Cactaceaes of the Brazilian semiarid: source of bioactive compounds

ABSTRACT

The semiarid region of Brazil stands out as one of the spaces with the highest diversity of plant species in the world, and the Cactaceae family the one that best represents the Brazilian semiarid.However, although there are many species of cacti in Brazil, their chemical potential has yet to be discovered. Given this, the present review aims to record the bioactive metabolites of native cactaceaes or not in Brazil, encompassing a description of its habitat and traditional uses.Compilations of ethnobotanical studies point to the importance of cacti species in the daily life of local cultures. Cactaceaes are used for food, economic, ornamental, and mystical purposes, among others, and stand out for their importance in traditional medicine, used to treat various diseases.Bioactive compounds in this family belong mainly to alkaloid groups, such asbetalain, phenolic acids, terpenes and fatty acids. This review displays the relevance of the Cactaceae family in the face of the remarkable production of bioactive compounds.

Keywords: Cacti; Ethnobotanical; Bioactive metabolites; Caatinga.

1.0 INTRODUCTION

Cactaceae is the term in the Latin language attributed to the family of plants that belong to the cacti. Cactaceaes are native to the American continent, having their most extensive st distribution in the arid and semiarid regions of the Americas. This family has approximately 1.500 species and 130 genera, divided into four subfamilies, of which three, Pereskioideae, Opuntioideae, and Cactoideae, occur in Brazil [1].In the Brazilian territory, 37 genera and 275 species are recognized so far, of which 14 genera and 188 are endemic[2].

The geographical space of the semiarid, where it has the largest distribution of cactaceaes in Brazil, extends to eight states in the Northeast Region (Alagoas, Bahia, Ceará, Paraíba, Pernambuco, Piauí, Rio Grande do Norte and Sergipe) plus the north of Minas Gerais [1]. In this area, the dominant biome is caatinga, characterized by low precipitation, high temperature, and xerophyte vegetation [3].

Anatomical, ecological, and physiological aspects peculiar to the Cactaceae family are responsible for adapting it to the semiarid climate. Its efficiency in water use is based on the Specialized Photosynthetic mechanism CAM (Crassulacean Accident Metabolism), where the stomats open at night, with the lower temperatures, and keep them closed during the day, enabling high efficiency of the use of water [4].

Cactus species are usually xerophytic, succulent and perennial.They have arboreal, shrubby, subshrub, climbing, epiphyte, or geophyte strata and fibrous or tuberous roots [5]. They have a photosynthetically active stem of variable color, shape and size, forming cladodes, which can be smooth, cylindrical, columnar or globular and are usually covered with thorns [6].

The various cactaceae found in the Brazilian semiarid are used and known for various purposes, such as food, medicine, forage, religious mystical, for ornamentation, biodiversityconservation and as a rain bioindicator [7].In the scope of traditional medicine, *Cereus jamacaru* (mandacaru), *Opuntia ficus-indica* (palm), *Melocactus zehntneri* (friar's crown), *Pilosocereus gounellei* (xique xique), *Pilosocereus pachycladus* (facheiro) and *Opuntia palmadora* (palmadora), used by rural communities for back problems, diabetes, rheumatism, urinary tract infections, kidney problems, appendicitis, bronchitis and flu [8,9].The traditionally used parts are mainly the cladodes and roots, in the form of infusion and decoction [10].

In consonance with its applicability in traditional medicine, these plants have important metabolic characteristics, such as the production of bioactive compounds.The accumulation of these compounds is one of the response mechanisms to biotic agents and abiotic stresses, which, as stimuli, trigger the synthesis of alkaloids, terpenes, betalains, phenolics and nitrogenous compounds [11].

However, although there are many species of cacti in the Brazilian semiarid region, their phytochemical potential still needs to be discovered. Ttherefore, be the subject of study given these plants' importance. In this sense, the present review aims to identify the bioactive metabolites of cacti, whether or not native to Brazil, encompassing a description of their habitat and traditional uses. To this end, a search was carried out in scientific databases, where important publications concerning cacti were extracted.

2.0 CACTACEAE FAMILY - HABITAT AND TRADITIONAL USES

The Cactaceae family belongs to the Angiosperms group, divided into three subfamilies: Opuntioideae, Pereskioideae and Cactoideae – the latter is the most numerous in genera [12]. However, a fourth subfamily, Maihuenioideae, has also been recognized by some authors, being restricted to South America (Argentina and Chile) [13]. This family is native to the American continent, where it occurs with high richness and abundance of species, from British Columbia and Alberta in Canada to Patagonia in Argentina, including the island regions of the continent. Few cactus species are seen occurring naturally on other continents [14].

