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Edible Cacti and Their Fruits: A Potential Source of Bioactive Compounds for Human Health

Cactus Comestibles y Sus Frutos: Una Potencial Fuente de Compuestos Bioactivos Para la Salud Humana

C. Contreras, S. A.[1], González-Martínez, D. W.[1], Casas-Rodríguez, A. D.[1], Morales-Martínez, T.[1], Rodríguez-Herrera, R.[1], Barrera-Martínez, C.[2], Sepúlveda, L.[1]*

[1]*Departamento de Investigación en Alimentos, Facultad de Ciencias Químicas Universidad Autónoma de Coahuila, Blvd. Venustiano Carranza and J. Cárdenas s/n, Col. Republica Oriente, 25280 Saltillo, México.*
[2]*Centro de Investigación para la Conservación de la Biodiversidad y Ecología de Coahuila, Universidad Autónoma de Coahuila, Miguel Hidalgo 212, Cuatro Ciénegas de Carranza, Zona Centro, 27640 Cuatro Ciénegas de Carranza, México.*

**Corresponding Author: leonardo_sepulveda@uadec.edu.mx*

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Resumen

En esta revisión se examinan los frutos comestibles de los cactus *Stenocereus queretaroensis*, *Cereus repandus*, *Ferocactus pilosus*, *Eulychnia acida*, *Opuntia ficus-indica*, *Hylocereus undatus*, *Matyllucactus geometricans* y *Carnegiea gigantea*, apreciados tanto por su sabor como por sus beneficios para la salud. Estos cactus se distribuyen principalmente en las regiones áridas y semiáridas de América, sobre todo en México y Sudamérica. El consumo de estos frutos ha formado parte tradicionalmente de la dieta de las comunidades locales debido a sus propiedades nutricionales y bioactivas. Entre los compuestos bioactivos presentes en estos frutos destacan las betalaínas por sus propiedades antioxidantes y antiinflamatorias. Las betalaínas han demostrado su eficacia para neutralizar los radicales libres y reducir la inflamación, lo que contribuye a la prevención de enfermedades crónicas. Se discute el potencial de estos cactus para la industria alimentaria y farmacéutica, destacando la importancia de su conservación y uso sostenible para garantizar la sostenibilidad de estas especies de cactus y la preservación de sus hábitats naturales. La sobreexplotación y la expansión agrícola pueden poner en peligro estas plantas, por lo que es importante promover prácticas de cultivo y recolección que respeten el equilibrio ecológico.

Palabras clave: Betalainas, Alimentos funcionales, Nutraceúticos, Farmaceúticos, Metabolitos secundarios.

Abstract

This review examines the edible fruits of the cacti *Stenocereus queretaroensis*, *Cereus repandus*, *Ferocactus pilosus*, *Eulychnia acida*, *Opuntia ficus-indica*, *Hylocereus undatus*, *Matyllucactus geometricans*, and *Carnegiea gigantea*, appreciated both for their flavor and health benefits. These cacti are distributed mainly in the arid and semi-arid regions of the Americas, especially in Mexico and South America. The consumption of these fruits has traditionally been part of the diet of local communities due to their nutritional and bioactive properties. Betalains stand out for their antioxidant and anti-inflammatory properties among the bioactive compounds in these fruits. Betalains have demonstrated their efficacy in neutralizing free radicals and reducing inflammation, which contributes to preventing chronic diseases. The potential of these cacti for the food and pharmaceutical industry is discussed, highlighting the importance of their conservation and sustainable use to ensure the sustainability of these cactus species and the preservation of their natural habitats. Overexploitation and agricultural expansion can endanger these plants, so promoting cultivation and harvesting practices that respect the ecological balance is important.

Keywords: Betalains, Nutritional Properties, Antioxidants, Pharmaceuticals, Secondary Metabolites.

INTRODUCTION

The cacti family (*Cactaceae*) consists of approximately 111 to 118 genera, which include between 1200 to 1500 species. These are perennial trees or shrubs with leaf spines characterized by their succulent stems. They can also be cladodes (as in the Opuntias) and may be radially folded (as in the barrel cactus), as well as having reduced or absent leaves and flowers with numerous tepals and stamens. Their classification is into four subfamilies: *Pereskioideae*, which has persistent and broad vegetative leaves, no glochids, and exarillate seeds; *Opuntioideae*, with cylindrical, deciduous leaves, specialized glochids, and arillate seeds; *Maihuenioideae*, which has persistent leaves; and *Cactoideae*, with absent leaves and glochids, and exarillate seeds (Simpson, 2010; de Araújo et al., 2021; Carpena et al., 2023). Cacti thrive in desert or semi-desert regions as they adapt to thermal stress through the diurnal closure of stomata, which reduces water loss through transpiration, and the MCA (malate-citrate-aspartate) cycle, which allows them to regulate pH and ion balance in the cytoplasm and vacuoles (Bhattacharyya, 2022). Affect antiproliferative effects of the extracts.

