Adv. Hort. Sci., 2021 35(4): 389-397 DOI: 10.36253/ahsc-10660

Review paper

AHS
Advances in Horticultural Science

Hexachlamys edulis (Berg) Kausel & Legrand, "ubajay", a native fruit species from South America

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Key words: Ethnobotany, Myrtaceae, nutraceutical fruit.

Abstract: *Hexachlamys edulis* (Berg) Kausel & Legrand, "ubajay" is a native fruit species from South America belonging to the Myrtaceae family. Undoubtedly, it is a prominent species that provides potentially nutraceutical fruits, leaves with secondary metabolites of interest, and other organs with great benefits for human health and new alternatives for production systems. The aim of this work is to carry out a bibliographic review of all the scientific material published on this species to date. Research of this species could reveal and register its ethnobotanical potential.

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Citation:
POVILONIS I.S., ARENA M.E., RADICE S., 2021 - *Hexachlamys edulis (Berg) Kausel & Legrand, "ubajay", a native fruit species from South America.* - Adv. Hort. Sci., 35(4): 389-397

Data Availability Statement:
All relevant data are within the paper and its Supporting Information files.

Competing Interests:
The authors declare no competing interests.

Received for publication 26 February 2021
Accepted for publication 2 August 2021

1. Introduction

South America occupies a prominent place with 263 underutilized fruit species, among which several of them play an important role in food and human nutrition. They have compounds that make them functional foods, have resilience to inclement weather, resist biotic stress and finally have important genes for their breeding (Brauch, 2016).

Furthermore, these species are underutilized for various reasons such as: the ignorance of their nutritional value and commercial potential, botanical misinformation, lack of promotion and popularization and the rapid disappearance of the ecosystem due to habitat destruction.

Non-traditional fruits are considered to play an important role in mitigating the problems of world food in a context with growing population and malnutrition (Nandal and Bhardwaj, 2014; Dandin and Krishna Kumar, 2016; S Ajay Vino and Sinija, 2016).

In addition, Denardin *et al*. (2015) support that there is substantial evidence of the beneficial effects of diets rich in fruits and vegetables.

There is a preference to choose the consumption of fruits with superior qualities; thus, their health benefits and perception as exotic have led to a growing demand from consumers disposed to pay higher prices than the most traditional fruits (González Vega, 2013). However, little is known about these species, and it is essential to research for being part of our economic, social and cultural heritage (Alonso and Desmarchelier, 2014).

Hexachlamys edulis (O. Berg) Kausel & D. Legrand, "ubajay" (*H. edulis*) is certainly a prominent species, distributed naturally in an important area of South America, which provides potentially nutraceutical fruits, leaves with secondary metabolites of interest, and other usable organs that provide great benefits for human health and new alternatives for production systems.

The aim of this study was to conduct a review of all scientific literature on *H. edulis* to date.

2. Materials and Methods

In order to get comprehensive information on this species, we have extensively explored available databases like Science Direct, Google Scholar, Mendeley and PubMed.

In total, we selected 55 articles through database searching with the names "*Eugenia myrcianthes*", "*Hexachlamys edulis*" and "*Myrcianthes edulis*".

Finally, the articles were used for data extraction and analysis, which were related to endemic area, systematic and phylogeny, morphological characterization, chemistry composition and ethnobotany.

3. Results

Endemic area

There are no references about *H. edulis* distribution on another continent, therefore it can be confirmed that this is an endemic species of South America. Area of collection and conservation of this species by different researchers is showed in figure 1.

Hexachlamys edulis has been studied or cited in the Argentina provinces of Entre Ríos, Corrientes, Misiones, Santa Fe, Formosa and Chaco. In Uruguay it grows spontaneously in Soriano, Río Negro, Paysandú and Artigas departments, while in Paraguay it was found in Central and Cordillera departments. Finally, in Brazil its distribution was more widespread to Rio Grande do Sul, Paraná, Santa Catarina, Mato Grosso do Sul, Minas Gerais, Sao Paulo and Goiás states.

Hexachlamys edulis has been observed in areas near water courses, where Paraná, Uruguay and Paraguay rivers are the most important. Also, it has been referred in gallery forest, delta, islands and the Paranaense jungle.

