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# Chemical profiling of *Trichocereus* species from northern Argentina

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**Abstract.** The first nutritional profiling of all *Trichocereus* species of columnar cacti from northern Argentina is reported. Commonly called 'cardones' by locals, they are iconic elements of the flora and cultural heritage in the region. A general chemical characterization of the four species (*T. atacamensis, T. terschekii, T. tarijensis* and *T.schikendatzii*) was performed. Stem tissues for each species in terms of humidity, ash, protein content, carbohydrates, and reducing sugars, as well as phenols and anti-radical activity were profiled. The results constitute an advance in terms of general knowledge of these vulnerable and exploited Andean cacti and will contribute to ponder the most appropriate method of conservation and the possibility of bioprospecting and regulating its sustainable use.

***Keywords***: *Cacti; cardon; ethnobotany; nutrition; Puna; vitamins.*

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## Introduction

Cacti conservation is a central concern in the American continent, mainly focused on cacti communities of southwestern USA and Mexico (Oldfield, 1997). In South America, Brazil, Argentina and Bolivia are also considered mega-diverse centers with demanding conservation urgencies (Ortega-Baes and Godínez-Alvarez, 2006; Ortega-Baes *et al.,* 2010, Saint Esteven *et al*., 2021).

Columnar cacti are keystone species of arid ecosystems sustaining a great number of ecological interactions with the rest of the biota (Fleming and Valiente-Banuet, 2002; Ruiz *et al.,* 2002). In Argentina, there are about 36 genera and 200 to 300 species, 50% of which are endemic (Kiesling, 1975; Ortega-Baes *et al.,* 2015, 2010) with the highest levels of richness and endemism recorded in the western and northwestern arid ecoregions (Ortega-Baes *et al.,* 2012). Northwestern Argentina is the most diverse region and part of the second most important biodiversity hotspot of cacti worldwide: the Central Andes (Oldfield, 1997). Jujuy is the north-westernmost province of Argentina with the highest number of species (Ortega Baes *et al*., 2015) and with striking levels of endemism: less than 20% of the species present could be found in other provinces (Mourelle and Ezcurra, 1996, 1997).

Cacti radiation represents an example of morphological and metabolic adaptive evolution (e.g., leaf loss, succulent tissue development, spines and CAM metabolism, among others; Mauseth, *et al*., 2002) that has turned this group of plants into the dominant flora of most Neotropical arid environment

An important part of metabolic adaptations undergoes changes in the expression and synthesis patterns of certain compounds that fulfill different functions, such as antiherbivore or pathogen defenses, interaction with other plants, signals to pollinators, etc. (Barbehenn and Constabel, 2011; Seigler, 1998; Wink, 2003). Cacti´s complex chemistry is tightly linked to their ecological interactions and a better understanding of this trait is fundamental to the correct assessment of each species economic potential, individual health and ecological role.

Historically, humans have consumed cacti for medicinal, religious or recreational uses and the psychotropic properties of some species which are promoting research focused on the isolation and chemical characterization of those compounds of interest. Peyote (*Lophophora williamsii* Lem. Ex Salm-Dyck JM Coult.) consumption is mentioned in Spaniards records from 1790 and incorporated into the Mexican Pharmacopoeia of 1841 (Ewell, 1896). However, more general descriptions or reports of the chemical/nutritional characteristics of cacti are still scarce and scattered in the literature (Trout, 2014).

Due to their economic value, cultural importance and use history, the most studied species belong to the Opuntioideae subfamily (Carreira *et al.,* 2014; Ervin, 2012; *Inglese et al.,* 2002). In Mexico, for example, some species have been cultivated for, at least, the past 14,000 years (Casas and Barbera, 2002). Particularly, various *Opuntia* species have medicinal properties (Trejo-González *et al.,* 1996; Laurenz *et al.*, 2003; Huang *et al.*, 2008) and *Opuntia ficus-indica* (L.) is the most widespread, human-exploited species being cultivated for uses as diverse as erosion control, natural fences or as food source (Le Houérou, 1996; Feugang et *al.*, 2006; Hernández-Urbiola *et al.*, 2010, 2011). Their fruits ('tunas') are usually consumed by humans, as well as the cladodes of young maturational stages ('nopales' or 'pencas'), which are eaten in salads (Feugang *et al.,* 2006; Hernández-Urbiola *et al.*, 2010, 2011; Ervin, 2012).