Opuntia ficus-indica

Opuntia ficus-indica, commonly known as nopal or Indian fig, is a cactus species of significant economic and ecological importance (Ferreira et al., 2023). Originating from Mexico, this plant has naturalized in various parts of the world, particularly in arid and semi-arid regions (Zamboni et al., 2024). The flowers of the nopal cactus are large and showy, typically yellow, although they can exhibit shades ranging from white to red. The fruits develop, providing food for local wildlife and human consumption (Brahmi et al., 2022). In addition to its culinary uses, *Opuntia ficus-indica* has applications in traditional medicine, where it is attributed to anti-inflammatory and antidiabetic properties (de Albuquerque et al., 2021). Internationally, approximately 150,000 hectares are dedicated to the commercial cultivation of *Opuntia*. In Mexico, the largest producer and consumer, approximately 72,000 hectares are cultivated for fruit production, primarily of the species *Opuntia ficus-indica*, and around 10,500 hectares for nopalitos (young pads) (Issami et al., 2024).

The plant *Opuntia ficus-indica* is drought-resistant, and irrigation is required during the establishment phase to promote good root development. Once established, the plants require less water, but proper irrigation during the growing season can enhance fruit production and forage quality (Barrientos-Sanhueza et al., 2023). Although the nopal can tolerate poor soils, it responds positively to fertilization. Soil analysis is recommended to determine specific nutrient requirements, and the application of organic fertilizers or compost can improve soil structure and provide balanced nutrition (Alam-Eldein et al., 2021).

The harvest of the tunas (fruit) occurs when they reach full maturity, indicated by their color and ease of separation from the cladode. The fruit must be carefully harvested to avoid damage and handled with care to maintain their quality. After harvesting, the fruits should be sorted, packed, and refrigerated as soon as possible to extend their shelf life and preserve their quality until they reach the consumer (Valadez-Moctezuma et al., 2023). Tunas are known for their low caloric content and richness in essential nutrients. They are an excellent source of vitamin C, vital for the immune system and skin health. They also provide B-complex vitamins such as thiamine and riboflavin, which are important for energy metabolism and neuronal health (de Wit & Fouché, 2021). Furthermore, prickly pears are rich in dietary fiber, which aids in digestion and may contribute to constipation prevention. The bioactive compounds in prickly pears, such as betalains and flavonoids, possess antioxidant properties that protect against cellular damage and reduce the risk of chronic diseases, including heart disease (Bouazizi et al., 2020).

Scientific research has explored these benefits, emphasizing the antioxidant activity of prickly pears and their potential as a functional food (Sirotkin, 2022). A study conducted in Mexico and other countries identified that certain varieties of prickly pears exhibit significant antioxidant activity, suggesting their use in creating value-added functional food products (Bouazizi et al., 2020). Another study compared the antioxidant capacity of *Opuntia apurimacensis* and *Opuntia ficus-indica*, finding that both have beneficial compounds, albeit with varying

concentrations of vitamin C and total polyphenols (Jorge & Troncoso, 2016).

Hylocereus undatus

The plant *Hylocereus undatus*, belonging to the cactus family, is known for its fruit called pitaya, also known as white dragon fruit. It is found in tropical areas of Africa, South America, and South Asia—countries with tropical climates (Li et al., 2023). The pitaya is an exotic fruit with juicy and sweet flesh. While it is popular for its taste and appearance, it has also been researched for its potential medicinal benefits. Its fruits are consumed fresh or processed into juices, jams, or ice creams (Asghar et al., 2024). The use of *Hylocereus undatus* for medicinal purposes is documented in traditional medicine systems. Several compounds in *Hylocereus undatus* contribute to its biological activities. In southern China, the flowers of *H. undatus* have been used as food and popular medicine to treat various conditions (Li et al., 2023).

