

Byrsonima crassifolia L. Kunth a bio-resource with potential: Overview and opportunities

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ABSTRACT

Byrsonima crassifolia L. Kunth is a plant native to the Americas that grows in tropical and subtropical areas. Fresh *B. crassifolia* fruits are a good source of ascorbic acid and carotenoids and contain volatile compounds such as butyric and caproic acids. Although *B. crassifolia* is commonly exploited from wild natural ecosystems, it exhibits the potential to become a crop plant. When optimal agronomic management systems support propagation by seed, fruits with more homogeneous characteristics can be produced compared to those obtained from wild or backyard plants. *B. crassifolia* fruits can be found in local markets in Central and South America. The pulp, peel, and other *B. crassifolia* fruit components can be processed to make traditional and innovative food products, namely candies, cookies, cakes, candied fruits, ice creams, sorbets, jellies, juices, liqueurs, jams, nectars, pickles, and fruit drinks as an alternative to avoid the waste of overripe fruits. Additionally, the woody fraction of the *B. crassifolia* tree is used as a source of firewood, as shade, and for constructing living fences. These uses also allow the maximum use of biomass by establishing support for cultivation with the circular economy and strengthening food security. Therefore, this review aims to provide insights into the generation and dissemination of knowledge supporting the development of strategies in the areas of agronomy, postharvest management, and technological processing of *B. crassifolia* to promote its sustainable use and exploitation.

Keywords: bioactives, crops, food security, murici, nanche

INTRODUCTION

Food security is a challenge for humanity in an ever-increasing world population and is interrelated with the use and conservation of biodiversity (Fischer et al.,

2017; Glamann et al., 2017). The generation of local and global food security conditions simultaneously requires the promotion and conservation of

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biodiversity (Fischer et al., 2017; Glamann et al., 2017; Ulian et al., 2020). In other words, the use of biodiversity resources for food security should focus on solving the sustainability problems caused by modern intensive agriculture (Renard and Tilman, 2021).

Globally, multiple plants are known to be suitable for human consumption. Still, few plant species are used as commercial crops (Baldermann et al., 2016). An estimated 500,000 species of land plants exist (Corlett, 2016), of which 30,000 are edible, but only about 150 are cultivable crops (Shelef et al., 2017). Conventional crops have impacted plant biodiversity through intensive agriculture and the insertion of foreign species. For this reason, it is necessary to explore alternatives using endemic plants to develop sustainable and environmentally friendly agriculture. Many endemic plant species have been neglected and underutilised, including wild, domesticated, or semi-domesticated plants (Ulian et al., 2020). Thus, the current demand for natural and functional products highlights the relevance of harnessing little-known plants with high nutritional and functional value (Reis and Schmiele, 2019).

Byrsonima crassifolia L. Kunth is a plant native to the Americas that is mainly exploited from wild natural ecosystems, and although it has been regionally used for fruit production, it may not currently be considered a commercial crop (Porto et al., 2020). It has been suggested that *B. crassifolia* is a 'neglected plant species' in North and South America (Baldermann et al., 2016). This may explain why only a few studies have addressed the commercial activities related to this species. In this regard, generating and disseminating knowledge related to the characteristics and cultivation of *B. crassifolia* can promote the development of regional agribusiness with available non-exploited bioresources to generate conditions for food security (Brussaard et al., 2010; Santos et al., 2020). The present study aims to show the

potential of *B. crassifolia* for developing a cultivable crop and promoting food security through an overview and analysis of future opportunities.

***B. crassifolia* L. Kunth**

The *B. crassifolia* tree (order: Malpighiales; family: Malpighiaceae) is part of the perennial plants found in tropical and subtropical zones from the Mexican Pacific to Central and South America (Figure 1).

After seed germination, the plant grows 40–60 cm in height for approximately 3 months (Cordero and Boshier, 2003), and further develops a small structure with a height of 3–7 m (up to 15 m in some adult trees) and 30 cm trunk diameter (Vázquez-Yanes et al., 1999). *B. crassifolia* common names 'nance' or 'nanche' derives from the Nahuatl *Nantzincocotl*, meaning 'sour fruit of the mothers or older women'. Others common names, depending on the region, are yellow nanche, nance, murici, changunga, nananche, and peralejasu. The distribution and commercialisation of *B. crassifolia* are limited to local markets (Moreno, 2000; Moreno-Martínez et al., 2016; Irías-Mata et al., 2018; Rivas-Castro et al., 2019; De Oliveira et al., 2021). Although different tissues of this plant have been applied for pharmaceuticals, cosmetics (Reis and Schmiele, 2019), forestry, ornaments, and fodder (Guzmán-Pozos et al., 2013), the fruit is the most used organ.

