

ANNONA RETICULATA L. A NATIVE TROPICAL SPECIES OF INTEREST

GEORGINA VARGAS-SIMÓN^{1*}, MANUEL L. NUÑEZ-PIEDRA², JULIO MOGUEL-YANES¹,
 JULIA LESHNER-GORDILLO¹ AND REINALDO PIRE³

¹ Universidad Juárez Autónoma de Tabasco, Villahermosa, Tabasco, Mexico.

² El Colegio de la Frontera Sur, Villahermosa, Tabasco, Mexico.

³ Universidad Centroccidental Lisandro Alvarado, Barquisimeto, Venezuela.

*Corresponding author: georgina.vargas@ujat.mx

Abstract

Annona reticulata is an important native American species recognized since pre-Columbian times. Although rarely cultivated, it has become a major source of natural medicine, among other applications of global importance. To obtain general and up-to-date information on the different aspects of this species, a comprehensive bibliographic review was conducted using digital sources such as Web of Science and Google Scholar, as well as reviews in physical and virtual herbaria to obtain georeferenced data and determine their current and potential eco-geographic distribution (Global Biodiversity Information Facility, Universidad Juárez Autónoma de Tabasco, Herbario Nacional de México, and Instituto de Ecología). The morphological varieties were identified and characterized through fruit collections in the Sierra Subregion, in Tabasco, Mexico. The literature review focused on the botanical description, anatomy, physiology, propagation, and associated diseases and pests of the plant, as well as its economic importance. High-level information was recorded regarding phytochemical aspects and application in medicine outside Mexico. It was determined that there is little specific data on the plant's anatomy, physiology, and post-harvest physiological factors. Moreover, in some topics, the existing information is obsolete: this is the case for themes of agronomic and phytosanitary management, as well as studies of phylogenetics and molecular markers for conservation and breeding. Its status as a native species suggests a need for conservation. However, for preservation in germplasm banks, it is essential to determine the seed tolerance to desiccation and low temperatures.

Keywords: economic importance, local varieties, potential distribution

Resumen

Annona reticulata es una especie nativa de América, conocida desde la época prehispánica. Aunque es raramente cultivada, es una planta con importantes propiedades medicinales, entre otras aplicaciones para la población global. Para obtener información general y actualizada sobre diferentes aspectos de esta especie, se realizó una revisión bibliográfica exhaustiva, utilizando fuentes digitales como Web of Sciences y Google Académico así como revisiones en herbarios físicos y virtuales para obtener datos georreferenciados y determinar su distribución ecogeográfica actual y potencial (Global Biodiversity Information Facility, Universidad Juárez Autónoma de Tabasco, Herbario Nacional de México e Instituto de Ecología). Se identificaron y caracterizaron variedades morfológicas mediante colectas en la Subregión Sierra, Tabasco, México. La revisión bibliográfica se enfocó a la descripción botánica, su anatomía y fisiología, propagación y enfermedades y plagas asociadas, así como su importancia económica. Se registró información de alto nivel enfocado a aspectos fitoquímicos y su aplicación en la medicina fuera de México. Se determinó que hay pocos datos específicos sobre su anatomía, fisiología y factores fisiológicos postcosecha. Así mismo, en algunos tópicos, la información existente es obsoleta: es el caso de los temas de manejo agronómico y fitosanitario, así como los estudios filogenéticos y marcadores moleculares para la conservación y mejoramiento. Su condición de especie autóctona hace que sea necesario su conservación. No obstante, para su preservación en bancos de germoplasma, es esencial determinar su tolerancia a la desecación y a las bajas temperaturas.

Palabras clave: distribución potencial, importancia económica, variedades locales.

The Annonaceae family is a large group comprising around 110 genera and 2,450 species (Couvreur *et al.* 2019), found in tropical and subtropical climates across the Americas and South Asia. One notable member, *Annona reticulata*, belongs to the subfamily Annonoideae (Stevens 2001). This species has a variety of local names in Mexico, such as “manzana de ilán”, “saramuyo”, “anona colorada”, “quaultzapotl” (in Nahuatl), and “pox” (in Mayan). Varieties with yellow-greenish pericarp are called “anona amarilla” or “blanca”, also known as “anona verde” when unripe. In other languages, it is known as: “coração de boi” (in Portuguese), “bull-oak’s heart” (in English), or “coeur de boeuf” (in French), among other names (Morton 1987). In Asia, it is known as ramphal (in Hindi) (Kumari *et al.* 2021) and (牛心果 niú xīn guǒ) (in Mandarin) (Jamkhande & Wattamwar 2015).

The species is considered native to the Americas and is not widely cultivated. However, the fruits are appreciated for their sweet and creamy flavor. They are marketed for personal consumption and sold in local markets (Hernández Fuentes *et al.* 2022, Vargas-Simón *et al.* 2022). Beyond its culinary appeal, the plant has medicinal potential given its high content of secondary metabolites, among other attributes described in this paper.

This paper summarizes information from a comprehensive search of digital sources, including Web of Science and Google Scholar, to provide a detailed view of the botanical and physiological aspects of the species, as well as its potential uses. While we primarily utilized the results of current research, some older references were included to address topics with limited recent data. The authors also contributed original, unpublished research, including a geographical distribution map for the state of Tabasco, Mexico, based on data from herbaria (MEXU, UJAT, XAL) and the GBIF (2025), along with observations of morphological variants of fruits collected directly from the field.

Botanical and anatomical description. The species is represented by trees between 5 and 12 m in height (Figure 1A) with deciduous leaves. The leaves are between 8-20 cm in length and between 2-5 cm in width, lanceolate to oblong-lanceolate with acute to rounded base, acuminate apex, entire margin, appressed-pilose upper and lower surface in juvenile leaves, glabrous in adults (Figure 1B). Internodal inflorescences with bisexual flowers in 1-3, greenish or yellowish, purple inside, pedicels 1-2 cm in length (Figure 1C). Fruits between 7-13 cm in diameter, globose-ovoid (Figure 1D), with “v” shaped areoles on their surface (Awachare *et al.* 2018, Kelly 2000).

Folorunso & Olorode (2006) conducted a morphological study of leaves and flowers of individuals of five *Annona* species, including *A. reticulata*, cultivated as ornamentals in Nigeria. The identification of distichous phyllotaxy and eucamptodromous and camptodromous venation is highlighted (Folorunso & Modupe 2007), which corroborates the morphological characteristics of the leaves previously determined by Kelly (2000).

The pulp is made up of the arils that cover the seeds, corresponding to 69.22 % of the weight of the fruit, its shiny seeds, dark brown to almost black, smooth, ellipsoidal, which had 116.8 units per fruit in the case of fruits with red pericarp and red pulp, with an average length of 14.5 mm (Vargas-Simón *et al.* 2022), thus coinciding with that reported by Kelly (2000). They have a ruminated endosperm with brown plates and a small embryo of approximately 3 mm in length in seeds soaked in water for 24 h (Vargas-Simón *et al.* 2022).

