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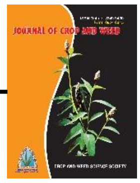

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Research Article

Morphological characters and proximate constituents in cladodes of prickly pear (*Opuntia* spp.)

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ABSTRACT

The morphological characteristics and proximate components of 23 accessions of prickly pear (Opuntia Spp.) were investigated. Variation was seen in the cladode's length, width, thickness, and weight, as well as the height and spread of plants. Cladodes were good water reservoirs and had an acidic pH. They were composed of mucilage, which possesses a great capacity for retaining water and oil. They were rich in crude fibre and total carbohydrates while low in true protein and crude fat. They were also abundant in macro-minerals, viz. calcium and potassium, and in micro-minerals like ferrous and manganese, followed by zinc and copper. There was a wide variability of various parameters amongst the Opuntia accessions. The high water content and the presence of health-promoting agents such as crude fibre, macro and micro minerals ensure the utility of this plant as a fodder and vegetable in the arid and semi-arid regions of India.

Keywords**:** Cladode, morphological characters, prickly pear and proximate constituents

The family Cactaceae comprises about 1500 extant species, of which 300 belong to the genus *Opuntia*. Only 10 to 12 species are being used for their fruit, tender leaves (cladodes), forage and cochineal or colorant production (Uzun, 1996). The species most commonly grown for commercial processing in semi-arid areas of the world is the prickly pear, *Opuntia ficus-indica* (Coria *et al*., 2011; Moussa *et al*., 2014; Diaz *et al*., 2017). The cultivation of prickly pear is just beginning in India and commercial cultivation is yet to start (BAIF, 2017). It has high water use efficiency and high temperature tolerance, making it suitable in dry land areas (Acharya *et al*., 2019). It is an inexpensive source of fruits, tender cladodes that can be used as vegetables for human consumption, and mature cladodes that can be used as animal feed (Estrada-Luna *et al*., 2008). *Opuntia* species are high in dietary fibre, protein, and minerals, which contribute to their high nutritional value. All vegetative parts of *Opuntia* including the pear, roots, cladodes, seeds and juice possess high concentration of phenolic acids, antioxidants and pigments (Diaz *et al*., 2017). *Opuntia ficus-indica* is popular as animal feed. Depending on the growth conditions, the cladodes contain a high percentage of water (>85%) by fresh weight. High levels of palatability, digestibility, water content, soluble carbohydrate, ash, calcium, potassium, and vitamin A content set it apart from other foods (BAIF, 2017). A study was conducted to characterize the prickly pear accessions based on their variation in terms of morphological traits and proximate constituents.

MATERIALS AND METHODS

The cladodes of 22 accessions of prickly pear (*Opuntia ficus indica)* were collected from the Nimbkar Agricultural Research Institute (NARI), Satara, Maharashtra, and wild cladode sample was collected from Junagadh, Gujarat in the year 2017. The list of the accessions along with relevant details is given in table 1. Secondary and tertiary cladodes of each accession (approximately 2 and half years old plant) were selected for further study. As per the protocol, fresh cladode sample or dry cladode powder was used in the experiment.

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The cladodes were washed under running tap water for removal of dirt and soil. Cladodes were cut into 1 cm^3 pieces after the spines of the spiny sample were removed with a sharp knife. These samples were used for parameters that required a fresh sample, while the rest of the samples were kept in the shadow for 24 hours before being dried in a hot air oven at 80°C for 6 hours. The completely dried samples were powdered using miller. The powder was filled into sealed plastic sachets and stored in a cool, dry place.

