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ACKNOWLEDGEMENTS. We thank Dr Bakshi Ram, Director, ICAR-Sugarcane Breeding Institute (ICAR-SBI), Coimbatore for encouragement and support; late Dr P.N. Gururaja Rao (ICAR-SBI) for help with the leaf area meter; Dr K. Chandran (ICAR-SBI Research Centre, Kannur) for light microscopy work; Dr K. Gunasekaran (Tamil Nadu Agricultural University, Coimbatore) for SEM sections of leaves; and Mr O. R. Palaniswamy (ICAR-SBI) for assistance in field and laboratory work.

Received 28 April 2015; revised accepted 18 August 2015

doi: 10.18520/v109/i12/2288-2295

Minerals of cactus (*Opuntia dillenii*): cladode and fruit

Pavithra Kalegowda[1], Devendra Jagannath Haware[2], Somasundaram Rajarathnam[1] and Mysore Nanjarajurs Shashirekha[1,*]

[1]Department of Fruit and Vegetable Technology, and
[2]Department of Food Safety and Analytical Quality Control Laboratory,
Central Food Technological Research Institute (CSIR),
Mysuru 570 020, India

Cladode (modified stem) and fruit of cactus (*Opuntia dillenii*) were analysed for their mineral content, following ashing and analysis by ICP-AES and Atomic Absorption Spectroscopy (AAS). Values are expressed as mg per 100 g dry weight of the material. Cladode was analysed at three stages of growth; differences were noticed for K, Ca, Mg, P and Na, and also for Al, Ba, Cr, Mn and Pb contents. Cladode was observed to be a good source of K, Ca, Mg, Na, Fe and Zn. Toxic elements such as Cd, Cu, Cr and Ni were well within the permissible limits; Pb and As were below detection levels. The fruit was found to contain 34%, 36%, 4% and 26% of pulp, peel, seed and waste (including spines) on fresh weight basis. Pulp was found to be a good source of K, Na, Ca, Mg and Fe. Toxic elements such as Pb, As, Hg and Se were below detection levels/ within permissible limits. These values of pulp were compared with the mineral contents of fruit peel and seed. Accordingly, both cladode and fruit can be used for edible purposes as food supplements, without endanger of toxicity from the angle of mineral constitution. The scope for their possible use in food formulation is highlighted.

Keywords: Cactus, cladode, fruit, mineral content, spectroscopy.

*For correspondence. (e-mail: shashirekhamn@cftri.res.in)

IN the light of global desertification and declining water resources, *Opuntia* spp. is gaining even more importance as an effective food production system, including both vegetative and fruit parts. At present, *Opuntia* plants are grown in more than 30 countries on about 100,000 ha area[1,2]. These include Mexico, the Mediterranean (Egypt, Italy, Greece, Spain, Turkey), California, South America (Argentina, Brazil, Chile, Columbia, Peru), the Middle East (Isreal, Jordan), North Africa (Algeria, Morocco, Tunisia), South Africa and India[1,3,4]. For cladodes, mean hectare yield of 30–80 tonnes can be achieved annually[5,6]. Mexico is the only country planting cladodes for commercial use on 10,000 ha, with a total production of 600,000 tonnes per annum[7].

Cacti have a special carbondioxide fixation pathway, known as crassulacean acid metabolism (CAM), and can have a four-to five-fold greater efficiency in converting water to dry matter than even C4 plants such as maize[8]. Being water-use efficient, they should be useful in arid and semi-arid regions[9]. As a CAM plant, *Opuntia* spp. are characterized by a high water-use efficiency of 4–10 mmol CO_2 per mol H_2O compared to C3 and C4 plants with 1.0–1.5 mmol and 2–3 mmol CO_2 per mol H_2O respectively. Through succulence, the ability to store considerable quantities of water, the plant may survive despite harsh environmental conditions[10]. Furthermore, *Opuntia* exhibits the highest production rate of overground growing plants[11,12]. Interestingly, the biomass production was even found to increase in atmospheric CO_2 concentrations[2,13,14], thus counteracting the green house effect[15].