Within Cereoideae, the chemistry of the stems of highly alkaloidiferous species of columnar cacti of the genus *Trichocereus*, has long been a topic of interest (Agurell, 1969a, 1969c). However, these studies have been limited to these secondary metabolites excluding other relevant chemical aspects of the plants. *T. terschekii* has received special attention due to its high concentration of alkaloids (between 0.25-1.2% dry weight) and was the first case where mescaline was reported in a species other than *Lophophora williamsii* (Reti and Castrillón, 1951, Corio *et al*., 2013). Padró and Soto (2013) expanded the chemical description of this species by studying its nutritional properties. The results indicate that *T. terscheckii* has a high content of water and dry samples have a high proportion of non-digestible fiber, high values of sugar proteins, and a profile of fatty acids represented mostly by α-linolenic acid (29.2%), linoleic (23.1%) and palmitic (19.6%). Interestingly, it also included cis-vaccenic acid, a rare isomer of oleic acid representing nearly a 7% of the fatty acids present (Padró and Soto, 2013). Given the fact that humans regularly exploit columnar species, expanding knowledge of the chemical composition of more species is necessary and have to be improved on those properties that have favored certain uses (including their consumption).

In the eastern valleys of Jujuy there are three large species with columnar habit belonging to the *Trichocereus* genus: *T. atacamensis* (Phil.) W.T. Marshall & T.M. Bock, *T. terschekii* (Parm. ex Pfeiff.) Britton & Rose and *T. tarijensis* (Vaupel) Werderm. (Figure 1). They are iconic elements of the flora in the Puna and Prepuna and are commonly called 'cardones' by locals. Another species *T. schickendantzii* (F.A.C. Weber) Britton & Rose is also registered as small 'cardon' by inhabitants (Barbarich and Suárez, 2018). The 'cardón' or 'pasacana' (*T. atacamensis*; Figure 1a) is abundant in the biogeographic province of Prepuna and it is typical of the Andean region. Along their


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distribution they are accompanied by the 'little cardon' (*T. tarijensis*; Figure 1b), very similar but with red flowers, and several other cacti belonging to *Opuntia*, *Cylindropuntia*, *Tephrocactus*, *Parodia* and *Lobivia* genera. On slopes and by the side of streams that exceed 4,000 meters above sea level in the Puna area, it is also possible to find *T. atacamensis* (Cabrera, 1976). Further south, in the area of the Chaqueño domain in Jujuy, the 'cardonals' are exclusively formed by *T. terscheckii* specimens (Cabrera, 1976; Figure 1c).

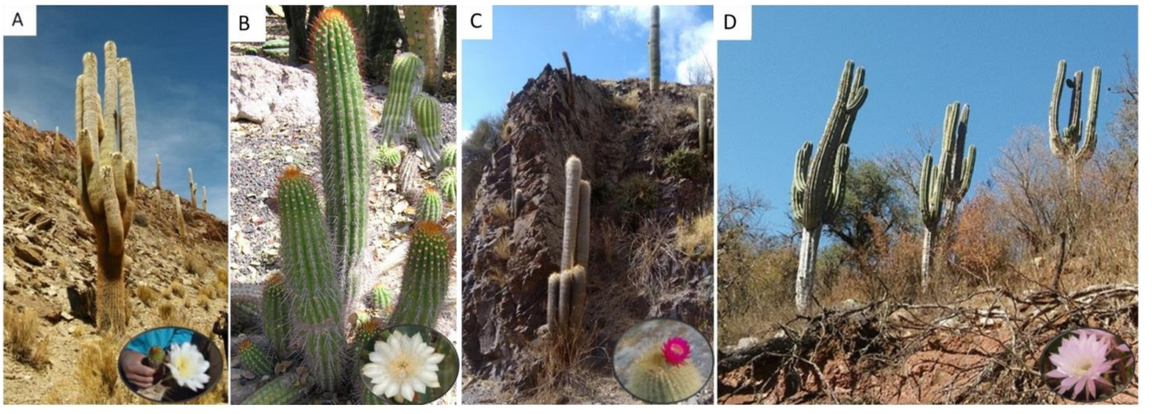


**Figure 1.** *Trichocereus* species in Jujuy Province, Argentina: **a)** *T. atacamensis*, **b)** *T. schickendantzii*, **c)** *T. tarijensis* and **d)** *T. terschekii*. Flowers detailed in the insets. Photos: Florencia Barbarich.

These species provide essential ecological services like food source, shelter or shade for other animal species (Bustamante and Burquez, 2005). Other uses have been reported as forage, construction materials and as ornamental plants; and in many places its excessive use has caused their population to decline exposing other species to risk (Casas, 2002; Esquivel, 2004; Fuentes, 2005; Kiesling, 2001; Ortega-Baes *et al.*, 2010). Besides the economic-utilitarian perspective, cacti are also fundamental for local people as central symbolic and cultural elements (Barbarich and Suárez, 2018). Lately, residents are reporting that the health status of *T. atacamensis* is worrisome and warn about different symptoms associated with contamination or environmental degradation (Barbarich and Suárez, 2018, Barbarich *et al.*, 2021). These type of cacti have been shown to have a limited growth and renewal density, mainly associated with regional temperatures (both frost-free days and average temperature) (Barthlott and Hunt, 1993; Hunt, Taylor and Charles, 2006) making them particularly vulnerable to massive pest infestation or high levels of exploitation (Barbarich and Suárez, 2018, Barbarich *et al.*, 2021).

