present in the fruit. The use as a diuretic can be partially explained by the presence of flavonoids. Iridoids **57** and **58** have been identified in *A. patinoi* extracts and are mentioned in conjunction with its antioxidant and antimicrobial effects [131].

Of the compound families identified in the phytochemical screenings shown in Table 4, alkaloids, cardiotonics, coumarins, leucoanthocyanidins, quinones, triterpenes and saponins are not represented in the compounds shown in Table 5 because no compounds from these families have been identified or isolated, which may be due to a false identification or to isolation methods not targeted to these compound families. This opens the possibility of targeting these families for compound identification and evaluation of their bioactivity. We are aware of the limitations of phytochemical screenings, but we believe it is worth pursuing the identification of these families through quick, low-cost methods i.e., via

infrared spectroscopy, to rule out false positives. A study of closely related species *A. sorbilis* volatile compounds found a variety of aldehydes and ketones, alcohols, esters and terpenes [132]. Another study on *A. sorbilis* found neutral polysaccharides with antitumor potential [133].

6.2 Aphrodisiac activity

According to the FDA "Any product that bears labeling claims that it will arouse or increase sexual desire, or that it will improve sexual performance, is an aphrodisiac drug product" [134]; in that sense, there are several mechanisms by which a product could be considered as an aphrodisiac, e.g.: (a) improving nutrition, consequently improving sexual performance and libido; (b) specific physiological effects, such as improving blood flow, or allowing psychoactive substances to cross the blood–brain barrier and stimulate some area of sexual arousal in the brain; (c) increase in testicular, serum cholesterol and testosterone levels, and regulating Luteinizing hormone [12, 135]. The goal of treatments is always to ensure improvement in the quantity, duration, and quality of penile erection suitable for satisfactory intercourse, which can be provided by Phosphodiesterase inhibitors—the most commercially successful of which is Sildenafil (Viagra), and Adenyl cyclase stimulants (ACE) [7, 136].

Concerning the aphrodisiac affect attributed to the Borojó fruit, there are no studies on the subject, but the nutritional composition of the fruit, in the form of sugars, minerals such as calcium, potassium, magnesium and zinc [137], and vitamin B3 [138] supports the feasibility of an aphrodisiac effect. Also, several compounds found in verified aphrodisiac plants, such as flavonoids [139] are also present in borojó. Plant species with high concentrations of phenols such as gallic acid, chlorogenic acid, quercetin, rutin, isoquercitrin and kaempferol that exhibit antioxidant properties also have ACE and arginase inhibitory effect [140–142]. This suggests that *A. patinoi* has therapeutic potential in the management of erectile dysfunction. Table 6 and Fig. 9 describe several studies that mention mechanisms previously described with compounds present in *A. patinoi* fruit. Also, sexual potency is closely linked to male fertility, which is why we have also included studies related to sperm quality, quantity, and viability times in Table 6. The promising activity of these