The pitaya is highly nutritious, with a high water content, natural sugars, minerals, and antioxidants, while being low in calories. It also contains seed oil, betacyanins, triterpenoids, and steroids, which have laxative, hypocholesterolemic, anti-inflammatory, anticancer, and antidiabetic effects. Due to its functional and medicinal attributes, pitaya has excellent potential for use in the food, pharmaceutical, and cosmetic industries. However, further research is needed to obtain consistent and reliable data, allowing unrestricted exploration of its use (Michelle et al., 2017).

In a recent study, three new glucosides were isolated from the flowers of this plant, along with other known compounds. These glucosides exhibited antioxidant, anti-inflammatory, and antitumor properties (Havas et al., 2023). These antioxidants help protect cells from oxidative stress caused by free radicals, reducing the risk of chronic diseases such as cardiovascular diseases, diabetes, and cancer (Nur et al., 2023). *H. undatus* is also rich in bioactive compounds. It has been reported that this plant contains bioactive compounds such as vitamins, saponins, and condensed tannins. Additionally, it presents molecules like betacyanin, *p*-coumaric acid, vanillic acid, and gallic acid. Dry pitaya peel powder has been used for rumen fermentation, enhancing gas production and reducing methane concentration. Therefore, pitaya has the potential to be utilized as a feed additive to mitigate methane emissions from ruminants (Matra et al., 2019; Nishikito et al., 2023). Furthermore, *Hylocereus undatus* has demonstrated antimicrobial properties, showing activity against various types of bacteria and fungi, which makes it potentially valuable for infection treatment (Clemente Jr et al., 2021).

In another study, the presence of betacyanin in *H. undatus* was investigated. Betacyanin is uniformly distributed in the shell cells and remains intact in the vacuole. The estimated concentration in the shell is 95 ± 0.873 mg/g fresh weight. In addition, the pigment extract is stable with ascorbic acid and citric acid. Betacyanin inhibits xanthine oxidase with an IC50 of 9 mM. It could be a natural inhibitor to prevent uric acid-related diseases (Dey et al., 2022). In the food industry, *H. undatus* has been used to develop edible films. The authors utilized pitaya peels, mixed them with distilled water in a 1:2 ratio, and subjected them to ultrasonication for 30 minutes to obtain the mucilage. Glycerol and pectin were added to enhance its properties without compromising visual appeal. Furthermore, these films are biodegradable (López-Díaz et al., 2023).

Myrtillucactus geometrizans

Myrtillocactus geometrizans, also known as Garambullo, blue myrtle cactus, or Mesoamerican blue cactus, is a succulent plant belonging to the cactus family. The fruits are small and round and dark red when ripe (Sanjuan-Trejo et al., 2021). "Garambullo" is native to arid and semi-arid regions of Mexico and Central America. It is found mainly in desert areas, mountain slopes, and ravines. In addition, it can withstand high temperatures and can survive in drought conditions. It can be found at altitudes ranging from sea level to 2,500 meters (Sandoval-Gallegos et al., 2022).

Garambullo fruits are consumed fresh and are used in the preparation of jellies, jams, liqueurs, ice creams, and traditional dishes. They stand out for their sweet and sour flavor and high content of betalains, compounds with nutritional value. The fruits are rich in vitamin C, fiber, and antioxidants, which make them beneficial to health, including the treatment of diabetes and cancer prevention. Dehydration is a technique used to prolong the fruit's postharvest life, allowing garambullo

raisins to be produced (Herrera-Hernández et al., 2011; Montiel-Sánchez et al., 2021a).

The cactus *M. geometrizans* has a long history of traditional and medicinal uses. In traditional medicine, it has been used for various purposes, including treating various ailments such as diabetes, diarrhea, inflammation, fever, fungal infections, bacterial infections, and liver protection. Some compounds identified in *M. geometrizans* are polysaccharides, flavonoids, phenolic acids, and alkaloids (Herrera-Hernández et al., 2011; da Silveira Agostini-Costa, 2020). These compounds contribute to the pharmacological activities of the plant, which have been extensively studied. Studies have shown garambullo exhibits antidiabetic activity by improving insulin sensitivity and lowering blood glucose levels. In addition, the plant has demonstrated antioxidant properties, which help neutralize harmful free radicals and protect against oxidative stress (López-Palestina et al., 2018). The mechanisms of action underlying these bioactivities are still under investigation. However, some studies suggest that Garambullo bioactive compounds may act by modulating various molecular targets and signaling pathways. For example, polysaccharides from *M. geometrizans* have been found to stimulate insulin secretion and enhance glucose uptake into cells (Reynoso-Camacho et al., 2015).