In Tabasco, the fruiting season for this species is from March to May (Moguel-Yanes & Vargas-Simón unpublished data), which coincides with that reported by González-Esquinca (2016). Furthermore, these authors report that flowering occurs in December, based on data from collections in the state of Chiapas.

Varieties. - In the state of Veracruz, Mexico, Vidal *et al.* (2015) identified three varieties of *A. reticulata* based on the characteristics of the fruit pericarp and pulp: red pericarp with white pulp; red pericarp with red pulp; and yellow pericarp with white pulp. At one point, the variety with yellow pericarp fruits was classified as *A. lutescens*; however, morphological data from the leaves, hypocotyl, and fruiting dates, among other traits, did not serve as conclusive evidence for classifying this a separate species, so it continues to be classified as *A. reticulata* until molecular analyses can be performed (Ocampo & Castro-Moreno 2016).

In fruit collections from different municipalities in the state of Tabasco, three varieties have been identified to date: red-purple pericarp with red to purple pulp, stained entirely or partially on the periphery of the fruit (PRPR); red pericarp with entirely white pulp and traces of pink staining on the periphery (PRPW); and yellow pericarp with white pulp (PYPW) (Figure 2). The coloration in the fruits seems to be due to the presence of anthocyanins, associ-



Figure 1. *Annona reticulata* tree (A), Leaves and flowers (B), detail of inflorescences (C) and branch with fruit (D).

ated with a single or double recessive gene (Ocampo & Castro-Moreno 2016, Leal & Paull 2023). The highest values of the variables measured in the fruits correspond to PRPW ([Table 1](#)), although this variety presents lower values in terms of the dimensions of its seeds compared to the other varieties.

A preliminary correlation analysis was performed between the different morphological parameters of the aforementioned varieties. An association was found between fruit weight and equatorial diameter ($r = 0.7666$; $P = 0.0159$), and between the number of seeds per fruit and seed width ($r = 0.7460$; $P = 0.0210$) for the PRPW variety; between fruit weight and the number of seeds per fruit ($r = 0.7816$; $P = 0.0220$) for the PRPW variety; and between fruit weight and its polar ($r = 0.8634$; $P = 0.0057$) and equatorial diameters ($r = 0.9398$; $P = 0.0005$) for the PYPW variety (unpublished data). The overall correlation results are shown in [Table S1](#) ([Supplementary material](#)). The calculations show directly proportional relationships between the significant variables in the morphology of these varieties: fruit weight, polar and equatorial diameters, and the number of seeds per fruit. These attributes, among others, are necessary to identify promising genotypes for improvement and commercialization (Hasan *et al.* 2025).

In the USA (Florida), Java, and Indonesia, several commercial varieties of this species with a red pericarp and pulp have been created, as well as one variety with an orange pericarp and pulp (Leal & Paull 2023). The natural hybrid *A. cherimola* $\times$ *A. reticulata*, called atemoya or ‘Red Israel’, is known and marketed in Egypt, although the name atemoya is also assigned to the hybrid formed by *A. cherimola* $\times$ *A. squamosa*. Another hybrid called ‘Cuatemoya’

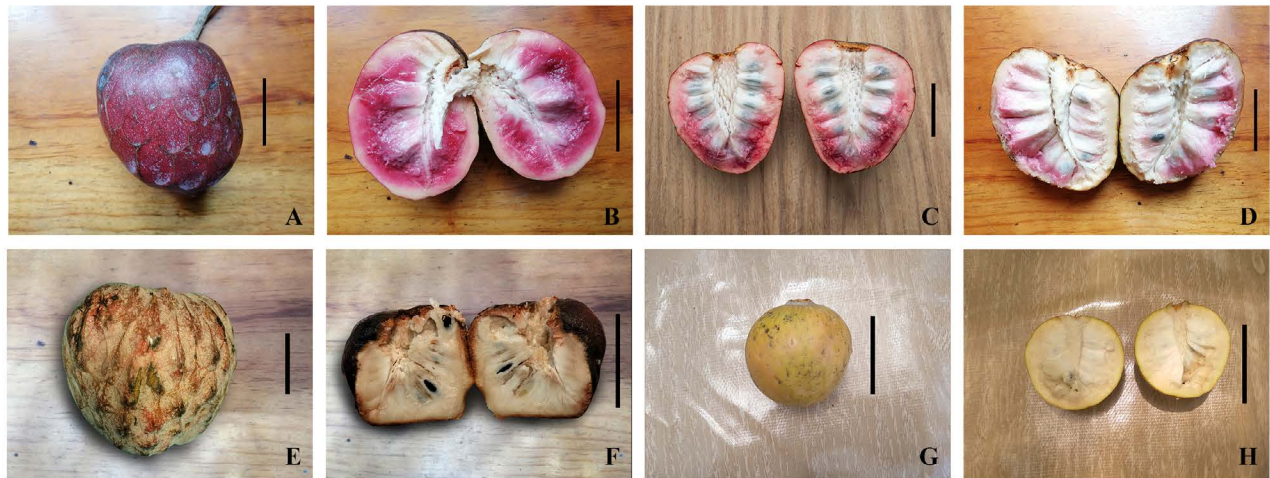


Figure 2. *Annona reticulata* varieties collected in Sierra Subregion, Tabasco, Mexico. A, B, C and D) purplish red pericarp with red to purple flesh, stained totally or partially in its periphery (PRPR); E and F) red pericarp with entirely white flesh (PRPW); G and H) yellow pericarp with white flesh (PYPW). The line corresponds to 5 cm.

Table 1. Fruit and seed dimensions of three different varieties of *Annona reticulata* (means $\pm$ SD) collected in Tabasco, Mexico. Fruits with purple pericarp, red pulp (PRPR); fruits with red pericarp, white pulp (PRPW); fruits with yellow pericarp, white pulp (PYPW).

	PRPR	PRPW	PYPW
Fruits			
Polar diameter (cm)	9.6 $\pm$ 1.6	10.6 $\pm$ 1.4	8.13 $\pm$ 1.4
Ecuatorial diameter (cm)	10.0 $\pm$ 1.1	10.8 $\pm$ 1.2	9.4 $\pm$ 1.3
Weight (g)	527.0 $\pm$ 143.7	568.3 $\pm$ 130.7	364.0 $\pm$ 142.3
Number of seeds/fruit	73 $\pm$ 26.2	110.8 $\pm$ 32.0	64.6 $\pm$ 20.2
Seeds			
Length (mm)	16.6 $\pm$ 1.3	14.3 $\pm$ 0.7	15.1 $\pm$ 1.5
Width (mm)	7.6 $\pm$ 0.3	7.2 $\pm$ 0.3	7.8 $\pm$ 0.6
Number of seeds/kg	4,037.4 $\pm$ 442.5	4,436.3 $\pm$ 794.9	3,780.2 $\pm$ 329.4

Fruits number: PRPR (13), PRPW (9), PYPW (8); seed number (500 each one variety)

Source: Moguel-Yanes & Vargas-Simón (data not published).

(atemoya $\times$ *A. reticulata*) was selected in India, although the cross of *A. macrophyllata* $\times$ *A. reticulata* is also registered under this name (Leal & Paull 2023).