Four areas in the world are identified as having high richness and endemism of species; they are: 1) Mexico and the southwest of the USA; 2) the central Andes region involving Peru, Bolivia, southern Ecuador, northeastern Chile, and northwestern Argentina; 3) Eastern Brazil, covering the northeastern region and part of the southeastern region, excluding the southern portion of the State of Rio de Janeiro and the entire State of São Paulo; and 4) the region that includes Paraguay, Uruguay, northern Argentina and Brazil [1].

The term cactus is used to designate the group of species belonging to the Cactaceae family, which have morphological and physiological adaptations that collaborate with the conservation of species diversity in northeastern Brazil. Cacti generally have a thick cuticle, mucilaginous tissues, succulent and thorny stems, leafless branches and areolas producing thorns [3,15].

As these plants develop in adverse environments, accumulating secondary metabolites are one of the response mechanisms to environmental stress. Thus, the water deficit, the high saline concentration in the soil and the light stress are stimuli that trigger the synthesis of compounds such as terpenes, phenolics and nitrogen compounds [15].

The Caatinga species of Cactaceae are classified as xerophilous; they have specific characteristics for semiarid regions, such as the ability to tolerate water scarcity and resist the drought period [3]. Therefore, these plants have a specialized survival mechanism, with physiological adaptations to high temperatures. These adaptations are related to the ability of cacti to convert water into dry matter through a specialized photosynthetic mechanism called MAC (Crassulacean Acid Metabolism), which allows them to remain succulent during the dry season [16,17].

Crassulacean Acid Metabolism (CAM) is one of three possible atmospheric carbon (CO_2) assimilation types via photosynthesis. The CAM plants have increased water use efficiency, constituting a necessary physiological adaptation that allows the plants to occupy habitats characterized by intermittent water availability [16,17].

The Cactaceae is among the most used plants by man, mainly in the semiarid region. The diversity of uses brings it into four categories: medicinal, food, ornamentation,fuel, and fodder plant (table 1). In this way, one can notice that this botanical group has excellent economic, biological and ecological value, mainly because it always remains green, even in water stress conditions and under high temperatures[18].

Table 1. Traditional uses of Cactaceae from the Brazilian semiarid region.

Species	Vernacular name	Traditional uses (Categories of use)	Reference
Cereus jamacaru DC.	Mandacaru Mandacaru de boi	Food Fuel Construction Fodder plant Medicinal	Lucena et al. (2013) [9]. Santana et al. (2018) [29] Andrade et al. (2006b) [21] Lucena et al. (2015) [10].
Melocactus bahiensis (Britton & Rose) Luetzelb. *Melocactus sergipensis. Melocactus zehntneri, Melocactus violaceus.*	Coroa de frade Coroa de frade branco	Ornamentation Technology Food Fodder plant Mystic Medicinal	Lucena et al. (2013) [9]. Santana et al. (2018) [29] Lucena et al. (2015) [10].
Nopalea cochenillifera (L.) Salm-Dyck	Palma doce Palma de engorda	Ornamentation Food Fodder plant	Lucena et al. (2013) [9]. Santana et al. (2018) [29] Lucena et al. (2015) [10].
Opuntia ficus indica (L.) Mill.	Palma forrageira Palma-de-gado	Medicinal Food Fodder plant Personal hygiene Religious magic Shade	Lucena et al. (2013) [9]. Andrade et al. (2006b) [21] Lucena et al. (2015) [10].
Opuntia stricta	Palma de espinho	Feeding	Lucena et al.

(Haw.) Haw.		Construction Fodder plant Ornamentation	(2013) [9]. Lucena et al. (2015) [10].
Pilosocereus gounellei (F.A.C. Weber) Byles & Rowley	Xique xique	Feeding Construction Fodder plant Ornamentation Medicinal	Lucena et al. (2013) [9]. Santana et al. (2018) [29] Lucena et al. (2015) [10].
Pilosocereus pachycladus F. Ritter	Facheiro	Food Fuel Fodder plant Ornamentation Techonology	Lucena et al. (2013) [9]. Lucena et al. (2015) [10].
Pilosocereus catingicola subsp. salvadorensis	Facheiro	Construction Fodder plant	Santana et al. (2018) [29]
Tacinga inamoena N.P. Taylor & Stuppy	Cumbeba Quibá	Fodder plant Food	Lucena et al. (2013) [9]. Lucena et al. (2015) [10]. Santana et al. (2018) [29]
Tacinga palmadora (Britton & Rose) N.P. Taylor & Stuppy	Palmatória	Food Medicinal	Lucena et al. (2013) [9]. Lucena et al. (2015) [10]. Andrade et al. (2006b) [21]
Harrisia adscendens	Rabo de rapousa	Medicinal	Andrade et al. (2006b) [21]

The robust structure of several cacti, such as *C. jamacaru* DC. and *Echinopsisattackamensis*(Phil.), makes them suitable for building fences, battens, boards, doors and windows [19,9]. Other uses, such as the mucilage of the cactus *Opuntia ficus* and *Pereskia aculeata*, have been applied in the food packaging industry as a raw material for films and coatings. It has been used, more recently, as a food preservative [20].