According to these studies and mentions, *H. edulis*

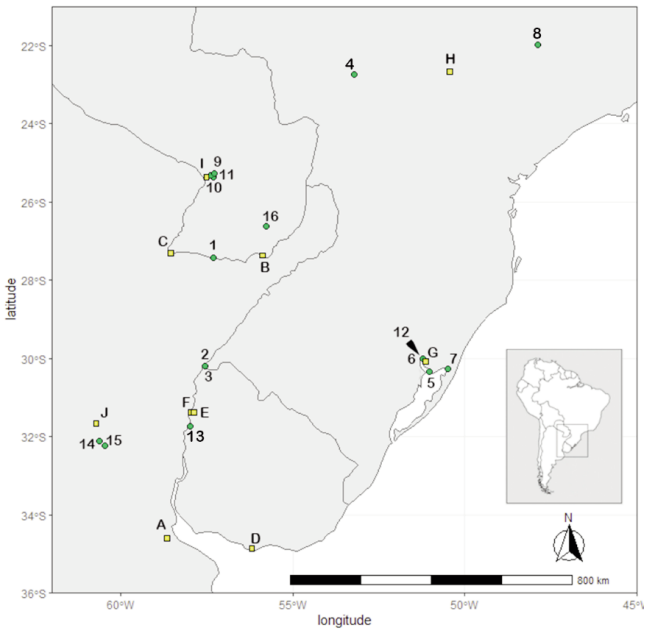

Fig. 1 - Map showing the collection sites of *Hexachlamys edulis* samples cited in this study. The circles represent samples collected from wild populations and the squares show material from herbaria or non-wild populations. Data was compiled using Microsoft Excel and R programming language (R Core Team, 2018).

References	Latitude S	Longitude W
A Molina, 2016	34°36'34.96"	58°40'31.31"
B Lorca *et al.*, 1995	27°21'53.28"	55°53'36.84"
C Franceschini, 2000	27°18'34.35"	58°33'44.03"
D Grela, 2004	34°51'32.03"	56°11'58.76"
E González, 2003	31°22'36.55"	57°58'34.22"
F Vignale and Bisio, 2005	31°23'5.84"	57°53'3.79"
G Kinupp and De Barros, 2008	30° 4'11.54"	51° 8'23.17"
H Branco *et al.*, 2016	22°39'16.36"	50°26'13.43"
I Schmeda-Hirschmann, 1995	25°21'14.12"	57°31'9.01"
J Rozycki *et al.*, 1997	31°40'8.99"	60°43'44.47"
1 Cecotto *et al.*, 2007	27°25'52.04"	57°19'25.70"
2 Cardoso Marchiori and Santos, 2010	30°12'26.71"	57°33'35.91"
3 Santos *et al.*, 2014	30°12'26.68"	57°33'33.27"
4 Romagnolo and Souza, 2004	22°45'2.92"	53°13'20.05"
5 Da Cruz, 2012	30°20'43.71"	51° 1'26.89"
6 Da Cruz, 2012	30° 3'7.35"	51°10'32.41"
7 Da Cruz, 2012	30°15'52.20"	50°29'59.84"
8 Takao *et al.*, 2015	21°58'29.68"	47°52'28.53"
9 Theoduloz *et al.*, 1988	25°21'36.36"	57°19'48.44"
10 Rodriguez *et al.*, 1992	25°18'19.62"	57°23'13.40"
11 Schmeda-Hirschmann *et al.*, 1996	25°16'0.56"	57°17'3.71"
12 Apel *et al.*, 2005	30° 0'21.60"	51°14'13.28"
13 Bertucci *et al.*, 2008	31°43'30.03"	58° 0'1.48"
14 Fagundez, 2011	32° 06' 19 6''	60°38' 25 5''
15 Fagundez, 2011	32°13'21 2"	60°27'51.4"
16 Dujak, 2015	26°36'36.09"	55°46'26.88"

is distributed at least in one million Km^2.

Systematics and phylogeny

Myrtaceae family has 131 genera and more than 4620 species (Stevens, 2017) and up to 5800 species according to Stefanello *et al*. (2011). The family is divided into two large tribes according to the fruit consistence: Leptospermeae if the fruit is dry or Myrteae if it is fleshy.

