PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 12(1): 1-16
https://doi.org/10.14719/pst.5157

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REVIEW ARTICLE

Nutritional, medicinal and biological activities of *Ferocactus* species: Recent findings and research opportunities

Bosede Ruth Faleye[1], Adriana Carolina Flores-Gallegos[1], Juan Alberto Ascacio-Valdes[1], Sandra Cecilia Esparza-Gonzalez[2], Sonia Yesenia Silva-Belmares[1], Sendar Daniel Nery-Flores[1], Lizeth Guadalupe Campos-Muzquiz[1] & Raul Rodriguez-Herrera[1]*

[1]School of Chemistry, Autonomous University of Coahuila, Saltillo Campus, Saltillo, Coahuila, 25280, México

[2]School of Dentistry, Autonomous University of Coahuila, Saltillo Campus, Saltillo, Coahuila, 25125, México

*Email: raul.rodriguez@uadec.edu.mx

OPEN ACCESS

ARTICLE HISTORY

Received: 19 September 2024
Accepted: 11 November 2024

Available online
Version 1.0 : 12 February 2025
Version 2.0 : 22 February 2025

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
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Faleye B R, Flores-Gallegos A C, Ascacio-Valdes J A, Esparza-Gonzalez S C, Silva-Belmares S Y, Nery-Flores S D, Campos-Muzquiz L G, Rodriguez-Herrera R. Nutritional, medicinal and biological activities of *Ferocactus* species: Recent findings and research opportunities. Plant Science Today. 2025; 12 (1): 1-16. https://doi.org/10.14719/pst.5157

Abstract

Ferocactus is a genus of the family Cactaceae found in the arid and semi-arid regions of the American continent, especially in Mexico. The species serve various purposes such as food, cosmetics, fodder and for relief from certain ailments. The fruits of *Ferocactus* species such as *Ferocactus herrerae* and *Ferocactus glaucescens* have valuable amounts of macronutrients, micronutrients and bioactive components which make them nutrient-dense. They are also a potential raw material for new product development in the food and cosmetic industries, industrial extraction and production of antimicrobials and antioxidants. However, many of the species are understudied, underproduced, underutilized or overexploited, resulting in a significant waste or risk of extinction due to overexploitation. Therefore, the objective of this review was to discuss and provide an in-depth and recent overview of the description, morphology, ethnobotanical uses, nutritional composition, bioactive composition and biological activities of different species of *Ferocactus* reported in the literature from different databases such as Google Scholar, ResearchGate and Scopus. Proper exploration and maximization of these species of cactus can provide huge economic, technological and nutritional benefits for all. Moreover, the challenges, possible solutions and future directions for maximum production and utilization of these species have also been discussed.

Keywords

Barrel cacti; bioactive compounds; Cactaceae; ethnobotanical uses

Introduction

The family Cactaceae comprises approximately 130 genera and 2000 species that thrive in arid and semiarid regions (1, 2). High and low temperatures, low relative humidity, low and unpredictable rainfall, high evapotranspiration, high wind speed (especially in summer) and high sunshine accompanied by high solar energy are characteristics of semi-arid regions. These areas have extensive portions of sandy soil which affect crop productivity due to low fertility, high salinity and extreme climatic conditions. Production of agricultural crops is also difficult due to increased evaporation of water and reduced rainfall in this region (3). However, Cactaceae are characterized by high water retaining capacity, shallow roots, thick cuticles, multiple spines, mucilaginous tissue and absence of leaves, which help them to thrive in arid and semi-arid regions (4). Therefore, they are highly resistant to different climatic stresses but frequently suffer overexploitation and disturbances of habitat (5).

Cactaceae are usually consumed by both humans and livestock, as evident from the results of a recent investigation carried out (6), where the native plant species that are used as food in the Gulf of Mexico were evaluated. It was reported that out of the 482 plant species selected, Leguminosae, Solanaceae and Cactaceae ranked first, second and third place respectively, for food sources. Cacti are also used for making cakes, desserts and jellies. The fruits are good for different categories of people, including the healthy ones and those at risk of diseases. The use of cacti as forage for animals cannot be overemphasized, especially in drought as shepherds depend on them as the major food source for their animals (7, 8). Cacti also have the potential of being used in food, as well as in the food industries. Additionally, they have been applied in the construction industry for manufacturing windows and doors. Worthy of note is the use of cactus plants as ornamental plants (for all kinds of indoor and outdoor decorations) and in the cosmetic industry (4, 9). In traditional medicine, they are used to provide treatment for diverse types of diseases. Moreover, they are collected as fuel for cooking (as a source of wood), especially in rural areas (3).

A few genera of the Cactacaeae include *Pilosocereus*, *Ferocactus*, *Mammillaria*, *Opuntioideae*, *Echinocactus*, *Hylocereus* and *Cereus* (4, 9-11). The cactus plant has various parts: the cladodes, flowers, fruits, roots, mucilage and seeds. The fruits, roots and cladodes have gained much popularity due to their use in traditional medicine. For example, some species of *Pereskia* are used for treating anaemia, osteoporosis, constipation and even cancer. Cases of fever, gastritis, skin and pulmonary diseases have been cured traditionally with *Hylocereus* species. *Pilosocereus* species have been demonstrated to reduce serum glucose. Moreover, the treatment of intestinal, renal and gastric problems, fever, cough and inflammatory diseases has been achieved with the use of *Cereus* and *Melocactus* species (7, 9). In general, the nutritional and medicinal benefits of cactus plants cannot be overemphasized, however, the *Ferocactus* genus is discussed.

Ferocactus is a genus (one genus out of the 130 genera) of the Cactaceae, comprising of about 30 species. They are found in the arid and semiarid regions of the American continent, especially in Mexico and some southwestern parts of the United States. The plant is also known as "biznaga", "borrachitas" or devil's tongue and "huamiches" or claw of crow. *Ferocactus* have a ball or barrel shape with a gray-green color. The upper part is flat, with radial whitish or reddish spines (12).

Ferocactus plants are succulents with thick, fleshy parts which are useful for their adaptation in the arid regions to store water. The structure of the plants is developed to retain as much water as possible, whenever they have access to little moisture. They make use of fog as a supplementary source of water. Their thick waxy coating also helps them to minimize the loss of water to the atmosphere (13, 14). *Ferocactus* species include *Ferocactus pilosus*, *F. latispinus*, *F. glaucescens*, *F. wislizenii*, *F. emoryi, F. peninsulae, F. histrix, F. robustus, F. alamosanus, F. hamatacanthus, F. stainesii, F. flavovirens, F. chrysacanthus* and *F. gatesii* among others (15, 16).

Ferocactus has diverse uses and applications according to locality and culture, but most populations generally use them as food, fodder, medicine and cosmetics. As food, they possess excellent flavor and are rich in nutrients; the fruits are consumed raw, cooked as vegetables and salad dishes, or processed to obtain juice. Some species of *Ferocactus* primarily produce edible fruits in South and North America, especially in Mexico, where they are used to manufacture candies in the food industry. For example, *F. pilosus* and *F. histrix* are used to make sweets of biznaga, called acitron (17). Ethnobotanical studies of cactus plants, especially the genus *Ferocactus* expound the significance of the various species, revealing the importance of including them in the human diet and applying them in other areas of human lives. In medicine, *Ferocactus* species are used in the treatment of ailments and disorders, making it gain more importance and recognition in the last decades. Moreover, they are ornamental plants used for beautifying houses and surroundings and for ceremonial purposes (17).

Although this genus has not gained so much popularity in comparison to other cactus plants such as *Opuntioideae*, *Echinocactus*, *Mammillaria* and *Cereus*, it is very important to review the information available on the various species of *Ferocactus* to provide concise, relevant and up-to-date information on the subject as well as to unveil potential areas of research for the benefit of mankind. Therefore, this article presents a bibliographic review of the uses of the genus *Ferocactus*, its nutritional composition, biological activity of compounds isolated from distinct species of *Ferocactus*, as well as the phytochemical and pharmacological potentials.

Materials and Methods

A diligent review was conducted by searching for all the research and review articles on *Ferocactus* species that were recently published by Scopus, Wiley, Springerlink, ResearchGate, Elsevier, PubMed, Google and Google Scholar databases. Headings and terms related to Cactaceae (including the different genera), *Ferocactus*, nutritional composition of *Ferocactus*, morphology, botanical names, ethnobotanical and medicinal uses, food uses, bioactive composition, antioxidant, anticancer, antimicrobial, anti-inflammatory potential of *Ferocactus* were used for the search. The various species of *Ferocactus* were also included in the search such as *F. latispinus*, *F. histrix*, *F. pilosus*, *F. glaucescens*, *F. peninsulae*, *F. emoryi*, *F. herrerae*, *F. gatesii* and *F. wislizenii* among others. A detailed analysis was done to extract relevant information on ethnobotanical, nutritional and biological uses, with recent advances and applications in human health.