B. crassifolia fruit is known as yellow nanche; the mature fruit peel is predominantly yellow but can present dark orange, or green shades (Duarte, 2011). Of the fruit, 79%–89.55% is pulp (Saldívar and Blándon Navarro, 2021); and the fruit has 0.64%–0.77% acidity, 9.8–11.76 °Brix, a total phenolic content of 143–307 mg GAE · 100 g⁻¹, and 36–58 mg · 100 g⁻¹ ascorbic acid (Maldonado-Peralta et al., 2020; Aniceto et al., 2021; Siriano et al., 2022). The peel composition is <0.10% lipids, 4.30% proteins, 1.7% acidity, and 5.57 °Brix. The values of total phenolic content and tannins have been



Figure 1. *B. crassifolia* tree in the forestal from 'Huitzuc de los Figueroa' Guerrero, Mexico.

reported as 4.47 mg GAE · 100 g⁻¹ and 2.74 mg · 100 g⁻¹, respectively (Carlos et al., 2017; Irías-Mata et al., 2018; Robles-Melchor et al., 2021; Alves et al., 2020). Finally, seeds represent 22.23% of total fruit weight and contain 15% lipids, 8.8% protein, 27.5% fibre, 0.03% acidity, and 4.14 °Brix, 404 mg GAE · 100 g⁻¹ total phenolic, and 3.56 mg tannins · 100 g⁻¹ (Carlos et al., 2017; Araújo et al., 2018; Alves et al., 2020; Robles-Melchor et al., 2021).

Fresh fruit

One aspect to consider for fruit marketing is establishing appropriate storage conditions. The classification of *B. crassifolia* as a climacteric or non-climacteric fruit has been controversial. Nanche fruit ripening shows ethylene-dependent climacteric patterns (Da Silva et al., 2016; Rivas-Castro et al., 2019). However, Rivera-Correa et al. (2022a) found that nanche fruit showed a non-climacteric behaviour. Nevertheless, when harvested at a specific physiological state, fruits exhibited ripening-associated changes, suggesting that nanche fruit postharvest metabolism is modulated by the stage of development at harvest. Rivas-Castro et al. (2019) also proposed that the first peel colour changes indicate an appropriate harvest maturity. Da Silva et al. (2016) recommend harvesting nanche 28–35 days after anthesis, which agrees with the onset of abscission after anthesis (Brady and Speirs, 1991). However, Medina-Torres et al. (2012) report 90 days for harvesting nanche, and according to fruits harvesters in Guerrero (Mexico), from anthesis to fruit harvest (May–August), 90 days elapse (personal communication with harvesters and collectors), while Duarte (2011) report that fruit development from anthesis to harvest takes 5–6 months. Further studies are necessary to advance the knowledge on the ripening metabolism of nanche fruit, which may help to understand its phenology and to define an optimal harvest time. Studies regarding the postharvest quality and behaviour of yellow nanche are scarce, and inadequate supply chains limit nanche fruit commercialisation.

Fully ripe fruits are characterised by an utterly yellow colouration. Rivas-Castro et al. (2019) classify yellow nanche according to three maturity stages: ‘green with fully developed size harvested from tree (M1), greenish-yellow harvested from tree (M2), and fully yellow in the natural abscission (M3)’. Similarly, green, transient, and yellow were suggested by Rivera-Correa et al. (2022a) as three maturity stages for nanche fruit.

Some practices for improving postharvest handling and increasing the shelf life of *B. crassifolia* fruit are sanitising, packing, and storing at low temperatures. According to Rivas-Castro et al. (2019), sanitisation with 1% sodium hypochlorite for 5 min increased fruit shelf life. Currently, no studies have evaluated other sanitising methods and their impact on the shelf life, sensory, nutritional, and functional properties of *B. crassifolia*. Postharvest handling using plastic packaging reduces physical deterioration. Polypropylene, nylon-polyethylene, and polyamide-polyethylene are packaging

alternatives that positively affect the shelf life of the fruit (Gomes et al., 2021a, 2021b). Vacuum packaging has also positively affected fruit quality (Gomes et al., 2021b). Commercial refrigerated storage at 12 °C has been evaluated (Belisário and Cavestré, 2013). In this case, Gomes et al. (2021a) reported postharvest shelf life of up to 16 days with fruits harvested at an M2 stage of maturity where the skin colour is yellowish-green (80% green and 20% yellow) at 12 ± 2 °C. Alternatively, Rivas-Castro et al. (2019) reported a shelf life of up to 15 days when stored at 15 °C. Both studies agree on a 2-week shelf life period at commercial refrigeration temperatures. Also, Rivera-Correa et al. (2022b) mentioned that refrigeration reduced weight loss without significant colour changes and established that postharvest handling at consumption maturity at 8 °C is feasible.