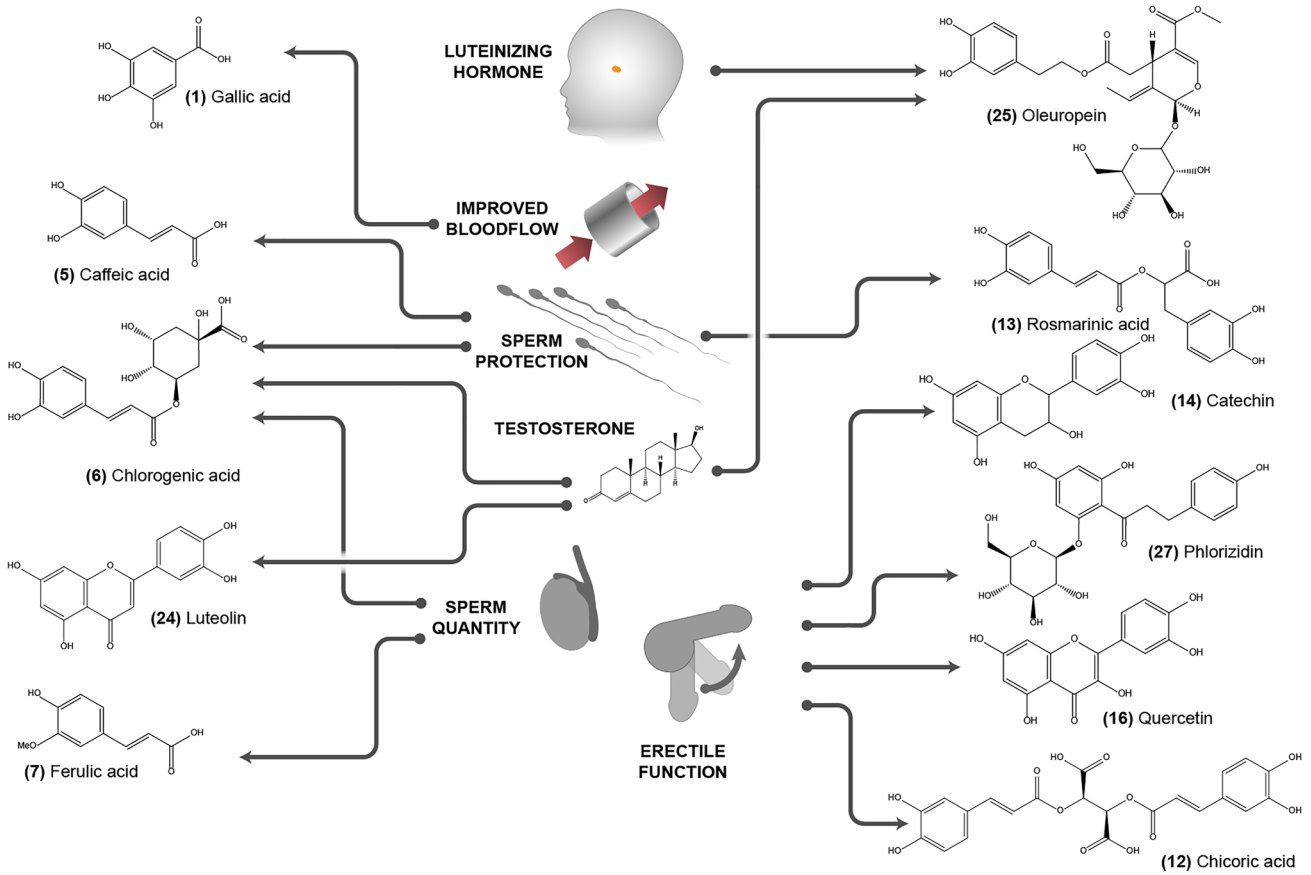


Fig. 9 Some existing mechanisms for possible aphrodisiac effects of *Alibertia patinoi*

compounds, coupled with the incomplete phytochemical elucidation of *A. patinoi* leaves the door open for the confirmation of the effect.

Eleven compounds with varied aphrodisiac-like activities have been identified in borojó. Direct validation of the aphrodisiac activity is still pending, but this presence leads credibility to the ethnopharmacological use of the fruit. Direct research is needed to validate or disprove this claim in biological models.

7 Conclusion

Borojó (*Alibertia patinoi*) is a fruit that has local nutritional, food safety and ethnopharmacological importance, currently with limited geographical distribution but with solid commercial cultivation procedures that may help its expansion. A significant portion of the research concerning this species is not available in global scientific databases, but in regional databases and non-English publications, mainly Spanish and Portuguese.

Several bioactive compounds have been identified in borojó with antioxidant, antibacterial and anticancer activities. Even though the aphrodisiac effect has not been validated, eleven compounds -mainly phenolic acids and flavonoids- present in borojó are present in proven aphrodisiac species. This opens the possibility of validating the effect through studies and possibly, not yet identified phytochemicals. The identification of phytochemical constituents in the species is far from exhaustive and presents a bioprospecting opportunity.

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Data availability Not applicable.

Declarations

Conflict of interest The authors declare no conflict of interest.

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