Table 1: List of prickly pear (*Opuntia* spp.) accessions along with their origin and characteristics

Sl. No	Accession No.	Genus/ Species	Origin	Characteristics
1.	1258	*Opuntia ficus-indica*	Algeria	Fodder, spineless and green fruit
2.	1267	*Opuntia undulate*	Algeria	Spineless, red fruit and fodder
3.	1269	*Nopalea cochenillifera*	Brazil	Vegetable, spineless and fodder
4.	1270	*Opunitia inermis (Stricta)*	Brazil	Fodder, spineless and yellow fruit
5.	1271	*Opuntia ficus-indica*	Brazil	Fruit, spineless and fodder
6.	1278	*Opuntia ficus-indica*	Mexico	Spineless and fodder
7.	1279	*Opuntia ficus-indica*	Mexico	Spineless and purple fruit
8.	1280	*Opuntia ficus-indica*	Mexico	Spineless and yellow fruit
9.	1281	*Opuntia Spp.*	Mexico	Spineless and red fruit
10.	1282	*Opuntia ficus-indica*	Mexico	Spineless and vegetable
11.	1283	*Opuntia streptacantha*	Mexico	Spiny and yellow fruit
12.	1288	*Opuntia megacantha*	Mexico	Spiny and white Fruit
13.	1292	*Opuntia megacantha*	Mexico	Spiny and Yellow fruit
14.	1294	*Opuntia ficus-indica*	Mexico	Spineless, orange fruit and vegetable
15.	1296	*Opuntia ficus-indica*	Mexico	Spineless and fodder
16.	1298	*Opuntia streptacantha*	Mexico	Spiny and fruits
17.	1300	*Opuntia ficus-indica*	Mexico	Spineless, fodder and purple fruit
18.	1301	*Opuntia ficus-indica*	Mexico	Spineless and red fruit
19.	1315	*Opuntia ficus-indica*	Chile	Spineless and fruit
20.	1320	*Opuntia ficus-indica*	Chile	Spineless and orange fruit
21.	1321	*Opuntia ficus-indica*	Chile	Spineless and light yellow fruit
22.	1326	*Opuntia ficus-indica*	Argentina	Spineless and Fodder
23.	Wild	*Opuntia elatior*	Local (Junagadh)	Small pinkish-red fruits, spiny

Morphological characteristics such as plant height, spread, cladode's width and length were measured in the field at the time of sample collection using measuring scale, while cladode thickness was measured with vernier calipers (Mendez *et al*., 2015).

The moisture content of the fresh sample was measured by the method of AOAC (2000). The pH value of the fresh sample was measured with the help of a pH meter Garcia *et al.* (2015). The ash content of dry cladode powder was measured by the method of AOAC (2000). By using the Witham *et al.* (1971) method, chlorophyll was extracted from a fresh cladode sample and the carotenoid content was also estimated using the protocol of Diaz *et al*. (2015).

The method of Bayar *et al.* (2016) was used to estimate the mucilage content and its water and oil holding capacity (WHC and OHC). For mucilage content, dry cladode powder in the ratio of 1:10 (w/v) with distilled water was stirred at 250 rpm on a rotatory shaker for 90 minutes. The solution was centrifuged at 4500 rpm for 15 minutes. In order to induce precipitation, the supernatant was transferred into a fresh centrifuge tube along with two volumes of isopropanol. On the next day, the mucilage was washed with methanol and dried at 50°C for 24 hours. The weight of the dried tube containing the mucilage was measured, and then 10 ml of water and 1 ml of vegetable oil were added respectively, to determine the mucilage's ability to hold both water and oil. For water holding capacity, the mixture was held for 1 hour at room temperature with intermittent stirring, whereas for oil holding capacity, the mixture was stirred for 5 hours. The samples were centrifuged at 5000 rpm at 4ºC for 20 minutes. Supernatants were discarded and the weight of tubes after drainage was recorded.

The true protein content was measured from the fresh cladode powder by the method of Lowry *et al.* (1951). Total carbohydrate in dry cladode powder was estimated by the phenol sulfuric acid method (Dubois *et al*., 1956). Fat content in the dry cladode powder was estimated by using a solvent with the help of a Soxtherm instrument (AOAC, 2000). Crude fibre was extracted from the defatted dry cladode powder by giving acid-alkali wash by using the crude fibre extraction unit (Maynard, 1970).