Results and Discussion

Description of various *Ferocactus* species

Out of about 30 species in the genus *Ferocactus*, recent information was found on only about 12 species with the pictorial display presented in Fig. 1.

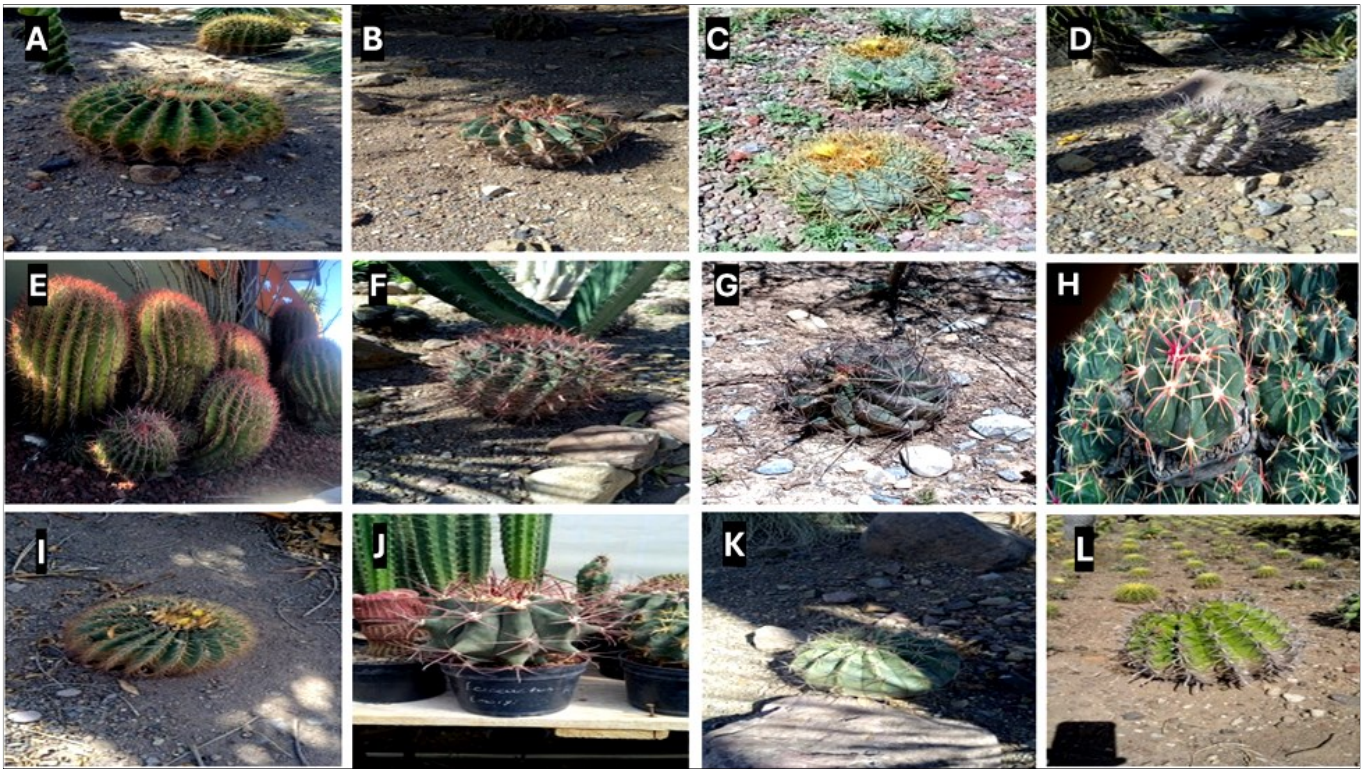

Fig. 1. Various species of *Ferocactus*. (**A**): *F. histrix*, (**B**): *F. latispinus* or *F. recurvus*, (**C**): *F. wislizeni*, (**D**): *F. peninsulae*, (**E**): *F. pilosus*, (**F**): *F. gatesii* or *F. gracilis*, (**G**): *F. hamatacanthus*, (**H**): *F. macrodiscus*, (**I**): *F. glaucescens*, (**J**): *F. emoryi* or *F. covellei*, (**K**): *F. pottsii*, (**L**): *F. herrerae.*

Ferocactus histrix

F. histrix (DC.) Lindslay has a diameter and height of about 30 to 45 and 55 to 110 cm, while the fruits are 2.6 to 3.6 and 1.8 to 2.6 cm in length and width. This species is widely distributed in Mexico (Querétaro, Hidalgo, San Luis Potosí and Durango states) (12), where it is known as "tuna of biznaga", "guamuchis", "limitas", "jarritos", "borrachitas" and "huamiches". The fruits are red or yellow, small, usually acidic, with an oval shape having thick walls and a dehiscent base. The flower is yellow and is produced in spring while its fruits begin to ripen in spring and early summer until May, when it gets to the peak (2).

Ferocactus latispinus or Ferocactus recurvus

F. latispinus (formerly called *F. recurvus*) is a barrel-shaped cactus widely distributed in the Chihuahuan desert, Tehuacan-Cuicatlian valley and semi-arid regions of Southern and Central Mexico. It is known as the devil's tongue pink spined cacti (18).

Ferocactus wislizenii

F. wislizenii has structures with conical geometry and grooves. The fruits are used to make cactus candy (13).

Ferocactus peninsulae

F. peninsulae (Engelm ex Weber) Britton and Rose is an oval-shaped and medium-sized columnar species with a height of about 70 cm. Its stem is dark blue-green, flowers are red to yellow, midveins are orange to red with yellow globose and fruits and black seeds of medium size. It is endemic to Baja California Sur, Mexico (16).

Ferocactus pilosus

F. pilosus (Salm-Dyck) Werderman, is referred to as biznaga, biznaga roja, fire barrel biznaga and red-thorn biznaga. It is endemic to Mexico and can be found in the Northern states of Mexico including Coahuila de Zaragoza, San Luis Potosí, Nuevo León, Zacatecas, Tamaulipas and Durango (6, 19). This species is of the least concern and its population is threatened (20). The species disperses slowly and migrates only a short distance, with insects and birds involved in its pollination (17).

Ferocactus gatesii or Ferocactus gracilis

F. gatesii G. Lindsay, also known as *F. gracilis* and locally called 'biznaga', is an edaphic and endemic species restricted to specific soil lithologies on small islands. It is found in Bahia de Los Angeles (BLA), Baja California, Mexico. This plant can reach around 1.5 m in height, 0.3 m in diameter and stem ribs about 30–32. The flowers, fruits and seeds could reach 6 cm in length, 7.5 cm and 2.5 mm respectively (21).

Ferocactus hamatacanthus and Ferocactus macrodiscus

F. hamatacanthus (Weber) Britton and Rose has brown juicy fruits which are used as lemons and limes. It is also called biznaga de tuna. *F. macrodiscus* (Mart.) Britton and Rose is also known as biznaga, is used for ornamental purposes (6).

Botanical and morphological characteristics of *Ferocactus*

Barrel cacti present the largest diversity of cacti, yet there are very few studies on them, thus information about their reproduction is very scarce in the literature. *Ferocactus* are self-fertile, hence they form seeds, which are usually viable for many years due to their physiological dormancy (1). Their growth is very slow and they have long life cycles. Aridity increases or extreme temperature and climate change are some of the factors that influence species' richness (quality of seedlings and survival) and endemism (21). According to a study, increase in temperature negatively affected and threatened cactus plants resulting in low survival and low seedling formation (22), whereas it was established that an increase in temperature increases the stability of the species (23), which called for a divergent finding (21). It is important to emphasize that temperature plays a key role in carbon dioxide (CO_2) uptake and tissue acidification in succulent plants, especially with minimum temperatures and some cactus plants utilize low temperatures for their survival and seed formation. On the other hand, endemic cacti have a distinct feature of quickly acclimatizing to rising temperatures for CO_2 uptake. These adaptations to high and low temperatures explain their ability to survive long-term drought and unpredictable climates. Moreover, the rate of adaptation, seed formation and survival depend on the cactus plant under consideration, as some present a spontaneous adaptation while others may be slow (24, 25).

Generally, the breeding system of all Cactaceae can be self-compatible or incompatible, with or without inbreeding depression and xenogamous (26). Self-compatible species do not require vectors to transfer pollen grains while self-incompatible species require vectors to transfer pollen. The botanical aspects of some species of *Ferocactus* are described below.