One of the prominent uses for Cactaceae species is in folk medicine, food and forage [21,22]. According to Andrade *et al.* (2006b)[21], traditional medicine using cactus is ancient in the semiarid region and is based on traditional knowledge passed down through generations. In the same study, the author mentions the use of cactus for various health problems recorded by the research participants, namely: "heat", vaginal inflammation, urinary infection, flu, inflammation in the uterus, bellyache, "choking", "dryness", back pain, syphilis, kidney problem, urethra problem, colic, bowel problem, prosthesis problem, toothache, "swollen belly" and dysentery".

In human food, the ingestion of fruits can be mentioned, mainly of the genera *Cereus* and *Pilosocereus*. Their consumption can be for generating some products or in nature[23,24]. Given that, Mizrahi (2014) [23] conducted a study with the fruits of *Cereus peruvianus*, using the ripe fruit to develop jam, dried fruit and aromatic liqueur.

Furthermore, according to Shetty *et al.* (2012) [22], cacti have excellent properties; they have flavour, are nutritious and can be eaten fresh, as vegetables and in salad dishes. Food products such as cookies, candies, puddings and cakes have also been developed using the cactus. In addition, other commercial products can be mentioned, such as shampoos and soaps, produced from different species of this family[9,18]. Cactaceae is also used in animal feed, such as cattle and goats. The high content of vitamin A and iron present in these plants canmeet the nutritional needs the region's animals, especially in drought [8].

However, due to the popularity of Cactaceae as a medicinal plant, studies have been developed to evaluate the chemical composition of these plants. Since then, alkaloids, carbohydrate polymers, phenolic compounds, carotenoids, natural pigments and terpenes have been described in Cactaceae, especially those belonging to the subfamilies of Cactoideae[18,25].

Considering the great diversity of use and the variety of cactus species, studies that focus on the biochemical characterization of this family are of paramount importance since factors such as habitat destruction threaten these species, putting them in danger of extinction [26]. The Red List of Threatened Species of the International Union for the Conservation of Nature (IUCN) includes about 139 cactus species as vulnerable to extinction [27], highlighting the subfamilies Cactoideae and Opuntioideae with the most significant number of species represented on the IUCN Red List. Brazil has the highest proportion of threatened species on a global scale with 18%, followed by Mexico (10%), Ecuador (9%) and Peru (7%) [14].

3.0 BIOACTIVE COMPOUNDS OF CACTACEAE

Cacti contain many chemical substances with pharmacological and biological relevance, synthesized in response to biotic and abiotic factors. The main compounds produced are alkaloids [30], betalains[31] and phenolic compounds [32], terpenes [33](table 2) and fatty acids [34].

Table 2. Secondary metabolites present in cacti from the Brazilian semiarid region.

Specie	Chemical group	Metabolite	Tissue	Technique used	Reference
	Alkaloids	Phenethylamine, hordenine, tyramine, N-methylthyramine and tyrosine	Cladode	Liquid Chromatography-Mass	Schwarz et al. 2010[36]; Davet et al. 2009 [37]; de Medeiros et al. 2019 [38]
Cereus jamacaru	Terpens	Geranylacetone, camphor	Cladode	Liquid chromatography-tandem mass spectrometry 12	Schwarz et al. 2010 [36]
	Polyphenols	p-coumaric acid, phenol	Fruit	High-Performance Liquid Chromatography - Diodearray Detector	Santos et al. 2021[39]
Opuntia ficus indica	Alkaloids	Betalain, betaxanthins (indicaxanthin isomer I, indicaxanthin isomer) betacyanins (Betanidin-5-O-β-sophoroside, Betanidin-5-O-β glucoside	Peels	Performance Liquid Chromatography - Diodearray Detector	Melgar et al (2017) [40]

		(betanin), Isobetanin, Gomphrenin I and Betanidin).			
	Polyphenols	kaempferol, quercetin, kaempferol 3-methyl ether, quercetin 3-methyl ether, narcissin, (+)-dihydrokaempferol (aromadendrin,6), (+)-dihydroquercetin (taxifolin,7), eriodictyol.	Fruit and stem	High-Performance Liquid Chromatography - Diodearray Detector	Lee et al. (2003) [41]
	Terpens	α-Tocopherol, β-tocopherol, γ-tocopherol, linoleic acid, palmitic acid, lauric acid, myristic acid.	Cladode	High performance liquid chromatography	Lanuzza et al. (2017) [31]; Wright and Setzer (2014) [33]
Opuntia stricta	Polyphenols	Eucomic acid, isorhamnetin-3-O-rutinoside, kaempferol-3-O-rutinoside.	Fruit	High performance liquid chromatography	Thi Tran et al. (2019) [42]
Pilosocereus catingicola	Alkaloids	Betanin, 2′-O-apiosylisobetanin, isobetanin, 17-decarboxybetanin, phyllocactin, 15-decarboxybetanin, isophyllocactin, 6′-O-malonyl-2 decarboxybetanin, 2′-O-apiosylphyllocactin, 2′-(5”-O-E-feruloylapiosyl) betanin, lampranthin II.	Fruit	High performance liquid chromatography	Silva-Barbosa et al. (2017) [43]