All in all, a deeper knowledge of these species is needed in order to take appropriate conservation measures, as these are species of great ecological value, but also respectful of human-plant ties, as they are also of cultural relevance to the communities that relate to them, occupying a fundamental role in their economy, cosmogony and conception of nature.

Here the first nutritional profiling on *Trichocereus* species of northern Argentina is reported. General chemical characterization of the species was performed, in order to collect basic information about the nutritional-toxicological properties of their stems, their composition, as well as certain physiological characteristics was performed.

## Methodology

Plants samples of aerial parts (stem) of cacti were collected in the sites showed in Figure 2 in summer and winter months. For each species, 5 stems from different adult cacti were sampled. Given that these are highly valuable species, protected by law, (specially *T. atacamensis*), it was decided to reduce the number of individuals sampled as much as possible. Specimen removal for this experiment was approved by the Environment Ministry of Jujuy Province (Res. Nº 106/2015-DPB, Nº 044/2016-S-B and Nº091/2017-S-B). Samples were transported refrigerated to the laboratory where spines were removed. Fresh material was used to establish pH and then totally dehydrated (using a lyophilizer AdVantage Pro Freeze Dryer de SP Scientifics) and ground to dust, the dry material was preserved without moisture or sun exposure until use.

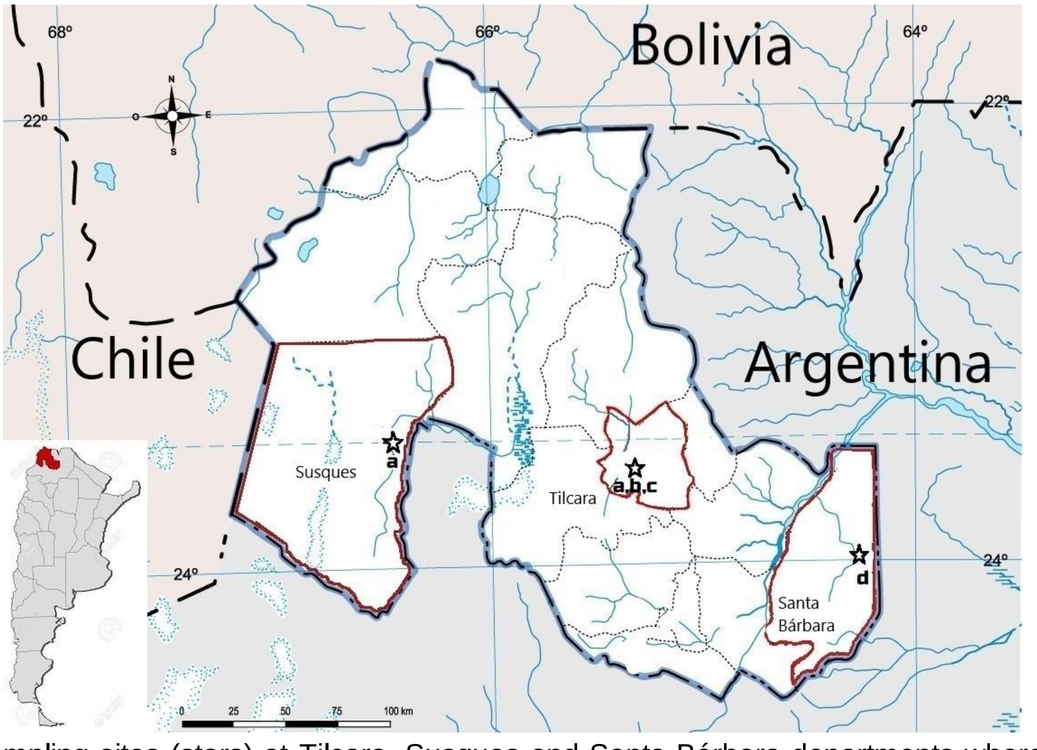


**Figure 2**. Sampling sites (stars) at Tilcara, Susques and Santa Bárbara departments where the studied species were collected: **(a)** *T. atacamensis*, **(b)***T. schickendantzii*, **(c)** *T. tarijensis,* and **(d)***T. terschekii*.

### *Chemical profiling*

Analytic essays were conducted following AOAC (Association of Official Analytical Chemists) standards. AOAC 'Official Methods of Analysis' have been defined by regulations promulgated for enforcement of the Food, Drug, and Cosmetic Act (21 CFR 2.19), recognized in Title 9 of the USDA-FSIS Code of Federal Regulations, and in some cases by the U.S. Environmental Protection Agency.