Anatomical studies.- Overall, studies on the anatomy of *A. reticulata* are scarce, but one of the most prominent is an analysis of the stems of juvenile specimens from Nigeria (Folorunso 2011), which describes the epidermal layers, collenchyma, its vascular members, rays, and fibers. Its wood is defined as diffusely porous, and the presence of tannins is observed. These characteristics, such as diffuse and solitary vessels and a uniseriate epidermal layer, are consistent with the primitive status of other Annonaceae. The authors conclude that *A. reticulata* and *A. squamosa* exhibit similar characteristics, including axial parenchyma cells, which is paratracheal confluent, but vessels in *A. reticulata* have a larger diameter (40 μ m), whereas those in *A. squamosa* are 35 μ m; similarly, the rays height in *A. reticulata* is 680 μ m, compared to 400 μ m in *A. squamosa*. In addition, there are osteosclereids in the pith of both species.

Another important article on the leaf anatomy of leaves collected in Manipal, India, provides data on the epidermis, mesophyll, and midrib (Kumar *et al.* 2008). The authors conclude that it is a dorsiventral leaf, with straight-

walled epidermal cells, more or less rectangular in shape, with unicellular, uniseriate, simple or stellate trichomes, although also sometimes multicellular (3 cells). Hypostomatic leaves, paracytic stomata, the mesophyll composed of palisade and spongy tissue, although this work is descriptive and lacks quantitative data on leaf tissues. Adeniran *et al.* (2020) classified stomata as paracytic, and brachyparacytic in hypostomatic leaves; the normal epidermal cell shapes are identified on each surface as polygonal, and the anticline wall pattern as wavy. In this study of leaves from trees planted in Nigeria, the stomata measured an average of 9.0 μm in length, 1 μm in width, and presented a stomatal index of 18.2 %. These authors also provide data on the midrib and leaf blade architecture. Anatomical differences in leaves are observed between the countries where the studies were conducted.

Current distribution and potential distribution modeling. The species is distributed in Mexico, Central America, the Caribbean, and northern South America (Colombia and Venezuela). It is considered an introduced species in the USA (Florida), Ecuador, Peru, Bolivia, and Brazil. It is also present in central and southern Africa and Madagascar, southern Asia (India and Bangladesh), and Australia, where it is considered an invasive species (Plants of the World Online 2025).

In Mexico, it is distributed along the Caribbean and Pacific coastlines, and in the central area of the country, such as in the states of Morelos and State of Mexico (Herbarium: Nacional de México (MEXU), Universidad Juárez Autónoma de Tabasco (UJAT), Instituto de Ecología, A.C. (XAL), Global Biodiversity Information Facility (GBIF 2025)). Segura *et al.* (2012) obtained georeferenced data from different herbaria and correlated these with the environmental conditions for the different *Annona* species, including *A. reticulata*. For this species, two climatic groups were generated by cluster analyses: the first is located in the mountainous forest from Sonora to Michoacán and part of the highlands, while the second corresponds to the Gulf of Mexico and Yucatan Peninsula area.

In the state of Tabasco, the species has been observed in the Centro subregion (municipalities of Centro, Nacajuca, and Jalpa de Méndez). However, the greatest diversity has been found in the Sierra subregion (municipalities of Jalapa, Tacotalpa, and Teapa) (Moguel-Yanes & Vargas-Simón unpublished data). The literature mentions that in Mexico it is part of the medium sub-deciduous and low deciduous forests (Maldonado *et al.* 2004). However, the specimen records of the consulted herbaria (MEXU, UJAT, XAL, GBIF 2025) specify other vegetation types: tropical evergreen forest, tropical high evergreen forest, tropical high subevergreen forest, tropical medium subevergreen forest, disturbed oak forest, riparian forest, secondary forest, as well as in home gardens, the CICY Botanical Garden, ruderal environments, grazing areas, and living fences, at a minimum elevation of 6 and a maximum of 2,450 m in the State of Mexico.

Potential distribution. - In a recent analysis (unpublished), a potential distribution modeling exercise was conducted for Mexico based on georeferenced data from virtual and physical herbaria (see [Table 2 Supplementary Materials](#)), using a method based on the framework of Naimi & Araújo (2016), who integrate 21 state-of-the-art algorithms. This strategy allows selection of the model with the best predictive performance, using statistical performance metrics to ensure the highest accuracy in predicting species distribution (see Methods, [Supplementary material](#)).

The distribution analyzed, based on the environmental variables of temperature, precipitation, seasonality, and elevation, together with a suitability map considering a threshold of 85 % climatic suitability, provides information on the ranges of *Annona reticulata* and its possible expansion in temperate and tropical regions of Mexico ([Figure 3](#)).

This species has a projected range of 399,429.87 km² and shows a preference for sites in which the minimum temperature of the coldest month is between 8.3 and 13.2 °C, indicating an affinity for regions with temperate winters, with no intense frosts or extreme temperature drops. These conditions commonly occur in mid-elevation tropical zones or in subtropical areas with a maritime influence or constant humidity. It thrives in areas where the isothermality index ranges between 59.2 and 83.47 and prefers environments with stable temperatures. Moreover, the environmental predictors retained in the final model exhibited acceptable levels of multicollinearity, with no values of the Variance Inflation Factor (VIF) exceeding the threshold of 10. Notably, most variables showed low to moderate VIF values, supporting the reliability and interpretability of their individual contributions to the potential distribution model ([Table 2](#)).

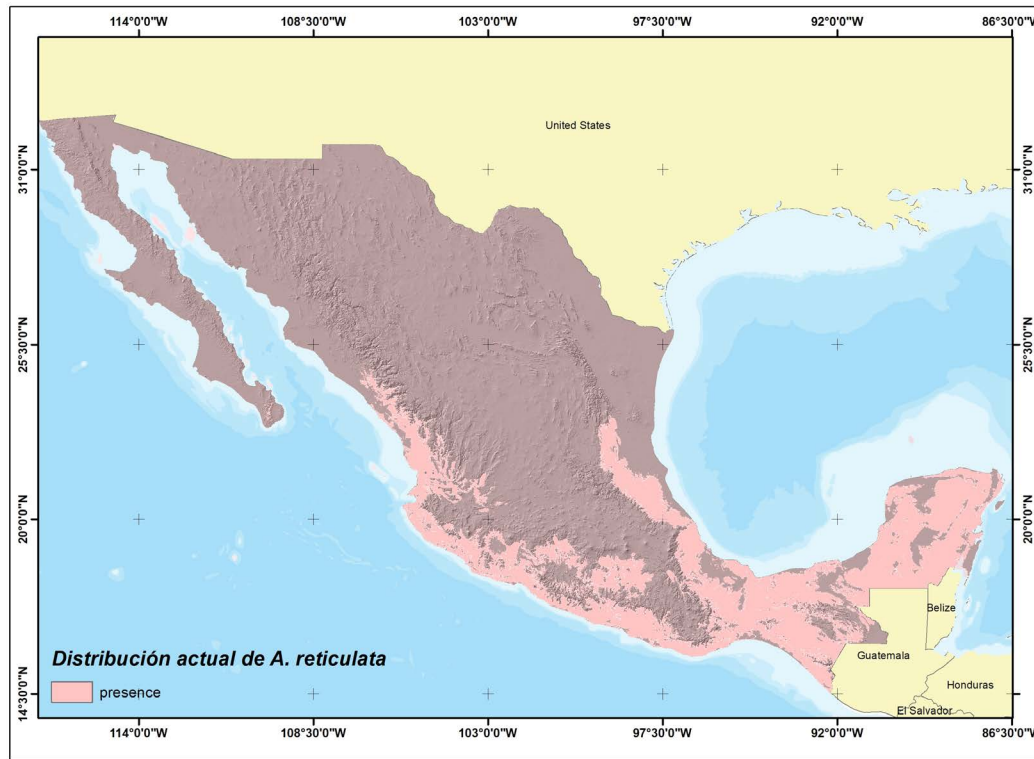


Figure 3. Potential distribution in Mexico of *Annona reticulata* based on environmental variables.