F. latispinus

The seeds of *F. latispinus* have a high imbibition property with mucilage that has water-retaining capacity (with the aid of its conical spines with small barbs), reduced germination time and the ability to maintain a high viability for a long period of time. This is achieved through the small barbs which collect water droplets on their tips until a certain size is reached and afterwards, the droplets move to the base of the conical spine (due to the gradient of curvature which provides Laplace pressure gradient), where the plant can access and absorb the water (3, 13, 16). They make use of both seeds and fruits for their reproduction. Moreover, they demonstrate co-adaptation between their flowers and pollinators and vary their floral display in color, scent and size, easing their ability to attract different pollinators (insects, bats and birds) (18). Morphometrically, the flowers exhibit hermaphroditic behavior and have herkogamy. They develop their reproductive structures at the apical region of their stem where they are exposed to potential pollinators and dispersers. Their floral buds appear between October and January and the fruiting period is between February and March, with 2-3 months for the fruits to mature, after which most of the fruits naturally detach from the plant (18). Native bees are the main floral visitors that contact the reproductive structure of this plant and this is typical for all barrel cacti and other species in this area (27). They have flowers with large corollas, diurnal anthesis and large amounts of pollen grains but do not produce nectar (18).

F. peninsulae

The seeds of *F. peninsulae* require light to germinate, that is, they are photoblastic. Rojas-Aréchiga and García-Morales (16) reported that *F. peninsulae* seeds have physiological dormancy which can be broken after ripening and can maintain a high viability (germination up to 70%) for a period of 48 months when kept at room condition.

F. gatesii

During climate change, the seedling survival of *F. gatesii* may be challenged by an increase in aridity and low seed dispersal. The permeability, the porosity of the soil or rock, the mineral composition and the rock topography represent the main factors that give rise to an optimal substrate for the growth of *F. gatesii* in BLA (21). The dominant rocks in BLA are metamorphic, volcanic and granite, but granite is the most frequent host of *F. gatesii,* while volcanic rocks are the least frequent. This species prefers areas with a coarse, highly permeable and porous surface, therefore, it grows better on granite lithologies than volcanic and metamorphic because they have finer grains.

F. hamatacanthus

Differences in the structural composition of vascular tissues of around 34 Cactaceae, including 2 species of *Ferocactus* (*F. hamatacanthus* and *F. pilosus*), were recently identified using fluorescence microscopy and conventional staining methods (with safranin O/fast green) to differentiate the lignin composition in the cell wall (28). *F. hamatacanthus* presented greenish tones in the elements of the vessel, evidencing more syringyl monomers, while *F. pilosus* presented various colors such as orange, lime green and fluorescent red, evidencing the presence of guiaicyl lignin. The morpho-anatomical characterization of *F. hamatacanthus* (Weber) Britton and Rose showed that the stem is cylindrical with a dimorphic wood type. *Ferocactus pilosus* (Galeotti) Werderm also has a dimorphic wood type, but the shape of its stem is columnar.

F. pilosus

F. pilosus, a xerophyte, as well as other species of *Ferocactus,* can survive and germinate under different soil conditions such as in valleys, plains, hills, alluvial fans, shallow soils, limestone soils and areas with a lot of surface stones. The plant produces a large quantity of seeds that measure less than 1 mm which contributes to their conservation in the soil and dispersion by wind. However, they are exposed to predators, environmental factors and harvesting and the extensive anthropogenic use of their fruits and flower buds which interrupt and affect their cycle of reproduction. Additionally, the plant has a high mortality rate during germination under natural conditions, hence transplanting ex-situ reproduced seedlings is the alternative for their propagation (2).

Ferocactus species use their spines as a defense mechanism by piercing herbivores and predators, which scares old and mature plants away. However, they take advantage of new plants or branches with few or no thorns

(18, 29). Predators or herbivores of *Ferocactus* could be vertebrates (such as mammals, birds and reptiles) or invertebrates (such as insects and molusks). Another important function of spines to *Ferocactus* is that of thermoregulation as they protect the plants from extreme temperatures (very high and very low). The thorns absorb energy when exposed to high temperatures to protect their stems from overheating. They increase their length when temperature and xerophytic conditions increase (30). Furthermore, altitude increases the density of thorns to protect the stems during low temperatures (31).

Ethnobotanical uses of *Ferocactus*

Ferocactus has cultural and economic importance in Mexico. Some species are useful in the food industry to produce cactus candy, some are consumed raw like lemons and limes, while others are cooked to make special delicacies (15). The role of *Ferocactus* in the food industry, in medicine and in ornamentation cannot be overemphasized. Table 1 presents a summary of the ethnobotanical, medicinal and food uses of various *Ferocactus* species.

F. histrix

The stems, flowers and fruits of *F. histrix* are consumed in rural communities for their sweet and sour flavor. The flowers are consumed raw or used to prepare non-alcoholic beverages, while the fruits are eaten fresh or dipped in a brine solution. Due to its color and flavor, it is used to make sweets called acitron, also known as cactus candy and sweet of biznaga, which is produced from the fleshy filling (parenchyma) of three species of barrel cacti (2 species of *Ferocactus* and one species of *Echinocactus*), namely, *Ferocactus histrix* (barrel cactus), *Ferocactus pilosus* (lime barrel cactus) and *Echinocactus platyacanthus* (giant biznaga). The sweet is very popular in the central and northern parts of Mexico. While the fruit is used to make acitron, the succulent tissue (stem), which is about 90 % of the fresh weight of the plant, is used as food, a source of water and medicine. It serves well as medicine due to the presence of flavonoids, rhamnose, galactose and alkaloid 3-sitosterol in it (17). Moreover, the stalk of *F. histrix* is locally applied to external bruises and inflammations. Other uses of this species include making rugs, ropes, blankets, fillings and fabrics.

F. pilosus, F. latispinus and F. peninsulae

F. pilosus is another species of *Ferocactus* that is used to produce acitron as earlier mentioned. It is primarily used for food and its flowers and fruits as an exotic snack (17). The seeds of *F. herrerae* (J. G. Ortega) are used to make

Table 1. Ethnobotanical and medicinal uses of *Ferocactus* sp

Scientific name	Local name	Part used	Medicinal use	Food use	References
F. covilei Britt. And Rose 1	Biznaga, Simi kaokl (large cactus), Kail it isiml	Fruit	Hemostatic after childbirth	Edible fruits	(32)
		Seeds	-	Grounded and prepared as gruel	(12)
		Buds and flowers	Anaesthesia	-	
F. pilosus (Salm-Duck) Werderman	Biznaga, biznaga roja, fire barrel biznaga and red thorn biznaga	Fruits and flowers	-	Acitron (cactus candy), snacks	(17)
		Fruit	-	Lime (used to make water that has a lemon-like lemon)	
F. stainesii (Holk.) Britt and Rose 1	Red biznaga	Floral primordia	-	Feed	(32)
F. histrix	Biznaga, cabuches, caballona, huitnahuac	Flowers	-	Eaten fresh or in brine	
		Fruit	Healing of burns, inflammations on external body parts	Consumed raw, as a non-alcoholic beverage or a popsicle	(32)
		Plant (fruit pulp and parenchyma)	Treatment of diabetes mellitus	Production of sweets- acitrón	(17)
F. latispinus	Devil's tongue pink spined cactus	Fruit pulp	Treatment of diabetes mellitus and kidney disease	-	(11)
F. herrerae J. G. Ortega	Onobachia	Seeds	-	Making tortillas,	(15)
		Raw flesh	Control of high blood pressure	Roasted with sugar to produce a delicious, cooked starch	
F. acanthodes (Brit and Rose)		Seeds	-	Grounded and prepared as gruel	(12)
F. wislizenii (Brit and Rose)		Seeds	-	Grounded and prepared as gruel	(12)
		Flowers and buds	-	eaten, cooked with water and sugar	
F. hamatacanthus (Muhl.) Britt. and Rose	Hookworm, biznaga de tuna	Stem	-	cooked with sugar and eaten as sweet	(32)
		Fruit	-	Edible fruits, also used as a substitute for lemon	
F. uncinatus (Gal.) Britt. and Rose	Biznaga vaca	Penca	Eaten raw as a rehydrator and to quench thirst	Edible fruits	(32)

tortillas and they could also be consumed in another form by roasting them with sugar to make a sourly cooked starch (12). In local areas, its raw flesh is used to reduce high blood pressure in patients with this health condition (15). *F. latispinus* has edible fruits and stems and *F. peninsulae* is used in making candy. Moreover, *F. latispinus* and *F. peninsulae* are important ornamental plants (5, 27).

F. covilei

F. covilei has other local names such as "Kail it isiml" which means "large cactus in the dried-up lake"; "siml yapxwt k'eel" which means "large cactus that blooms red"; Seri, Biznaga, viznaga (San Luis Potosí). To achieve a good result with *F. covilei*, the pulp is squeezed into a glass and the juice is taken orally to combat feminine diseases, especially after childbirth. The juice also relieves pain, especially headaches and chest pains and in this case, a slice of *F. covilei* would be placed on coal, salted and roasted until all its juice ran out. It would then be wrapped in a piece of cloth and placed on the affected part of the body to relieve pain (32).