In addition, flavonoids present in *M. geometrizans* may exert their antioxidant and anti-inflammatory effects by inhibiting reactive oxygen species and proinflammatory cytokines. The phenolic acids in garambullo have also been shown to have anti-inflammatory and antimicrobial properties, possibly through inhibition of the activity of enzymes involved in inflammation and disruption of microorganism cell membranes. *M. geometrizans* has a wide range of traditional and medicinal uses due to its bioactive compounds. These compounds contribute to the pharmacological activities of the plant, which have been extensively studied. (Céspedes et al., 2005; Salazar et al., 2011; Domenico Prisa, 2021)

Carnegiea gigantea

Carnegiea gigantea, commonly known as saguaro, is a large columnar cactus that can reach impressive heights, emblematic of desert regions of North America, and is native to the Sonoran Desert in Arizona, the Mexican state of Sonora, and some areas of California. The saguaro is known for its extremely slow growth, reaching 1 meter in about 25 years. Its longevity can be 150 to 200 years, and some specimens reach 16 to 18 meters in height. This cactus can withstand significant temperature differences, from -9 °C to over 50 °C (Renzi et al., 2019). Saguaro has been widely used by the indigenous peoples of Sonora, such as the Papago, who consume its fruits, flowers, and seeds, which are rich in sugars and are a fundamental part of their diet. *C. gigantea* is known for its traditional uses by indigenous peoples, who have used various parts of the cactus for medicinal purposes (Jiménez-Sierra et al., 2023). For example, the fruit of *C. gigantea* has been used for its high vitamin C content and as a remedy for indigestion and gastrointestinal problems. The flowers and stems have also prepared teas or infusions for their diuretic and laxative properties. In addition, the cactus is considered to have anti-inflammatory and antioxidant effects due to its phenolic compounds (Zheng et al., 2021).

In addition to its traditional uses, *C. gigantea* has also been studied for its potential pharmacological properties. Biochemical analysis has revealed the presence of various bioactive compounds, such as phenolic compounds, flavonoids, and polysaccharides. These compounds are believed to contribute to the pharmacological activities of this cactus, which have been demonstrated in several studies. For example, studies have shown that *C. gigantea* extracts exhibit antioxidant activity, which may help protect against oxidative stress and reduce body inflammation. In addition, the extracts have been found to have antimicrobial properties, inhibiting the growth of certain bacteria and fungi (Tamayo Ordoñez et al., 2023).

Eulychnia acida

The cactus *Eulychnia acida*, known locally as 'copao,' is a columnar cactus that varies in shape, generally arboreal, 1.5-4 meters high, with a defined trunk 1 meter long and then more or less branched, forming a rounded crown, but sometimes shrubby, very branched, without trunk, forming a low mass of 1 meter high or less, with branches often prostrate or ascending. It belongs to the Cactaceae family and is native to arid and semi-arid regions. A perennial plant thrives in dry, harsh conditions,

making it well-adapted to survive in arid climates (Cares et al., 2018). This cactus is endemic to western Chile, which can be found in Coquimbo and up the middle of the Atacama region. It grows from sea level to 1,300 meters above sea level. It prefers rocky slopes where fog and mist condense on the plant's branches and nearby rocks and drip down to the roots, but also on gentler slopes and even plains, only where there is some rain. Even in these locations, plants rarely receive more than 50 mm of rain annually (Salvatierra, 2020).

The 'copao' cactus is mainly consumed for its fruit. The fruit is eaten fresh and is known for its tart and refreshing flavor. In the regions where it grows, it is consumed locally, and juice is extracted from the fruit, which can be drunk directly or used as an ingredient in mixed drinks. In addition, jams and preserves are made with the fruits. Traditionally, local medicine has used the fruit to treat various ailments, although caution should be exercised. (Masson S et al., 2011). Scientific research on the benefits of copao has highlighted that the fruit of the *Eulychnia acida* cactus is a good natural source of vitamin C and has a high sodium and potassium content, which helps regulate water balance through a rehydrating effect. It also contains minerals lost through sweating, provides soluble dietary fiber, is low in calories, and contains antioxidant compounds. These properties give copao great potential as a superfood and raw material to produce higher value-added products (Jiménez-Aspee et al., 2015).