3.1 Alkaloids

Alkaloids are a heterogeneous group of nitrogenous substances, of fundamental character andpharmacological action, generally of plant origin. Approximately 12.000 compounds are present in plants and act as the defensemechanism against herbivores and some species of pathogens. Notably, the concentration of alkaloids in plants can be highly variable. Several factors, such as genetics, environment, age, climate, time of year or time of day, growth stage and wild or cultivated plants are considered capable of influencing the content and/or composition of alkaloids in plants[15].

Several alkaloids with important biological properties have already been identified in cacti. Among them is mescaline, present mainly in *Lophophora williamsii*, *Lophophoradiffusa*, *Trichocereuspachanoi*, *Trichocereusperuvianus* and *Trichocereusbridgesii*; pellotine, present in *Lophophoradiffusa*, and hordenine, present in the genera *Turbinicarpus*, *Mammillaria* and *Ariocarpus*. These alkaloids have been widely investigated due to their hallucinogenic properties, among other biological effects of interest [28].However, these species and genera are not native to Brazil, and are not cultivated in the country[1].

Other alkaloids have been identified in cacti, about 50 phenethylamines and about 80 isoquinolines, N-methyltyramine, tyramine and macromerine, which are the most commonly found in these plants [28]. In the genus Cereus, common in the Brazilian semiarid region, the most abundant alkaloids are N-methyltyramine (an adrenergic agonist), hordenine (stimulating norepinephrine) and tyramine (precursor of dopamine) (Fig.1) [15]. N-Methyltyramine has also been identified in *Turbinicarpusalonsoi*, *Obregoniadenegri* and *Lophophora williamsii*. This compound is related to its beneficial effect on treating gastrointestinal disorders [34,35].

In the species Cereus jamacaru, endemic to Brazil, with greater geographic distribution in the northeast region, hordenine, tyramine, N-methyltyramine, Tyrosine and phenethylamine have already been reported [38].

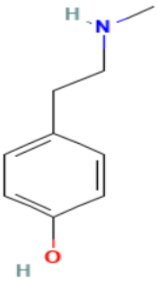
3.2 Betalains

*Betalains*are nitrogenous and water-soluble substances that belong to alkaloids consisting of betacyanins and betaxanthins and are classified as vacuolar pigments. These compounds have many applications in the food, cosmetics and pharmaceutical industries, and can be used as a natural dye, constituting an alternative to synthetic dyes [44].

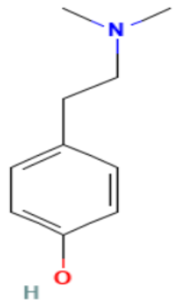
These compounds are mainly produced by the genus Opuntia, and by other genera such as *Hylocereus, Mammillaria and Schlumbergera*[31,46]. The betalain profile of *O. ficus-indica var sanguigna* was described by Melgar et al. (2017) [40] using the LC-DAD-ESI/MS technique. The authors identified seven betalain fractions, two betaxanthins (indicaxanthin isomer I, indicaxanthin isomer) and five betacyanins (Betanidin-5-O-β-sophoroside, Betanidin-5-O-β glucoside (betanin), Isobetanin, Gomphrenin I and Betanidin) (Fig.1).

Betalains were also identified in fruits of the species *Stenocereuspruinosus* and *S. stellatus* by HPLC-DAD ESI/MS, revealing the predominance of indicaxanthin, gomphrenin I, phyllocacthin and their isomers, with betaxanthin content being higher than that of betacyanins in both species [46].

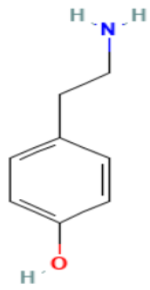
Studies demonstrate that cactus fruits have a more significant predominance of betalainsthanclododium and seeds. For example, the fruit of *Hylocereus polyrhizus*, specifically in the fruit peel, were identified as betanin, isobetanin, phyllocactin, butyrylbetanin, hylocerenin, isophyllocactin, isobutyrylbetanin, 20-apiosyl-phyllocactin and 20-apiosyl isophyllocactin[47]. In fruits of *Mammillaria spp.,* the presence of betacyanins has been described, such as: betanidin 5-O-β-sophoroside, isobetanidin 5-O-β-sophoroside, betanin, isobetanin, betanidin 5-O-(60-O-malonyl)-β sophoroside, isobetanidin 5-O-(60-O-malonyl)-β-sophoroside, betanidin 5-O-(40-Omalonyl)-β-sophoroside, isobetanidin 5-O-(40 Omalonyl)-β-sophoroside, phyllocactin, isophyllocactin, 40-O-malonyl-betanin, 40-O-malonylisobetanin, 20-O-apiosyl-phyllocactin and 20-Oapiosyl-isophyllocactin [48].