F. stainesii, F. hamatacanthus, F. wislizenii and F. uncinatus

F. stainesii can be boiled, stewed or eaten alone or with eggs. Also, its spineless parenchyma could be cooked with lime, sweetened with sugar and consumed as a sweet. *F. hamatacanthus* also serves as sweets; the thorns are removed, the stems are cut into pieces, soaked in water with lime for a few hours and then cooked with sugar until the sweet is ready. On the other hand, *F. wislizenii* and *F. uncinatus* have high water content, therefore they are used as rehydrators and as water substitutes to quench thirst during prolonged droughts (12, 31). Apart from the ethnobotanical uses of *Ferocactus*, information about their physicochemical composition is hereafter provided.

Physicochemical and nutritional composition of *Ferocactus*

Physicochemical composition

The amount of Total Soluble Solids (TSS) in *F. glaucescens* fruits was 13.5 °Brix which was a little higher than the value reported for *F. histrix* (12.72 °Brix) and *Cereus jamacaru* (8.00 – 11.03 °Brix) (33). This indicates a higher percentage of sugars and other dissolved solids in the fruit. Hence, *F. glaucescens* fruits would be very good raw material for producing jams and marmalades in the food industry, thereby improving the economy (4, 7). However, the TSS of *F. herrerae* fruits (14.7 °Brix) was higher than the values reported for *F. glaucescens, F. histrix* and *C. jamacaru*. Increased levels of total soluble solids in fruits infer low acidity levels. The ratio of soluble solids (SS) to total acidity is a crucial factor for measuring the shelf life and sensory quality of fruits. In other words, a high value of SS in fruits implies sweetness while a low value implies acidity (34).

The pH value reported for *F. herrerae* fruits was 4.60 while a pH of 4.70 was reported for *F. glaucescens* fruits (7, 15). These values are very close, indicating that both *F. herrerae* and *F. glaucescens* fruits are slightly acidic. Acidic pH value is beneficial due to its ability to reduce the formation of plague. Also, a low pH value for food, especially fruits, is important to prevent food spoilage due to attack by pathogenic organisms and to induce the erosion of enamel (4, 35). The determination of pH in fruits is an important parameter for post-harvest activities such as processing in the food industry and controlling microbial infestation. It was reported that an acidic pH value helps to maintain the quality of fruits and vegetables to prevent pathogenic microbial attack (35). The results of the physicochemical analysis of *F. herrerae* and *F. glaucescens* fruits have shown their potential value for developing new products in the food industry, apart from the benefits derived from consuming them in their raw forms.

Macronutrient composition

Information about the nutritional composition of the various *Ferocactus* species is very scarce in the literature. From the review conducted, only 2 studies on *F. herrerae* (15) and *F. glaucescens* fruits (7) provided recent and explicit information on the nutritional significance of *the Ferocactus* species. The summary of the physicochemical and nutritional information of *Ferocactus* fruits is shown in Table 2.

The results of the macronutrient determination (carbohydrates, proteins and fats) of both *F. herrerae* and *F. glaucescens* showed that both fruits have a high carbohydrate content but low protein and fat content. Total carbohydrates (TC) of *F. herrerae* fruits were 20.60 ± 0.55 g/100 g DW

Table 2. Physicochemical and nutritional composition of *Ferocactus* fruits

Parameters		*F. herrerae*	*F. glaucescens*	References
Macronutrients	Carbohydrate (g/100 g D.W.)	20.6	18.8	
	Protein (g/100 g F.W.)	0.8	1.2	
	Lipid (g/100 g D.W.)	0.9	1.3	
	Dietary fiber (g/100 g D.W.)	11.8	10.1	
Physicochemical	pH	4.6	4.7	
	Total soluble solids (°Brix)	14.7	13.5	
Micronutrients	Vitamin C (mg/100 g F.W.)	712.33	503.12	(15)
	Vitamin E (IU/100 g F.W.)	3720	3565.07	(7)
	Pro-vitamin A (IU/100 g F.W.)	2100.45	1083.3	
	Calcium (mg/100 g D.W.)	50.29	41.35	
	Magnesium (mg/100 g D.W.)	9.73	13.85	
	Sodium (mg/100 g D.W.)	33.64	29.7	
	Iron (mg/100 g D.W.)	2.71	3.91	
	Zinc (mg/100 g D.W.)	0.11	0.31	
	Copper (mg/100 g D.W.)	0.20	0.14	
	Manganese (mg/100 g D.W.)	0.08	0.1	

with free sugars analysis indicating the presence of glucose (3.14), fructose (4.67) and sucrose (0.65 g/100 g DW) while the TC of *F. glaucescens* fruits was 18.8 g/100 g DW with glucose, fructose and sucrose being 2.017, 3.189 g/100 g and 0.358 g/100 g respectively. This trend is not strange (33) reports on similar trend and stated that the values were due to the fruit pulp seeds. However, the TC and free sugars of *F. herrerae* were a little higher than those obtained from *F. glaucescens* (7, 15).

Low values of protein and fat were detected in both *F. herrerae* and *F. glaucescens* fruits (Table 2) in comparison with the values obtained for *Pilosocereus pachycladus* fruits (2.66 g/100 g DM and 2.10 g/100 g DM for lipid and protein respectively) (4, 8). However, the fruits are rich in essential amino acids and non-essential amino acids (Table 3), which are important for protein synthesis and metabolism. Thus, consuming these fruits would produce beneficial physiological effects. It was also reported that both *F. herrerae* and *F. glaucescens* fruits are good sources of dietary fiber (15).

Table 3. Amino acid composition of *Ferocactus* sp.

Amino Acids	*F. herrerae*	*F. glaucescens*	References
Essential amino acids (mg/g D.W.)			
Histidine	0.06	0.09	
Isoleucine	0.12	0.10	
Leucine	0.20	0.18	(15)
Lysine	0.12	0.16	
Phenylalamine	0.55	0.46	
Threonine	0.38	0.48	
Valine	0.12	0.28	
Non-essential acids (mg/g D.W.)			
Alanine	0.18	0.36	
Arginine	0.99	0.108	
Glutamic acid	0.25	0.34	
Serine	0.67	0.45	
Proline	0.002	0.006	
Tyrosine	0.38	0.25	
Glycine	0.76	0.65	

Micronutrient composition

Micronutrients (vitamins and minerals) are essential nutrients required by the body in small quantities (less than one hundred milligrams in a day). They perform specific and indispensable functions in the human body, such as the formation and maintenance of bone and teeth, tissue maintenance, coordinating and regulating physiological and biochemical functions of the body and serving as cofactors and coenzymes to enzyme systems. They are basically vitamins and minerals (36), but minerals could be macro or micro depending on the quantity (level) of their requirement in the body.

Extracts of *F. herrerae* fruits are rich in vitamins, which are known for their antioxidant activity. The vitamin C, vitamin E and provitamin A content were 712.33 mg/100 g, 3720.02 IU/100 g and 2100.45 IU/100 g of the fresh fruits respectively (FW). *F. glaucescens* fruits presented vitamin A content of 1083.3 IU/100 g. Vitamin A is important for vision, proper functioning of the immune system, full expression of genes, growth and development. Also, fruits are a rich source of vitamin C (503.12 mg/100 g), which is an antioxidant and plays a significant role as a cofactor for many metabolic reactions (7). The vitamin C content of fruits increases as the fruit ripens (4). Also, the ripe fruits had more vitamin E (3565.07 IU/100 g).

F. herrerae fruits presented macro-minerals calcium (50.29 mg/100 g DW), magnesium (9.73 mg/100 g DW) and Sodium (33.64 mg/100 g DW). Calcium is a vital component in the formation of strong bones and teeth, it aids blood coagulation and is essential for transmitting nerve signals. Magnesium helps in regulating different biochemical reactions in the body, such as the control of blood glucose and blood pressure, protein synthesis, muscle and nerve function. Sodium maintains fluid balance in the body, helps muscles to contract and relax and assists in the transmission of nerve impulses. The micro-minerals include iron (2.705 mg/100 g DW), zinc (0.108 mg/100 g DW), manganese (0.076 mg/100 g DW) and copper (0.20 mg/100 g. Iron prevents anemia while manganese serves as an antioxidant (37, 38). *F. glaucescens* fruits also contain calcium (41.35 mg/100 g), magnesium (13. 85 mg/100 g) and iron (3.905 mg/100 g) (7).