The marketing of fresh fruit from *B. crassifolia* has high-value health markets (Neves et al., 2015) partly because of its sensory characteristics (Uekane et al., 2017) wished by consumers, including specific needs such as those of vegetarians and vegans (Santos et al., 2020). However, the main challenge to overcome lies in ensuring postharvest handling conditions that positively impact shelf-life during fruit transport and storage. For instance, active coatings and packaging, infrastructure for temperature control, and controlled atmospheres are technologies and treatments used in other fruit species that could be evaluated for *B. crassifolia* fruit. Nevertheless, implementing postharvest technologies can increase the cost of fresh fruit, especially when markets are in areas far from the harvest site. Then, the transformation of nanche fruit into products that do not require low temperatures is an option for processed food derived from *B. crassifolia*.

PROCESSING AND TRANSFORMATION OF FRUIT

The development of processed food products from fruits is a practice that aims to increase shelf life and ensure accessibility to fruits in areas where it is not possible to obtain fresh fruit. Furthermore, processing confers added value and diversification to the use of fruit, in which techniques to preserve foods, such as drying, freezing, chilling, pasteurisation, and chemical preservation, can be used (Amit et al., 2017). Numerous food formulations based on pulps, peels, and other fruit components can be found on the market. One factor for consumer acceptance is the cultural background, and traditional processed products are well-accepted in most societies today, or at least a specific market may exist. Therefore, traditional preservation and processing techniques have been developed for *B. crassifolia*. Among traditional and innovative food products from *B. crassifolia* are candies, cookies, cakes, crystallised fruit, ice cream, sorbets, jellies, juices, liquors, jams, nectars, brines, fruit drinks, and others (Duarte, 2011; Moreno-Martínez et al., 2016; Medina-Torres et al., 2017; Matildes-García and Gallardo-Navarro, 2017; Da Cunha et al., 2020).

Pulps, juices, and drinks

Pulp and juice production is an agroindustrial activity that adds economic value to the commercialisation of fruits (De Souza et al., 2020). The pulp can be marketed by increasing its shelf life through procedures such as pasteurisation. In *B. crassifolia*, pasteurisation processes at 63 °C for 30 min and 73 °C for 15 s have been evaluated to reduce the microbial load. Both treatments showed good bioactive compounds and antioxidant capacity retention, with almost no detrimental effects compared to the unpasteurised pulp stored at refrigeration conditions (4 ± 1 °C) for 3.5 months (Urquieta-Herrero et al., 2021). Therefore, the packaged pasteurised pulp can be an ingredient in the production of juices and beverages. Beverages made with *B. crassifolia* pulp have good sensory acceptance by consumers; the combination of yellow colour and sugar content is an attribute that has favoured its approval (De Souza et al., 2020; Aniceto et al., 2021). Also, fermented alcoholic drinks have been well-accepted by consumers (Bizimoto et al., 2015; Moreno-Martínez et al. 2016).

Dehydrated products

Dehydration by hot air (60 °C) and lyophilisation (−55 °C) of *B. crassifolia* did not affect the functional properties of the fruit (López et al., 2014; Saldívar Ruiz et al., 2021). Osmotic dehydration partially removes moisture from food by generating intermediate moisture products (Ahmed et al., 2016). Some osmotic agents are sucrose, corn syrup solution, salt, fructooligosaccharides, maltose, honey, maltodextrin, ethanol, high fructose corn syrup, and maple syrup (Ahmed et al., 2016); however, in *B. crassifolia*, there have been few studies addressing osmotic dehydration.

The jam and jelly are intermediate moisture foods with total soluble solids content >65%, elaborated from cooked fruits and sugar with or without added pectin (Shinwari and Rao, 2018; Richter Reis, 2019). Jam and jelly allow extended shelf life by evaporation concentration at temperatures close to 100 °C, acidic pH, and high concentration of soluble solids (Reis and Schmiele, 2019). These products have been prepared from yellow nanche pulp and have shown acceptable sensory characteristics and desirable nutritional attributes, with a shelf life of >12 months (Caballero Roque et al., 2012; Monteiro et al., 2015; Da Cunha et al., 2020).

Other products

Products such as sorbet, ice cream, cookies, and canned syrup (Moreno-Martínez et al., 2016; Matildes-García and Gallardo-Navarro, 2017) have been elaborated with *B. crassifolia* ingredients; however, studies regarding the shelf life, nutritional, and organoleptic traits in these products are scarce or not available.

INDUSTRIAL AND ENVIRONMENTAL OVERVIEWS

The *B. crassifolia* tree has multiple potential uses and applications; it can be used as a timber tree, as a source of

plant tissues, a specimen for environmental remediation, a source of fruit for direct consumption, and its leaves and fruit fractions can be used as a source of bioactive compounds. These applications allow maximum biomass utilization and promote a circular economy favoring the local economy.