Water content (moisture) was determined by dehydrating the samples through the lyophilization process, recording the initial and final weight after two complete cycles until constant weight was reached. Lyophilization required cutting each sample into cubes of approximately 1 cm per side. Then, they were freeze-dried using an SP Scientifics AdVantage Pro Freeze Dryer. Lyophilization cycle was started at -40 °C until equilibrating with sample´s internal temperature. The condenser was set at a temperature of -70 °C. During sublimation, vacuum was applied (60 mTorr) and temperature was increased to 10 °C until thermal equilibrium was achieved. This procedure was repeated rising 10 °C in each cycle until the sample temperature reached 40 °C, the total running time was 32 hours.

Ash content was obtained by charring the samples 1 hour at 70 °C and a subsequent burning of 3 h, until the disappearance of white fumes and the observation of the presence of white ash.

From 100 g of fresh material proteins, carbohydrates and reducing sugars estimations were performed (García-Carreño, 1993). The amount of water naturally occurring in succulents facilitated the formation of homogenate when subjected to the action of a mixer. Afterwards, the homogenate was filtered using a double gauze. Extracts were centrifuged at 4000 rpm in a refrigerated ultracentrifuge at 4 °C for 15 min; the supernatant was retained and used for the analyses. Samples were analyzed thrice.

Total protein content was estimated by total nitrogen using the Kjeldahl method of digestion with concentrated sulfuric acid, using a mixture of potassium sulfate and selenium as catalyst (Bradstreet, 1954). The nitrogen formed was distilled in an alkaline medium with steam. The ammonia released was titrated with 0.1 N sulfuric acid. The conversion factor of total nitrogen to vegetal proteins was 6.25 according to the specie´s characteristics.

Carbohydrates determination was performed by using the phenol-sulfuric method, dehydrating saccharides derived from hydrolyzates to furfural (Dubois *et al.*, 1956). Furfural derivatives were detected by illuminating with a wavelength of 490 nm. Sucrose was used to construct the calibration curve.

Reducing sugars were analyzed using the Somogyi-Nelson technique (Nelson, 1944), illuminating with a wavelength of 540 nm and using glucose for the calibration curve.

Methanol extracts were prepared under low exposure to light and used for phenols and reducing compounds (antioxidants) determination. Three replicates of each sample were extracted and subsequently filtered and evaporated in a vacuum to record the total solids. They were then resuspended in methanol for analysis. Total phenolic compounds were determined by the Folin-Cicalteau method, providing colored derivatives capable of being determined spectrophotometrically at 765 nm, using gallic acid for the calibration curve.

Antioxidant capacity was determined by DPPH free radical method, detecting reduction of the 2,2-Diphenyl-1-picrylhydrazyl reagent (Sigma Aldrich) against an antiradical observed as loss of signal at 515 nm, the results are expressed as a percentage compared with the control signal. Measurements were made on a multichannel spectrophotometer with an automatic program, taking measurements every 1 minute for one hour and using a gallic acid calibration curve.

Vitamins B1 and B2 extraction was performed using Tang, Cronin, and Brunton protocol (2006). An acid hydrolysis was performed and subsequently neutralized. An enzymatic hydrolysis continued with commercial enzymes takadiastase and papain (Sigma Aldrich). Vitamin B1 determination required a derivatization with potassium ferriocyanide and extraction with isobutanol.
Quantification was performed on HPLC (C18 column: 150 x 4.6 mm; Kromasil 100-5C18) Mobile phase for vitamin B2: MeOH: H20 (40:60); Flow: 0.8 mL min$^{-1}$ (running time 10 min). Excitation: 450nm; Emission: 510nm.
Mobile phase for vitamin B1: MeOH: H2O (80:20); Flow: 0.8 mL min$^{-1}$ (running time 10 min) Excitation: 366nm; Emission: 434nm.

Beta-carotenes were determined according to Official Standard AOAC 970.64, by means of extraction with hexane:acetone:ethanol:toluene followed by saponification with KOH, separated by chromatography on a column of silica and diatomaceous earth, eluting with hexane:acetone.


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Measurement was carried out on a spectrophotometer at 450 nm. Commercial 1-Phenylazo-2-naphthol, SolventYellow 14 (Sudan I) was used as the standard.

The tocopherols analysis protocol included an initial saponification with KOH, followed by five extractions with ethyl-ether and a subsequent neutralization. The extract was evaporated and re-dissolved in hexane. Quantification was performed on normal phase HPLC, with a fluorescence detector.