The Myrteae tribe or subfamily, contains three subtribes: Myrcinae Berg, Orthotestimoninae Berg, and Eugeniinae Berg. The latter tribe includes the genus *Hexachlamys* (Legrand, 1962) that presents approximately 10 species distributed in South America (Cruz *et al*., 2011), among which is *H. edulis*.

Authors cited the species *H. edulis* with several names and also including it in different genera (Table 1). *Psidium amygdalinum* (Hooker and Arnott, 1833) is the oldest available name for this species. Sometime later the species was named *Myrcianthes edulis* by O. Berg, and then Bentham and Hooker rename this taxon to *Eugenia*. This species became known as *Eugenia edulis* until Niedenzu showed that the name already existed and introduced *Eugenia myrcianthes* Nied. Finally, Kausel and Legrand published the new nomenclature as *Hexachlamys* (Proença, 2006).

The name *H. edulis* was first published in 1950 and since 1968 the genus *Hexachlamys* was independent (McVaugh, 1968). *Hexachlamys* was differentiated from *Eugenia* by Berg based on the number of chalice pieces and the embryo morphology. Flowers of *Eugenia* gender have tetrameric chalice while those of *Hexachlamys* have pentameric or hexameric calix, and the embryo of *Hexachlamys* have hypocotyl visible and exserted and cryptic in *Eugenia* (Da Cruz *et al*., 2013); however, some authors considered this argument inconsistent to separate the genus (Ciarlante, 2003; Da Cruz, 2012).

Other names used for the species were *Luma grisebachii, Luma myrcianthes, Myrtus excelsa, Calomyrtus excelsa, Myrcia gemmiflora* (eds), *Campomanesia cagaiteira, Myrcia sparsifolia, Hexachlamys excelsa, Eugenia montevidensis, Eugenia edulis* ex Grisebac, *Myrciaria edulis* Skeels, *Myrciaria plicatocostata* O. Berg, *Eugenia plicatocostata* Glaz, *Marlierea edulis* Nied, *Plinia anonyma* Sobral, *Plinia edulis* Vell, *Plinia plicatocostata* O. Berg Amshoff (Rotman, 1982; Borges *et al.*, 2014).

Since the publication of Mattos (1995) and Landrum and Kawasaki (1997) it was discussed whether *Hexachlamys* should be considered as a different genus or as a synonym of *Eugenia*.

In addition, new phylogenetic molecular analysis have revealed that *Hexachlamys* species do not form a monophyletic clade, so the *Hexachlamys* proposal as a synonym for *Eugenia* was corroborated (Cruz *et al*., 2011; Da Cruz, 2012; Da Cruz *et al*., 2013; Mazine *et al*., 2014, 2016, 2018).

Mazine *et al*. (2018) suggested more consistent and stable classification: *Hexachlamys* as a subgenus of *Eugenia*. This last denomination, *H. edulis*, is the most currently used as is observed in figure 2 (Proença, 2006; GBIF, 2019).

Different authors (Niedenzu, 1893; Mattos, 1995; Landrum and Kawasaki, 1997; Sobral, 2003; Proença, 2006; Da Cruz, 2012; Mazine *et al*., 2014, 2016;

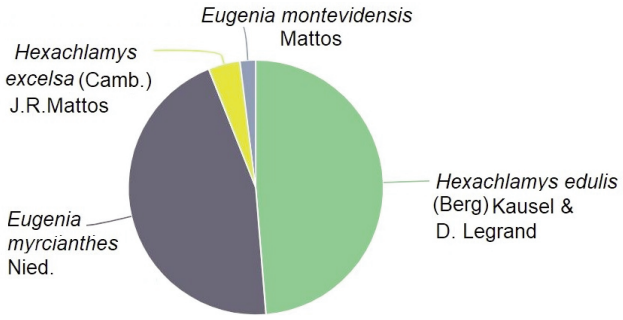

Fig. 2 - Different names used to classify *Hexachlamys edulis*. Figure taken from GBIF (2019).

Table 1 - Different names assigned to the species by botanists over the years

Year	Botanists				
	Hooker & Arnott	O. Berg	Bentham & Hooker	Niedenzu	Kausel & Legrand
1833	*Psidium amygdalinum*				
1857		*Myrcianthes edulis*			
1865			*Eugenia edulis*		
1893				*Eugenia myrcianthes*	
1950					*Hexachlamys edulis*

WCSP, 2020) argue that it is correct to accept the synonymy between *H. edulis* (Berg) Kausel & Legrand and *Eugenia myrcianthes* Nied.