Mineral content in the dry cladode powder was extracted using di-acid mixture according to the method of AOAC (2000). Potassium (K) was measured using flame photometry, and copper

(Cu), ferrous (Fe), manganese (Mn), zinc (Zn), and calcium (Ca) were all measured using MP-AES.

All parameters were tested out in triplicate and mean values were used for analysis. The data were subjected to a one-way analysis of variance (ANOVA) in SPSS (version 20.0), and the means were compared with the DNMRT ($p< 0.05$). The parameter data distribution were represented graphically with the aid of Box and Whisker plots, where each quartile accommodates 25% of test accession (Ferreira *et al*., 2016).

RESULTS AND DISCUSSION

The morphological observations were taken for complete plant and cladode. For the majority of the morphological parameters, there was significant variation among the accessions (Table 4). Accession -1292 exhibited the highest plant height and cladode length (135.67 and 40 cm, respectively), while accession-1269 was having the lowest plant height and cladode length (51 and 20 cm, respectively). The plant spread ranged from 30.33 cm (accession-1278) to 126 cm (accession-1300). Accession 1269 had the lowest cladode weight and width (283.04 gm and 8.27 cm, respectively), while accession-1326 had the highest cladode weight and accession-1270 had the highest cladode width. Cladode thickness ranged from 1.35 (Accession-1269) cm to 3.33 (Accession-1300). Similar findings were reported by Mendez *et al*. (2015), Reyes *et al*. (2005) and Boutakiout *et al*. (2015b) while Rodriguez and Cantwell (1987) observed lower cladode length.

Proximate constituents like moisture content, pH, ash content, chlorophyll carotenoids, mucilage, true protein, total carbohydrates, crude fat, crude fibre, macro and micro minerals were analyzed (Table 5, 6, 7). Significant variation was observed amongst the accessions for these constituents.

The moisture contents ranged between 92.45 to 94.49 %. About 60 % of accessions exhibited more than 93.25% moisture content (Fig.1 A). Ayadi *et al*. (2009), Carreira *et al*. (2014), and Lopez *et al*. (2015) also reported this type of variability for moisture content. *Opuntia* plants have the CAM type of photosynthetic system, which synthesizes various organic acids, including malic, citric, and oxalic acids (Cushman and Bohnert, 1999). The pH of the cladode sap ranged from 4.48 (accession 1326) to 5.01 (accession 1258) proving its true acidic nature. The majority of the accessions had pH less than 4.80 (Fig. 1 B). This acidic nature of *Opuntia* plants was also revealed in many earlier studies (Betancourt *et al*., 2006; Alves *et al*., 2016; Garcia *et al*., 2015 and Mendez *et al*., 2015). Accessions 1315, 1301 and 1278 showed the lowest ash content (1.53, 1.72 and 1.90 % respectively), whereas accession 1282 and 1270 had the highest ash content (4.95 and 4.73 %). Overall about 56 % accessions had more than 2.60 % ash while the remaining accessions had less than 2.40 % ash (Fig. 1 C). These results were in agreement with Mendez *et al*. (2015); Carreira *et al*. (2014); Alves *et al*. (2016) and Boutakiout *et al*. (2015a) but were lower than Garcia *et al*. (2015) and Delgado *et al*. (2016).

Approximately 65 % of accessions had a chlorophyll content more than 0.240 mg g^{-1} (Fig. 1 D). It ranged from 0.193 to 0.329 mg g^{-1}, the lowest and highest chlorophyll content being exhibited by accession 1269 and 1292, respectively (Table 5). Carotenoids are considered important for the synthesis of vitamin A and their antioxidant activity (Rodriguez and Cantwell, 1987). More than 65 % of accessions had carotenoid content above 0.150 mg g^{-1} (Fig. 1 E).