Table 2. Optimal ranges for *A. reticulata* based on variables with major contribution in the construction of the potential distribution model.

Variables	Minimum	Maximum	Range	Units	VIF
bio_02: Range of diurnal temperature	8.33	13.2	4.87	°C	2.9
bio_03: Isothermality	59.2	83.47	24.27	Index	2.8
bio_08: Mean temperature of the wettest quarter per year	24.68	26.17	1.49	°C	3.3
bio_09: Mean temperature of the driest quarter per year	20.48	24.97	4.49	°C	6.9
bio_13: Precipitation of the wettest month	205.08	273.28	68.2	mm	8.3
bio_14: Precipitation of the driest month	8.23	36.22	27.99	mm	7.1
bio_15: Seasonality of precipitation (coefficient of variation)	68.92	112.25	43.33	%	3.5
bio_18: Precipitation of the warmest quarter per year	252.49	1,013.41	760.9	mm	4.6
bio_19: Precipitation of the coldest quarter per year	1	197.22	196.2	mm	5.6
CEM (Mexican Elevation Continuum 3.0)	52.36	716.36	664	m	6.0

At temperatures ranging from 24 to 26 °C during the wettest quarter, *A. reticulata* appears to exhibit good physiological performance, likely associated with greater efficiency in processes such as photosynthesis and reproductive development. During the driest quarter, the species can tolerate temperatures between 20.4 and 24.9 °C, maintaining a certain level of metabolic activity even under conditions of limited water availability. However, the positive response decreases significantly under extreme drought scenarios, suggesting a marked sensitivity to prolonged water deficits.

Considering the precipitation values during the wettest (205 to 273.2 mm) and driest (bio_14, 8.2-36.2 mm) months, the species seems to adequately tolerate such variation. This is confirmed in the precipitation seasonality index (bio_15), which presents values of between 68 and 112.

Precipitation values during the warmest quarter (BIO_18), from 252 to 1,013 mm, and during the coldest quarter (BIO_19), where values of up to 197 mm are recorded, suggest that the species can tolerate conditions of high temperatures combined with rainfall, as well as present adaptations to non-extreme dry seasons.

Optimal elevation records for the species occur between 52 and 716 m, encompassing tropical lowlands and mid-altitude zones of Mexico, particularly in the coastal regions, valleys, and mountain ranges with warm humid and sub-humid climates. Soils associated with the species include: Acrisols, Andosols, Cambisols, Kastanozems, Chernozems, Phaeozems, Fluvisols, Gleysols, Lithosols, Luvisols, Nitisols, Regosols, Rendzinas, Solonchaks, and Vertisols.

For the reasons stated above, *Annona reticulata* is a species with a great capacity to establish in different tropical and subtropical conditions in Mexico. Its tolerance of relatively wide temperature ranges during periods of greater water scarcity (driest quarter and seasonality of precipitation) confers resilience to moderate environmental variability; however, this tolerance has limits. *Annona reticulata* does not respond favorably to prolonged drought conditions, so its physiological performance could be affected in areas that present significant reductions in precipitation or increased thermal variation, based on the conditions of current projected climate change scenarios.

Currently, the main threats to the species are land use change, pollution, and changes in landscape structure. However, it also is important to consider its vulnerability to accelerated changes in climatic conditions, as well as to conserve populations in areas with high climatic stability, support the maintenance of practices and presence in home gardens, living fences, and cocoa and coffee plantations, which constitute refuge options for this species (Vidal *et al.* 2015, García-Flores *et al.* 2019, Watton 2020), and to promote diversification in agroforestry systems, which will significantly help to ensure its long-term persistence.

Annona reticulata is not currently considered a protected species in Mexico (SEMARNAT 2010), while the species is classified as Least Concern on the IUCN Red List (Verspagen & Erkens 2020).

Economic importance. *Annona reticulata* is not a widely cultivated species; however, its fruits are appreciated for their sweet and creamy flavor and are marketed for personal consumption and sold in local markets (Hernández Fuentes *et al.* 2022, Vargas-Simón *et al.* 2022). They are rich in minerals and vitamins, and mostly consumed fresh. In Cuba, the unripe fruits are sliced, wrapped in sugar, and sun-dried for preservation (Cordero & Boshier 2003). The chemical composition of the fruit is shown in [Table 3](#).

Table 3. Chemical composition of *Annona reticulata* in 100 g of pulp.

Carbohydrates (g)	Fiber (g)	Total Fats (g)	Crude protein (g)	Minerals	(mg)	Vitamins	(mg)
25.20	3.4	0.60	2.34	Calcium	30.0	Ascorbic acid	9.40
				Phosphorus	27.0	Thiamine	0.08
				Magnesium	18.00	Riboflavin	0.11
				Sodium	4.00	Niacin	0.70
				Potassium	382.00	Pyridoxin	0.22
				Iron	1.00	Vitamin A µg	2.00

Source: Morales *et al.* (2016)

Folorunso & Modupe (2007) obtained higher values of protein content in fruits from plantations established in Nigeria (0.85 %), along with a lower fat content (0.5 %) and slightly higher value of carbohydrates (27.92 %) compared to the analysis carried out in Mexico.

A biochemical analysis was performed with the fruit of *A. reticulata* to determine total soluble sugars (TSS) and ascorbic acid content in the pulp, which are reported in the research conducted in India by Anuragi *et al.* (2016) ([Table 4](#)).

In that study, the former variable had a value of 14.89 % and the latter was 23.36 mg/100 g. In addition, these authors conducted sensory analyses for the selection and subsequent improvement of the fruit. Cordero & Boshier (2003) report that the wood of the species can be used to make boxes, fence posts, fishing net floats, or firewood, and its cellulose is useful for making paper.

Table 4. Biochemical composition of *Annona reticulata* (fresh weight basis)

MC (%)	AC (%)	TC (%)	TSS (%)	RS (%)	FC (%)	PC (%)	PhC (%)	TA (%)	OC (%)	Asc (mg/100 g)
73.00	1.48	22.71	14.89	4.80	2.18	1.85	0.41	0.36	29.33	19.60

MC: moisture content, AC: ash content, TC: total carbohydrates, TSS: total soluble sugars, RS: reducing sugars, FC: fibre content, PC: protein content, PhC: phenol content, TA: titratable acidity, OC: seed oil content, Asc: ascorbic acid content. Source: Anuragi *et al.* (2016).