These benefits make copao an interesting option for food and for exploring its medicinal properties. In addition, the exploitation of copay is still low, and its harvesting is quite artisanal, so efforts are being made to better understand its commercial potential and improve its agronomic management (Venegas et al., 2016).

Cereus repandus

Cereus repandus, commonly known as the Peruvian cactus or Peruvian apple, is a columnar cactus species found in various regions of South America (Singh Yadav et al., 2024). Its presence is notable in Brazil, Uruguay, and Argentina, where it adapts to various environments, from arid areas to dry forests (De Faria-Tavares et al., 2013).

Cultivation is relatively simple, as this cactus prefers well-drained soil and direct sun exposure, although it tolerates partial shade. It is drought-resistant thanks to its ability to store water in its fleshy tissues, allowing it to survive prolonged periods without irrigation. However, for optimal growth, moderate watering during the growing season and a significant reduction during the winter is recommended (Yang & Pritchard, 2022). The flowers of *Cereus repandus* appear mainly on warm summer nights, opening at dusk and closing at dawn. These nocturnal flowers are large, up to 15 centimeters in diameter, and feature pure white petals that contrast with the brownish-green center (Becker et al., 2023).

Pitaya is a nutrient-rich, low-calorie food. It contains vitamins such as vitamin C, which is essential for the immune system, and significant amounts of vitamin B, which aids in cellular metabolism. In addition, it is a good source of minerals such as calcium and iron. The presence of antioxidants such as betalains and carotenoids helps neutralize free radicals in the body, which can reduce the risk of chronic diseases. (de Alcântara Oliveira et al., 2020).

Stenocereus queratorensis

Stenocereus queretaroensis, also known as pitayo or yagüarey, is a cactus found in arid areas of central and northern Mexico. It has an arboreal appearance and is robust. During spring, it flowers and produces fruits that ripen in April and May. The fruits of *S. queretaroensis* are globose or ovoid, with spiny areoles. They can range in color from carmine to red to white. They contain numerous black seeds, and their weight varies between 85 and 400 grams (García-Cruz et al., 2022). Pitayos play an important role in Mexican culture and tradition. They have been consumed since pre-Hispanic times and have been used as medicine. Some people obtained pitayo flour and even used the seeds. It has been demonstrated that these uses are due to the high content of phenolic compounds and betalains in the fruits, which causes a high antioxidant potential, being also a source of natural pigments with potential application in the food industry (Delia et al., 2019).

The fruit of *Stenocereus queretaroensis* is rich in betalains, water-soluble compounds responsible for the fruit's vibrant colors. Studies suggest that these betalains have health benefits, such as cardiovascular and anti-inflammatory properties. In addition, cells high in

betalains show antimicrobial and antifungal activities (Ceja-López et al., 2022; Gonzalez-Campos et al., 2022). The study used phytochemicals extracted from this fruit peel to synthesize silver nanoparticles. These nanoparticles demonstrated antimicrobial activity against gram-negative bacteria (*E. coli*, *S. enterica*, and *P. aeruginosa*) and gram-positive bacteria (*S. aureus* and *MRSA*). The authors suggest that these nanoparticles could be helpful in the food industry, either as coatings for food packaging or as disinfectants on different surfaces. (Padilla-Camberos et al., 2021).

Ferocactus pilosus

Red biznaga, or biznaga cabuchera (*Ferocactus pilosus*), is a cactus native to America. It grows solitary or in large groups and is cylindrical, with diameters up to 50 cm. The cactus is endemic to the northern part of the Sierra Madre Oriental and the Chihuahuan Desert (Mascot-Gómez et al., 2021). *F. pilosus* has flowers approximately 4 cm long; they do not open completely because thorns surround them, and these flowers can be red or yellow. The flowers give way to an ovoid fruit covered with yellow bracts. The flower buds of this cactus are known as cabuches and are famous for their nutritional properties and culinary potential. Cabuches are harvested raw in the spring, from March to May, are cooked in different ways, and are characterized by their texture similar to that of asparagus and their slightly acidic and herbaceous flavor (Díaz-Reyes et al., 2020). Cabuches are rich in fiber, vitamin C, and minerals. They are traditionally attributed to a diuretic effect, which may help eliminate toxins from the body. These fruits also contain antioxidants that may help protect against cell damage. Some studies also suggest that compounds present in cabuches may have anti-inflammatory properties (Salas Hernández, 2023b). The cabuchera biznaga is a protected species, so it is important to harvest cabuches responsibly and sustainably. For this reason, these fruits are not currently exploited, but research is being carried out to propagate these cacti in vitro (Salas Hernández, 2023a). Figure 1 shows a summary of the main cacti.