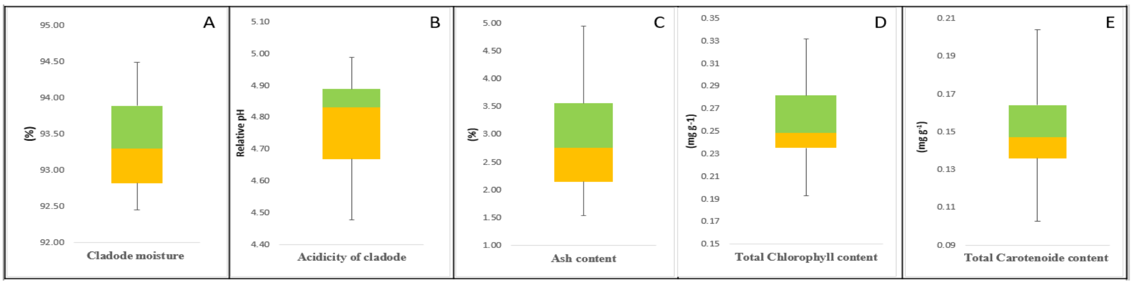

Fig 1: Box and whisker plots showing the average distribution of proximate and pigment constituents of *Opuntia* spp. cladode [Orange colour=quartile-2 (≤median value of particular data); green colour=quartile-3 (≥ median value) and the line in these two boxes= median value of data]

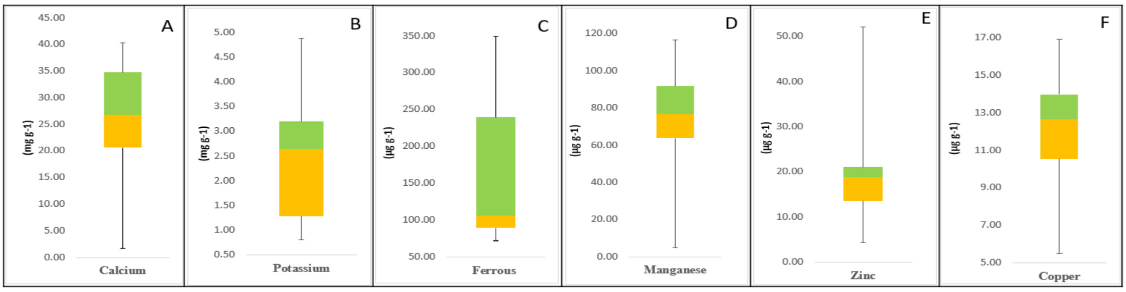

Fig 2: Box and whisker plots showing the average distribution of macro and micronutrients constituents of *Opuntia* spp. cladode

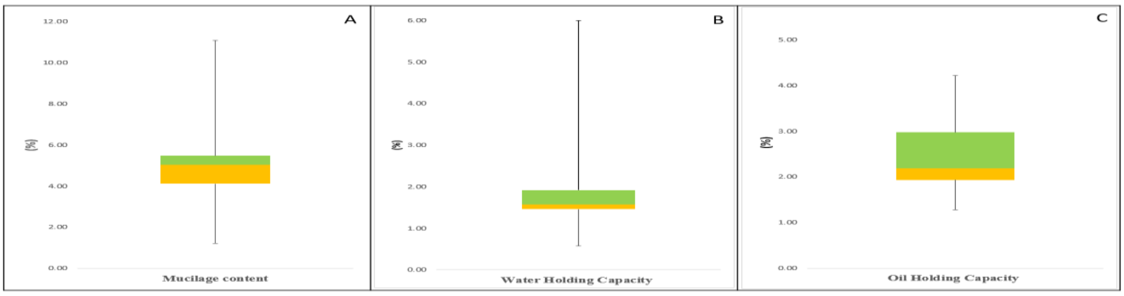

Fig 3: Box and whisker plots showing the average distribution of mucilage content, WHC and OHC in cladode of *Opuntia* spp.