Bioactive Compounds

Several bioactive compounds have been identified in some species of *Ferocactus*, even though many species have not been studied recently. Different parts (including the stems and fruits) of the *Ferocactus* species have been studied using different methods of extraction and different solvents. Table 4 shows the bioactive compounds identified in *Ferocactus* species with the extraction method and solvent used. The main bioactive compounds identified are phenolic compounds, flavonoids and alkaloids (Fig. 2), all of which have excellent potential applications in food and pharmacological industries.

Phenolic compounds

Polyphenols are plant secondary metabolites which contribute to the sensory properties of plants and foods of vegetal origin. They are important to plants because they aid the neutralization of different types of stress which are the leading cause of many diseases. Consuming foods rich in polyphenols has helped to reduce the level of lymphocytic DNA oxidative damage to the body, thereby protecting the cells and reducing the risk of developing degenerative diseases (7). Phenolic compounds are made up of about 8000 different structures, which are classified into flavonoids and non-flavonoids. Flavonoids include phenolic acids, tannins, lignans, stilbenes and so on while the non -flavonoids include flavanols, flavonols, anthocyanins, isoflavones, flavones and flavanones. They are characterized by the presence of a benzene ring and at least one hydroxyl group in their structure. They also exhibit different bioactivities in relation to their chemical structure (39-41).

Ferocactus fruits are a rich source of phenolic compounds and flavonoids as evident from the results of the HPLC-DAD analyses performed on 6 species of *Ferocactus*

(42). The analysis indicated that the stem extracts of *F. gracilis, F. horridus, F. pottsii, F. glaucescens, F. herrerae* and *F. emoryi* contain 4 different polyphenolic compounds which are protocatechuic acid, caffeic acid, 3,4-dihydroxyphenylacetic acid and vanillic acid. In another investigation (15), analysis of the methanolic extract of

Table 4. Bioactive compounds identified in *Ferocactus* sp.

***Ferocactus* species**	**Part of plant**	**Method of extraction**	**Extraction solvent**	**Compounds**	**Ref-erence**
Ferocactus echidne		Maceration with agitation	Ethanol (3 days)	gentisic acid, diosmetin, alkaloids, saponins, cardiotonic glycosides, nicotinic acid, N-methyltyramide and- hordenine	(11)
F. latispinus				saponins, cardiotonic glycosides and sesquiterpene lactones, nicotinic acid, gentisic acid, N-methyltyramide, hordenine and chlorogenic acid	
	Stem extract	-		1-Penten-3-ol, β-Pinene, ethyl hexanoate, limonene, *p*-Cymene, β-Phellandrene, benzyl alcohol, β-Ocimene, β-Linalool, 3-methyl octadecane, octadecanoic acid, α-	
F. herrerae		-		Phenolic acids: rosmarinic, sinapic, *p*-coumaric, benzoic, gallic, chlorogenic, caffeic and cinnamic acids	(15)
		-		Flavonoids: rutin, naringenin, quercitrin, luteolin, astragalin, kaempferol, quercetin, apigenin	
F. glaucescens	Fruit extract	Sonication		Flavonoids: epicatechin, naringin, catechin, quercitrin, luteolin, kaempferol, hesperidin, quercetin, rutin, apigenin, hesperitin and naringenin	(7)
				Phenolic acids: p-hydroxy benzoic, benzoic, O-coumaric, P-coumaric, vanillic, gallic, pyrogallol, protocatechuic, caffeic, ferulic, chlorogenic, syringic, catechol, ellagic, rosmarinic, 4-aminobenzoic, cinnamic, iso-ferulic, 3,4,5 trimethoxy cinnamic acids	
F. horridus				Phenolic acids: Protocatechuic, 3,4-dihydroxyphenylacetic, caffeic and vanillic acids	
				Flavonoids: Rutoside and quercitrin	
F. gracilis			Methanol	Phenolic acids: Protocatechuic, 3,4-dihydroxyphenylacetic, caffeic and vanillic acids	
				Flavonoids: Rutoside and quercitrin	
F. pottsii				Phenolic acids: Protocatechuic, 3,4-dihydroxyphenylacetic, caffeic and vanillic acids.	
	Stem extract	Ultrasonic bath		Flavonoids: Rutoside and quercitrin	(42)
F. emoryi				Phenolic acids: Protocatechuic, 3,4-dihydroxyphenylacetic, caffeic and vanillic acids.	
				Flavonoids: Rutoside and quercitrin	
F. glaucescens				Phenolic acids: Protocatechuic, 3,4-dihydroxyphenylacetic, caffeic and vanillic acids.	
				Flavonoids: Rutoside and quercitrin	
F. herrerae				Phenolic acids: Protocatechuic, 3,4-dihydroxyphenylacetic, caffeic and vanillic acids.	
				Flavonoids: Rutoside and quercitrin	
F. histrix	Fruit extract	Spectophotometry		Phenolic acids, flavonoid and betalain (betaxanthins, betacyanins)	(48)
F. glaucescens	Plant extract	Cold percolation	Ethanol	Phenolic acids: syringic, rutin, naringenin, naringenin-7-glucoside, hydroxy methoxy dimethyl, caffeoyl feruloyl tartaric, coumaroyl quinic, phloretic, feruloyl hexoside, sinapoyl hexoside, caffeoyl quinic, coniferyl ferulate, chicoric acids	(47)
				Flavonoids: Trihydroxy methoxyflavone triacetate, aromadendrin pentosyl hexoside, kaemferol rhamnoside, rutin, liquiritigenin dihexoside, pentahydroxy trimethoxyflavone, tetrahydroxy tetramethoxyflavone, isorhamnetin rhamnosyl, tetrahydroxyflavanone pentoside, eriodyctiol *O*-hexoside, naringenin dihexoside, diosmin, kaempferol tri-rhamnoside, fustin, Quercetin pentosyl hexoside, Apigenin O-pentosyl hexoside, Myricetin pentosyl hexoside, Hydroxy trimethoxyflavone, Aromadendrin, myricetin, Apigenin *O*-hexoside, Hydroxy dimethoxyflavone hexoside, naringenin, Morelloflavone, Naringenin hexoside, Linarin methyl butyrate Pentahydroxy, Quercetin acetyl rhamnosyl rhamnoside, Prenyl naringenin, Prenylapigenin, Kaempferol *O*-hexoside, Tetrahydroxy flavanone dihexoside, Quercetin malonyl dihexoside, Quercetin acetyl dihexoside, kaempferol	
				Procyanidins and anthocyanins: Catechin rhamnosyl bocoemshexoside, Epigallocatechin gallate, Epiafzelchin-epicatechin methyl gallate, Delphinidin malonyl hexoside, Cyanidin pentosyl hexoside, (epi)Afzelechin, Petunidin, Pelargonidin pentosyl hexoside, epiafzelechin-epiafzelechi	
				Sterols and triterpenes: Cholestane-tetrol, Oxo-hydroxy sitosterol, Campesterol, betulin, Campestenone, amyrin, Methyl arjunolate, Ergosterol, Sitosterol	
				Fatty acids: Hydroxy decanoic, Hydroxy dodecanedioic, Trihydroxy eicosapentaenoic, Dodecenoic, Trihydroxy eicosatetraenoic, Octadecanedioic, Heptadecenedioic, Octadecenoic, Dihydroxy octadecadienoic, Hydroxy octadecadienoic, Hydroxy octadecatrienoic, Hydroxy tetracosanoic, Myristeolic, Pentacosenoic, Oxo-nonadecanoic, Hydroxy eicosatetraenoic, Docosenoic, Dihydroxy eicosatrienoic, Nonadienoic, Dihydroxy octanoic acids	
				Miscellaneous compounds: Umbelliferone, Lariciresinol, Magnolol, Resveratrol	

F. herrerae	Plant extract	Cold percolation	Ethanol	Phenolic acids: syringic, p-coumaric, benzoic, caffealdehyde, methyl ester, Coniferyl ferulate, Hexosyl hydroxycinnamate, Sinapoyl malate acids Flavonoids: kaempferol rhamnoside, tetrahydroxy tetramethoxyflavone, isorhamnetin rhamnosyl, Kaempferol tri-rhamnoside, Trihydroxy dimethoxyflavone, Hexahydroxyflavanone hexoside, Apigenin trimethyl ether, Morelloflavone, Amentoflavone, Tricetin diglucuronide, rhamnoside, Linarin, methyl butyrate, Pentahydroxy, Quercetin glucuronide sulfate, Quercetin acetyl, rhamnosyl rhamnoside, Prenylapigenin, Laricitrin dihexoside, Quercetagetin, Quercetin malonyl dihexoside, Quercetin acetyl dihexoside Procyanidins and anthocyanins: Catechin O-hexoside, (epi)Afzelechin, Petunidin, Cyanidin, Delphinidin dihexoside, epiafzelechin-epiafzelechi Sterols and triterpenes: Cholestane-tetrol, Oxo-hydroxy sitosterol, Arjunolic acid, Stigmasteryl hexoside, Uvaol, Campesterol, Methyl arjunolate, Avenasterol, Spinasterol, sitostenone, Sitosterol Fatty acids: Pimelic, Dihydroxy docosapentaenoic, Hydroxy octadecadienoic, Arachidic, Hydroxy eicosenoic, Hydroxy eicosatetraenoic, Docosenoic, Dihydroxy eicosatrienoic, Dodecatetraenedioic, Nonadienoic, Dihydroxy octanoic, Dodecatetraenoic, Pelargonic Miscellaneous compounds: Magnolol, Resveratrol,	(47)