Morphological characterization

Hexachlamys edulis is a fruit tree with globular treetop (Fig. 3A), with an altitude up to 10 meters according to Rotman (1982), 12 meters according to Legrand and Klein (1977), Cardoso Marchiori and Santos (2010) and 15 meters by Dematté (1997).

Persistence of the foliage is contradictory (Carrere, 2008). Rotman (1982) consider this species as evergreen but in Uruguay it shows leaf fall from late May to late August and blooming at the beginning of the spring without leaves. Foliage unfolds later, when the anthesis declines and vegetative growth stops in early December (González, 2003). A more exhaustive observation allowed determining that this species is phanerophytes - by the aerial location of its buds (Raunkiaer, 1934) - and deciduous with concomitant foliar renewal and that apparently low temperatures accelerate defoliation (González, 2003).

Leaves are described as petiolated, with a coriaceous leaf blade, pubescent, oval or elliptic-oblong, briefly acuminate, obtuse base, (3-) 5-9 cm of length by (1-) 2.5-3.4 cm, reticulate venation, with the median nerve prominent on the abaxial face; pubescent

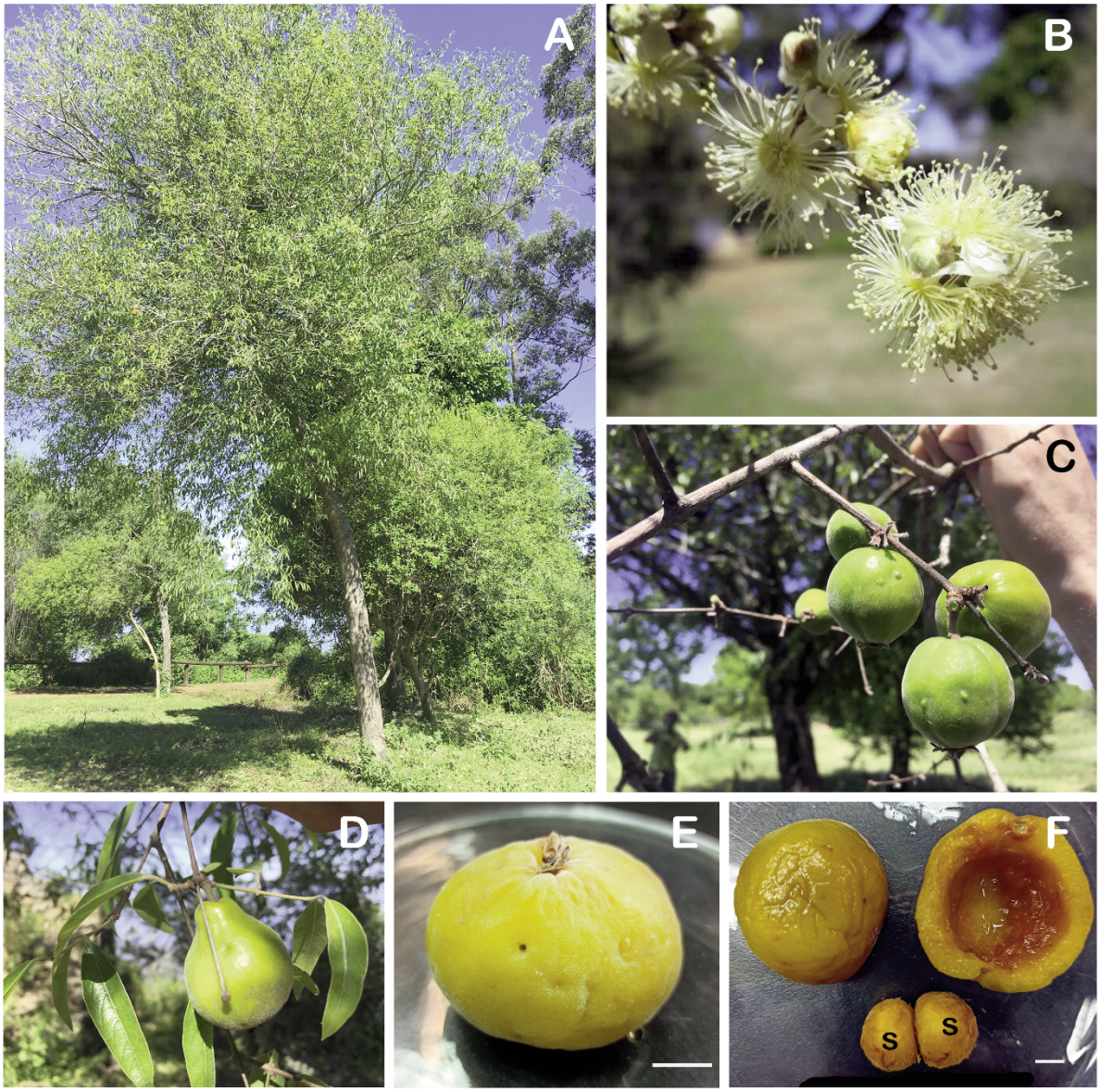

Fig. 3 - *Hexachlamys edulis* grown in Argentina. (A) tree grown in Parque Nacional El Palmar, Entre Ríos; (B) cluster of flowers; (C-D) inmature fruit; (C) globose; (D) piriform; (E-F) mature fruit; (F) disected fruit with seeds (s). Bars = 1 cm.

petioles, (3-) 7-10 mm of length (Rotman, 1982). Lorca *et al*. (1995) described polygonal to sinuous cells of various sizes and sparse trichomes stand out in the adaxial epidermis; the cuticle is thick and striated. In their abaxial epidermis they describe abundant single celled trichomes and clustered and raised stomata. Stomata are paracytic, that is, they have 2 adjoining cells arranged parallel to the occlusive cells. Also, the presence of hypodermis towards the adaxial face, palisade