Most of the accessions had 4-5% mucilage content (Fig. 3A). Mucilage content was observed highest in wild *Opuntia* cladode (11.07 %) which was at par with theAccession-1267 (9.82 %) while Accession-1321 had lowest mucilage content (1.21 %). The WHC of mucilage was highest in accession 1267 (6.01 g g^{-1}) followed by 1321 (5.18 g g^{-1}), while the lowest WHC was found in accession 1270 (0.58 g g^{-1}) (Table 6). Such variability in mucilage content and WHC was also reported by Bayar *et al.* (2016); Delgado *et al.* (2016); Valdivia *et al.* (2012) and Chaouch *et al.* (2015). The OHC values indicate that mucilage can enhance the texture of food products (Monrroy *et al.*, 2017). In the present experiment maximum OHC was found in accession 1315 (4.23 g g^{-1}) which was at par with accession 1320 (4.22 g g^{-1}), while lowest OHC was found in accession 1258 (1.27 g g^{-1}). The OHC values were higher than the earlier reports of Monrroy *et al.* (2017) and Saenz *et al.* (2004) indicating the potential of the accessions presently studied. Mucilage is mainly composed of galactose, mannose, xylose, and other sugars (Matsuhiro *et al.*, 2006) and thus, has a high capacity to bind or retain water there by finding its utilization in foods, cosmetics, and pharmaceuticals, where it can be dissolved and dispersed (Saenz, 2013). Viscous solutions are influenced by the WHC, which can speed up industrial processes (Valle *et al.*, 2005).

Wide variation was observed among the accessions for true protein content (1.16 to 3.66 mg g^{-1}), total carbohydrate (1.35-23.38 mg g^{-1}), crude fat content (1.26 to 3.67 %) and crude fibre content (18.99-26.65 %) (Table 7). About 65 % of accessions had more than 1.75 mg g^{-1} true protein and about 70 % accessions had more than 12 mg g^{-1} total carbohydrate content (Fig .4. A and B). The true protein and crude fat was highest in wild type accession and 1278 respectively, while accession-1301 and 1321 had the highest total carbohydrate and crude fibre content respectively. Alves *et al.* (2016), Jun et al. (2013) and Rocchetti *et al.* (2018) had observed the higher amount of crude protein whereas obtained crude fat content was higher than the results of Jun *et al.* (2013) and Toit *et al.* (2018) but lower than Njoku *et al.* (2017). For total carbohydrate content our results were in accordance with Garcia *et al.* (2015) but more than Ayadi *et al.* (2009) whereas Njoku *et al.* (2017) and Lopez *et al.* (2010) observed higher value than ours. The observed values of crude fibre content were in agreement with the results reported by El-Safy (2013) and Perez *et al.* (2014) while higher than Alves *et al.* (2016) and Lopez *et al.* (2010).

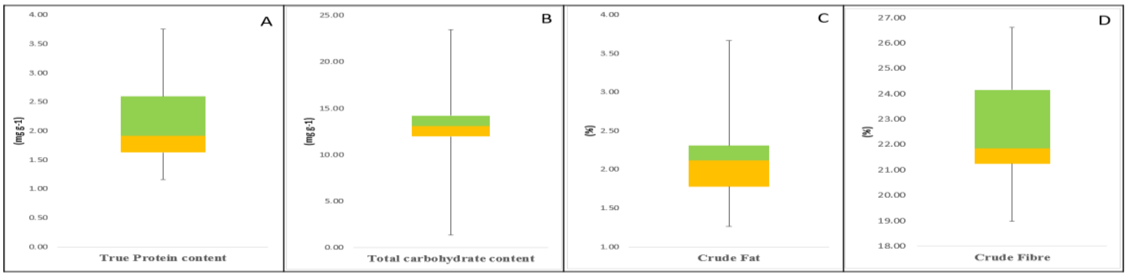

Fig. 4: Box and whisker plots showing average distribution of proximate constituents of *Opuntia* spp. cladode