Tree

Some American rural populations and native indigenous people use the tree as a source of firewood, shade, and construction of living fences, and in rare cases, the wood is used for carpentry or handicrafts and light construction (Jiménez-Ferrrer et al., 2010; Áviles-Peraza, 2015; De Oliveira et al., 2017). The woody fraction is utilised to produce forest charcoal and as a renewable energy source (Marques et al., 2020). It can be used to increase organic carbon in soils, helping water retention capacity and decreasing acidity in established crops (Lima et al., 2021). Also, it helps the recovery of coastal ecological spaces (Vieira-Serra and Bezerra-Almeida, 2021), and supports nests of pollinators and propagation of other plant species (Mendes and De Santana Rêgo, 2007; Vieira-Serra and Bezerra-Almeida, 2021) in areas where the tree is endemic. Pollinating species of the genus *Centris* are among those that have adapted to the *B. crassifolia* tree (Rego et al., 2006).

Fruit

The fruits of *B. crassifolia* are a good source of ascorbic acid and carotenoids such as lutein and zeaxanthin (De Souza et al., 2020; De Oliveira et al., 2021). Also, it has volatile fractions such as butyric acid (11.46%), ethyl hexanoate (26.15%), caproic acid (44.54%), and others (Uekane et al., 2017). Some biological activities of these compounds have been characterised. Caproic acid can be used in feed formulates, antimicrobials, and plant growth promoters (Chen et al., 2017). Flavonoids with antioxidant properties have been associated with protection against chronic and cardiovascular diseases (De Oliveira et al., 2021). However, the yield of pure compound extraction must be thoroughly evaluated.

The seed extracted oil is composed of 25.54% and 74.46% saturated and unsaturated fatty acids, respectively. The main unsaturated fatty acids are palmitic (16.66%), stearic (8.88%), and linoleic (74.66%) (De Moraes et al., 2017). Linoleic acid is a nutrient typically provided by enteral nutrition (Whelan and Fritsche, 2013). Also, hexane extract contains sesquiterpene lactones with antioxidant, hypoglycaemic, and hypolipidemic activities (Gutiérrez and Ramírez, 2016). The endocarp can be utilised in the development of selective sorbents for the treatment and purification of polluted wastewater (Monroy-Figueroa et al., 2015), for removing metals such as Cd (II), Pb (II), and Ni (II) (Di Bitonto et al., 2021), and methylene blue (Monroy-Figueroa et al., 2015; Bernal-Jácome et al., 2020; Espinosa-Rodríguez et al., 2020; Robles-Melchor et al., 2021). The latter has also been removed from effluents treated with fibrous matrices found in

the peel of yellow nanche (Robles-Melchor et al., 2021). One advantage is the higher availability of this biomass that can be obtained as a by-product after processing the fruit pulp, compared to traditional activated carbon sources (Di Bitonto et al., 2021).

Leaves

Leaf extracts from *B. crassifolia* are rich in bioactive compounds. Some active phytochemicals identified in alcohol extracts are triterpenes, sterols, flavonoids, aromatic esters, and amino acids (Bejar et al., 1995). The most abundant are terpenes (94.19%) as α -pinene, camphene, and eucalyptol (González-Saucedo et al., 2019). In addition, the alcoholic extract exerts antispasmodic, anti-inflammatory, antioxidative, and antimicrobial activities and does not exhibit mutagenic activity and genotoxicity (Bejar et al., 1995; Pompeu et al., 2012; De Souza et al., 2018; Vasconcelos et al., 2020). Also, essential oils inhibit the growth of pathogenic bacteria, including *Staphylococcus aureus* and *Bacillus cereus* (Vázquez-Cahuich et al., 2013).

Regarding the extraction methods of bioactive compounds, in comparing the output of nanche leaf subject to the enzyme-assisted extraction (EAE) process vis-à-vis solvent extraction, it was found that the former yields up to 25% higher concentration, and accordingly, EAE could be considered an effective alternative to solvent extraction techniques (De Oliveira et al., 2020). In addition, some of the food technology

applications that have been evaluated for nanche extracts are nanoparticle-based coatings formulations for the preservation of quality and safety parameters in plant materials such as tomatoes (Gutiérrez-Molina et al., 2021) and bell pepper (González-Saucedo et al., 2019).

ADVANCES IN AGRONOMIC CROPS

Species and phenotype

B. crassifolia has different common names depending on the region where it is found, and there may be confusion in identifying the biological species. This situation is evidenced in some reports; for example, De Carvalho Soares et al. (2021) mentioned that although there are monographs of the Malpighiaceae family members, they do not provide taxonomic tools applicable on a regional scale, which makes it challenging to recognise the diversity of species that belong to this genus.