Determinations of neutral and acid fiber, and lignin in acid detergent with sulfuric acid were performed in duplicate, using the technology and protocols of the manufacturer of the ANKOM200/220 fiber analyzer digester (Ankom 158 Technol. Corp., Fairport, NY, USA). In all cases, the sample was originally dry, milled and homogeneous.

## Results and Discussion

The chemical and nutritional profiles of *T. atacamensis, T. schickentdantzii, T. tarijensis* and *T. terschekii* in northern Argentina were characterized. Given the lack of previous information, these results constitute significant contributions to the specie knowledge and can be related to the recent ethnobiological reports of the species (Barbarich and Suárez, 2018, Barbarich *et al.*, 2021). Table 1 reports pH, percentage of humidity, ash, protein content, carbohydrates and reducing sugars, as well as phenols and anti-radical activity for each species.

**Table 1.** Profiling of *T. atacamensis, T. tarijensis T. terschekii* and *T. schickendatzii* samples*.* pH, humidity percentage at dry basis (H) and ash percentage (standard error)/ 100 g fresh tissue. Total nitrogen proteins (P) / 1ml homogenate, Carbohydrates (CH) / 1ml homogenate, reducing sugars (RS) /100 g dry basis, fenols expressed as galic acid gr /100 g dry tissue and antiradical activity (ARA%) / 100 g dry tissue. Fiber determinations were conducted to establish the neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin in acid detergent (LAD) each 100 g of dry weigh.

| Species | Season | pH | H % | Ash % | P | CH g/ml | RS g/ml | Fenols | ARA % | Fiber % | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | NDF | ADF | LAD |
| *T. atacamensis* | Summer | 6.00 ± 0.03 | 97.58 | 0.76±0.02 | 2.81 | 0.48 | 0.73 | 2.629 | 78.93±5.21 | 37.72 | 19.12 | 2.15 |
| | Winter | | 93.54 | 1.21±0.21 | (0.81 g/kg) | 0.47 | 0.88 | 3.028 | 75.04±6.21 | | | |
| *T. tarijensis* | Summer | 5.30 ± 0.03 | 96.80 | 0.70±0.08 | 0.82 | 0.59 | 0.88 | 6.473 | 78.6±0.94 | 48.18 | 22.88 | 5.30 |
| | Winter | | 91.28 | 1.89±0.43 | (0.25 g/kg) | 0.48 | 0.87 | 7.313 | 83.82±0.18 | | | |
| *T. terscheckii* | Summer | 5.00 ± 0.02 | 93.54 | 0.96±0.03 | 2.02 | 0.82 | 0.82 | 1.775 | 80.6±2.11 | 62.41 | 14.97 | 0.85 |
| | Winter | | 93.25 | 0.87±0.39 | (0.67 g/kg) | 0.85 | 0.81 | 1.278 | 83.26±1.41 | | | |
| *T. schickendantzii* | Summer | 4.30 ± 0.04 | 89.63 | 0.97±0.14 | 0.93 | 0.66 | 0.56 | 0.799 | 33.67±3.04 | 84.86 | 6.14 | 0.13 |
| | Winter | | 90,43 | 0,95±0,14 | (0.33 g/kg) | 1,12 | 0,75 | 0,345 | 10,78±1,10 | | | |

The samples of *T. atacamensis* presented a pH close to neutral; the percentage of humidity exceeds 97% in summer, being the species with the highest percentage of water, consistent with the role as a water reserve reported by Barbarich and Suarez (2018). It presented a high percentage of ash (31% expressed at dry weight), and it is the species under study that presented the highest total nitrogen content (related to proteins content) and a high percentage of anti-radical activity. These values could be important in the study of host-species interactions related to the health status. *T. terschekii* presents an intermediate pH (5) for the species under study, value consistent with that reported by Padró and Soto (2013). Regarding the percentage of humidity, the values were slightly lower than those reported by Reti and Castrillon (1951) of 95.4%, which may be given by the environmental characteristics of each collection site. The percentage of ashes was lower than that reported in other species, varying between 13-14% in dry samples. The proteins content reached the highest values, below *T. atacamensis*. This result could be related to the choice of these species for human consumption reported by Barbarich and Suárez (2018). With some extreme values, *T. schickendantzii* has a slightly acidic pH (pH = 4.5) and the lowest values for the percentage of ash, lower than those reported in other species of cacti and the lowest values of antiradical activity. At the other extreme, this same species has the highest concentration of carbohydrates. This result was also evident in the laboratory, since this sample was the one that formed more compact mucilage when homogenized. This characteristic could be of special relevance in the selection of cactus mucilage for the plastering of local constructions (Rivet and Barada, 2018; Veliz, 2018). The samples of *T. tarijensis* present an intermediate pH, close to that of *T. atacamensis*, the percentage of humidity is the most variable in the species under study, and the percentage of ash in dry matter was among the lowest values: 21.5%. Something similar occurs with protein and carbohydrate values, which are low for this species. The opposite occurs for the records of radical activity, where this species stands out against the others analyzed. The humidity, ash and pH results for the species show variations as expected. The pH ranges from 4.30 to 6.00. The pH values initially recorded in the field presented a consistent color for all species at a value around 5, particularly. *T. schickendantzii* was between 4-5. The maximum differences between the pH values are represented by *T. atacamensis* (with 6) and *T. schickendantzii* (with 4.30). The percentage of humidity resulted in high values, as in the rest of the cacti that reach values of up to almost 95% (Padró *et al.*, 2008; Sánchez Herrera *et al.*, 2011), which is consistent with the ability to accumulate water in extremely dry environments. A slightly higher percentage is observed for all species at the end of summer, with more marked variations for the species: *T. atacamensis* (93 to 97%) and *T. tarijensis* (91 to 97%). The accumulation in summer is consistent with being the rainy season, it has even been reported that due to the accumulation of water the diameter increases in this season (Halloy, 2008).