Other uses.- The plant is also used as firewood, livestock fodder, support for the climbing fruit species *Sicana odorifera* (Vargas-Simón *et al.* 2022), and as a wildlife shelter, since its fruits are a food source (Lazos-Ruiz *et al.* 2016, García-Flores *et al.* 2019). The leaves contain a blue or black pigment used in tanning hides (Morton 1987). The wood is used to make ox yokes and is characterized as being yellow, soft, and fibrous, with a moderately close grain and a specific gravity of 0.65 (Orwa *et al.* 2009).

The species can be used for its resistance and adaptability as a rootstock for other *Annona* spp., such as *A. muricata* and *A. glabra*, in addition to being cultivated as an ornamental (Hoyos 1994). García-Flores *et al.* (2019) consider it an important species for restoration actions, in addition to providing fuelwood and fodder (Moreno-Calles *et al.* 2013).

Phytochemical analysis and its applications. Many bioactive compounds from the diverse phytochemical groups have been identified in the *Annona* genus: phenolic compounds, cyclopeptides, alkaloids, fatty acids, and acetogenins in its different organs (fruits, leaves, roots, and seeds). The phenolic compounds are classified as exogenous antioxidants: for example, the acetogenins, compounds particular to this genus and of great importance due to their therapeutic applications (González-Esquinca *et al.* 2014, Hernández Fuentes *et al.* 2022).

For *A. reticulata* in particular, qualitative analyses of the secondary metabolites were revised by Shahriar *et al.* (2016) and Ramiz *et al.* (2024), who used a range of solvents to identify different phytochemical groups in leaves (Table 5). It is revealed that chloroform was the most effective solvent for extracting different groups of secondary metabolites. A similar study was conducted with leaves of trees grown in India, showing the presence of the same metabolites indicated in Table 5 (Mallick & Chandra 2020), in addition to amino acids, terpenoids, and anthraquinones, using different reagents in each case. However, these authors did not detect saponins. In that study, different amounts of metabolites were recorded according to the climatic season of the area. For example, the highest contents of tannins were recorded in winter, while alkaloids and flavonoids were more abundant in the summer. The authors highlight the close relationship between the environment and the production of these metabolites.

Regarding secondary metabolites, a qualitative study was conducted on fruit pulp using different solvents in India, the results of which are presented in Table 6. The presence of tannins, saponins, reducing sugar, and alkaloids was highlighted in all the extracts performed (Sharma *et al.* 2025).

Likewise, volatile compounds were analyzed in the pulp of *A. reticulata* from Cuban varieties, and 49 components were identified using gas chromatography. Some of the most important are α -pinene, β -pinene, and germacrene D. According to the author, these metabolites are responsible for the flavor and aroma of fruits (Pino 2011).

Kumari *et al.* (2022), researchers from India, used gas chromatography to identify 47 compounds in *A. reticulata* leaves, mainly finding: vitamin E, neophytadiene, phytol, and gamma-sitosterol. These authors related their findings to the medicinal properties of the species. Similarly, Pathak *et al.* (2022) identified gallic acid and quercetin (flavonoids) using high-performance thin-layer chromatography in methanolic extracts of leaves from specimens from Thailand.

Table 5. Qualitative phytochemical analyses of *Annona reticulata* leaf extracts in three solvents.

Secondary metabolites	Methanol	Ethanol	Chloroform	Ethyl acetate
Alkaloids	-	+	+	+
Flavonoids	-	-	-	+
Carbohydrates	+	+	+	+
Glycosides	-	-	+	-
Tannins	+	+	+	-
Steroids	+	+	+	+
Phenols	-	+	+	
Saponins	+	+	+	

The symbol (+) indicates presence and the symbol (–) indicates absence. Source: Shahriar *et al.* (2016), Ramiz *et al.* (2024)

Table 6. Qualitative phytochemical analyses of *Annona reticulata* pulp in three extracts.

Secondary metabolites	n-Hexane	Ethanol	Aqueous extract
Alkaloids	+	+	+
Flavonoids	-	+	+
Carbonyl compounds	-	-	-
Reducing sugar	+	+	+
Tannins	+	+	+
Steroids	-	-	-
Phenolic compounds	-	+	+
Saponins	+	+	+
Terpenoids	-	+	-

The symbol (+) shows presence and the symbol (–) shows absence. Source: Sharma *et al.* (2025)

Dilrukshi & Abhayagunasekara (2020) performed analyses of *A. reticulata* and other *Annona* spp. with Sri Lankan materials (leaves, seeds, bark, roots, ripe and unripe fruits) using spectrophotometry, finding high values of total phenolic content in unripe fruits (2.72 ± 0.02 mg GAE /g FW) and in the roots 82.08 ± 0.74 mg GAE /g FW. Regarding the total antioxidant capacity, the roots are prominent with 337.70 ± 0.85 mg TE/GDW, while the ripe fruits present 5.00 ± 0.01 TE/GDW. These are higher values than those found in other *Annona* species, according to these authors.

Two triterpenoids, rotundic acid and pedunculoside, as well as two phenolic compounds, eleutheroside B and sinapaldehyde glucoside, were identified in seeds in Tien Giang, Vietnam, using spectroscopic analysis (Hung 2016). A compilation of secondary metabolites identified in different parts of the plant is also available (Jamkhande & Wataamwar 2015, Pathak & Zaman. 2013 (Table 7).

A qualitative analysis of leaves and seeds was performed for the yellow pericarp anona (*A. lutescens*, synonym of *A. reticulata*) utilizing different reactive agents (Mex-Álvarez *et al.* 2024). In the leaves, the presence of phenolic compounds, alkaloids, saponins, flavonoids, lipids, leucoanthocyanidins, reductive sugars, and condensed tannins was found. In the seeds, phenolic compounds, alkaloids, quinones, proteins, leucoanthocyanidins, and reductive sugars were found.

One of the alkaloids identified in the yellow pericarp anona (*A. lutescens*, synonym of *A. reticulata*) is liriodenine. This compound is found in all organs except the leaves and seeds, but particularly in the roots, regardless of phenological stage (González-Esquinca *et al.* 2014). These authors also refer to the presence of acetogenins: laherradurine, rolliniastatin-2, and iso-anno-reticuline in the seeds and roots of yellow anona.

Table 7. Main phytochemical components of *Annona reticulata* in different parts of the plant.