B. crassifolia is identified with the common name *mirixi* or *murici* in some areas (De Souza et al., 2020; Oliveira et al., 2020), and *B. verbascifolia* with the common name *orelha-de-burro* (Oliveira et al., 2020), but other authors mention that *murici* is *B. verbasciflora* (Dos Reis Barbosa et al., 2015; Morzelle et al., 2015). The two species have similar fruit (Dos Reis Barbosa et al., 2015), but characteristic features allow differentiating between *B. crassifolia* and *B. verbascifolia* (Table 1).

Also, sometimes, species of *B. crassifolia* and *Malpighia mexicana* DC are known indistinctly as nanche,

Table 1. Some characteristics reported of species of Malpighiaceae family identified as nanche or murici in some areas of the Americas.

Characteristic	Species		
	<i>Byrsonima crassifolia</i>	<i>Byrsonima verbascifolia</i>	<i>Malpighia mexicana</i>
Tree height (m)	3–7 (up to 15)	1–5	3–4
Leaf size (cm)	6–16 × 3–8	14–20 × 6–12	3–16 × 2–8
Fruit size (cm)	1.5–2.0	1.3–1.5	1.9–2.5
Seedling morphology group	Phanerocotylar, epigeal, foliaceous	Phanerocotylar, hypogeal, foliaceous	–
Hypocotyl size (mm)	10–20 × 1.3–1.5	6–10 × 1.5–1.8	–
Cryptogeal germination	Absent	Present	–
Photo fruits			

– Data not found or not applicable. Data from: Dos Reis Barbosa et al. 2014; Hamacek et al., 2014; Bárcenas 2018; Rocha et al., 2018; CONABIO, 2022. Photo credits: *B. crassifolia* – M. Costea and I. García Ruiz/PhytoImages.siu.edu (http://www.phytoimages.siu.edu/imgs/Cusman1/t/Malpighiaceae_Byrsonima_crassifolia_77316.html); *B. verbascifolia* – João Medeiros/Useful Tropical Plants (<https://tropical.theferns.info/viewtropical.php?id=Byrsonima+verbascifolia>); *Malpighia mexicana* – Graciela Ángeles Carreño/NaturaLista Mexico (<https://www.inaturalist.org/photos/86208470>).

but the differentiation of the species lies in the colour of the fruit pericarp in the mature state. *B. crassifolia* is yellow (yellow nanche), although it can present orange and brown shades that may vary according to the phenotype, while *Malpighia mexicana* DC is red (red nanche) (Maldonado-Peralta et al., 2016) (Table 1).

Plant phenotypic description includes macroscopic and molecular characteristics such as height, biomass, water status, yield, gene expression levels, the three-dimensional structural conformation of proteins from the fruit, and others (Wagner, 2012; Shakoor et al., 2017; Huang et al., 2020). The phenotype is a characteristic determined by genetic–environmental interactions. Consequently, the range of phenotypes for a given genotype can be expressed as a function of the interaction with the environment (Monaghan, 2008; Nicotra et al., 2010). In *B. crassifolia*, depending on the region where the tree is located, the physicochemical characteristics of the fruit vary according to the environmental conditions of the locality (Agredano-de la Garza et al., 2021). In wild trees, morphological variations of fruits and seeds related to phenotype and production environment have been reported (Rojas-García et al., 2021). The phenotypic divergence has also been found to influence fruit physicochemical parameters, for instance, the content of total soluble solids, acidity, and fibre (Santos et al., 2020; Agredano-de la Garza et al., 2021), as well as variations in sugar content according to the time of harvest and precipitation patterns (Maldonado-Peralta et al., 2020). Sugar content and acidity are essential characteristics that differentiate sweet and sour yellow nanche. Thus, defining and identifying the phenotypic characteristics is necessary to develop nanche cultivation properly.

The molecular markers to identify and discriminate genetic material containing desirable traits are significant (Rodrigues et al., 2016). The development of cultivars requires an integrated mix of classical breeding approaches and one or more tiers of phenotyping (Ghanem et al., 2015). Several strategies have been used to identify specimens with desirable traits and obtain improved cultivars in agricultural practices, among which is the selection of specific phenotypes using omics tools such as genomics, transcriptomics, proteomics, metabolomics, and phenomics (Hamany Djande et al., 2020; Raza et al., 2021) or integrated into PANOMICS for the development of elite lines (Weckwerth et al., 2020). Also, other molecular marker tools for DNA barcoding, such as random amplified polymorphic DNA (RAPD), restriction fragment length polymorphism (RFLP), simple sequence repeats (SSR), inter-simple sequence repeats (ISSR), amplified fragment length polymorphism (AFLP), single nucleotide polymorphism (SNP), high-resolution melting (HRM), and biosensor technologies, can be helpful in the selection of species with food potential (Azizi et al., 2021). Although these tools have been scarcely used in the study of nanche, they are a window of opportunity for future research focussed on establishing cultivars and varieties of

nanche. Some genetic improvement programmes have been initiated to characterise species and their botanical varieties to generate outstanding cultivars through hybridisations to obtain high yields, adaptations to specific climates, disease resistance traits, and other nutritional and nutraceutical characteristics of plant species (Helgadóttir et al., 2018).

