

Overview of custard apple (*Annona reticulata* L.), pharmacology and phytochemicals. A review.

Generalidades de la anona (*Annona reticulata* L.), farmacología y fitoquímicos. Una revisión.

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ABSTRACT

Annona (*Annona reticulata* L.) is produced in outfield conditions or backyard orchards. Its structural organs, mainly leaves, root, stem bark, seeds, and pulp contain phytochemical compounds, such as tannins, alkaloids, phenols, glycosides, terpenes, flavonoids, and steroids, these compounds have pharmacological, antihelmintic, analgesic, anti-inflammatory, antihyperglycemic, antioxidant and cytotoxic properties for several types of cancer. The pulp contains sugars, vitamins, and minerals, having the potential for the development of new food products with bioactive compounds.

CLAVE KEY WORDS :*Annona reticulata* L., bioactive compounds, pharmaceutical.



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RESUMEN

La anona (*Annona reticulata* L.) se reproduce en condiciones de campo abierto o bien en huertos de traspatio. Sus órganos estructurales, principalmente hojas, raíz, corteza del tallo, semillas y pulpa contienen compuestos fitoquímicos, tales como taninos, alcaloides, fenoles, glucósidos, terpenos, flavonoides y esteroides, estos compuestos tienen propiedades farmacológicas, antihelmínticas, analgésicas, antiinflamatorias, antihiper glucémicas, antioxidantes y citotóxicas para varios tipos de cáncer. La pulpa contiene azúcares, vitaminas y minerales, teniendo potencial para el desarrollo de nuevos productos alimenticios con compuestos bioactivos.

PALABRAS CLAVE: *Annona reticulata* L., compuestos bioactivos, farmacéutica.

Introduction

The Annonaceae family is composed of 108 genera and 2,400 species, distributed in tropical and subtropical climates (Hernández-Fuentes *et al.*, 2016; Couvreur *et al.*, 2012). In Mexico, in the states of Chiapas, Veracruz, Tabasco, Guerrero, Oaxaca, Nayarit, Michoacán, Yucatán, and Campeche, the genus *Annona* is the most important for the production of edible fruits (Andrés & Andrés, 2011; Pino, 2010), 15 species have been recorded and also the Atemoya, which is a variety derived from the cross of *Annona cherimola* x *Annona squamosa* (atemoya); the species cultivated for commercialization are soursop (*Annona muricata* L.), custard apple (*Annona cherimola* Mill.) and saramuyo (*Annona squamosa* L.) (Hernández-Fuentes *et al.*, 2016). Efforts are being made to rescue the anona (*Annona reticulata* L.) and encourage its cultivation for the production of fruits since these are rich in carbohydrates, proteins, calcium, phosphorus, iron, thiamin, niacin, riboflavin, magnesium, ascorbic acid, and carotenoids, which constitutes an alternative for fruit production (Andrés & Andrés, 2011). Additionally, the Food and Agriculture Organization of the United Nations (FAO, 2012) indicates the use of crops that allow countries to take advantage of their potential, to promote economic development, reduce hunger and poverty, as well as the need to consider the anona in situ conservation activities (Andrés & Andrés, 2011). In this context, the objective of this review is to collect information on the generalities, pharmacology, and phytochemicals of *A. reticulata* to highlight its economic, social, and medicinal importance.

Methodology

This research focused on the collection of information with the words *Annona reticulata*; in the Elsevier, Scielo, Wiley online library, Redalyc, Springer and Scopus, and ScienceDirect

databases, from 1991 to August 2022, taking as a source of information scientific articles published in indexed and refereed journals.

Results and Discussion

Botanical description. According to the Integrated Taxonomic Information System (ITIS), the taxonomic description of the anona (*Annona reticulata* L.) is as follows:

Table 1. Taxonomy of the *Annona reticulata* L.

Kingdom	Plantae
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Order	Magnoliales
Family	Annonaceae
Genus	Annona L.
Species	<i>Annona reticulata</i> L.

Source: Integrated Taxonomic Information System (ITIS, 2022)

Generalities

Custard apple (*A. reticulata*) is native to Guatemala and Belize (Pino, 2010) and is distributed throughout America, Africa, and Asia (Chavan *et al.*, 2014). In Mexico, the soursop is found in the tropical regions of Veracruz, Tabasco, Yucatán, Oaxaca, Chiapas, Guerrero, Sinaloa, Puebla, Quintana Roo and Michoacán, at an altitude between 50 and 1150 masl. They develop in tropical and subtropical climates, between 0 and 1,500 m altitude in areas of Central America and South America, in Guatemala and Ecuador they are found below 1,220 masl and 1,500 masl, respectively, and in the Philippines and Sri Lanka for below 800 masl and 915 masl, respectively (Chavan *et al.*, 2014). They adapt to conditions of low rainfall (dry season) and resist low temperatures (-2.78 °C to 2.22 °C), remaining dormant during the winter without suffering serious damage (Morton, 2013), still reporting fruit production. Although conditions may be favorable for its cultivation, soursop is found mainly in backyard orchards or the wild along rural roads (Andrés & Andrés, 2011). It is observed that this fruit tree is widely distributed and easily adaptable to adverse conditions, ecophysiologically speaking. The propagation of the anona is by seed (sexual), although it can also be asexual; grafts have been made between the soursops themselves or as soursop, saramuyo, and atemoya rootstocks (Chavan *et al.*, 2014; Morton, 2013). This fruit tree is an important vehicle to propagate other species of the same family.