Part of the plant	Phytochemicals
Leaf	Dopamine, sesquiterpenes, solamin, annomonicin, rolliniastarin 2, and others ¹ . Anonaine, roemerine, norcorydiene, corydine, norisocorydine, dienone isocorydine, norlaureline, glaucine hyperoside, rutin and quercetin, n-hexacosanol, and others ²
Stem	Annosquamosin A, annosquamosin C, annosquamosin D, annosquamosin E, annosquamosin F and annosquamosin G ²
Stem bark	Dopamine, Salsolinol, coclaurine, diterpenes, Reticullacinone, Rolliniastarin-2, and others ¹ . Kaurenoic acid, phenolic and nonphenolic alkaloids, two crystalline alkaloids –muricine, muricinine, (2, 4-cis and trans)-squamolone,(2, 4-cis and trans)-9-oxoasimicinone, and others ²
Root bark	Anonaine, michelalbaine, oxoushinsunine and other unidentified compounds ¹
Fruits	Pinene, myrcene, limonene, terpinen-4-ol, germacrene D, and others ¹
Seed	Cytotoxic acetogenins as squamocin, cis-trans-isomurisolenin, annoreticuin, and others more ¹ . Annotemoyin-1, annotemoyin-2, squamocin and cholesteryl lucopyranoside, samoquasine A – a benzoquinazoline alkaloid, annonaceous acetogenins-squamocin, reticulatain-2, squamocin-I, squamocin-B, and others ²

Sources: ¹Jamkhande & Wattamwar 2015, ²Pathak *et al.* 2013

Medicinal uses.- In Asia, the plant is traditionally used to treat epilepsy, dysentery, heart conditions, constipation, and ulcers. The bark is said to have astringent properties, while the leaves are useful for helminthiasis (Jamkhande & Wattamwar 2015). Similar data are reported by García-Flores *et al.* (2019) for the states of Tabasco and Chiapas, Mexico.

Likewise, in Asia, studies have been carried out on the *in vitro* medicinal attributes of the plant: antimicrobial activity, due to the presence of phenolic compounds; anti-tumor, anti-malarial, and anti-bacterial against *Bacillus subtilis*, *B. cereus*, *Escherichia coli*, *Listeria* spp., *Pseudomonas aeruginosa*, *Salmonella typhi*, and *Staphylococcus aureus*. Anti-fungal activity for *Aspergillus flavus*, *A. niger*, *Candida albicans*, *Fusarium moneliforme*, *Penicillium chrysogenum*, and *Trichoderma viride* has also been reported (Jamkhande & Wattamwar 2015, Jayaprakash 2017, Ramiz *et al.* 2024).

Pulp and peel extracts were analyzed in India for their anti-inflammatory, antibacterial, and anticancer activities. In particular, a cytotoxicity assay was performed with the MCF-7 cell line using the MTT colorimetric assay to evaluate cellular metabolic activity. Shagirtha *et al.* (2025) demonstrated its effectiveness in treated cells, with untreated cells showing reduced size and abnormal shrinkage. These authors also registered an IC₅₀ (Mean Inhibitory Concentration) with values of 202 ± 1.01 and 298 ± 1.90 µm in pulp and peel extracts, respectively. Khan *et al.* (2021) demonstrated the efficacy of ethanolic extracts of leaves in colorectal cancer *in vitro*, concluding that said extract could be used to prevent the development of this type of cancer and dysplasia. The anticancer property has also been identified in other *Annona* species such as *A. muricata* and *A. squamosa* (Gnanga *et al.* 2021, Pathirana *et al.* 2024).

The seeds have similar properties, as demonstrated against *Bacillus subtilis* and *Staphylococcus aureus* in Colombian research, where they achieved a 20 % inhibition of growth in both (Guerrero-Álvarez & Giraldo-Rivera 2023). Similarly, their antipyretic, antihyperglycemic, and antiulcer properties have been tested in rats. They are also anthelmintic in earthworms (*Pherentima posthuma*) and have produced satisfactory results as an antioxidant (Jamkhande & Wattamwar 2015).

Considering the medicinal properties, leaf extracts were tested for the green synthesis of copper oxide nanoparticles as a substitute for chemical drugs, and it was concluded that the flavonoids and phenolic compounds contain a stabilizing molecule for the synthesis of said nanoparticles (Chauhan *et al.* 2019). Similarly, Malathi *et al.* (2019) carried out a synthesis of silver nanoparticles obtained from *A. reticulata* leaf extracts for use as a repellent against

Sitophylus oryzae larvae, as well as bacteria (*Bacillus subtilis*, *Escherichia coli*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus*), with promising results.

Other applications.- In the veterinary field, *in vitro* tests on methanolic extracts of fresh leaves of different custard apples, including *A. reticulata*, have been conducted to inhibit egg hatching of a cattle parasite (*Haemonchus contortus*), demonstrating excellent ovicidal activity (92.8 %) (Castañeda-Ramírez *et al.* 2020).

The foliar extracts have potential as an allelopathic agent, which could replace synthetic herbicides. It has been shown to inhibit the growth of shoots and roots in seedlings of *Lepidium sativum* L., *Medicago sativa* L., *Lactuca sativa* L., *Echinochloa crus-galli* (L.) P. Beauv., *Lolium multiflorum* Lam., and *Phleum pratense* L. at concentrations of 0.01-0.03 g DW/mL in methanolic extracts. The identified compounds were Loliolide, 5-hydroxy-3, 4-dimethyl-5-pentylfuran-2(SH)-one, and Dihydroxyphenylethanol (Khatun *et al.* 2022). Moreover, oil from the seeds has been utilized in the experimental production of biodiesel (Omkaresh *et al.* 2023), in which the technique includes the use of magnesium phosphate to catalyze the extraction of the oil. The authors conclude that its production is feasible and that the extracted biodiesel complies with the ASTM 6751 standards (Advancing Standards Transforming Markets).

Other uses of *A. reticulata* include insecticidal properties (seeds, leaves, and young fruits). In this regard, methanolic extracts of the seeds have been used to control females of *Callosobruchus maculatus* (Siahaya 2023, an important pest insect affecting stored grain, *in vitro*). A concentration of 0.45 % was successful in promoting paralysis and death in insect specimens, which was attributed to the presence of acetogenins.

Unprocessed aqueous extracts of yellow anona leaves (*A. lutescens*, synonym of *A. reticulata*), in the solvents methanol, ethanol, dichloromethane, and hexane, were used to evaluate the repellent effect against white fly (*Trialeurodes vaporariorum*). They were tested on tomato leaflets in field as well as laboratory conditions, and it was determined that 0.5-2 % concentrations of hexane extracts had a 91 % efficiency (Astudillo *et al.* 2021).

Likewise, the aqueous extracts of yellow anona leaves in a 100 µg·mL⁻¹ concentration produced a 92.8 % mortality rate in *Anastrepha ludens* larvae after 72 h of feeding on an alimentary mixture infused with these extracts, under *in vitro* conditions (González-Esquinca *et al.* 2012).

Physiological aspects. Photosynthesis is one of the physiological parameters: Awachare *et al.* (2018) measured different photosynthetic responses of several *Annona* species, including *A. reticulata*, in 10-year-old juvenile trees in Bengaluru, India; the recorded values included: 212.2 µmol m² · s⁻¹ (photosynthetically active radiation, PAR), 5.8 µmol m² · s⁻¹ (photosynthetic rate), 0.17 mol m² · s⁻¹ (stomatal conductance), and 1.7 mmol m² · s⁻¹ (transpiration rate), among others.