Opuntia is a large genus of succulent shrubs with over 360 species, widely grown in the warmer parts of the world. It is commonly known as prickly pear and belongs to the family Cactaceae. Many species of cactus are found growing as wild plants in arid (less than 250 mm annual precipitation) and semiarid (250–450 mm annual precipitation) regions of India. *Opuntia* plants show high ecological adaptivity and can therefore be encountered under all climatic conditions: the Mediterranean, North, Central and South Africa, North, Central and South America, the Middle East, Australia and India[15].

Opuntia dillenii (ker-gawl) Haw, commonly seen in the southern parts of India, is popularly known as pear bush, tuna, Indian fig. This plant is a spreading fleshy shrub usually growing 50–200 cm tall. The stem is much branched and consists of flattened, fleshy segments called cladodes, which are dull-green or bluish-green in colour. The leaves are reduced to tiny cylindrical spines (1.5–6 cm long)[16]. The immature fruits are green in colour but turn reddish-purple as they mature, and are fleshy, obovoid in shape. Each fruit/cladode has several tufts of glochids on its surface[17].

Opuntia cladode and fruit serve as a source of varied number of phytoconstituents, mainly composed of pectin, mucilage and minerals. The composition varies depending on the edaphic factors at the cultivation site, climate and age of the plant[18].

Because cactus pear has several uses and can grow well with low inputs even under wasteland conditions, great potential was recognized for its adoption as a commercial crop in arid regions of India[19]. Wild edible cladode and fruit are becoming increasingly important in our diet for their nutritional and pharmacological characteristics. Therefore, it is necessary to study the levels of essential elements in *Opuntia*.

Minerals are chemical elements made of metals and other inorganic compounds originated in the soil. Mineral ions are of prime importance in determining the nutritional value of fruits and vegetables. Most of the minerals in the human diet come directly from plants, such as fruits and vegetables; they are essential for body functions[20].

The objective of this work was to critically evaluate the mineral contents of cladode and fruit (at different maturity stages) of wild *Opuntia*, in order to determine the nutritional contribution to human diet.

The cladode and fruit samples were collected from various localities of Mysuru district, Karnataka, India. The fresh, ripened, purple fruits collected and were washed, peeled manually after removing the spines, then stored at –20°C for further analysis. Cladodes at different stages of growth were collected; the stages were designated as I (7–11 cm), II (12–17 cm) and III (18–30 cm) corresponding to a range of sizes and thickness of the stem base.

The samples were dried in a hot-air oven at ~55°C to residual moisture of ~5%, and the dried samples were powdered to ~1 mm particle size and stored at room temperature in pre-cleaned polyethylene bottles until analysis.

All reagents were of analytical grade; double-deionized water was used for all dilutions. MERCK standards were used for analysis.

One gram of dry sample was placed in a porcelain crucible and ashed at 450°C for 5–6 h; then the ash was dissolved in 2 ml concentrated HNO_3 (Merck) and subjected to low heat for 1 min. Then, it was cooled and filtered through Whatman No. 42 filter paper to a 50 ml volumetric flask and was made to volume with triple-distilled water. Three independent samples with two replicates were studied.

The mineral contents were determined employing atomic absorption spectrometer (AAS, Analyst & Perkin Elmer, USA) with air-acetylene burner for flame, and inductively coupled plasma atomic emission spectrometer (ICP-AES) with argon plasma.

Aliquot of the ash solution was aspirated to the instrument (AAS/ICP-AES) for the determination of metals/minerals, viz. Ca, Mg, Na, K, Al, Ba, Fe, Zn, Mn, Cu, Cr, Ni, Se, Pb, P and Cd.

Calibration of AAS was done using the working standard prepared from available metal/mineral standard solutions (1000 μg/ml, Merck, Germany). The most appropriate wavelength, hallow cathode lamp current, gas mixture flow rate, slit width and other AAS instrument parameters for metals/minerals were selected as given in the user's manual, and background correction was applied during determination of metals/minerals. Measurements were made within the linear range of working standards used for calibration[21].

Working conditions of AAS are as follows: instrument, AAS (Perkin Elmer A Analyst 700); flame temperature, 2800°C; acetylene pressure, 0.9–1.0 bar; air pressure, 4.5–5 bar; reading time, 1–10 sec and flow time, 3–4 sec.