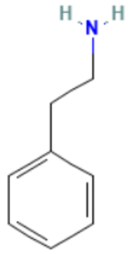
N-Methyltyramine ($C_9H_{13}NO$)



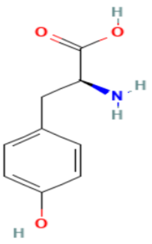
Hordenine ($C_{10}H_{15}NO$)



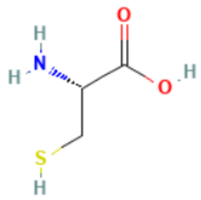
Tyramine ($C_8H_{11}NO$)



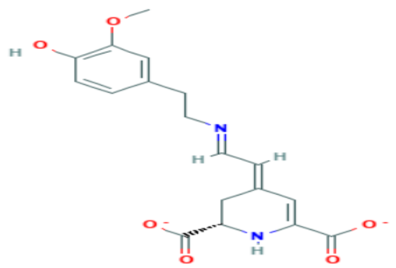
Phenethylamine ($C_8H_{11}N$)



Tyrosine ($C_9H_{11}NO_3$)



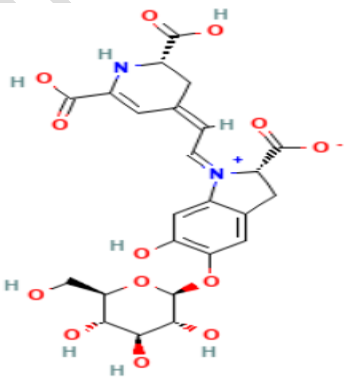
Cysteine ($C_3H_7NO_2S$)



Betaxanthin ($C_{18}H_{18}N_2O_6^{-2}$)

Betaxanthin

indicaxanthin isomer I, indicaxanthin isomer



Betacyanin ($C_{24}H_{26}N_2O_{13}$)

Betacyanin

Betanidin-5-O-β-sophoroside, Betanidin-5-O-β-glucoside (betanin), Isobetanin, Gomphrenin I e Betanidin

Fig.1: Chemical structures of the main nitrogen-containing compounds identified in the genera *Cereus* and *Opuntia*.(Images available at PubChem).

3.3 Phenolic compounds

The main phenolic compounds described in the cactus are phenolic acids, flavonoids, tannins, coumarins, lignans and stilbenes. These compounds have essential biological functions related to their chemical structure, consisting of a benzene ring with one or more hydroxyl groups [49,31,50].

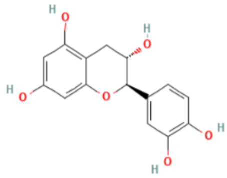
A wide variety of phenolic compounds has already been described in the genus *Opuntia*, such as catechin [31,51], chlorogenic acid [31,51], ferulic acid [31], p-coumaric acid, quercetin, and its derivatives [52], kaempferol, isorhamnetin, gallic acid [54,53], protocatechuic acid, salicylic acid, rutin [52], kaempferol-3-O-rutinoside [53] (Fig.2).*Opuntia ficus-indica* is one of the most studied species due to its metabolite profile; phenolic compounds are present in the cladode, fruits, and flowers, both in wild and cultivated species [54].

Mena et al. (2018) [50] analyzed the presence of phenolic compounds, through liquid chromatography-mass spectrometry (UHPLC-ESI-MS) in the clododium and fruit of *Opuntia ficus-indica* (L.) Mill. of different cultivars. The results showed that the highest content of phenolic compounds was identified in young cladodes, with 26 compounds, with flavonoids (in particular, flavonols) being the leading group of polyphenolics. Identifying isorhamnetin, rutin, and ferulic acid-hexoside derivatives was also possible. Regarding the peel and pulp of the fruits, 26 phenolic compounds were identified in the peel, with a predominance of phenolic acids in detriment of flavonols; in the pulp, the amount was smaller, with 21 phenolic compounds, with a ferulic acid derivative being the major representative. In the fruit peel of most cultivars, the following compounds were identified in high concentrations: ferulic acid hexoside, sinapic acid-hexoside, dihydrosinapic acid hexoside and isorhamnetin-rutinoside.