Ash content for each of the samples showed variations between species and between seasons in the case of *T. atacamensis* and *T. tarijensis*. The greatest amount of ash (with high percentages) is evident at the end of winter. These results could be explained by the fact that sampling season has been atypical rainy, leaving more minerals available, since they were not expected because ash is a stable parameter. The possibility that some of the samples may have had a significant contribution due to being in hypermineralized soil cannot be ruled out either. When calculating the percentage of ash in dry matter, this effect is reversed for *T. tarijensis*, but not for *T. atacamensis*, which makes us orient ourselves towards the local effect factor. In relation to the values reported in the bibliography for *Opuntia spp*. species, where ash contents of 18% are considered high, it can be affirmed that comparatively all species contain high ash contents.

Protein, carbohydrate and reducing sugar content was calculated based on a cactus homogenate that was processed with the sample water itself. In this way, the data expressed indicates aspects of the nutritional quality of the fresh sample. Protein contents are higher in *T. atacamensis* and *T. terschekii*, both species that according to Barbarich and Suárez (2018) local inhabitants consume. Although bibliography has focused on tests of fruits and seeds of cacti and not of green tissue, in relation to that described for example for species of the genus *Coryphantha*, where the protein content was 0.63-1.56% (Sanchez-Herrera, 2011), the results of the species under study present an order of magnitude less in terms of their protein content.

There are very few reports related to the presence of carbohydrates or polysaccharides in the tissues of columnar cacti. However, they are fundamental compounds since they form three-dimensional network-like structures that are responsible for the accumulation of water (Rees, 1972) and that probably explains the behavior observed in the laboratory, where in many cases the determinations were complicated by the formation of a gel with the rehydrated samples. The results of the carbohydrate content are in the order of those reported for *Cereus peruvians* (L.) Mill. (1.6%) by Saag *et al*. (1975) the in-depth characterization of mucilage could be of interest in the cosmetics and medical industry; Saag *et al*. (1975) register two patents for the industrial use of mucilage of *Opuntia fulgida*, and many more are the traditional uses of the mucilage of cacti. As they do not have reducing ends, the polysaccharides involved in the formation of the mucilage are not detected by detection techniques for reducing sugars. Even so, this last parameter is of interest for the reports and results related to cardon consumption. The values recorded for reducing sugars vary between 0.56 to 0.88 g / 100 g of dry matter, results similar to those recorded in *Epiphyllum hookeri* with 0.45 g / 100 g of dry matter (Padrón Pereira *et al*., 2008) or to various *Opuntia* species that vary between 0.64–0.88 g / 100 g of dry matter (Stintzing and Carle, 2005).

The study of antioxidants is interesting in terms of bioprospecting compounds for medicinal purposes, as several compounds have been recognized as preventive agents of degenerative, cardiovascular and brain diseases (Ames *et al.*, 1993). Furthermore, among the various uses that have been registered in the field for the species, properties linked to stomach painkillers could be related to the presence of phenols with anti-inflammatory, hepatoprotective, antineoplasic and antimicrobial activity. The equivalents of grams of gallic acid per 100 grams of dry matter are like those obtained in juices of different fruits of *Opuntia* species, which are around 0.5-2 g / 100 g and that are considered to have a good antioxidant capacity (Chavez- Santoscoy *et al.*, 2009). The values of antiradical activity are related to the previous ones. Very high percentages of antiradical activity are found in *T. terschekii*. *T. atacamensis*, and T. *tarijensis.* These results are novel and constitute a basis to study the medicinal uses of these species, as well as to establish if there is a link between them and the nutritional ecology of organisms that consume them.