Considerations for cultivar development

A cultivar is developed from a massive selection of individuals with desirable characteristics and higher production (Da Silva Chaves et al., 2021). *B. crassifolia* cultivation is still in the process of technification, and some producers manage this species empirically (Medina-Torres et al., 2017). In some localities, production depends on wild specimens; therefore, there is no agronomic management. According to producers who are ‘domesticating’ or making efforts to establish crop propagation by seed and grafting, the obtained specimens can be classified as sour, sweet, and bittersweet (Medina-Torres et al., 2015).

Additional methods include propagation from terminal leafy cuttings, hardwood cuttings, or air layering (Duarte et al., 2004; Duarte and Escobar, 2007; Nascimento and Silva, 2022), but few studies are reported. The importance of generating nanche cultivars goes beyond establishing a crop. Da Silva Chaves et al. (2021) mentioned that ‘*the genetic breeding of native species [...] promotes cultural appreciation of the local society and enables the opening of new markets*’. However, the lack of resources, specialised labour, and logistics poses a challenge in establishing this fruit as a crop. The challenges to establishing perennial species can be classified into intrinsic and extrinsic. The intrinsic ones involve the pre-existing domestication status, perennial nature, and extrinsic factors such as financing, human resources, and logistics (Da Silva Chaves et al., 2021).

When seed propagation includes an agronomic management system, it generates fruits with more homogeneous characteristics than those obtained from wild or backyard crops (Agredano-de la Garza et al., 2021). Germination (sexual reproduction) increases with pretreatments such as soaking with water, gibberellic acid, solutions, and sulphuric acid (Carvalho and Do Nascimento, 2013; Guzmán et al., 2013; Dos Reis Barbosa et al., 2020). After germination, seedlings can grow in different substrates, allowing the selection of low-cost and accessible substrates in the propagation area. For example, greenhouse-grown seedlings showed good development in basaltic rock with a 0.05 mm grain size (Ferreira-Melo et al., 2021). The use of Canadian *Sphagnum* moss and vermiculite has also been evaluated (Guzmán et al., 2013). However, a drawback of propagation by seed is that the nanche seed is recalcitrant, making it difficult to store at low temperatures (Jaimes-Albíter et al., 2014). Also, the vegetative propagation (asexual reproduction) by indole butyric acid-treated stem cuttings was evaluated but resulted in low survival

and sprouting rates (Maldonado-Peralta et al., 2017). Seed propagation is the most documented technique, and thus future studies are needed to obtain seedlings that retain the desirable gene expression to produce sweet, bittersweet, or sour fruit varieties.

B. crassifolia shows a great phenotypic variation because it is cross-pollinated (Duarte, 2011; Medina-Torres et al., 2012). Pollination generally occurs between species of the genera *Centris*, *Epicharis*, and *Paratetrapedia*; some examples of successful applications of cross-pollination are *Centris flavifrons* (Friese), *Antichera capucina* (Scarabaeidae, Rutelinae), and *Epicharis umbraculata* (Apidae, Centridini) (Rego et al., 2006; Martins et al., 2010; De Carvalho et al., 2016). However, no studies in *B. crassifolia* relate pollination with fruit quality.

Another factor for cultivar development is irrigation. Irrigation is essential in agricultural practice, where water is artificially applied in an endeavour to promote plant growth and development (Abioye et al., 2020). Nevertheless, only a few studies have been conducted in nanche to evaluate various water access conditions with an irrigation system. The *B. crassifolia* tree can tolerate water stress; Dos Santos Nogueira et al. (2016) report a tolerance of up to 25 days in the absence of irrigation with decreases in the concentration of

photosynthetic pigments but with increases in the concentration of soluble carbohydrates and sucrose as a response mechanism to prevent dehydration. Owing to its broad adaptation to water regimes, in the range of 700–2,200 mm of annual precipitation, *B. crassifolia* can survive drought conditions (Ruíz-Corral et al., 2013) and is adaptable to areas with little access to water.