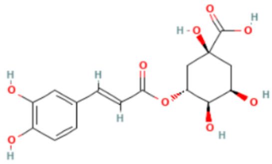
The fruits of *Pilosocereusarrabidae* were also evaluated for the composition of phenolic compounds. Gonçalves *et al.* (2015) [49] evaluated the peel and pulp of *Pilosocereusarrabidae* by HPLC-MS, identifying the presence of important flavonoids: Catechin, Dihydrokaempferol, Quercetin, Quercetin 3 or 4′-O-glucoside and Rutin, in both botanical parts (Fig.2). The high rutin content was found in the pulp of *Stenocereuspruinosus* and *S. stellatus* fruits [48], as well as in the peel of fruits of *Hylocereus undatus*[54].

The main phenolic compounds present in cactus flowers are phenolic acids and flavonoids. Ammar *et al.* (2018) [55] evaluated the flowers of *Opuntia ficus-indica* using the LC-MS/MS technique, identifying quinic acid as the main phenolic acid, followed by gallic, protocatechuic, chlorogenic, 4-O-caffeoylquinic, caffeic, p coumaric, trans ferulic and rosmarinic acids. Among the flavonoids, they identified kaempferol-3-O-rutinoside, rutin, hyperoside, 4,5-di-O-caffeoyl quinic acid, quercetin-3-Orhamoside, isorhamnetin-3-O-rutinoside, isorhamnetin, 3-O-glucoside, apegenin and kaempferol 3-O-arabinoside. It is important to note that most studies have focused on the cladode and fruit, with few studies focused on flowers.

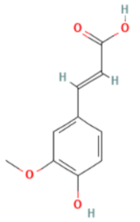
Despite the presence of polyphenols being reported mainly in *Opuntia* species, particularly in *O. ficus-indica,* in other genera such as *Hylocereus*[56]*, Pereskia*[26] and *Coryphantha*[57],the presence of these compounds is also described. Gallic, vanillic, syringic, protocatechuic, p-hydroxybenzoic, p-coumaric and caffeic acids have been described in the species *Hylocereus undatus* and *Hylocereus polyrhizus*[46,56].



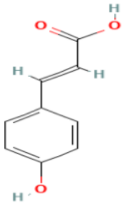
Catechin
($C_{15}H_{14}O_6$)



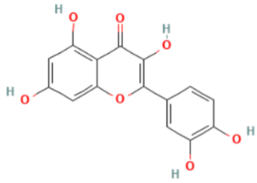
Chlorogenic acid
($C_{16}H_{18}O_9$)



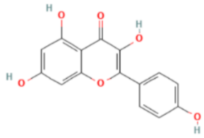
Ferulic acid
($C_{10}H_{10}O_4$)



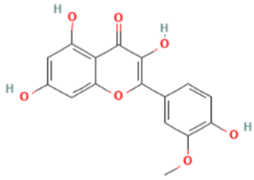
P-Coumaric acid
($C_9H_8O_3$)



Quercetin
($C_{15}H_{10}O_7$)

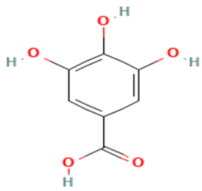


Kaempferol
($C_{15}H_{10}O_6$)

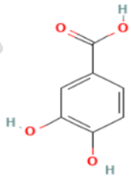


Isorhamnetin
($C_{16}H_{12}O_7$)

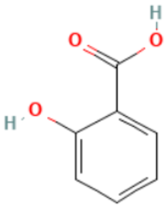
Galli
c
acid



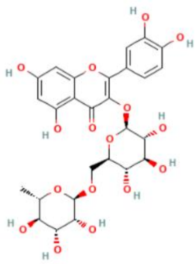
($C_7H_6O_5$)



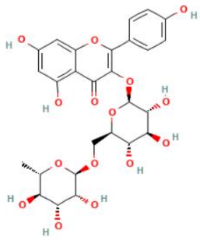
Protocatechuic acid
(3,4-Dihydroxybenzoic
acid)
($C_7H_6O_4$)



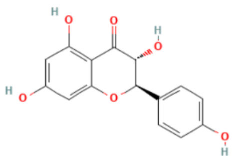
Salicylic acid
($C_7H_6O_3$)



Rutin
($C_{27}H_{30}O_{16}$)



Kaempferol-3-O-
rutinoside
($C_{27}H_{30}O_{15}$)



Dihydrokaempferol
(Aromadendrin)
($C_{15}H_{12}O_6$)

Fig.2: Chemical structures of the main polyphenols identified in the Cactaceae family, which occur in the Caatinga.(Images available at PubChem).

3.5 Terpenes

Terpenes can be defined as “natural alkenes”; they have a carbon-carbon double bond and are characterized as an unsaturated hydrocarbon. Despite having structural differences, all terpenes/terpenoids are structured in five-carbon blocks – isoprene units (C_5H_8) – usually linked together in the “head-to-tail” order (link 1-4) [15].