The anona tree is between 3 and 10 m tall, has an extended or rounded crown, its trunk measures 25 to 35 cm in diameter, and is considered the most vigorous of the *Annona* genus (Figure 1). It has many lateral branches, cylindrical stems with lenticels, and very short brown

tomenta (Figure 1). The leaves are lanceolate to oblong-lanceolate, dark green, and measure 25 to 30 cm long and 7 cm wide (Chavan *et al.*, 2014; Lim, 2012; Andrés & Andrés, 2011; Waghulde *et al.*, 2021) (Figure 1). The inflorescences are found in drooping clusters and are grouped from 2 to 10, with external narrow fleshy petals that never open completely and pedicels that measure between 1.5 and 3 cm in length (Andrés & Andrés, 2011; Chavan *et al.*, 2014) (Figure 1). The inflorescences present inefficient pollination, due to the slow opening of the petals, the position of the gynoecium to the androecium, the low number of pollinators, and the fact that they do not make uniform contact with the area of the gynoecium curve (Pinto, 1995) so it is necessary to practice artificial or manual pollination (Andrés & Andrés, 2011).



Figure 1. Tree (A), branches (B), leaves (C) and inflorescences (D) of *A. reticulata* L. Source: Own elaboration.

The fruit weighs between 0.1 and 1.0 kg, is heart-shaped, almost spherical or irregular, and measures 10 to 12 cm in length and 8 to 16 cm in diameter. The color of the epicarp, the shape of the areoles, and the type of reticulation in the fruits can vary (Pino, 2010). Vidal *et al.* (2015) describe red, yellow, purple, and pink epicarp colors.

According to Chavan *et al.* (2014), the epicarp is thin and yellow to brown when ripe, and reticulated. Andrés & Andrés (2011), mention that the epicarp is coriaceous and reddish yellow, with areoles above the carpels. Morton (2013) reports that the epicarp is thin but resistant and can be yellow-brown, pink, reddish, or reddish-brown when the fruits are ripe and with a slight, moderate, or marked reticulation. Pareek *et al.* (2011) mention that the maturity index of cherimoya, atemoya, saramuyo, and anona includes changes in the color of the epicarp, from dark green to light green or yellow-green. Finally, Lim (2012) mentions that the fruits have more or less smooth, rhomboid or hexagonal areoles separated by a marked reticulation, not tuberculate, with a reddish-brown or red epicarp when ripe (Figure 2).



Figure 2. Epicarp colors of fruits of *A. reticulata* L. Source: Own elaboration.

The pulp is creamy-white, somewhat granular, and moderately juicy (Morton, 2013; Chavan *et al.*, 2014). It has a pointed central fibrous core that is attached to the thick stem that extends to more than half of the fruit, this being a particularity of the fruit (Chavan *et al.*, 2014). The seeds are small, about 1.25 cm long, oblong, laterally compressed, smooth, hard, shiny, dark brown or black, and there are commonly 40 to 76 seeds per fruit (Morton, 2013; Andrés & Andrés, 2011; Lim, 2012) (Figure 3). Chavan *et al.* (2014) mention that the seeds are viable for more than 12 months in dry air storage at 5°C.



Figure 3. Seeds of the fruit of *A. reticulata* L. Source: Own elaboration.

Phenology. The phenological characteristics of cultivated plants provide useful tools to understand the relationships between plants and their environment. For anona, bud development is between June and April, leaf display from April to December, and senescence from December to April. As for the flowers, their growth occurs in November-December and flowering in December. The development of the fruits goes from December to February and fruiting from March to May (González-Esquinca *et al.*, 2016), finding that it is an annual harvest fruit tree.

Pharmaceutical uses

The structural organs of the anona tree, such as the leaves, pulp, bark, root, and seeds, are used as medicinal sources since they have pharmacological properties such as anthelmintic, analgesic, anti-inflammatory, antihyperglycemic, antipyretic, antioxidant, antimicrobial, healing and cytotoxic; in addition to containing phytochemicals such as tannins, alkaloids, phenols, glycosides, flavonoids and steroids (Jamkhande & Wattamwar, 2015; Ngbolua *et al.* 2018). Chithra *et al.* (2016) evaluated the phytochemical components of soursop and anona, concluding that the fruits of both have terpenoids, tannins, alkaloids, and ascorbic acid, potential in the field of pharmacology as antioxidants and antibacterials for the development of possible drugs to cure some diseases such as diabetes, cancer, acquired immunodeficiency syndrome, and various degenerative diseases. It is an important fruit tree for its potential in the pharmaceutical industry since all its structural organs can be used for this purpose.

Leaves. Various bioactive compounds with important biological activities have been found in the leaves (Table 2). In this regard, Zaman & Pathak (2013) reported the presence of phytochemicals such as alkaloids, tannins, phenolic compounds, flavonoids, glycosides, and steroids in methanolic extracts of leaves of anona. On the other hand, Rahman *et al.* (2011) have reported that methanolic extracts from anona leaves have antihyperglycemic activity in mice, measuring glucose tolerance and blood glucose levels by the glucose oxidase method, obtaining a reduction in blood glucose level of 56.1 %, being an alternative for the treatment of diabetic patients; anti-inflammatory activity has also been demonstrated in rats, possibly due to the presence of acetogenins or the inhibitory activity of cyclooxygenase-2 (Bhardwaj *et al.* 2019). In this regard, Pathak *et al.* (2021) observed anti-inflammatory and antioxidant activity in methanolic extracts in anona leaves due to quercetin and gallic acid. In addition, in leaf extracts, the terpenoid has been chemically investigated: anonaretin A (Chavan *et al.*, 2014) among others; bioactive phytochemicals such as quinones, coumarins, steroids, tannins, phenols, glycosides, alkaloids, terpenoids, flavonoids, and saponins have been found (Sangeetha *et al.*, 2014), these are antioxidant, antibacterial and antimicrobial agents (Ahirwar & Tembhre, 2021). Mazumdar *et al.* (2022) found β -sitosterol and quercetin in ethanolic extracts of anona leaves, which increased the proliferation of lymphocytes (CD4, CD8, and B cells) and improved the intracellular expression of IL-2 and IL-6, so it can be a potential alternative for various diseases related to the immune system. Sankpal (2022) identified 33 phytochemicals, such as phenolics, flavonoids, alkaloids, tannins, glycosides, and terpenoids in methanolic extracts of the leaves, most of which have been reported to have important biological activities with antioxidant properties (copaene), antimicrobial ((-)-spatulanol), anticancer (p-dioxane-2,3-diol) and anti-inflammatory (caryophyllene). Likewise,