Calibration of ICP-AES was done using the working standards prepared from available multi-element standard solution (100 mg/l, Merck, Germany). The most appropriate wavelength, argon gas flow, plasma stabilization and other ICP-AES instrument parameters for metals/minerals were selected and measurements were made within linear range of working standards used for calibration.

Working conditions of ICP-AES are as follows: Instrument, ICP-AES (ACTIVIA-M, Horiba Jobin-yvon);

Table 1. Macro mineral concentration (mg/100 g on dry weight basis) of cactus fruit

Element	Pulp	Peel	Seed
K	876.3 ± 0.0197	2120.7 ± 0.0197	295.6 ± 0.0197
Ca	17.6 ± 0.0018	26.0 ± 0.0018	29.2 ± 0.0018
Mg	9.51 ± 0.0167	14.4 ± 0.0167	16.4 ± 0.0167
Na	124.3 ± 0.0078	196.6 ± 0.0078	8.87 ± 0.0078
P	29.2 ± 0.0015	4.67 ± 0.0015	16.7 ± 0.0015

Each value is the mean of three independent samples ± standard deviation. BDL, Below detectable level.

Table 2. Micro mineral concentration (mg/100 g on dry weight basis) of cactus fruit

Element	Pulp	Peel	Seed
Fe	5.16 ± 0.0003	1.55 ± 0.0003	1.02 ± 0.0003
Zn	0.884 ± 0.0016	0.687 ± 0.0016	0.997 ± 0.0016
Cu	BDL of 0.1	BDL of 0.1	1.22 ± 0.00
Mn	1.285 ± 0.15	1.47 ± 0.01	2.65 ± 0.03
Se	BDL of 0.1	BDL of 0.1	BDL of 0.1
Al	1.16 ± 0.00	2.29 ± 0.00	2.68 ± 0.00
Ba	1.27 ± 0.01	1.695 ± 0.01	1.53 ± 0.00
Cr	BDL of 0.1	0.28 ± 0.00	0.116 ± 0.00

Each value is the mean of three independent samples ± standard deviation.

Table 3. Toxic mineral concentrations (mg/100 g on dry weight basis) of cactus fruit

Element	Pulp	Peel	Seed
Ni	0.816 ± 0.01	0.142 ± 0.00	0.162 ± 0.00
Pb	BDL of 0.1 ± 0.00	BDL of 0.1 ± 0.00	BDL of 0.1 ± 0.00
Cd	0.021 ± 0.00	0.021 ± 0.00	0.021 ± 0.00
As	BDL of 0.02 ± 0.00	BDL of 0.02 ± 0.00	BDL of 0.02 ± 0.00
Hg	BDL of 0.02 ± 0.00	BDL of 0.02 ± 0.00	BDL of 0.02 ± 0.00

Each value is the mean of three independent samples ± standard deviation.

Table 4. Macro mineral concentration (mg/100 g on dry weight basis) of three stages of cladode

Element	First stage	Second stage	Third stage
K	2945.1 ± 0.0197	2948.2 ± 0.0197	2243.4 ± 0.0197
Ca	3656.5 ± 0.0018	3382.2 ± 0.0018	2937.9 ± 0.0018
Mg	1307.7 ± 0.0167	1179.5 ± 0.0167	986.2 ± 0.0167
Na	593.8 ± 0.0078	444.3 ± 0.0078	303.5 ± 0.0078
P	16.6 ± 0.0015	11.8 ± 0.0015	15.2 ± 0.0015

Each value is the mean of three independent samples ± standard deviation.

Table 5. Micro mineral concentration (mg/100g on dry weight basis) of three stages of cladode

Element	First stage	Second stage	Third stage
Fe	4.52 ± 0.0003	4.92 ± 0.0003	2.19 ± 0.0003
Zn	1.94 ± 0.0016	1.82 ± 0.0016	1.41 ± 0.0016
Cu	5.21 ± 0.00	0.70 ± 0.00	0.45 ± 0.00
Mn	50.6 ± 0.04	54.8 ± 0.08	25.9 ± 0.03
Se	BDL of 0.1 ± 0.00	BDL of 0.1 ± 0.00	BDL of 0.1 ± 0.00
Al	5.95 ± 0.01	6.805 ± 0.01	4.735 ± 0.00
Ba	15.65 ± 0.02	20.95 ± 0.06	12.43 ± 0.01
Cr	0.48 ± 0.00	0.39 ± 0.00	0.16 ± 0.00

Each value is the mean of three independent samples ± standard deviation.