Compounds in common within the genus Cactaceae

The compounds in the family *Cactaceae* are varied and have different biological activities. The biological activities of the compounds in the Cactaceae family are of interest to scientific studies. Cacti contains various bioactive compounds, most notably phenolic acids and flavonoids (Agostini-Costa, 2022). Figure 2 shows some chemical structures of these compounds; among the different compounds found in cacti, a very particular family stands out: the Betalains (Sadowska-Bartosz & Bartosz, 2021).

Betalains are pigments present in a tiny group of botanical families. These pigments are responsible for the colors of flowers and fruits, especially in plants such as cacti. Betalains accumulate in the vacuoles of plant cells and contain nitrogen. They also possess antioxidant properties and act as a barrier against UV rays. Betalamic acid is a key component in their structure (Figure 3-a) (Dias et al., 2016). Betalains are subdivided into betacyanins and betaxanthins (Figure 3-b,c). The betacyanins (Figure 3-b) are red to violet-colored compounds with an absorption maximum of 540 nm (Madadi et al., 2020). Betacyanins are formed from betalamic acid and cyclo-DOPA, to which sugar or hydrogen molecules can be attached as substituents. Betaxanthins (Figure 3-c) are yellow to orange compounds with an absorption peak in the visible spectrum at 480 nm. Betaxanthins result from the condensation of amines and betalamic acid, and an amine group and hydrogen usually join this nitrogen as substituents (Valencia et al., 2017).

These compounds, like polyphenols, are more stable due to the following factors: low water activity, pH between 3 and 7, low temperatures, darkness, and absence of oxygen. Betalains undergo different reactions that are degradation pathways, which can be dehydrogenations or decarboxylations (Polturak & Aharoni, 2018).