a study carried out on three species of *Annona* (soursop, saramuyo, and anona) to determine the antioxidant capacity by the DPPH ABTS, nitric oxide and hydroxyl methods, observing that the extracts of anona leaves showed higher antioxidant capacity compared to Saramuyo (Baskar *et al.*, 2007). The presence of acetogenins in anona leaves, such as 9-one anoreticuin, squamona, solamin, anomonisin, and rolliniastatin-2, has been reported (Roham *et al.*, 2016; Anaya-Esparza *et al.*, 2020). These compounds have antitumor activity in cancer cells of the breast, prostate, liver, colon, and lung, among others. Leaf extracts are an important source of phytochemicals that act on cancer cells from different organs or cell lines.

Pulp. Phytochemical compounds have been reported in the pulp of the anona fruit (Shetty *et al.*, 2020) (Table 2), 17 polyphenols were quantified in methanolic extracts by HPLC-MS/MS, finding higher concentrations of salicylic acid, 3-hydroxybenzoic acid, 2,4-dihydroxybenzoic acid and gallic acid, in comparison to the reported in soursop and custard apple with antioxidant activity. Polysaccharides were extracted from the epicarp and pulp of anona, showing antioxidant activity by the DPPH method and antimicrobial activity through the release of tetrahydrocurcumin; therefore, they can be used for application on wounds (Senthilkumar *et al.*, 2022; Shetty *et al.*, 2020). The presence of catechins in the pulp has been reported, with *in vitro* antioxidant activity which was measured by the DPPH method, and *in vitro* anticancer activity by the 3-(4,5-dimethylthiazol-2-yl)-2-bromide methodology, 5-diphenyltetrazole (MTT), against breast cells (Rayar & Manivannan, 2016). In addition, in the pulp of anona, aromatic phytochemicals have been reported through CG-MS, Wong & Khoo (1993) identified 47 of these, mainly terpenoids (98.3 %) and monoterpenoids (91.2 %); of volatile compounds, the most abundant are terpen-4-ol (70.5 %) and α -terpineol (10 %). Jamkhande & Wattamwar (2015) report pinene, myrcene, limonene, terpinene-4-ol, and germacrene Pino *et al.* (2019) analyzed the flavor composition of four commercial Cuban soursop cultivars and identified 180 volatile compounds, of these 120 were reported for the first time in the pulp of this fruit; among the identified compounds, α -pinene, β -pinene, myrcene, limonene, terpinene-4-ol and germacrene stand out. Bhardwaj *et al.* (2019) reported the existence of essential oils in the leaves, roots and fruits of anona, such as β -pinene, spatulenol, elemol, bisabolene, (E,E)-farnesyl acetate, benzyl benzoate, and the arthurmerone. There is an important source of these for use in the pharmacological area through the extraction of compounds with antioxidant, antimicrobial, and anticancer activity from the anona pulp.

Cortex. The bark of the tree is used as a uterotonic, antispermatogenic, anti-infertility, antifungal, antiplatelet, abortifacient, antiovaratory, diuretic, antiseptic, anticonvulsant, vermifugal, analgesic as a growth disturbing agent (Pathak & Zaman, 2013). Phytochemicals have been reported in this structural organ (Table 2). Saad *et al.* (1991) isolated reticulacin and bulatacin acetogenins from bark extracts by NMR; in addition to two diterpenes and an alkaloid called limodenine. Hisham *et al.* (1994) elucidated the structure of acetogenin: reticulacinone, isolated from bark extracts of soursop stems by NMR. Bhalke & Chavan (2011) evaluated custard apple bark extracts in mice, reporting analgesic activity and mild to moderate central nervous system depressant activity, probably due to increased concentration of gamma aminobutyric acid in the brain. Obenu *et al.* (2022) extracted secondary metabolites in extracts with n-hexane in the bark of anona, such as steroids, flavonoids, and alkaloids; however, its antioxidant capacity, determined by DPPH, was very weak. Phytochemicals with different pharmacological activities have been identified in the bark of anona trees, although some with low antioxidant capacity.