parenchyma 1-stratified and spongy parenchyma 5-6-stratified, with large intercellular spaces stand out. The central rib has flabeliform xylem and phloem in bundles located on the abaxial and adaxial sides of the xylem. Sclerenchymal sheath interrupted on the sides. Collenchyma present on the abaxial side and 3-4 hypodermis stratified on the adaxial side.

Flowers are typical of Myrtaceae; appear in the leaf axils in apical position, are white, solitary and hermaphroditic (Fig. 3B). Rotman (1982) describes clusters with 2-4 flowers with pubescent pedicels from 1 to 22 mm in length, puberulous, linear lanceolate, up to 5 mm in length; pubescent hypanthus; sepals (4-) 5, puberulous, deltoid, acute, persistent, 3-5 mm in length; petals (4-) 5, obtuse, ciliolate, pubescent on the outer, face spacedly hairy on the inner face, 5-9 mm length; stamens 5-9 mm in length, pubescent staminal disc; 2-3 locular ovary with axillary placentation. Although there are no morphological references of nectariferous glands, Fagundez (2011) cites *H. edulis* as a native pollen-nectariferous species of interest.

Flowering season is variable according to diferent the researchers. Flowering, occurs from August to January in northeastern Argentina, in the department of Artigas, Uruguay, and in Asunción, Paraguay by Rotman (1982). Instead, for Dematté (1997) it happens between August and November, that is, it reduces the range, without specifying the location, while Vignale and Bisio (2005) reports a shorter flowering period, during September, in Salto, Uruguay. In the same locality, González (2003) observes that in early October flowering declines and ends entirely in the middle of the month. For plants grown in the locality of Lajeado, Brazil, Guizzo and Jasper (2005) recorded flowering from August to September. Finally, Fagundez (2011) found that *H. edulis* reaches full bloom during the month of October in Diamante, Argentina.