The assay for vitamins identification in *T. atacamensis*, *T. terschekii* and *T. tarijensis* (Table 2) detected thiamine, in low concentrations compared with the 1.2 mg / day recommended in the human diet in adults (Martel and Franklin, 2019). The riboflavin in each sample was found in amounts similar to those of thiamine. Regarding tocopherols, compounds that have antioxidant activity (Burton and Ingold, 1981), it was decided to study each one in detail due to the sensitivity of the available equipment. The compound delta-tocopherol was not detected in any sample, and beta is neither present in *T. atacamensis* nor in *T. terschekii*. The increased presence of alpha tocopherol may be related to its role as an antioxidant that protects polyunsaturated fatty acids from membranes (Liebler *et al.*, 1986). *T. atacamensis* has almost an order of magnitude less tocopherols than *T. tarijensis*, which could have to do strictly with genetic characteristics or with compensation of certain activities with other compounds (i.e. that supply antioxidant activity, which for this species is high). Carotenes have fundamental roles in photosynthetic membranes, both for their role as antioxidants and membrane protectors and for their ability to capture light energy and therefore intervene in the process of photosynthesis (Siefermann and Harms, 1987). The values of ß-carotenes are higher in *T. terschekii* (31.34 µg / g), which almost double those of *T. atacamensis* (11.1 µg / g) and *T. tarijensis* (16.14 µg / g). This difference could be explained by differential selective pressures on each specie´s photosynthetic pigments depending on the places where they vegetate. For instance, *T. terschekii* vegetates in valleys with lower irradiation than higher open areas and in sympatry with many brush and trees of greater height that could compete for light while the remaining two species occur in Prepuna, with higher solar incidence and no competition for light. The values of ß-carotenes are comparable with those described for cactus species (*Opuntia spp*.), which are around 0.35 mg / g and which are considered as healthy sources of antioxidants for the human diet (Betancourt-Domínguez *et al.,* 2006).

**Table 2**. Vitamin content in tissues from *T. atacamensis, T. tarijensis* and *T. terschekii. T. schickendatzii* sample was not analyzed (see text).

| Sample | In 100g drytissue | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Vitamins | | | | | | | |
| | | | Tocoferols (mg/100g) | | | | | B-carotenes(A Vitamin) µg/g |
| | Tiamin (mg/100g) | Rivoflavin (V. B2) mg/100g | Alfa | Beta | Gamma | Delta | Total | |
| ***T. atacamensis*** | 0,061 | 0,062 | 1,024 | ND | 0,070 | ND | 1,095 | 11,1 |
| ***T. tarijensis*** | 0,048 | 0,044 | 12,167 | 0,125 | 0,171 | ND | 12,463 | 16,14 |
| ***T. terschekii*** | 0,016 | 0,026 | 7,198 | ND | 0,201 | ND | 7,399 | 31,34 |

It is interesting to consider that the values of chemical and nutritional compounds can vary not only from the individual effect or from the site where the specimens vegetate but depending on the stage of development. Pimienta-Barrios and Nobel (1994) observed in pitaya (*Stenocereus queretaroensis* Buxb. (FAC Weber ex Mathes.) the carbohydrates reserve (accumulating in early summer) and reducing sugars (increasing in summer), among other substances, tend to vary depending on the rate of vegetative and reproductive growth. Although in all cases adult specimens with similar morphological characteristics were collected, no test was carried out to determine that they were in the same growth stage, since the calculation of the age of these columnar cacti remains a subject of more doubts than certainties in the academic field (Halloy, 2008).

The fiber component in plant characterizations is usually made more frequently to refer to the portion with no nutritional value or little digestible. Based on the results linked to 'cardon' wood use (Barbarich and Suárez, 2018; Kiesling 1978), this result provides relevant data. Fiber, as vascular elements and a poorly defined three-dimensional framework (consisting of hemicellulose, cellulose, lignins, polysaccharides and others) has a structural role in plants and is therefore the main constituent of wood. *Trichocereus atacamensis* was originally expected to have the highest proportion of fiber, due to its outstanding wood use (Kiesling, 1978). However, the opposite was observed, being the species with the least fiber content among those studied. Nevertheless, it is important to note that the fiber component is not equally constituted in each of the species. In *T. atacamensis* the proportion of lignin within the total neutral fiber is much higher than in the other species (it constitutes 5.7%), while in *T. terschekii* the percentage of lignin is 1.36%, considering lignin in wood formation gives rigidity, this could be a positive characteristic of *T. atacamensis* wood. From the total represented by the acid detergent fiber (made up mainly of cellulose and lignin), almost half of the content represents neutral detergent fiber in *T. atacamensis*, while in *T. terschekii* it is only slightly more than a fifth. *Trichocereus tarijensis* represents a proportion of acid detergent fiber also half of the total, but lignin is much less represented (11%). The fiber percentages obtained constitute less than half of those estimated for light woods (Schultz and Taylor, 1990).