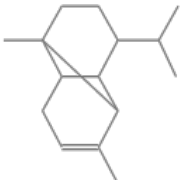
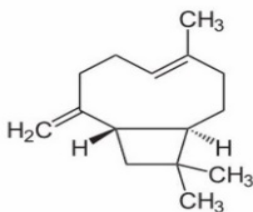
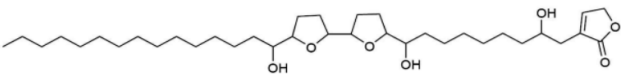
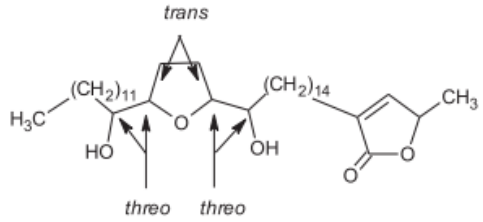
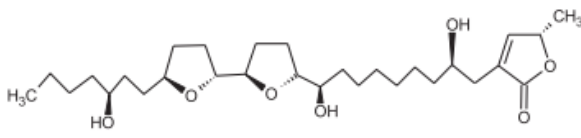
Root. As for the soursop root, it is known to have alkaloids such as anonaine, limodenine, norushinsunine and reticulin (murchinine), with biological properties (Morton, 2013; Anaya-Esparza *et al.*, 2020) (Table 2). Bharadwaj *et al.* (2019) have reported that a methanolic extract, within a carbopol gel, analyzed by GC-MS, has the potential to effectively treat skin cancer. Suresh *et al.* (2011) reported that anona root extracts significantly decrease tumor growth in mice, attributing this to the presence of acetogenins and alkaloids, so they can be used as a chemopreventive agent in cancer therapy. Phytochemical compounds with biological importance against some types of cancer have been extracted from the root.

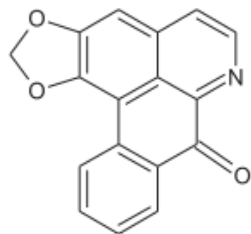
Seeds. Phytochemical antitumor compounds have been identified in anona seeds by NMR. Maeda *et al.* (1993) characterized a series of tryptamine acyl alkaloids and Chang *et al.* (1998) isolated a cytotoxic acetogenin (7-lactone acetogenin), and anoretichuin, 9-one anoreticuín, cis/trans-bulatationone, bulatacin, cis/trans-murisolinone, and squamocin (Table 2), in ethyl acetate extract from seeds of anona, these acetogenins caused death in different cancer cell lines (Hep. G2, Hep.2, 3, 15, KB, and CCM2), including bladder cancer (T24). Bulatacin has been reported to cause cancer cell death in leukemia and breast cancer (Ravimanickam *et al.*, 2018) and anonacin against bladder cancer (Yuan *et al.*, 2003), both found in the seeds. Anaya-Esparza *et al.* (2020) reported the presence of steroids in anona seeds: canphane, α -copaene, β -elemene, β -caryophyllene, β -bisabolene, δ -cadinene, and germacrene D, by GC-MS. In hexanic extracts of anona seed, acetogenins with anti-angiogenic activity were obtained in mice by GC-MS, decreasing tumor growth and metastasis (Hassan *et al.* 2021). The seeds contain a wide variety of antitumor compounds, which act on different cell lines, with the potential to be used in treatments for humans.

Food uses

Custard apple pulp is commonly consumed fresh or can be added to smoothies, custards, ice cream, and to make sauces for cakes and puddings (Morton, 2013); It is rich in carbohydrates, fats, proteins, vitamin A, vitamin C (Sasidharan & Jayadey, 2017; Jamkhande & Wattamwar, 2015; Morton, 2013) and minerals such as Ca, P, K, Mg, Na, Cl, S, Mn, Zn, Fe, Cu, Se, Co, Ni and Cr (Leterme *et al.*, 2006) (Table 3). Moo-Huchin *et al.* (2014) indicate that anona fruits represent great potential for the development of new food products with bioactive properties. Senadeera *et al.* (2018) added anona, soursop, and saramuyo pulp to yogurts, increasing the antioxidant capacity, analyzed by the DPPH and FRAP methods. Leterme *et al.* (2006) found that soursop contains 0.373 mg/g of vitamin C compared to 0.206 mg/g in soursop and considered that some chemical components found in this fruit show anticancer properties against bladder cancer and other cancer cells. Custard apple pulp has a large number of compounds that give it nutritional importance for human consumption and gives it the potential to be used in the food industry.

Table 2. Phytochemicals reported in different organs of *A. reticulata* L.

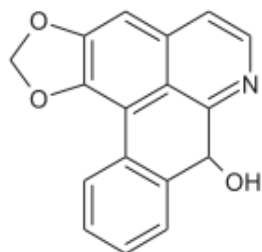
Phytochemical	Organ	References
 <p>Copaene</p>	Leaves	Sankpal (2022)
 <p>Caryophyllene</p>	Leaves	Sankpal (2022)
 <p>Rolliniastatin-2</p>	Leaves	Jamkhande & Wattamwar (2015) Ngbolua <i>et al.</i> (2018) Bhalke & Chavan (2011)
 <p>Reticulatacin</p>	Cortex	Jamkhande & Wattamwar (2015) Ngbolua <i>et al.</i> (2018)
 <p>Bulatacin</p>	Cortex Seeds	Jamkhande & Wattamwar (2015) Ngbolua <i>et al.</i> (2018) Bhalke & Chavan (2011)



Cortex
and root

Jamkhande & Wattamwar (2015)
Ngbolua *et al.* (2018)

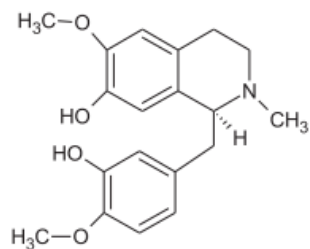
Liriodenine



Root

Jamkhande & Wattamwar (2015)
Ngbolua *et al.* (2018)

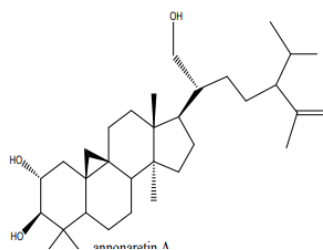
Norushinsunin



Root

Jamkhande & Wattamwar (2015)
Ngbolua *et al.* (2018)