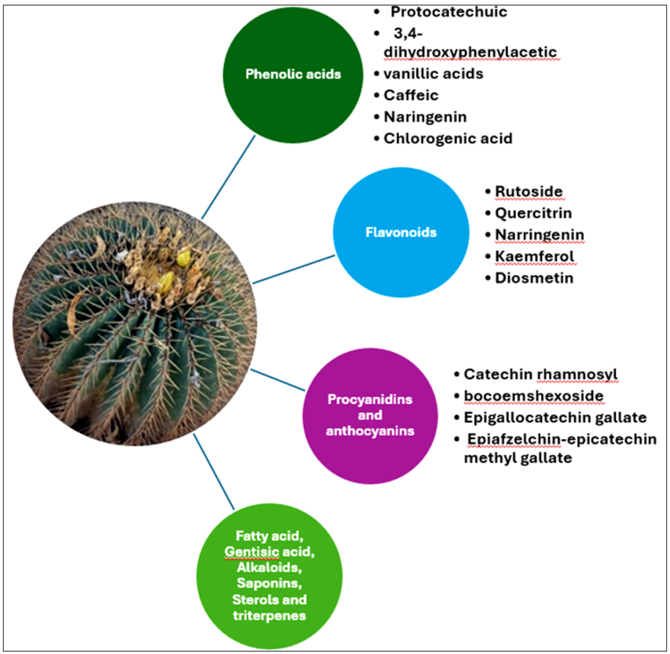

Fig. 2. Major identified bioactive compounds reported in *Ferocactus.*

F. herrerae fruits showed that the total phenolic content (TPC) was 9.17 ± 0.87 mg/g gallic acid equivalent (GAE), while the total flavonoid content (TFC) was 4.99 ± 0.23 mg/g quercetin equivalent (QE). Also, it was reported that a similar range of TPC (8.39 ± 0.074 mg/g GAE) and TFC (3.82 ± 0.019 mg/g QE) for *F. glaucescens* ripe fruits (42). Polyphenols are very important due to their antioxidant capacity, protecting against cancer, cardiovascular and other degenerative diseases (43).

Extracts of *Ferocactus* sp. also contain polyphenols which are effective against microorganisms and have been demonstrated to possess strong anti-bacterial properties against both Gram-positive (*Listeria monocytogenes, Bacillus subtilis* and *Staphylococcus aureus*) and Gram-negative bacteria (*E. coli* and *P. aeruginosa*). Therefore, these compounds are also natural sources of viable antimicrobials (44).

Alkaloids

Alkaloids are known as a popular group of plant chemicals that comprise at least one nitrogen atom in their structure. They are among the most beneficial bioactive compounds and are important in the management and treatment of diseases. They are an invaluable group of secondary metabolites and are found in some analyzed cactus species (39, 45). Phenethylamine and isoquinoline derivatives are the commonly encountered alkaloids as secondary metabolites in cacti, with hordenine and mescaline (phenethylamine derivatives) being the most widely investigated, due to their hallucinogenic effects and other biological activities (46).

Several studies have proven that alkaloids are effective in health care as antioxidants and anticancer agents. For example, alkaloids were found in the ethanolic stem extract of *F. echidne*, which was reported to reduce the viability of the mouse glioma C6 cell line (ATCC CCL-107) after treatment for 24 hr (11).

Other compounds

The chemical components of 6 halophytes including *F. glaucescens, F. herrerae* and *F. pottsii* (70% ethanol extracts) was determined using LC-HR-ESI-MS. Two hundred and 68 compounds were identified in the 6 samples. Basically, the identified metabolites were in 6 groups, namely, phenolic acids and their conjugates, flavonoids, anthocyanins/procyanidins, fatty acids, alkaloids and sterols/triterpenes, along with miscellaneous compounds (Table 4). Summarily, *F. glaucescens* was found to contain 13 phenolic acids, 34 flavonoids, 9 anthocyanins/procyanidins, 20 fatty acids, 9 sterols/triterpenes and 4 miscellaneoussucc compounds, while *F. herrerae* contains 8 phenolic acids, 22 flavonoids, 6 anthocyanins/procyanidins, 13 fatty acids, 11 sterols/triterpenes, 2 miscellaneous compounds and *F. pottsii* possesses 10 phenolic acids, 26 flavonoids, 4 anthocyanins/procyanidins, 14 fatty acids, 4 sterols/triterpenes and 3 miscellaneous compounds.

Biological activities of active compounds extracted from the *Ferocactus* species

Biological activities (also called bioactivities) refer to the ability of a bioactive compound or phytochemical to interact with living cells or organisms, with the potential of generating a desirable (health-promoting) response. The responses could be in the form of antimicrobial, antioxidant, analgesic, anti-diabetic, anti-inflammatory or anti-cancer. Bioactivities including antioxidants, antiproliferative and anticarcinogenic effects have been linked to the consumption of plant chemicals such as phenolic acids, carotenoids, flavonoids and anthocyanins (Fig. 3).

Also, investigations have shown that the consumption of fresh fruits, which are rich in natural antioxidants, prevents oxidative degradation from free radicals. Some species of *Ferocactus* have been scientifically reported to possess some important biological activities which are summarized in Table 5.

Antibacterial and antifungal potential of *Ferocactus*

Extracts of *Ferocactus* sp. contain polyphenols which are effective against microorganisms. An investigation on the antimicrobial activities of polyphenol extracts was performed from *Ferocactus* sp. (42) and discovered that 6 stem extracts of *Ferocactus* sp., namely *F. glaucescens, F. pottsii, F. emoryi F. horridus, F. herrerae* and *F. gracilis* (the

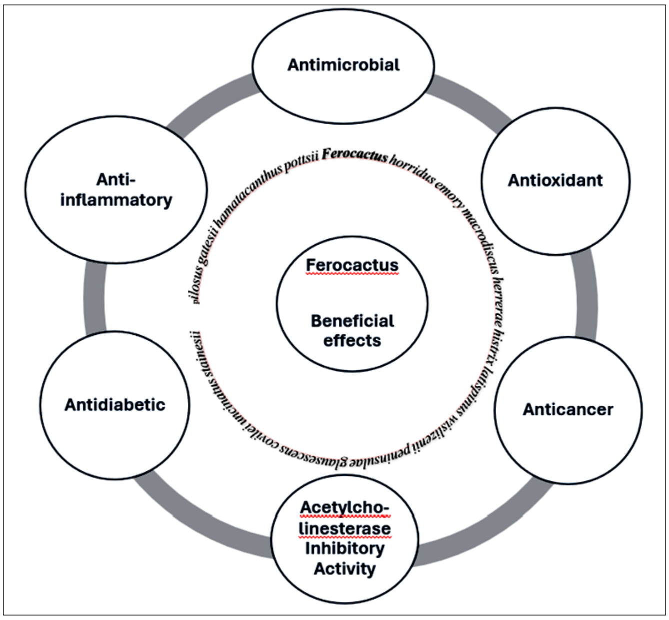

Fig. 3. Some biological activities of *Ferocactus.*

Table 5. Biological activities of active compounds extracted from *Ferocactus* sp.