Knowing the percentage of humidity in plant species is important, since it has a special role in tissue structure and flexibility, and acts as nutrient solvent and transport. Variations in humidity in the plant can occur due to factors such as soil characteristics, the rainfall regime, etc. In cacti, as in other plants in arid climates, the humidity values are usually high and this is also related to their consumption as a moisturizing potential, being able to reach more than 90% of the fresh weight. For its part, the fiber content has been studied in relation to the structure of some cacti. These values are modified increasing with the age of the individual (Nobel, 2002). The fiber content and the arrangement and growth of the secondary xylem is not only relevant for nutritional studies, but as a tool to understand the morphogenesis and characteristics of wood in cacti, which is usually typical for its holes on the main plate, product of holes generated by specialized vascular elements (Gibson, 1973). A high fiber content is expected in timber species, and the proportion of each of its components is related to the hardness and quality of the wood.

On the other hand, the ash content varies according to the available minerals, mainly due to the edaphic composition. The percentage of ash in dry material of *Opuntia* species, for example, ranges from lows of 8.63% to highs of 18.24% (Flachowsky and Yami, 1985).

Protein content has been shown to be highly variable in various *Opuntia* species that are used for animal and human food, with values ranging from 3.3 to 13.3 g / 100 g of dry matter (Matsuhiro *et al.*, 2006; McMillan *et al*., 2002; Salem *et al*., 2005). The maximum values are remarkable since the pastures considered to be of good nutritional protein quality reach values close to 19 g / 100 g of dry matter, proteins are important when considering the consumption of a plant species.

Antioxidant compounds have a high affinity for free radicals, molecules that can constitute damage to the molecular mechanisms of the cell, have toxic effects or have implications for the aging and carcinogenic processes of cells (Gercherman, 1945). Various medicinal properties make them interesting for the pharmaceutical industry, while in ecological terms they may have functions as antifungals, antimicrobials or protectors of cell membranes (Branen *et al.*, 1983; Fu *et al.*, 2010). There are vitamins that also have a strong antioxidant action, such as vitamin A, beta-carotenes and carotenoids, the latter being much more efficient. Vitamin E is also described as an important free radical scavenger (Krinsky, 1998).

The results constitute an advance in terms of general knowledge of the chemistry of columnar cacti in northern Argentina. Their relevance is enhanced by the specific need to generate scientific research about cacti in the Puna and Prepuna region of the province of Jujuy, based on the absence of academic data on chemical composition, nutritional value and deterioration aspects of these species. The deepening of chemical data in conjunction with complementary work published on the ethnobiological value of 'cardones' (Barbarich and Suarez, 2018; Barbarich and Tomasi, 2019) contribute to ponder the most appropriate methods of conservation and the possibility of regulating its sustainable use (Barbarich *et al.,* 2021). Any measure should guarantee to local inhabitants the possibility of continuing with their deep-rooted cultural practices but also generate new sustainable alternatives while refining the diagnosis, treatment and conservation of the species.

Given the fact that humans regularly exploit columnar species, expanding knowledge of the chemical composition of more species is necessary and have to be improved on those properties that have favored certain uses (including their consumption). With regard to cardones, these are species with high water content and low nutritional value in general. Our results are consistent with the results obtained on local uses in previous works that consider these properties more or less consciously. Finally, we want to highlight the need to carry out basic chemical characterizations of species of regional value for local people in order to contribute to their study by complementing disciplines or views that approach organisms from a natural, cultural and symbolic dimension.

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## Compliance with ethical standards

Not apply

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## Declaration of competing interest

The authors declare that they have no competing interests.

## Consent for publication

Not apply

## Availability of supporting data

Datasets used during the current study are available from the corresponding author on reasonable request.

## Author contribution statement (CRediT)

**Conceptualization:** María Florencia Barbarich, Ignacio M. Soto; **Data curation:** María Florencia Barbarich, Marisa E. Martínez, Laura Reñones, Ignacio M. Soto; **Formal analysis:** María Florencia Barbarich, Marisa E. Martínez, Laura Reñones, Ignacio M. Soto; **Funding acquisition:** María Florencia Barbarich, Ignacio M. Soto; **Investigation:** María Florencia Barbarich, Marisa E. Martínez, Laura Reñones, Ignacio M. Soto; **Project administration:** Ignacio M. Soto; **Resources:** Marisa E. Martínez, Laura Reñones, Ignacio M. Soto; **Supervision:** Ignacio M. Soto; **Visualization:** María Florencia Barbarich, Ignacio M. Soto; **Writing – original draft** Ignacio M. Soto; **Writing – review & editing:** María Florencia Barbarich, Marisa E. Martínez, Laura Reñones, Ignacio M. Soto

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