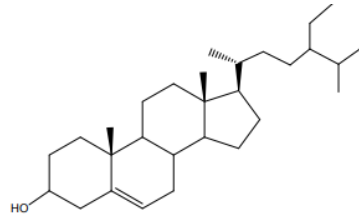
Reticulin



Leaves

Ngbolua *et al.* (2018)

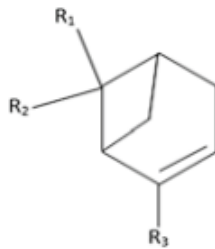
Anonaretin A



β -sitosterol

Leaves

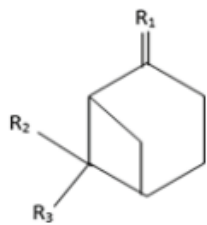
Ngbolua *et al.* (2018)



α -pinene

Pulp

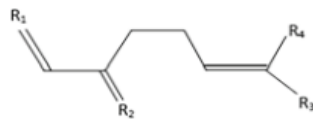
Bhardwaj *et al.* (2019)



β -pinene

Pulp

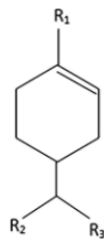
Bhardwaj *et al.* (2019)



Myrcene

Pulp

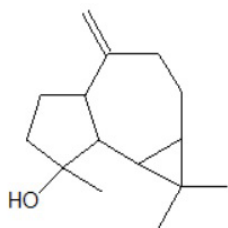
Bhardwaj *et al.* (2019)



Limonene

Pulp

Bhardwaj *et al.* (2019)



(-)-Spatunol

Leaves
and pulp

Sankpal (2022)

Source: Own elaboration based on Jamkhande & Wattamwar, (2015).

Table 3. Nutritional content per 100g fresh pulp*

	Quantity	Units
Energy	80 – 101	kcal
Moisture	68.3 - 80.1	g
Protein	1.17 - 2.47	g
Total lipids	0.5 - 0.6	g
Ash	0.5 - 1.11	g
Carbohydrates	20 - 25.2	g
Crude fiber	0.9 - 6.6	g
Calcium	17.6 – 27	mg
Iron	0.42 - 1.14	mg
Phosphorus	14.7 - 32.1	mg
Carotenes	0.007 - 0.018	mg
Thiamin	0.075 - 0.119	mg
Riboflavin	0.086 - 0.175	mg
Niacin	0.528 - 1.190	mg
Ascorbic acid	15.0 - 44.4	mg
Nicotinic acid	0.5	mg

* Maximum and minimum levels of analysis carried out on pulp, in Central America and the Philippines. Source: Morton (2013).

Parek *et al.* (2011) published data on the nutritional content in the anona pulp, reporting lipid and carbohydrate values below the minimum values (Table 3). In 2010, the United States Department of Agriculture (USDA) reported the composition of nutrients in anona pulp: 0.231 g of saturated fatty acids, 18 mg of magnesium, 2.4 g of total dietary fiber, 19.2 g of vitamin C, 382 mg

potassium, 0.135 mg pantothenic acid, 0.221 mg pyridoxine, 4 mg sodium, 33 U vitamin A, 0.007 g tryptophan, 0.037 g lysine, 0.004 g methionine, niacin below lower value and calcium above the upper value according to what is reported in Table 3. A large amount of nutrients contained in the anona pulp is observed, which gives it importance for its consumption by humans.

Toxicity

The bark of the anona tree contains 0.12 % of the alkaloid anonaine, which can cause paralysis in frogs; branch sap is irritating and can severely damage the eyes (Morton, 2013). However, Shivanna *et al.* (2019) indicate that the aqueous extracts of anona leaves supplied to mice did not have toxic effects on hematological and biochemical parameters. Furthermore, there were no adverse histopathological effects on the liver, kidney, and pancreas; therefore, these extracts could be used in food formulations with bioactive compounds.

Conclusions

The *A. reticulata* tree has potential for cultivation, since all its structural organs can be used from it because they have anticancer, anti-inflammatory, antihyperglycemic, analgesic, and antioxidant properties. The fruit is important for its nutrients, having the potential for the development of new food products with bioactive properties due to the high levels of antioxidants. The bioactive compounds present in the different organs of the anona plant have significant potential for possible industrialization and pharmaceutical use. The toxicity of the compounds present in the different organs of the soursop has not been sufficiently studied, so it represents an opportunity for future research.

Authors contribution

Conceptualization of the work, author 2, author 3; methodology development, author 3, author 4; software management, author 1, author 2; experimental validation, author 2, author 3; analysis of results, author 1, author 2; Data management, author 3, author 4, author 5 and author 6; writing and preparation of the manuscript, author 1, author 2; writing, revising and editing, author 3, author 4, author 5 and author 6; project manager, author 2; funding acquisition, author 2, author 3. All authors of this manuscript have read and accepted the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