Table 6. Toxic mineral concentration (mg/100 g on dry weight basis) of three stages of cladode

Element	First stage	Second stage	Third stage
Ni	0.969	1.98	1.66
Pb	0.147	BDL of 0.1	BDL of 0.1
Cd	BDL of 0.1	BDL of 0.1	BDL of 0.1
As	BDL of 0.02	BDL of 0.02	BDL of 0.02
Hg	BDL of 0.02	BDL of 0.02	BDL of 0.02

Each value is the mean of three independent samples ± standard deviation.

Table 7. Permissible limit/RDA of trace elements

Element	Permissible limit	Reference
Pb	0.42–0.49 mg/week	24
Cd	1.5–1.75 mg/week	24
Cu	2 mg/day	25
Fe	17 mg/day	25
Zn	15 mg/day	25
Mn	2–5 mg/day	5

RDA, Recommended daily allowance.

Power, 1000–1200 W; plasma gas flow, 12–16 l/min; auxillary gas flow, 0.8 l/min; plasma burning height, 5–22 mm; reading time, 1–10 sec and flow time, 2–3 sec.

The mineral contents of cladode and fruit of *Opuntia* were determined using ICP–AES. In this study, the mineral contents of pulp, peel and seed were analysed. Among macro minerals, potassium was the main mineral followed by sodium, calcium and magnesium (Table 1). Sodium and potassium were found in low quantities in seed and high in peel.

Magnesium and calcium were found in high quantities in seed and low in pulp. Phosphorus was found in high quantities in pulp and low in peel. Among micro minerals, iron was found to be the highest followed by manganese, barium, aluminium, zinc respectively. Copper, cromium and selenium were below detectable levels (Table 2). Barium was high in peel and low in pulp. Pulp had higher content of iron compared to seed and peel. Zinc, manganese, aluminium, copper were high in seed compared to peel and pulp. The amount of toxic elements is most important because their dietary excess may be injurious to health. Toxic elements like arsenic, mercury, lead, cadmium were found below detectable levels (Table 3).

The mineral content of cladode was determined at three stages (young, intermediate and mature stages). This study indicates higher level of calcium and phosphorus in the first stage compared to matured stages followed by potassium, magnesium and sodium, which are more in the first and second stages than mature stage of cladode (Table 4). The content of potassium was especially high in comparison to sodium, which is considered to be an advantage from the nutritional point of view[22]. This is a valuable contribution of cactus to populations suffering from high blood pressure. Calcium is an essential mineral which builds and maintains healthy bones[23]. Microelements like aluminium, barium, zinc, iron, copper, cromium and manganese are found in significant amounts in all stages (Table 5). Manganese was found to be the highest, the second being barium followed by aluminium, iron, zinc, copper, chromium and selenium. All micro minerals were found to be highest in stages I and II compared to stage III.

Toxic elements like arsenic, mercury and cadmium were found below detectable levels, whereas nickel and lead was found to be slightly high (Table 6). According to FAO/WHO[24] acceptable weekly intakes of cadmium and lead for adults are 0.42–0.49 and 1.5–1.75 mg respectively. Lead and cadmium levels in fruit and cladode are very low and thus, safe for consumption (Table 7).

Mineral nutrition is an important aspect and plays a pivotal role in human life for healthy growth. Such minerals are easily available in wild edible plants. Thus it was considered worthwhile to study the mineral nutrition of wild edible plant[9].

The young tender cladode of cactus has the highest content of minerals. It is a good source of calcium, potassium, iron, magnesium and zinc. Peel and pulp of fruit are a good source of many minerals like potassium, magnesium, calcium, zinc, iron and sodium. Toxic metals were observed to be below detectable levels in both fruit and cladode. Therefore, these species are good for human diet.

Further studies on bioavailability of minerals would throw more light on mineral nutritional value of cactus cladode and fruit.

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ACKNOWLEDGEMENTS. We thank the Director, CFTRI, Mysuru for support. This study was funded by the Department of Biotechnology, Government of India, New Delhi.

Received 22 June 2015; revised accepted 7 August 2015

doi: 10.18520/v109/i12/2295-2298