The photosynthetic variables were similar among the *Annona* spp., with only *A. muricata* standing out with its highest PAR value of 778.5 µmol m² · s⁻¹. Likewise, these authors measured the content of chlorophylls a and b and epicuticular waxes, with no major differences being found between them. However, the authors conclude that their data are important for the selection or improvement of custard apples in certain environmental conditions.

In a study conducted in a polluted Indian city, Unnisa *et al.* (2022) tested the Air Pollution Tolerance Index (APTI) and the percentage decline in various tree species, including *A. reticulata*. This species showed a lower performance (12.47 %), compared to *Pongamia pinnata*, which had a 24.36 % decline. The researchers related this capacity to the ascorbic acid content.

In a review of the biomass carbon stock contribution of trees in the green areas of the University of Sri Lanka (Madurapperuma & Kuruppuarachchi 2016), data were recorded from two individuals of *A. reticulata*, with a calculated value of 574 kg · C. The species that contributed the most carbon stock in that study was *Terminalia catappa*, with 71,875 kg · C in 66 individuals.

In an experiment conducted under controlled environmental conditions, seedlings of the yellow anona variety were subjected to hydric stress, revealing an increase in the lirioidenine alkaloid in the roots up to a level of 1,239.897 µg·g⁻¹ after 25 days of treatment. This compound is reportedly related to the osmotic adjustment in plants under drought conditions, and its chemical potential during that period was -2.54 MPa, on average (Cisneros-Andrés *et al.* 2024).

Agronomic management. *Annona reticulata* is one of the least cultivated species of the genus; however, for planting, spacings of 4×4 m or 6×6 m are recommended (Cordero & Boshier 2003). Morton (1987) mentions that the tree is fast-growing, with pruning recommended, and can produce 34-45 kg of fruit per year. Avilán *et al* (1992) state that this species is resistant to unfavorable conditions; Leal & Paull (2023) point out that it is resistant to high humidity and poorly drained soils, which is consistent with its presence in a variety of soils in the state of Tabasco, Mexico. It requires rainfall of between 500-700 mm per year, and proportions of 1:1:1.2 of nitrogen, phosphorus, and potassium (20 g/plant), respectively, a quantity that can be increased as the plant develops. Fruiting can begin as early as 4-9 years, although it is very likely that by the 4th or 5th year, it can produce 40 to 50 fruits annually (Cordero & Boshier 2003).

Propagation. Propagation in *A. reticulata* is generally by seed. Khot *et al.* (2019) tested different substrates to improve germination, soaking the seeds for 24 h in gibberellic acid ($250 \text{ mg} \cdot \text{L}^{-1}$), and sowing them in a soil + manure mixture (2:1). This was found to be the best treatment, producing 70.66 % germination at 80 days after sowing. Vargas-Simón *et al.* (2022) obtained 76.6 % germination at 31 days, performing mechanical scarification of the seed on the side opposite the hilum. Germination was classified as cryptocotylar epigeal.

Regarding vegetative propagation, Hazarika *et al.* (2022) tested different types of cuttings without the addition of auxins and concluded that semi-hard cuttings presented 44 % survival and 9.2 cm of adventitious roots.

Diseases and pests. Vidal *et al.* (2014) consider that around 296 species of arthropods are pests of the genus *Annona*, particularly members of the families Coccidae, Noctuidae, Oecophoridae, and Eurytomidae. *Annona reticulata* is also a host of several species of these insects. In observations on trees in Tabasco, Mexico, the possible presence of “mealybugs” (*Phenacoccus solenopsis*) has been detected on leaves and branches in the Centro subregion of Tabasco, Mexico (Figure 4), although Vidal *et al.* (2014) mention that seed borers are the most problematic pest. In this regard, in a study in Bangladesh, fruits were protected with 30×20 cm mesh cloth bags (Ahmed *et al.* 2022) with excellent results in terms of reducing insect proliferation and improving fruit quality. Fruit mummification, caused by *Colletothricum gloeosporioides*, is one of the most important diseases in this species; however, new genera of fungi that cause diseases in *Annona* spp., particularly in *A. muricata*, have been identified. These fungi include *Lasidiopodia theobromae*, *L. pseudotheobromae*, and *Nectria haematococca* (Villarreal *et al.* 2022).

Studies in phylogenetics and molecular markers. The chromosome number of *A. reticulata* is $2n = 14$ (Kelly 2000). Recent research has extensively investigated the isolation, characterization, and application of the natural antioxidants found in this species. Nevertheless, our understanding of its genome has been restricted. The chloroplast genome, a largely self-governing genetic system within plant cells, contains a wealth of genetic information encoding genes vital for photosynthesis and other key biological functions.

Consequently, the study of the chloroplast genome is important for analyzing plant evolution, identifying genetic relatedness, and assessing germplasm resources. In this context, Niu *et al.* (2020) undertook a study centered on the sequencing, assembly, and annotation of the complete chloroplast genome of *A. reticulata*. This investigation made a significant contribution to the understanding of the species by supplying extensive genomic data for the examination of its genetic relationships, evaluation of germplasm resources, and facilitation of variety selection.

The complete chloroplast genome of *A. reticulata* underwent sequencing and analysis, revealing a genome size of 201,906 base pairs (bp) organized within a large single-copy region (69,650 bp), a small single-copy region (3,014 bp), and two inverted repeat regions (64,621 bp).

Annotation of this genome identified 164 genes, encompassing 115 protein-coding genes, one pseudogene, 40 tRNA genes, and eight rRNA genes, which were functionally categorized into self-replication, photosynthesis, unknown function, and other groups. Phylogenetic analysis, based on a maximum likelihood tree constructed from 24 plant chloroplast genomes, identified *A. cherimola* as the nearest relative of *A. reticulata*.



Figure 4. Possible presence of “mealybugs” on *Annona reticulata* leaves in Centro Subregion, Tabasco, Mexico.

The research by Larranaga & Hormaza (2015) investigated the potential of the chloroplast *rbcL* and *matK* loci as barcodes with which to differentiate seven agronomically important *Annona* species (*Annona cherimola*, *A. reticulata*, *A. squamosa*, *A. muricata*, *A. macropophyllata*, *A. glabra*, and *A. purpurea*). The distance analysis of 21 genotypes conducted by these authors indicates low intraspecific variation (likely due to sample limitations), but *matK* successfully distinguished all seven species with a distinct separation between intra- and inter-species variation, outperforming *rbcL*, which exhibited an overlap. Phylogenetic analysis supported the efficacy of both genes, with *matK* showing particular promise. Utilizing specific polymorphic nucleotides in *matK*, the authors developed seven species-specific markers for rapid and cost-effective identification, a key tool for managing *Annona* genetic resources and detecting possible hybridization. However, the authors concluded that further research is necessary to create identification tools to adequately address the significant diversity that exists within the *Annona* genus.