Fruit is a globose drupe (Lughadha and Proenca, 1996) with a yellow color, about 5 cm in maximum equatorial diameter (Lorenzi *et al*., 2000) and up to 50 g of fresh weight in the mature state. Fruit set and ripening occur in a few weeks, staggered from mid October to the end of November when the harvest can be done (Vignale and Bisio, 2005). Rotman (1982) describes an edible fruit, globose or piriform (Fig. 3C-D), up to 9 cm long. Fruits are yellow, up to 4 cm in diameter according to González (2003). It is a barely fluffy fruit, with an orange flesh, very juicy, with a slightly sour taste and a pungent odor when fully ripe (www.descubriendocorrientes2012.com) (Fig. 3E-F). Also, it has been described as sweet sour, pleasant, and a quickly maturing (González, 2003) and as a very acidic fruit (Chebez and Masariche, 2010). However, other authors have characterized the ripe fruit by a disgusting smell, although it would seem that there is great diversity in the fruits between genotypes (Vignale and Bisio, 2005), to which Carrere (2008) attributes that more or less fruits could be found pleasant to smell depending on the subjectivity of those who perceive it.

Regarding to associated pathologies, González (2003) found that most of the fruits had insect bites, but without specifications; only Rossini *et al*. (2015) cites *H. edulis* as host of *Anastrepha fraterculus* (Wiedemann).

The seed is exalbuminated, globose and during germination it remains enclosed by a woody structure that some authors interpreted as endocarp (Rotman, 1982) (Fig. 3F); but it has not been anatomically corroborated (Franceschini, 2000). It has a single embryo (Lughadha and Proenca, 1996) solid, globose and glabrous (Franceschini, 2000) with fully welded cotyledons. Germination is hypogeal and cryptocotilar.

The seedling is completely covered with simple hairs, undeveloped hypocotyl, light green and cylindrical epicotyl. Alternate membranous cataphylls have acute apex, obtuse base and entire margin. Simple, alternate or opposite nomophiles; petiole ribbed on adaxial face; elliptical blade, chartaceous, light green, sharp apex and base and entire margin (Franceschini, 2000).

Chemistry composition

Researchers promote the consumption of diets rich in fruits and vegetables due to its health beneficial effects, such as lowering the risk of cardiovascular disease, cancer and conditions associated with aging and oxidative stress (Gomez da Silva *et al*., 2019). Studies show that these foods can prevent dis-

eases and disorders due to the presence of bioactive compounds with antioxidant properties. These compounds interfere with biological mechanisms such as the protection against free radicals, cellular signaling mediated for free radicals, inflammation, allergies, platelet aggregation, ulcers, viruses, tumors and hepatotoxicity (Denardin *et al*., 2015).

Several studies have shown that the fruits of Myrtaceae have antioxidant activity (Borges *et al*., 2014) due to the presence of anthocyanins, flavonoids, carotenoids or other secondary metabolites.

In particular, *H. edulis* fruit would have great potential as a functional food due to its compositional profile, outstanding nutritional value (Vignale and Bisio, 2005), very favorable for health, and considering that its vitamin content has been highlighted (Cecotto *et al*., 2007). In addition, fruit has vitamin C quantified in 75.1 mg/100 g of fresh matter (Rozycki *et al*., 1997). Also, different phenolic compounds (2181.42 mg GAE/100 g of dry matter), carotenoids (242.53 µg/g of dry matter) and antioxidant activity (153.09 µmol Trolox Equivalent/g of dry matter) have been quantified (Branco *et al*., 2016). It also stands out for its protein content of 8.05% in dry matter, and good relative amounts of Zinc and Boron minerals (Kinupp and De Barros, 2008).

Hexachlamys edulis was noted for its high content of total pectin (403.5 mg/100 g) in fresh fruits tissue (Rozycki *et al*., 1997). This high content explains the excellent quality of the fruit jelly of this species cited by Kinupp and De Barros (2008).

All these data show the potential of this fruit tree, especially for the fruit pulp, juice and jelly agroindustry. However, this species is not considered yet by Brazilian fruit producers and researchers (Kinupp and De Barros, 2008), unlike the manifest interest observed in other countries of South America.

On the other hand, the leaf of the species belonging to the Myrtaceae is the most used plant organ in South America for medicinal purposes (Camelo Munevar, 2016), and perhaps for this reason, the chemical composition of the leaves has been the most studied. *H. edulis* leaves contain steroid triterpenes, low molecular weight terpenes, tannins, polyphenols, saponins, alkaloids, flavonoids, and glycosides (Bertucci *et al*., 2008). Flavonoid glycosides: myricetin 3-O-rhamnoside; myrcetin 3-O-pentoside; quercetin 3-O-pentoside; quercetin 3-O-rhamnoside and myricetin deoxyhexoside-gallate (Schmeda-Hirschmann, 1995; Schmeda-Hirschmann *et al*., 1996; Celli *et al*., 2010; Takao *et al*., 2015). Essential oils have a predominance of sesquiterpenes, of which β-selinen (16.1%), β-caryophyllene (8.3%) and δ-cadinene (8.3%) are the most abundant (Apel *et al*., 2005). Also, Borges *et al*. (2014) found β-caryophyllene, its oxide and caryophyllene oxide (39.3%).