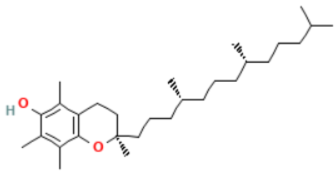
Many terpenes have already been identified in cacti - in the cladode, stem, peel, seed and fruit, especially in the genus *Opuntias*, mainly in the species *Opuntia comonduensis*[58], *Opuntia dilleniid*[50], *Opuntia ficus-indica* [31], *Opuntia humifusa*[58], *Opuntia littoralis*[32], *Opuntia macrorhiza*[60], *Opuntia polyacanta*var. arenaria[61]and *Opuntia phaeacantha*[61]. However, the presence of terpenes has also been reported in other genera, such as *Echinopsis*[58], *Hertrichocereus*[62], *Isolatocereus*[62], *Machaerocereus*[63], *Hylocereus*[56], *Pereskia*[25] and *Trichocereus*[62].

In the cladode of *Opuntia ficus-indica*, the presence of α-Tocopherol, β-tocopherol, γ-tocopherol, linoleic acid, palmitic acid, lauric acid and myristic acid (Fig.3) was identified with HPLC-UV [32,31].

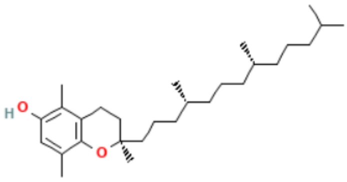
Linoleic, oleic, palmitic acids, cholesterol, campesterol, stigmasterol, and β-sitosterol have been described in *Hylocereus* seeds [56]. In the whole plant of *Isolatocereusdumortieri*, the presence of Dumortierinoside A (sapogenin), dumortierinoside A methyl ester, pachanoside I1 and pachanoside D1 was reported [62,64]. In the genus *Echinopsis*, specifically in the stem, there has already been the identification of: pachanosides C1, E1, F1 and G1 (1–4), bridgesides A1, C1, C2, D1, D2, E1, E2, 24-Methyl-cholesterol and sitosterol [58]. Bridgesigenin A and bridgesigenin B have also been described in the stem of the genus *Trichocereus*[62].

One can notice a wide variety of terpenes in Cactaceae species, as a diversity of triterpenoids, including unusual sterols, pentacyclic triterpenoids and saponins. These compounds,such as the terpenes of *Pereskia grandiflora*, have been studied for their biological activity. Sri Nurestri*et al.* (2009) [65] demonstrated that terpenes from the leaves of this species had an *in vitro* cytotoxic effect against five human carcinoma cell lines: nasopharyngeal, cervical, colon (HCT 116), hormone-dependent breast (MCF7) and lung (A549).

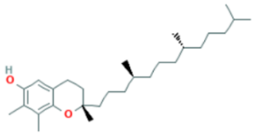
Isolatocereusdumortieri and *Stenocereusalamosensis* were also evaluated, demonstrating that triterpene saponins were related to type I antiallergic activity, detected by the inhibitory activity of the β hexosaminidase release from RBL-2H3 cells [65].



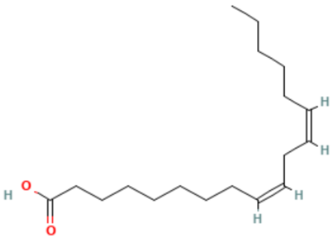
α-Tocopherol
($C_{29}H_{50}O_2$)



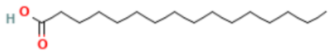
β-tocopherol
($C_{28}H_{48}O_2$)



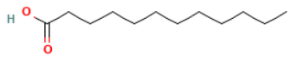
γ-tocopherol
($C_{28}H_{48}O_2$)



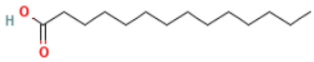
Linoleic acid
($C_{18}H_{32}O_2$)



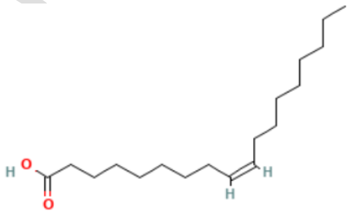
Palmitic acid
($C_{16}H_{32}O_2$)



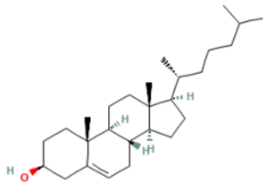
Lauric acid
($C_{12}H_{24}O_2$)



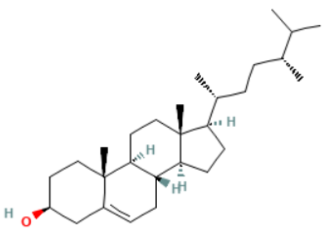
Myristic acid
($C_{14}H_{28}O_2$)