Minerals play a vital role in the metabolic processes of every living organism such as cofactors in the catalytic process and maintaining ionic balance of cells. Wide variations were observed for most of the minerals among the accessions for Ca, K, Cu, Fe, Mn, and Zn (Table 8). The macro-minerals like Ca and K ranged from 1.64 to 40.32 mg g^{-1} and 0.82 to 4.88 mg g^{-1}, respectively. About 60 % and 52 % of accessions had more than 26 mg g^{-1} Ca and 2.70 mg g^{-1} K, respectively (Fig. 2). The highest content of Cu, Fe, Mn and Zn were found in accessions 1278 (16.94 µg g^{-1}), 1279 (349.27 µg g^{-1}), 1288 (116.63 µg g^{-1}) and 1267 (56.90 µg g^{-1}) respectively (Table 8). Among all accessions, 65 % accessions had more than 100 µg g^{-1} Fe while 55 % accessions had more than 70 µg g^{-1} Mn whereas 45 % and 35 % accessions had less than 18 µg g^{-1} Zn and 12 µg g^{-1} Cu respectively (Fig. 2 C, D, E and K). Alves *et al*. (2016) also found similar results; however, Hernandez *et al*. (2010) reported similar Fe and Mn content and lower levels of Ca and K. The results reported by Amadi *et al*. (2017) were lower as compared with our results.

The accessions were grouped according to the presence of spines (as spiny and spineless) and were rated according to the purpose of utility. Mean values of grouped accessions have been considered for all parameters (Table 2, 3).

Table 2: Grouping of accessions on the basis of morphology- Spiny and Spineless*

Parameter	Spiny accessions	Spineless accessions
Moisture (%)	93.22	93.44
pH	4.79	4.78
Total chlorophyll (mg g^{-1})	0.278	0.253
Total ash (%)	3.10	2.88
Mucilage content (%)	5.05	5.20
WHC (g g^{-1})	2.15	2.03
OHC (g g^{-1})	2.18	2.56
Cu (µg g^{-1})	11.85	12.55
Fe (µg g^{-1})	123.73	169.18
Mn (µg g^{-1})	81.62	74.45
Zn (µg g^{-1})	17.14	24.34
Ca (mg g^{-1})	20.64	28.44
K (mg g^{-1})	2.10	2.80
True protein (mg g^{-1})	2.32	2.11
Total carbohydrates (mg g^{-1})	12.20	13.29
Crude fat (%)	1.97	2.14
Crude fibre (%)	21.44	22.70

Note: ** mean values of each group*

Among the 23 accessions, five accessions had spiny cladodes and remaining 18 were spineless. Spiny accessions were superior to spineless with respect to protein content, chlorophyll content, WHC, and total ash. The spineless accessions had higher content of both macro and micro minerals except manganese. They also exhibited more amount of mucilage with higher OHC than spiny accessions (Table 2).

Most of the cactus growing countries grow *Opuntia* for three purposes: fruit production, fodder production, and cacti as vegetables. When rated with the purpose of utility, we could classify the accessions as spineless-fodder (nine accessions), spineless- fruits bearing (thirteen accessions), spineless- vegetable (three accessions), and spiny fruits bearing accessions (five accessions).

The moisture, pH, and mucilage content were highest in spineless fodder purpose accessions while the total chlorophyll content and WHC of mucilage were highest in spiny fruit purpose accessions. The spiny and spineless fruit purpose accessions had a good amount of true protein while spineless fruit and fodder purpose accessions had more total carbohydrates. The spineless fodder and vegetable purpose accessions had higher crude fat and spineless vegetable and fruit purpose accessions had a good amount of crude fibre content (Table 3). The spineless fodder and spineless vegetable purpose accessions had the highest minerals followed by spineless fruit purpose accessions. The least mineral content was found in spiny fruit purpose accessions.