References

- Ahirwar, P., & Tembhre, M. (2021). Preliminary phytochemical analysis, antioxidant activity, phenolic and flavonoid contents of *Annona reticulata* leaf extract. *Asian Journal of Experimental Sciences*. 35(2),19-25. http://www.ajesjournal.com/PDFs/2021_2/paper-4.pdf
- Anaya-Esparza, L. M., García-Magaña, M. L., Domínguez-Ávila J. A., Yahia, E. M., Salazar-López, N. J., González-Aguilar, G. A., & Montalvo-González E. (2020). Annonas: Underutilized species as a potential source of bioactive compounds. *Food Research International*. 138,109775. <https://doi.org/10.1016/j.foodres.2020.109775>
- Andrés, A. J. & Andrés, H. L. (2011). *Biología, diversidad, conservación y uso sostenible de los recursos genéticos de Annonaceae en México*. Universidad Autónoma de Chapingo. Centro Regional Universitario Centro Occidente. ISBN: 978-607-12-0198-0.
- Baskar, R., Rajeswari, V., & Kumar, T. S. (2007). In vitro antioxidant studies in leaves of *Annona* species. *Indian Journal of Experimental Biology*. 45(5),480-485. <https://pubmed.ncbi.nlm.nih.gov/17569293/>
- Bhalke, R. D., & Chavan, M. J. (2011). Analgesic and CNS depressant activities of extracts of *Annona reticulata* Linn. bark. *Phytopharmacology*. Inforesights Publishing. 1(5),160-165. https://www.doc-developpement-durable.org/file/Culture/Arbres-Fruitiers/FICHES_ARBRES/cachiman-coeur-de-boeuf/Analgesic%20and%20CNS%20depressant%20activities%20of%20extracts%20of%20Annona%20reticulata.pdf
- Bharadwaj, R., Haloi, J., & Medhi, S. (2019). Topical delivery of methanolic root extract of *Annona reticulata* against skin cancer. *South African Journal of Botany*. 124,484-493. <https://doi.org/10.1016/j.sajb.2019.06.006>
- Bhardwaj, R., Pareek, S., Sagar, N. A., & Vyas, N. (2019). Bioactive compounds of *Annona*. In: *Bioactive compounds in underutilized fruits and nuts*. Springer Nature Switzerland AG. India. https://doi.org/10.1007/978-3-030-06120-3_5-1
- Chang, F. R., Chen J. L., Chiu H. F., Wu M. J., & Wu Y. C. (1998). Acetogenins from seeds of *Annona reticulata*. *Phytochemistry*. 47(6),1057-61. [https://doi.org/10.1016/s0031-9422\(97\)00675-4](https://doi.org/10.1016/s0031-9422(97)00675-4)
- Chavan, S. S., Shamkuwar, P. B., Damale, M. G., & Pawar D. P. (2014). A comprehensive review on *Annona reticulata*. *International Journal of Pharmaceutical Sciences and Research*. 5(1),45-50. [http://dx.doi.org/10.13040/IJPSR.0975-8232.5\(1\).45-50](http://dx.doi.org/10.13040/IJPSR.0975-8232.5(1).45-50)
- Chithra, K. N., Chinju, S., & Binu, T. (2016). Evaluation of mahor phytochemical constituents of two edible fruit yielding species of Annonaceae: *Annona muricata* L. and *Annona reticulata* L. *Journal of Medicinal Plants Studies*. 4(4),198-202. <http://www.plantsjournal.com/>

[archives/2016/vol4issue4/PartC/4-4-22-145.pdf](#)

Couvreur, T. L. P., Maas, P. J. M., Meinke, D. M. S., & Kebler, P. J. A. (2012). Keys to the genera of Annonaceae. *Botanical Journal of the Linnean Society*. 74-83. <https://doi.org/10.1111/j.1095-8339.2012.01230.x>

Food and Agriculture Organization (FAO) (2012). Resumen del segundo Plan de Acción Mundial para los Recursos Fitogenéticos para la Alimentación y la Agricultura. FAO. Italia. 20 p.

González-Esquinca, A. R., De la Cruz-Chacón, I., Castro-Moreno, M., & Riley-Saldaña, C. A. (2016). Phenological strategies of *Annona* species from the tropical deciduous forest of Chiapas, 94(3),531-541. <https://doi.org/10.17129/botsci.645>

Hassan, I. F., Razzaq, M. B. A., Al-Shammaril, A. M., & Rasheed, A. M. (2021). Anti-angiogenic activity of *Annona reticulata* n-hexane seeds extract: in vivo study. *Biochemical and Cellular Archives*. 21(2),4327-4335. https://www.researchgate.net/publication/356597569_ANTI-ANGIOGENIC_ACTIVITY_OF_ANNONA_RETICULATA_N-HEXANE_SEEDS_EXTRACT_IN_VIVO_STUDY

Hernández-Fuentes, L. M., Andrés-Agustín J., Espíndola-Barquera M. D. C., Castañeda-Vildózola A., Ballesteros-Patrón G., & Vera-Sánchez K. S. (2016). Recursos genéticos de Anonáceas (Annonaceae) en México: Situación actual y perspectivas. *Agro Productividad* 9(4),3-8. <https://revista-agroproductividad.org/index.php/agrop&roductividad/article/view/739/606>

Hisham, A., Sunitha, S., Sreekala, U., Pieters, L., De Bruyne, T., Van den Heuvel, H., & Claeys, M. (1994). Reticulacinone, an acetogenin from *Annona reticulata*. *Phytochemistry*. 35(5),1325-1329. [https://doi.org/10.1016/S0031-9422\(00\)94847-7](https://doi.org/10.1016/S0031-9422(00)94847-7)

ITIS (Integrated Taxonomic Information System). Disponible en: https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=18099#null.