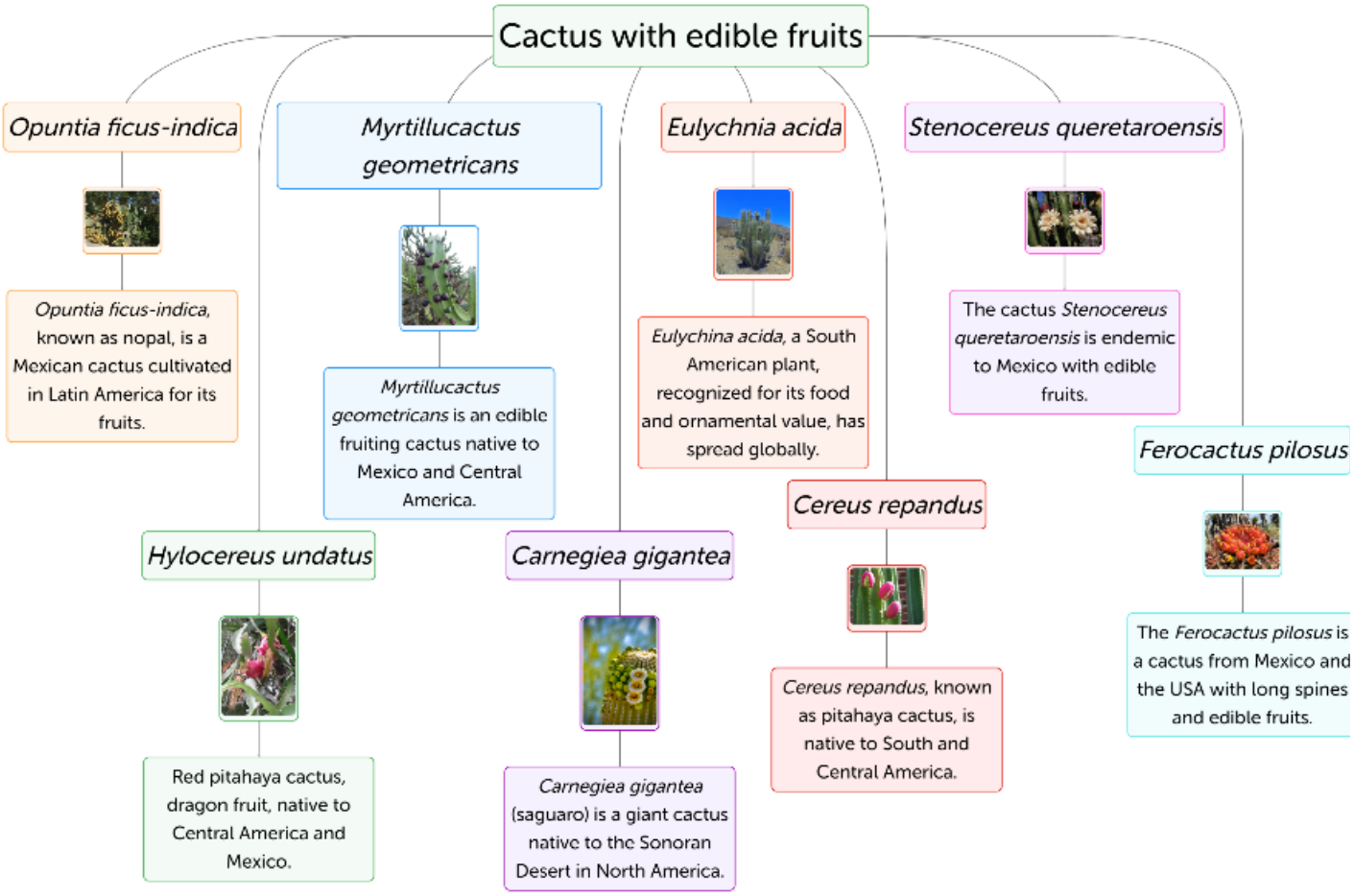

Figure 1. Main cacti with edible fruit are present in Mexico.

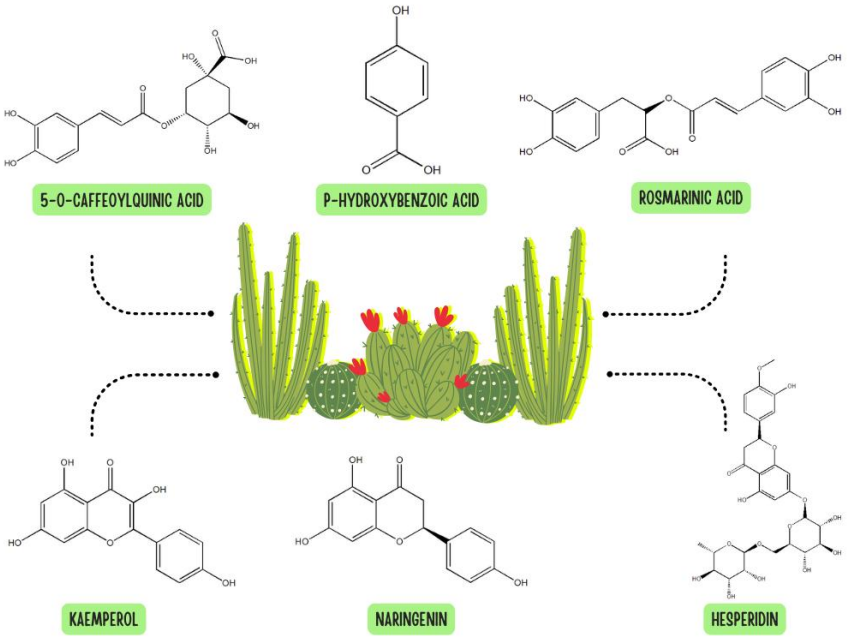

Figure 2. Main phenolic acids and flavonoids present in cacti.