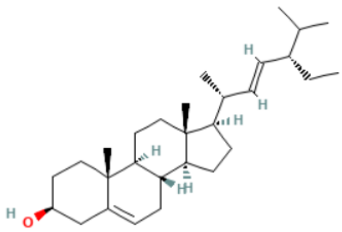


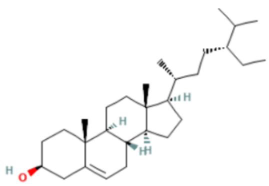
Oleic acid
($C_{18}H_{34}O_2$)



Cholesterol
($C_{27}H_{46}O$)







Campesterol ($C_{28}H_{48}O$) | Stigmasterol ($C_{29}H_{48}O$) | β-sitosterol ($C_{29}H_{50}O$)

Fig.3: Chemical structures of the main terpenes and fatty acids identified in the Cactaceae family, which occur in the Caatinga.(Images available at PubChem).

3.6 Other compounds

Besides the compounds mentioned above, other biocompounds such as saponins, carotenoids, carbohydrate polymers and unsaturated fatty acids were detected in cactus plants [64,25,66,33].

Cacti, particularly from the Cactioideae family, are rich in saponins. Kakuta*et al.* (2012) [64] isolated three triterpenoid saponins in *Isolatocereusdumortieri*Backbg, being dumortierinoside A methyl ester, pacanoside I1 and canoside D1, in addition to two more saponins isolated from *Stenocereusalamosensis*A. C. Gibson & K. E. Horak, being gummy side A and gummy methyl ester A. Other saponins such as stellatoside (sapogenin glycosides) have been identified in *Stenocereusstellatus*[67] and stellatoside B and erucasaponin A (betulinic acid glycoside) in other species of the genus *Stenocereus*[68].

The presence of carotenoids was reported mainly in the species *Pereskia aculeata* Mill and *Pereskiagrandifolia* Haw, highlighting high levels of β-carotene and α-carotene in berries of *Pereskia aculeata*, and high levels of β-carotene and xanthophylls (lutein and xanthophylls) in leaves of both species [25]. *Pereskiableo*, lutein and zeaxanthin were also identified in berries [69].

The Cactaceae family is especially rich in mucilage, with a high content of carbohydrates along with water-soluble O-glycosides (such as flavonols and saponins). Arabinogalactans-like polymers, pectin and oligosaccharides have already been described in cacti [70]. Martin *et al.* (2017) [70] evaluated the mucilage of the leaves of *Pereskia aculeata* using the GC-MS and NMR technique, revealing the presence of galactose, arabinose, rhamnose, fucose and partially esterified galacturonic acid, making it possible to characterize a type I arabinogalactan.

Studies have also reported the presence of fatty acids in cacti. Benattia *et al.* (2019) [33] analyzed the fatty acids in *Opuntia ficus-indica* seeds by GC-MS, revealing the presence of linoleic (C18:2) and oleic (C18:1) fatty acids. The presence of these fatty acids was also reported by Ciriminna et al. (2017) [66] in the seed oil of *Opuntia* *ficus-indica*, who also identified the presence of Sterols, such as b-sitosterol, Campesterol and Stigmasterol, in addition to Vitamin E (g- tocopherol).

4.0 CONCLUSION

There is much to be explored with the cacti of the Brazilian semiarid region, both with the cladodes and with the fruits and flowers. These plants have phytochemical potential for obtaining bioactive compounds of interest.

Among the cacti evaluated in this review, the genera Opuntia, Pereskia and Pilosocereus are the most studied and documented for their antioxidant capacity and biological properties. The presence of phenolic compounds, betalains and terpenes, saponins, carotenoids, carbohydrate polymers and unsaturated fatty acids, confers its effectiveness as a medicinal/functional and food plant.

The Opuntia ficus-indica species is one of the most investigated, demonstrating a promising profile of bioactive compounds, especially phenolics and Betalains. Cereus jamacaru, native to Brazil, also stands out in its a range of bioactive compounds, are related to antioxidant, antitumor and antimicrobial activities.

However, among the vast universe of cacti that occur in the caatinga biome, few species that have already been studied and documented in the literature. Many of these may also present functional properties.

Studies evaluating thisfamily's functional potential of this family can undoubtedly contribute to adding knowledge and value to the species. Because they are mainly rich in phenolic compounds and betalains, cacti have recognized antioxidant action and are related to health promotion. Thus, further scientific investigations can contribute to characterizing the plant and consequently stimulating the production and consumption of cacti as food.

Finally, the present review highlighted the variety of uses of the cactus, provided a broad view of its habitat and explored the immense phytochemical potential of these plants. Particularly notable are the bioactive compounds reported here, however, more in-depth studies, in vivo, are still needed to prove their efficacy and safety of use.

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