Jamkhande, P. G., & Wattamwar, A. S. (2015). *Annona reticulata* Linn. (Bullock's heart): Plant profile, phytochemistry and pharmacological properties. *Journal of Traditional and Complementary Medicine*. 5(3),144-152. <https://doi.org/10.1016/j.jtcme.2015.04.001>

Leterme, P., Buldgen, A., Estrada, F., & Londoño, A. M. (2006). Mineral content of tropical fruits and unconventional foods of the Andes and the rain forest of Colombia. *Food Chemistry*. 95(4),644-652. <https://doi.org/10.1016/j.foodchem.2005.02.003>

Lim, T. K. (2012). Edible medicinal and non-medicinal plants. Volume 1, Fruits. Springer Science & Business Media. 201-206. ISBN 978-90-481-8660-0. <https://doi.org/10.1007/978-90-481-8661-7>

Maeda, U., Hara, N., Fujimoto, Y., Srivastava, A., Gupta, Y. K., & Sahai, M. (1993). N-fatty acyl tryptamines from *Annona reticulata*. *Phytochemistry*. 34(6),1633-1635. [https://doi.org/10.1016/S0031-9422\(00\)90860-4](https://doi.org/10.1016/S0031-9422(00)90860-4)

Mazumdar, S., Ghosh, A. K., Purohit, S., Das, A. K., Bhattacharyya, A., & Karmakar, P. (2022).

- Immunomodulatory activity of etanol extract of *Annona reticulata* L. leaf in cultured immune cells and in Swiss albino mice. *Journal of Ayurveda and Integrative Medicine*. 13(2),100554. <https://doi.org/10.1016/j.jaim.2022.100554>
- Moo-Huchin, V. M., Estrada-Mota, I., Estrada-León, R., Cuevas-Glory, L., Ortiz-Vázquez, E., Vargas y Vargas, M. L., Betancur-Ancona, D., & Sauri-Duch, E. (2014). Determination of some physicochemical characteristics, bioactive compounds and antioxidant activity of tropical fruits from Yucatan, Mexico. *Food Chemistry*. Elsevier. 152,508-515. <https://doi.org/10.1016/j.foodchem.2013.12.013>
- Morton, J. F. (2013). *Fruits of warm climates*. Echo Point Books & Media. 550 p. ISBN: 1626549729
- Ngbolua, K. N., Inkoto, C. L., Bongo, G. N., Mokel, L. E., Lufuluabo, L. G., Ashande, C. M., Tshibangu, D. S. T., Tshilanda, D. D., & Mpiana, P. T. (2018). Phytochemistry and Bioactivity of *Annona reticulata* L. (Annonaceae): A Mini-review. *South Asian Research Journal of Natural Products*. 1(1),1-11. https://www.researchgate.net/publication/323759836_Phytochemistry_and_Bioactivity_of_Annona_reticulata_L_Annonaceae_A_mini-review
- Obenu, N. M. A., Adu, R. E. Y., & Bria, Y. A. A. (2022). Extraction and screening of phytochemical non-polar extracts “At Anonse” from plant’s bark (*Annona reticulata* L.), *Seminar Nasional Kimia dan Pendidikan Kimia* 1(1),118-125.
- Pareek, S., Yahia, E. M., Pareek, O. P. & Kaushik, R. A. (2011). Postharvest physiology and technology of Annona fruits. *Food Research International*. Elsevier. 44(7),1741-1751. <https://doi.org/10-1016/J.foodres.2011.02.016>
- Pathak, K., Das, R. J., Sarma, H., & Das, Aparoop. (2021). Evaluation of leaf fraction of *Annona reticulata* Linn. for antioxidant activity and anti-inflammatory potential against carrageenan induced rat paw edema model. *Indian Journal of Natural Sciences*, 12(68), 33877-33888. <https://researchgate.net/publication/355781867>
- Pathak, K., & Zaman, K. (2013). An overview on medicinally important plant- *Annona reticulata* Linn. *International Journal of Pharmacognosy and Phytochemical Research*. 5(4),299-301. <http://impactfactor.org/PDF/IJPPR/5/IJPPR,Vol5,Issue4,Article10.pdf>
- Pino, A. J. A. (2010). Annona Fruits (Chapter 14). In: *Handbook of Fruit and Vegetable Flavors*. Hoboken, John Wiley & Sons, Inc. 231–246. <https://doi.org/10.1002/9780470622834.ch14>
- Pino, A. J. A. (2019). El aroma de las frutas cubanas. La Habana: Editorial Científico-Técnica. Estudio de las frutas cubanas. ISBN. 978-959-05-1141-7
- Pinto, A. C. de Q., & da Silva, E. M. da (1995). A cultura da graviola. Empresa Brasileira de Pesquisa Agropecuaria. Centro de Pesquisa Agropecuaria dos Cerrados. Brasília. Embrapa-SPI. ISBN: 85-85007-59-1
- Rahman, M., Rashedul, I., Rahman, S., Mosaiab, T., Ahmed, R., Khatun, F., Nasrin, D., Nahar, N., Ahsan, S., & Rahmatullah, M. (2011). Antihyperglycemic studies with methanol extract of *Annona reticulata* L. (Annonaceae) and *Carissa carandas* L. (Apocynaceae) leaves in