Germplasm management. For *ex-situ* conservation of plant germplasm, it is necessary to identify their tolerance to low temperatures and low moisture content (Hong & Ellis 1996). Within the Annonaceae family, several species are considered orthodox (Ferreira *et al.* 2019). However, in the case of *A. reticulata*, classification is uncertain: SER (2024) and Leal & Paull (2023) consider the species as orthodox, while Akter *et al.* (2020) classify it as recalcitrant, although they do not mention the methods by which they reached this conclusion in any bibliographic reference. In the latter case, the classification is based on the fact that the seeds are immersed in pulp and, hypothetically, therefore exhibit recalcitrant behavior, coinciding thus with the theory of Hong & Ellis (1996).

On the other hand, an anatomical study of the seed coat of *A. squamosa* (a species phylogenetically close to *A. reticulata*) identified sclerenchymatous tissue, which prevents immediate imbibition and possible seed deterioration

(Martínez *et al.* 2013). This supports the need for pre-germination mechanical treatments for rapid and homogeneous germination (Vargas-Simón *et al.* 2022, Pompelli *et al.* 2023). Therefore, *A. reticulata* seeds could be classified as intermediate, although this still requires verification.

A collection of 30 accessions is reported in the Germplasm Bank at the National Institute of Forestry Research in Uxmal, Yucatán, Mexico (Agustín & Segura 2014), although the status of this collection is unknown since the INIFAP page has not been updated since 2016. It is deduced that *A. reticulata* is considered less important for Mexico, so there are no records for that species in the Mexican Germplasm Bank Information System (Sbd-Germoplasma 2025). Only cherimoya (*A. cherimola* Mill) and saramuyo (*A. squamosa* L.) exist in these collections.

In different departments of Colombia, there is an *in-situ* collection of approximately 167 accessions for *A. reticulata* and other custard apple species. Genetic studies have been conducted among these and have demonstrated variations between different areas, with leaf and apex length, as well as exocarp type and color, being the representative variables in species differentiation (Castañeda-Garzón *et al.* 2016).

Knudsen (2000) provides information on the accessions of this species found in different Latin American germplasm banks (see [Table S3 Supplementary material](#)).

Perspectives on necessary further studies. Likewise, anatomical studies on *A. reticulata* are scarce in the Americas, and those that do exist are generally outdated. However, these kinds of studies are necessary to recognize adaptations to different environments and identify Annonaceae species (Folorunso 2011).

Despite advances in the geographical and ecological knowledge of *Annona reticulata*, there remains a need to strengthen its study through species distribution models that integrate robust algorithms such as MaxEnt, Random Forest, or ensemble models (Elith *et al.* 2011, Hao *et al.* 2019). These models allow for a more precise delimitation of its current and projected ecological niche, identifying areas of climatic refuge and potential zones of expansion or contraction under climate change scenarios (*e.g.*, SSP245, SSP585) (Fick & Hijmans 2017, Khan & Verma 2022).

Incorporation of key bioclimatic variables, along with edaphic and elevation data, and georeferenced occurrence records, improves predictive capacity and reduces the incidence of spatial bias (Phillips *et al.* 2009, Fourcade *et al.* 2014). Furthermore, the use of multi-scenario projections allows prioritizing regions for conservation, productive diversification, or reintroduction, providing essential tools for the adaptive management of the species in the face of future environmental variability (Bellard *et al.* 2012).

Given the varietal diversity of the fruits in Mexico, biochemical analyses are necessary in freshly harvested fruits in correlation with the transformation of different post-harvest parameters (total soluble solids, titratable acidity, total sugars, total phenol content, antioxidant activity, ascorbic acid, total flavonoids, and dietary fiber and tannin content, etc.). All these elements confer an important nutritional value to these fruits.

Among the most important and up-to-date studies on *A. reticulata*, the most highlighted are those conducted in Asia on the phytochemistry of different parts of the tree and its application in medicine. However, at the national level, some contributions are unknown. It is noteworthy that the presence and quantity of secondary metabolites can vary depending on the environment (temperature, carbon dioxide, ozone, and light), with the substrate providing the nutritional support for the metabolic routes (Niu *et al.* 2020).

Agronomic management is another avenue of research, as there is currently little data to demonstrate the effectiveness of seed-propagated or cloned plants (grafts, cuttings, etc.) (Leal & Paull 2023). It is therefore necessary to create technological packages and define fertilization rates, spacing, and pruning, among others.

Association with mycorrhizae is an ecological alternative to improve nutrition and growth. Some research has been conducted on *A. muricata* in Mexico (González-López *et al.* 2024), and more particularly on *A. reticulata*, where successful associations with the native genera *Glomus* spp., *Acaulospora* spp., and *Gigaspora* spp. were reviewed in India (Sarwade *et al.* 2011).

Undoubtedly, one of the key issues for improving the commercial prospects of this species is to develop pest and disease control methods. It has been observed that fruits are sold with a spotted pericarp, which is a sign of disease ([Figure 5](#)). There is also an absence of data regarding fruit production losses due to the tree screw worm.



Figure 5. Possible fungal damage to *Annona reticulata* fruits. Market in Villahermosa, Tabasco, México.

Due to the limited genetic information available for *A. reticulata*, research into its diversity and genetic structure is urgently required. This is particularly critical for plant species such as *A. reticulata*, where their lack of economic value makes them highly vulnerable to displacement by other species, habitat loss, and the effects of human activities. These studies are therefore paramount for determining genetic variability within and among populations, and identifying distinct lineages, levels of inbreeding, and patterns of gene flow - all crucial for understanding the species' ability to adapt to different environments and environmental changes. Moreover, they enable the assessment of effective population size, extent of genetic diversity loss, and levels of isolation, which is essential information for designing effective conservation plans. By understanding the genetic makeup of local populations, we can ensure that reintroduction or population reinforcement efforts utilize appropriate genetic material, thereby safeguarding the genetic integrity of these populations. Without this genetic insight, we remain unaware of the level and distribution of genetic variation within the species. These studies will establish a vital baseline for evaluating the current and future conservation status of this species.

In this context, it is necessary to develop descriptors for germplasm banks, which are useful for their morphological and environmental description, since they only exist for the custard apple “chirimoya” (*Annona cherimola*), in the publication by Bioversity International (2008), which supports the achievement of the 2030 Agenda for Sustainable Development, the Global Biodiversity Targets, the 2016 Paris Climate Agreement, and the Bonn Challenge, among other international initiatives.

The species has restricted commercialization, although local residents appreciate it for its unique flavor. However, like *A. muricata*, it requires further research for careful post-harvest management due to its climacteric behavior (Hernández Fuentes *et al.* 2022), which leads to accelerated damage in storage (Anuragi *et al.* 2016). To further expand its market, other methods of harvesting and consumption could be explored, such as those used with frozen soursop (*A. muricata*) pulp, among other possibilities for alternative marketing options.

Given that this species has potential in various regards, including cultural, ecological, biotechnological, and economic aspects, it is necessary to conduct the various studies outlined above to contribute to its sustainable production for the benefit of the population, as well as its *in situ* and *ex situ* conservation. Currently, home gardens and multispecies agroecosystems are becoming alternative conservation hubs for *in vivo* plant biodiversity, as discussed by Cano *et al.* (2025).

Supplementary material

Supplemental data for this article can be accessed here: <https://doi.org/10.17129/botsci.3737>

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Supporting agencies: own resources

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