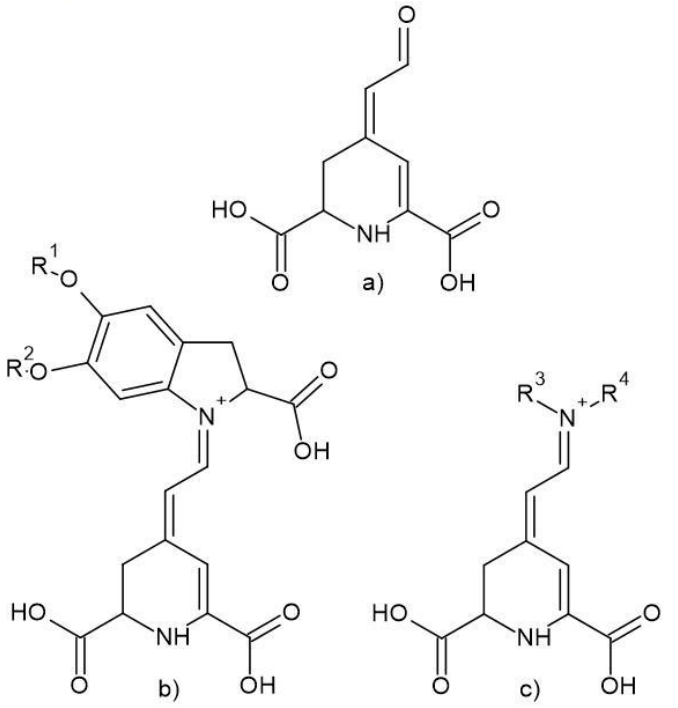

Figure 3. Chemical structures of betalamic acid (a), betacyanin (b), and betaxanthins (c) R^1 and R^2 are sugars or hydrogen; R^3 is an amine group or amino acid; R4 is mostly hydrogen

Health benefits

Betalains, in addition to pigmenting, have different properties, such as antioxidant and antimicrobial. One of the derivatives of betalains commonly used in the cosmetic industry is betacyanin (Abedi-Firoozjah et al., 2023). These compounds have a condition of structural degradation with time, where the color change becomes noticeable with temperature change, which would be optimal for use as time-temperature indicators in food. As well as for the development of intelligent packaging, as reported in works, since it is indicated that they have biological properties such as anti-radical, anticarcinogenic, and anti-lipidemic (Carreón-Hidalgo et al., 2022). Betalains have different biological properties, many of which contribute to preventing degenerative diseases. Betalains have the property of being useful in the prevention of some types of cancer, cardiovascular and gastrointestinal diseases, as well as diabetes and obesity. The advantage of betalains is that, compared to anthocyanins, they are less susceptible to degradation, which is why they also have applications in the food industry. Like most phenolic compounds, Betalains have a high antioxidant capacity, as they can capture reactive oxygen species and protect against lipid peroxidation catalysts (Rodrigues Vieira et al., 2024).

Betalains have been investigated as they demonstrated anti-inflammatory activity, and the ability to inhibit the expression of intercellular adhesion molecule (ICAM-1) in TNF-α-stimulated human endothelial cells has been tested. The activity of betatine was higher, even at micromolar concentrations (Gentile et al., 2004). Studies have shown that beet juice rich in betalains has an effect on the formation and release of interferon-γ, which results in the reduction of reactive oxygen species (ROS) formation, preventing conditions related to oxidative stress, such as cancer, atherosclerosis, Alzheimer's and Parkinson's disease (Montiel-Sánchez et al., 2021b). On the other hand, the antioxidant capacity of most betalains and betalamic acid is superior to that of common flavonoids, ascorbic acid, and tocopherols, which is why it is attractive to use extracts of these as artificial colorants (Bastos & Schliemann, 2021).

PERSPECTIVES

Research should begin to focus on the conservation of these species and their biodiversity since some species can be considered endangered, and this can be achieved through genetic improvement to make them resistant to pests and diseases and increase their nutritional value. Sustainable production must also be a priority, as well as improving cultivation techniques that reduce the use of water and resources and the use in arid and semi-arid zones. Finally, biotechnology is the key to making the best use of these cacti; bioplastics and other derived products can be produced, and food applications in the processing of fruits can be used to produce new products.

CONCLUSIONS

Cacti are a valuable source of bioactive compounds, especially betalains. Unlike other pigments such as anthocyanins and carotenoids, these compounds show remarkable physicochemical stability in industrial processes, being a promising alternative for pharmaceutical and cosmetic applications. The tendency to use natural pigments instead of synthetic ones is

increasing, which benefits human health and the environment. However, there is still a wide field of research that is needed to develop more environmentally friendly production methods, reduce the energy expenditure in obtaining these compounds, and explore applications in medicine by generating pharmaceuticals and in the food industry with possible food supplements. Research on cacti with edible fruits and polyphenolic compounds continues to be a promising field. The search for sustainable cultivation methods for these cacti, such as in vitro propagation of these cacti and the application of these compounds in medicine and the food industry, are exciting challenges that deserve further scientific research. Innovative processes such as fermentation and supercritical fluid extraction remain to be investigated in this field.

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