- swiss albino mice. *Advances in Natural and Applied Sciences*. 5(2),218-222. <https://www.researchgate.net/publication/284704848>
- Ravimanickam, T., Namitha, Y., Yaminipriya, D., & Yogananth, N. (2018). Evaluation of antitumor properties of *Annona reticulata* (L.) seed on cancer cell lines. *Journal of Pharm Research*. 7(7),132-5. <https://doi.org/10.5281/zenodo.1308605>
- Rayar, A., & Manivannan, R. (2016). Antioxidant and anticancer activities of (+)-catechin isolated from *Annona reticulata* Linn. *International Journal of Recent Scientific Research*. 7(3),9451-9456. https://www.recentscientific.com/sites/default/files/4576_1.pdf
- Roham, P. H., Kharat, K. R., Mungde, P., Jadhav, M. A., & Makhija, S. J. (2016). Induction of mitochondria mediated apoptosis in human breast cancer cells (T-47D) by *Annona reticulata* L. Leaves Methanolic Extracts. *Nutrition and Cancer*. 68(2),305-11. <https://doi.org/10.1080/01635581.2016.1142583>
- Saad, J. M., Hui, Y., Rupprecht, K., Anderson, J. E., Kozlowski, J. F., Zhao, G., Wood, K. V., & McLaughlin, J. L. (1991). Reticulatacin: A new bioactive acetogenin from *Annona reticulata* (Annonaceae). *Tetrahedron*. 4(16/17),2751-2756. [https://doi.org/10.1016/S0040-4020\(01\)87082-4](https://doi.org/10.1016/S0040-4020(01)87082-4)
- Sangeetha, V. S., Babu, M., & Lawrence, B. (2014). Phytochemical analysis of *Annona reticulata* L. leaf extracts. *International Research Journal of Pharmaceutical and Applied Sciences*. 4(5),4-8. <https://www.researchgate.net/publication/28010681>
- Sankpal, M. M. (2022). Determination of phytoconstituents in *Annona reticulata* Linn. Methanolic leaf extract using GCMS. *World Journal of Pharmaceutical Research*. 11(5),2178-2189. <https://doi.org/10.20959/wjpr20225-23998>
- Sasidharan, S., & Jayadev, A. (2017). Nutritional factors in three varieties of *Annona* species. *International Journal for Research in Applied Science & Engineering Technology*. 5(11),73-79. <https://doi.org/10.22214/ijraset.2017.11010>
- Senadeera, S. S., Prasanna, P. H. P., Jayawardana, N. W. I. A., Gunasekara, D. C. S., Senadeera, P., & Chandrasekara, A. (2018). Antioxidant, physicochemical, microbiological, and sensory properties of probiotic yogurt incorporated with various *Annona* species pulp. *Heliyon*. Published by Elsevier Ltd. 4(11), e00955 <https://doi.org/10.1016/j.heliyon.2018.e00955>
- Senthilkumar, C., Kannan, P. R., Balashanmugam, P., Raghunandhakumar, S., Sathiamurthi, P., Sivakumar, S., A. A., Mary, S. A., & Madhan, B. (2022). Collagen - *Annona* polysaccharide scaffolds with tetrahydrocurcumin loaded microspheres for antimicrobial wound dressing. *Carbohydrate Polymer Technologies and Applications*. 3; 100204. <https://doi.org/10.1016/j.carpta.2022.100204>
- Shetty, M. J., Vasudeva, K. R., Sakthivel, T., Suresh, G. J., Krishna, H. C., Vishnuvardhana, & Kumar, A. S. (2020). Polyphenolic profiles in edible *Annona* spp. using high-performance liquid chromatography (HPLC-MS/MS). *Environment Conservation Journal*. 21(3), 201-208. <https://doi.org/10.36953/ECJ.2020.21325>

- Shivanna, L. M., Sarjan, H. N., & Urooj, A. (2019). Acute toxicity study of *Annona reticulata* leaves extract in swiss albino mice. *International Journal of Pharmaceutical Investigation*. 9(2),71-75. <https://doi.org/10.5530/ijpi.2019.2.14>
- Suresh, H., Shivakumar, B., & Shivakumar, S. (2011). Inhibitory potential of the ethanol extract of *Annona reticulata* Linn. against melanoma tumor. *Journal Natural Pharmaceuticals*. 2(4),168-172. <https://doi.org/10.4103/2229-5119.92846>
- Department of Agriculture, Agricultural Research Service (USDA). (2010). National nutrient database for standard reference, Release 23. Nutrient Data Laboratory Home Page. <http://www.ars.usda.gov/ba/bhnrc/bdl>
- Vidal, L. E., Vidal M. N. A., & Vidal H. L. (2015). Anonáceas. Plantas antiguas. Estudios recientes. Parte 2. Universidad Autónoma de Chapingo. Universidad Veracruzana. Sociedad Mexicana de Anonáceas, A.C. 9-12. ISBN: 978-607-12-0411-0.
- Waghulde, S., Kale, M. K., & Patil, V. R. (2021). Cumulative Phytochemical Analysis And Identification Of Drug Lead Compounds From Medicinal Plant Extracts. *Chemistry Proceedings*. <https://sciforum.net/manuscripts/11782/manuscript.pdf>
- Wong, K. C., & Khoo, K. H. (1993). Volatile constituents of Malaysian *Annona* fruits. *Flavour and Fragrance Journal*. 8,5–10. <https://doi.org/10.1002/ffj.2730080103>
- Yuan, S. S. F., Chang, H. L., Chen, H. W., Yeh, Y. T., Kao, Y. H., & Lin, K. H. (2003). Annonacin, a mono-tetrahydrofuran acetogenin, arrests cancer cells at the G1 phase and causes cytotoxicity in a Bax- and caspase-3-related pathway. *Life Sciences*. 72(25),2853-61. [https://doi.org/10.1016/S0024-3205\(03\)00190-5](https://doi.org/10.1016/S0024-3205(03)00190-5)
- Zaman, K., & Pathak, K. (2013). Pharmacognostical and phytochemical studies on the leaf and stem bark of *Annona reticulata* Linn. *Journal of Pharmacognosy and Phytochemistry*. 1(5),1-7. <http://www.phytojournal.com/archives/2013/vol1issue5/PartA/1.1.pdf>