Water stress affects the absorption of nutrients from the soil (De Oliveira Neto et al., 2016), but although nanche's adaptation to inconvenient conditions such as sandy, acidic, and low-nutrient soils has been reported in the literature (Costa-Coutinho et al., 2021), it has also been assessed that such adaptations would require depths of up to 1.8 m of fertile loam, clay loam, silty-clay loam, and clay loam soils with good drainage, and pH in the range of 5.5–8.0 (Ruíz-Corral et al., 2013). There is also evidence of resilience to changing environmental conditions, thriving in places such as coastal dunes (De Souza et al., 2021), or ecological modifications generated by meteorological phenomena such as 'El Niño' that also affect the water relations (Palomo-Kumul et al., 2021). Although these studies show diverse effects on biomass due to lack of water, this deficiency increases wood density (Palomo-Kumul et al., 2021). This situation favours the use of the woody part of the nanche. In contrast, tolerance to salinity, adaptability to

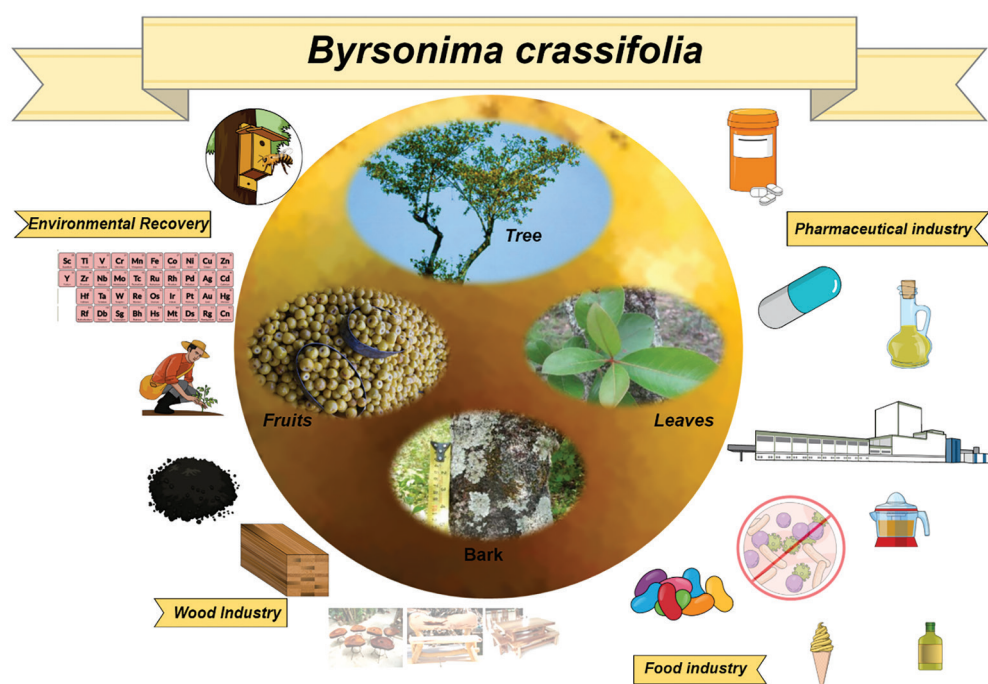


Figure 2. Tree, leaves, bark, and fruit of *B. crassifolia* and possible uses. Photo credits: Tree – Jerzy Rzedowski Rotter/CONABIO-Mexico; Fruit – Adalberto Ríos Szalay/CONABIO-Mexico; Leaves – José Luis Bautista Vidal, Instituto de Biología, Universidad Nacional Autónoma de México (http://unibio.unam.mx/irekani/handle/123456789/65568?mode=full&submit_simple=Muestra+el+registro+Dublin+Core+completo+del+%C3%ADtem&proyecto=Irekani); Bark – Miriam Icela Alvarado Flores, Instituto de Biología, Universidad Nacional Autónoma de México (<http://unibio.unam.mx/irekani/handle/123456789/43524?proyecto=Irekani>).