***Ferocactus* species**	**Part of plant**	**Mode of study**	**References**
Ferocactus echidne	Stem extract	DPPH scavenging assay, brine Shrimp Assay, microdilution assay and MIC study against *Listeria monocytogenes,* Methicillin-resistant *Staphylococcus aureus, Acineto- bacter baumannii, Escherichia coli, Klebsiella pneumoniae* and *Pseudomonas aeruginosa* and fungal strains *Candida albicans* and *Cryptococcus neoformans*	(11)
F. latispinus		DPPH scavenging assay, brine shrimp assay, microdilution assay and MIC study against *Listeria monocytogenes,* Methicillin-resistant *Staphylococcus aureus, Acineto- bacter baumannii, Escherichia coli, Klebsiella pneumoniae* and *Pseudomonas aeruginosa* and fungal strains *Candida albicans* and *Cryptococcus neoformans*	(11)
F. herrerae	Fruit extract	DPPH, ABTS and FRAP assays, Anti-inflammatory activity: Inhibitory action on both COX-1 and COX-2 enzymes	(15)
F. glaucescens		DPPH scavenging assay	(7)
F. echidne		Cytotoxicity effect on mouse glioma C6, acute myeloid leukemia U937, human epidermal skin HaCaT and human acute monocytic leukemia THP-1 Anti-inflammatory activity on THP-1 cells with ELISA kits	(11)
F. latispinus		Cytotoxicity effect on mouse glioma C6, acute myeloid leukemia U937, human epidermal skin HaCaT and human acute monocytic leukemia THP-1 Anti-inflammatory activity on THP-1 cells with ELISA kits	(11)
F. horridus		MTT and apoptotic assays on MCF-7, HeLa, Jurkat, HT-29, T24 and HEK-293 (human normal cells) Antibacterial activity against *B. cereus, L. monocytogenes, E. coli, M. flavus, S. aureus* and *P. aeruginosa* Antifungal activity against *C. albicans, A. flavus, P. ochrochloron, A. ochraceus, A. niger* and *P. funiculosum*	(42)
F. gracilis		MTT and apoptotic assays on MCF-7, HeLa, Jurkat, HT-29, T24 and HEK-293 (human normal cells) Antibacterial activity against *B. cereus, L. monocytogenes, E. coli, M. flavus, S. aureus* and *P. aeruginosa* Antifungal activity against *C. albicans, A. flavus, P. ochrochloron, A. ochraceus, A. niger* and *P. funiculosum*	(42)
F. pottsii	Stem extract	MTT and apoptotic assays on MCF-7, HeLa, Jurkat, HT-29, T24 and HEK-293 (human normal cells) Antibacterial activity against *B. cereus, L. monocytogenes, E. coli, M. flavus, S. aureus* and *P. aeruginosa* Antifungal activity against *C. albicans, A. flavus, P. ochrochloron, A. ochraceus, A. niger* and *P. funiculosum*	(42)
F. emoryi		MTT and apoptotic assays on MCF-7, HeLa, Jurkat, HT-29, T24 and HEK-293 (human normal cells) Antibacterial activity against *B. cereus, L. monocytogenes, E. coli, M. flavus, S. aureus* and *P. aeruginosa* Antifungal activity against *C. albicans, A. flavus, P. ochrochloron, A. ochraceus, A. niger* and *P. funiculosum*	(42)
F. herrerae		MTT and apoptotic assays on MCF-7, HeLa, Jurkat, HT-29, T24 and HEK-293 (human normal cells) Antibacterial activity against *B. cereus, L. monocytogenes, E. coli, M. flavus, S. aureus* and *P. aeruginosa*. Antifungal activity against *C. albicans, A. flavus, P. ochrochloron, A. ochraceus, A. niger* and *P. funiculosum*	(42)
F. glaucescens		MTT and apoptotic assays on MCF-7, HeLa, Jurkat, HT-29, T24 and HEK-293 (human normal cells) Antibacterial activity against *B. cereus, L. monocytogenes, E. coli, M. flavus, S. aureus* and *P. aeruginosa* Antifungal activity against *C. albicans, A. flavus, P. ochrochloron, A. ochraceus, A. niger* and *P. funiculosum*	(42)
F. glaucescens, pottsii and *herrerae*	Plant extract (ethanolic extract)	MTT assay (Griess assay), nitric oxide assay, iNOS western blot analysis, Assessment of the induction of NQO1, Kinetic DCPIP reduction assay for NQO1 on Murine hepatoma Hepa-1c1c7 cells	(47)

first 3 species being the most effective), exhibited antibacterial activity against *Pseudomonas aeruginosa, Mariniluteicoccus flavus, Bacillus cereus, Escherichia coli, Listeria monocytogenes* and *Staphylococcus aureus*. Moreover, in the same investigation, significant antifungal activity was recorded against *Aspergillus ochraceus* and *Aspergillus niger*. Rutoside, 3,4-dihydroxyphenylacetic acid and quercitrin were identified as the bioactive compounds responsible for these antibacterial effects. These compounds have been previously reported for their antibacterial and antifungal activities (44, 49-52).

Ethanolic extracts of *F. echidne* and *F. lastispinus* also demonstrated antibacterial activity against ten bacterial strains (*L. monocytogenes, S. aureus,* clinical *S. aureus, Methicillin-resistant S. aureus, Acinetobacter baumannii,* clinical *A. baumannii,* clinical *Klebsiella pneumoniae, Escherichia coli, P. aeruginosa* and clinical *P. aeruginosa*) and antifungal activity against 2 fungal strains (*Cryptococcus neoformans* and *Candida albicans*) with minimum inhibitory value between 200 and 2000 μg/mL. Gentisic acid, nicotinic acid, diosmetin and chlorogenic acid were identified to be responsible for this activity. Consequently, these plants would find applications as potential antibiotics to treat infections or communicable diseases that may be prevalent in this area (11).

Anticancer potential

Ferocactus species are potential and valuable natural sources of anticancer. For example, it was reported that the stem extracts of *F. glaucescens, F. pottsii* and *F. emoryi* showed excellent anticancer activity against human cancer (Hela and Jurkat) cell lines using MTT assay (42). This effect was attributed to the abundant presence of 4 bioactive polyphenol compounds, namely, 3,4-dihydroxyphenyl -acetic acid, rutoside, quercitrin and protocatechuic acid in the extracts. These compounds have been previously reported to have some biological activities. For example, 3,4-dihydroxyphenylacetic was reported to have an apoptotic effect on colon adenocarcinoma cells (53), human gastric carcinoma cells and (54). Rutoside, which is a flavonol is said to have antioxidants, cytoprotective and anticarcinogenic activities against some types of cancer cells (human leukemia HL-60 cells, human colon cell lines, among others) (55, 56). It also activates apoptosis in human neuroblastoma cancer cells (57). In addition, quercitrin has shown strong anticancer activities due to its apoptosis-inducing effects (58).

Moreover, the ethanolic extracts of *F. pottsii* (Salm-Dyck) Backeb, *F. herrerae* (J.G. Ortega) and *F. glaucescens* (D.C.) Britton and Rose were discovered to possess chemopreventive activity with the identification of 2S-naringenin, trans-dihydrokaempferol (aromadendrin), 2S-naringenin-7 -O-β-d-glucopyranoside and kaempferol-7-O-β-d-glucopyranoside (populnin) as the bioactive compounds present (47). It was also documented that nicotinic acid, gentisic acid, N-methyltyramide, hordenine and chlorogenic acid were identified in the extracts of *F. echidne* while nicotinic acid, gentisic acid, N-methyltyramide, hordenine and diosmetin were identified in *F. latispinus* and both species exhibited anticancer effects against C6 cell line (mouse glioma) (11).

Antioxidant potential

Antioxidants are compounds that delay and prevent oxidation. They scavenge radical species and convert them to non-radical or more stable radicals (59). Antioxidant potential is one of the most studied biological activities of the *Ferocactus* species. *F. echidne* has been reported as an antioxidant, acting as a reductant in the fabrication of metallic nanoparticles. An investigation carried out (60) demonstrated that the aqueous extract of *F. echidne* has capping and reducing potential. *F. echidne* acts as a reducing agent and an antioxidant due to the presence of polyphenols, flavonoids, ascorbic acid and alkaloids in the extract. It also presents potential applications in the pharmacological industry as an analgesic, anticancer, laxative, antiparasitic and diuretic (60). Nicotinic acid (niacin) is an important substance identified in the extracts of *F. echidne*. It has also been identified in the stems and fruits of some species of cactus belonging to *Selenicereus* and *Hylocereus* genera (61). It is an antioxidant which inhibits vascular oxidative stress, lipid peroxidation in cells and redox-sensitive genes. It also plays an important role in increasing the level of cytoplasmatic antioxidant enzymes which include catalases, superoxide dismutase and glutathione peroxide (11).

In another investigation, the ethanolic extracts of *F. echidne* and *F. latispinus* were analyzed for 2,2-diphenyl-1-picrylhydrazyl (DPPH) antioxidant activity (11). *F. echidne* accounted for 36.30% of the inhibition and *F latispinus* (14.37%), at a concentration of 0.40 mg/mL, although this was less than ascorbic acid (83.08%) which is an excellent source of antioxidants. This was attributed to gentisic acid and diosmetin in the extracts of *F. echidne* and these compounds have been reported as antioxidant compounds (62, 63).