Ethnobotany

According to Legrand and Klein (1977), *H. edulis* is a species frequently cultivated in Rio Grande do Sul (Brazil), for its tasty and fragrant fruits. Fruits are consumed fresh, in jams, juices, jellies (Da Cruz, 2012) and ice creams have been made with great acceptance. Kozel (1991) describes that consumption of *H. edulis* fruits favor fights bladder stones and nephritic stones. Also, two Mbyá Guaraní communities of the San Rafael Park Reserve harvest the fruit for food (Dujak *et al*., 2015). The fruit is considered by some people to be slightly laxative (Lorenzi *et al*., 2000).

Leaves are widely used as infusions in Brazil for the treatment of bronchitis, cough, whooping cough (Camelo Munevar, 2016) and diabetes (Rodriguez *et al*., 1992). *H. edulis* leaf extract causes a significant response in blood glucose levels due to its rich content of flavonoids and tannins. In addition, Lorca *et al*. (1995), highlight its use for the treatment of diabetes in the form of herbal teas or with *mate*. Consumption was reaffirmed by Pirondo *et al*. (2011), due to the supply of the product in the markets of Corrientes, Argentina. Other authors highlighted the benefits of the leaves and their medical use to reduce uric acid due to the inhibition of the enzyme xanthine oxidase, producer of uricate, whose excess is considered to cause hyperuricemia in gout (a form of inflammatory arthritis) (Lio *et al*., 1985). Theoduluz *et al*. (1988) analyzed *H. edulis* leaves and it was proved to be the most active among the 15 species in a comparative study.

Other possible secondary uses are the production of vinegar from the fruit (Carrere, 2008) or production of essential oils from its flowers (Cecotto *et al*., 2007). Also, its wood is useful (Molina, 2016) due to it is moderately heavy, hard, compact and resistant, suitable for common carpentry, tool handles, turning (Cardoso Marchiori and Santos, 2010) and its bark can be used in the chemical industry for the preparation of white ink and tannins (Carrere, 2008). It is used as alternative forage in Paraguarí, Paraguay (Benítez and Bertoni, 2015) or can also be used for reestablishing native woodland or forest gardens

(Lorenzi, 2002). Chebez and Masariche (2010) includes *H. edulis* in their list of healing trees.

H. edulis is known by many vernacular names such as "ubajay" and due to its similarity to the peach (*Prunus persica* L. Batsch.), it is called "duraznero de monte" (in Argentina and Uruguay) (Hanelt *et al*., 2001). Also, *H. edulis* was named "iba hay", "ibajai", "igu jhay mi", "uva jy" (Legrand, 1941; Rotman, 1982) and "Clagye locoic" in Mocovic lenguage (Rosso and Scarpa, 2012). In Brazil it is known as "cereja do rio grande", "ocorocil lo", "cerejeira", "ivai", "pessegueiro bravo", "pêssego do mato", "ubajaí" and "ibajaí" (Romagnolo and Souza, 2004; Proença, 2006). In Paraguay it is known as "yvahái" (Dujak *et al*., 2015).

4. Conclusions

Despite the ecological and economic importance, little is known about this species of the genus *Hexachlamys*, so it is important to revalue its use. *H. edulis* (O. Berg) Kausel & D. Legrand, "ubajay" research could reveal and record its ethnobotanical potential based on the chemical composition of its fruits and other organs. At the same time, we refer to a species with the possibility of cultivation that offers the opportunity to diversify production, in this case, for farmers on the Argentine coast, southern Brazil, Paraguay, western Uruguay, and why not in a future, in other regions.

Acknowledgements

This work was supported by the Secretariat of Science and Technology of the University of Morón PICT/18-06-MA-009.

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