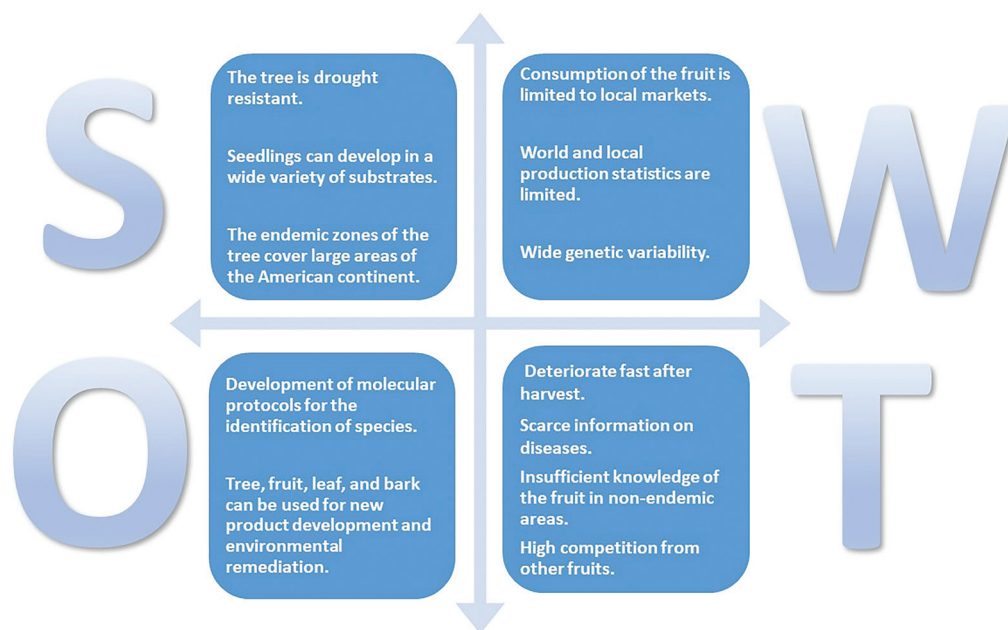


Figure 3. Pre-SWOT for developing a cultivar of *B. crassifolia*. SWOT, strengths, weaknesses, opportunities, and threats.

eroded soils, deep root systems, and resistance to high temperatures (Ramos-Carbajal et al., 2020) promise that nanche can be used in areas with low water availability. However, studies on the effects of absence of water on the fruit's development, production, and quality are incipient. In virtue of this crop's adaptability to climate change, in-depth agronomic studies are necessary to know the tolerance threshold of abiotic stress in tree metabolism and fruit development.

Pests and diseases

B. crassifolia is yet to be a fully established crop. Therefore, more information on the pests that can cause production losses is required. For example, Moreno-Velázquez et al. (2022) reported a scabby fruit disease in young *B. crassifolia* trees from Mexico caused by *Neopestalotiopsis australis*. Also, fruit diseases caused by *Penicillium* sp., *Phytium* sp., and *Sphaceloma* sp. have been reported (Castañeda-Salinas, 2007).

The incidence of fruitworm pests caused by *Cryptophebia* spp., *Carpophilus* spp., *Clastoptera* spp., *Membracis mexicana*, *Coccus viridis*, and *Planoccus citri* (Medina-Torres et al., 2013) has been reported. Similarly, Sousa et al. (2021) reported that flies (Diptera: Lonchaeidae) attack fruits and flower buds. For instance, *Bactrocera carambolae*, the carambola fruit fly, is a *B. crassifolia* pest (Jesus-Barroos et al., 2015). However, no phytosanitary problems related to *B. crassifolia* have been generated so far, probably due to natural control by parasitoids and predators (Medina-Torres et al., 2013). It should be noted that interactions of up to 32 species of mites have been reported in nanche leaves, some of which are predators (Da Silva Noronha et al., 2020) that could be a reference for designing

biological control strategies (Pérez et al., 2020) in *B. crassifolia*. Most phytosanitary problems appear in the rainy period, particularly in the fruit, reducing its quality and causing yield losses. A common practice after harvest is to wash the fruit and discard those damaged (Medina-Torres et al., 2013).

CLOSING REMARKS

Figure 2 presents the possible applications for *B. crassifolia*. More studies are still needed to establish a cultivar with well-characterised traits, to improve and standardise artisanal products prepared with nanche-derived ingredients, and to develop new *B. crassifolia* derivatives with potential for food, pharmaceutical, and environmental applications. The favourable adaptation to adverse environmental conditions and wide distribution in the American continent motivate the possibility of developing a cultivar of *B. crassifolia*. Of course, there are challenges to overcome, but also strengths (Figure 3) that can be exploited to create a productive chain as a driving force for strengthening local economies.

CONCLUSIONS

Although *B. crassifolia* has immense agro-economic potential, there is scarce information regarding the cultivation, processing, and valorisation for developing food products and other applications in the pharmaceutical and environmental areas. The generation of knowledge about the development of cultivars and the potential application of *B. crassifolia* can be a tool favouring the food security of local populations where the tree is endemic. Additionally, it is necessary to systematically explore the potential benefit to consumers' health arising

from consuming fruits, leaf extracts, or technologically processed foods derived from *B. crassifolia*, since this would promote the generation of a value chain involving this fruit, in its various raw and processed forms, that has yet to be developed.

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AUTHORS’ CONTRIBUTIONS

C.S.-M.-H., E.A.Q.-O., O.N.V.-A., and M.A.M.-T. – conceptualisation. C.S.-M.-H., E.A.Q.-O., L.X.L.-M., and E.H.-C. – writing of the original draft. E.A.-H. and M.S.-S. – reviewing and editing the manuscript.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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