Furthermore, the ABTS and DPPH assays on that methanolic extract of *F. herrerae* had a free radical-scavenging activity of 241.1 ± 5.03 and 132.06 ± 2.1 μM Trolox Equivalent/g accounting for 88.4 and 71.11% antioxidant activity respectively in comparison with ascorbic acid (272.7 ± 8.2 and 185.7 ± 1.8 μM TE/g). Also, the same extract exhibited antioxidant activity of 258.91 ± 1.75 μM TE/g for the FRAP assay, representing 89.24% antioxidant activity compared to ascorbic acid (290.1 ± 2.18 u μM TE/g). These results showed that *F. herrerae* fruits have a high antioxidant capacity which was attributed to the high content of vitamins and phenolic compounds in them (15). Moreso, some volatile compounds (benzyl alcohol, linalool and terpineol) found in the fruits have been reported to possess antioxidant capacities (64-67).

In another investigation (7), the DPPH scavenging assay revealed the ability of the antioxidant compounds present in the extracts of *F. glaucescens* to capture the DPPH radical at a rate comparable to that of ascorbic acid, which was used as the control. The concentration required to achieve a 50 % reduction in DPPH radicals (IC_{50}) was 120.24 ± 0.66 μg/mL compared to vit. C (IC_{50} = 90.37 ± 0.23 μg/mL).

The high antioxidant capacity of the fruits was traced to the high content of phenolic acids and flavonoids it contains. High temperature, low pH, oxygen and high acidity are factors that can reduce antioxidant activity (68).

Anti-inflammatory potential

The inflammatory response of the ethanolic extracts of *F. latispinus* and *F. echidne* was measured (11) using human monocyte-derived macrophages and THP-1 cells (*ex vivo* model). It was discovered that *F. echidne* showed an increase in the secretion of IL-10 (1377.03 pg/mL) in comparison with *F. latispinus* which showed a lower value. In another study of the anti-inflammatory activity of *Ferocactus*, the methanolic extract of *F. herrerae* fruits showed significant inhibition of COX-1 and COX-2 enzymes when compared with 2 known anti-inflammatory drugs (celecoxib and ibuprofen). This effect was attributed to the presence of flavonoids (naringenin and quercetin) and phenolic acids (chlorogenic and rosmarinic acids), which are known to bind strongly with COX -1 and COX-2 (15). A similar report was given concerning the extract of *F. glaucescens* which demonstrated a remarkable anti-inflammatory activity by inhibiting nitric oxide in LPS-induced RAW macrophage cells due to the presence of naringenin in it (47).

Antidiabetic potential

It was discovered that chloroform extracts of *F. latispinus* and *F. histrix* fruits have effects on hyperlipidemia and hypoinsulinemia through oral administration to normoglucemic and streptozotocin-induced diabetic rats (69). Blood glucose, triglycerides, lipid peroxidation, total cholesterol levels in the serum, glycogen content of liver and skeletal muscles, superoxide dismutase, catalase, glutathione reductase and glutathione peroxidase levels of the rats were determined to ascertain the antidiabetic effects of the extracts. From their research, they provided supporting evidence for the therapeutic potential of these fruits to act as an anti-diabetic agent and to prevent and delay the onset of diabetes milletus without causing any harmful effect.

Acetylcholinesterase Inhibitory (AchEI) Activity

There was an investigation on the acetylcholinesterase inhibitory activity of methanolic extract of *F. herrerae* fruits (15), which is one of the useful techniques in the treatment of mild to moderate Alzheimer's disease and inflammation associated with bacterial infections (70). Acetylcholine is a central and peripheral nervous system neurotransmitter which plays an important role in the pathogenesis of several diseases (71). It causes behavioural disturbances, memory difficulties and cognitive decline (72). This disease condition can be arrested through medication, with deep interest in acetylcholinesterase (AChE) inhibitors from plant origin (70). From this research, the authors affirmed that extracts of *F. herrerae* fruits exhibited significant acetylcholinesterase inhibitory activity with $IC_{50} = 1.01 \pm 0.39$ mg/mL in comparison to the standard drug, physostigmine, with $IC_{50} = 0.09 \pm 0.1$ mg/mL. This AchEI activity was attributed to the phenolic acids, flavonoids (quercetin) and vitamins identified in the extracts. It was previously documented the acetylcholinesterase inhibitory activity of phenolic acids and flavonoids (73) and quercetin derivatives have also been reported to exhibit *in silico* acetylcholinesterase inhibitory activity (74), as well as vitamins, which delay the advancement of irreversible neurocognitive decline (75).

Challenges and Future Directions

The various species of *Ferocactus* genus found in the arid and semi-arid regions and endemic to Mexico are multidimensional in their functions. The whole plant and the distinct parts (seeds, fruits, stem, flowers and cladodes) are used differently, performing significant functions. They are used not only as fresh food but also as raw materials for the food industry, as medicinal plants as well as for cosmetic and construction purposes. However, despite the nutritional, economic and medicinal importance of these species, very few recent studies are available in the literature on them. There is therefore a need for collaboration amongst different fields of research to join hands with the rural community members, who have a broad knowledge of the cultivation and ethnobotanical uses of these underutilized plants. This would enhance the propagation, cultivation and sustainable production of *Ferocactus* plants, thereby increasing the availability and usefulness of the fruits in biotechnological and pharmaceutical industries.

Many *Ferocactus* species are threatened and subject to special protection (included in the Official Mexican Standard 059). While some species of *Ferocactus* are underutilized, some are over-exploited and over-collected illegally, due to their continuous utilization and the habitat of some are destroyed making them to be at risk of urbanization and artificial grassland creation. For example, the process of producing acitron (sweet of biznaga produced from *F. hisrix* and *F. pilosus*) does not give room for the regeneration of the plant but exposes it to the risk of overexploitation, since it involves cutting the entire plant from the base, with each plant taking decades to reach maturity. Hence, this poses a threat to the long-term survival of these species (17). Overexploitation is a major cause of biodiversity decline in the world. It reduces population viability and makes the plant extinct quickly. It negatively affects ecosystem functioning and community structure and may affect other species (76). Moreover, most of these species are endemic to Mexico, which means that they do not naturally inhabit another country. Therefore, there is an urgent need to rescue these species and ensure their sustainability and propagation lest they go into extinction. This could be achieved through elaborate *in vitro* and *ex vitro* germination to ensure conservation by using appropriate nutrient medium to propagate various *Ferocactus* species in the laboratory (77-79).

Moreover, in research conducted (80), it was discovered that some species of *Ferocactus* (*F. glaucescens, F. macrodiscus* and *F. gatesii*) were highly susceptible to infections by *Fusarium oxysporum, F. proliferatum* and *Neocosmospora falciformis* causing a disease symptom known as Fusarium dry rot and soft rot. Specifically, *F. oxysporum* is a soilborne fungus that can be found in both cultivated and uncultivated soils in various climates all over the world. It can be pathogenic to both plants and humans and sometimes nonpathogenic. The plant pathogenic *F. oxysporum* is very destructive to cultivated crops, including plants in the family Cactaceae (*Ferocactus* species), therefore, there is a need for appropriate diagnostic molecular tools to detect and prevent infection by *F. oxysporum* (81).

Conclusion

This review provides an overview of one genus of the family Cactaceae, *Ferocactus* with current information on the description of various species, their botanical and morphological characteristics, ethnobotanical uses and their nutritional and bioactive composition. The fruits have high macro and micronutrient composition as well as amino acids and minerals. The medicinal properties of these plants are linked to their bioactive composition, which includes polyphenols, alkaloids and flavonoids among others, which provide the basis for their biological activities, enabling them to function as antioxidants, antimicrobial, anti-cancer and anti-inflammatory agents and find applications in the pharmaceutical industries for the development and production of new antibiotic, anticancer and anti-inflammatory drugs which could be used for prevention and treatment of some infectious, chronic and degenerative diseases. Furthermore, they have enormous potential to be used by the food and cosmetic industries as well as in the construction companies.

It is expected to have more investigations into the various species of *Ferocactus* and collaborative work is encouraged by researchers and rural dwellers to develop diverse ways for the sustainable production and conservation of these plants. It is also important to avoid overexploiting them since they take long years to mature. To the best of our knowledge, this is the first review providing information on the various species of *Ferocactus*.

Acknowledgements

BRF acknowledges the financial support of the Mexican National Council for Science and Technology, (CONACYT Project, CVU:2023-1322620). Also, thanks to Ruben Rojas from the Desert Museum-Saltillo Coahuila, for his assistance in the recognition of the various *Ferocactus* species.

Authors' contributions

BRF conceived the study and drafted the original manuscript. ACFG participated in the design of the study and its validation. JAAV validated the study, reviewed and edited the manuscript. SCEG provided resources and validated the study. SYSB provided resources, reviewed and edited the manuscript. SDNF designed the methodology, reviewed and edited the manuscript. LGCM provided the resources, reviewed and edited the manuscript. RRH conceived of the study and participated in its design, coordination and administration. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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