Table 3: Variation on the basis of utility purpose of *Opuntia* accessions

Proximate Constituents	Spineless fodder	Spineless fruit	Spineless vegetable	Spiny fruits
Moisture	+ + + +	+ +	+ + +	+
pH	+ + + +	+	+ +	+ + +
Ash	+ +	+	+ + + +	+ + +
Tot. chlorophyll	+++	++	+	+ + + +
Mucilage content	+ + + +	+ +	+ + +	+
WHC	+ +	+ + +	+	+ + + +
OHC	+	+ + + +	+ + +	+ +
True protein	+ +	+ + +	+	+ + + +
Total carbohydrates	+ + +	+ + + +	+	+ +
Crude fat	+ + + +	+ +	+ + +	+
Crude fibre	+ +	+ + +	+ + + +	+
Ca	+ + + +	+ +	+ + +	+
K	+ + + +	+ + +	+ +	+
Fe	+ + + +	+ +	+ + +	+
Zn	+ + +	+ +	+ + + +	+
Mn	+	+ +	+ + + +	+ + +
Cu	+ + + +	+ +	+ + +	+

Note: *+ : least, + + : Moderately low, + + + : Moderately high, + + + + : Highest*

Table 4: Morphological observations of *Opuntia* accessions

Sl. No.	Accession No.	Plant height (cm)	Plant spread (cm)	Cladode length (cm)	Cladode width (cm)	Cladode thickness (cm)	Cladode weight (g)
1.	Wild	70.00±21.51^{abc}	74.17±10.25^{bcdef}	24.00±2.82^{abc}	20.00±4.95^{ef}	2.77±0.42^{efg}	302.97±39.5^{ab}
2.	1258	82.33±16.15^{bcde}	59.67±19.85^{abc}	31.33±6.65^{abcde}	12.00±1.73^{ab}	2.43±0.58^{cdefg}	451.87±82.7^{abc}
3.	1267	53.00±20.66^{ab}	57.67±13.05^{abc}	25.67±5.13^{abcd}	14.33±3.51^{bcde}	1.90±0.36^{abcde}	614.65±75.3^{cde}
4.	1269	51.00±13.62^{a}	44.33±13.61^{ab}	20.00±2.64^{a}	8.27±0.70^{a}	1.35±0.18^{a}	283.04±15.67^{a}
5.	1270	61.67±20.66^{ab}	92.50±17.50^{defg}	23.67±3.21^{abc}	20.67±3.21^{f}	1.60±0.36^{abc}	459.22±56.1^{abc}
6.	1271	76.33±16.26^{abcd}	58.50±18.14^{abc}	28.00±4.35^{abcde}	15.33±1.15^{bcde}	2.27±0.25^{bcdef}	729.57±76.5^{efgh}
7.	1278	60.00±21.14^{ab}	30.33±8.14^{a}	23.33±4.93^{abc}	12.67±2.08^{abc}	3.15±0.20^{fg}	546.52±82.8^{cd}
8.	1279	83.00±15.28^{bcde}	65.00±4.58^{bcd}	30.00±5.29^{abcde}	14.67±3.05^{bcde}	2.53±0.75^{defg}	806.14±50^{fgh}
9.	1280	101.00±17.28^{cdef}	76.00±10.39^{bcdef}	31.33±4.16^{abcde}	13.83±3.40^{bcde}	2.27±0.25^{bcdef}	554.40±44^{cd}
10.	1281	80.00±14.08^{abcde}	74.67±11.01^{bcdef}	21.00±2.00^{ab}	14.50±3.04^{bcde}	1.67±0.28^{abcd}	714.51±38.5^{defg}
11.	1282	83.67±23.52^{bcde}	99.66±25.64^{efgh}	26.00±8.18^{abcd}	11.67±1.15^{ab}	2.40±0.17^{cdefg}	591.93±83.1^{bc}
12.	1283	97.67±28.84^{cdef}	64.03±29.73^{bcd}	35.00±4.35^{cde}	19.00±2.64^{ef}	2.63±0.51^{efg}	771.31±48.5^{fgh}
13.	1288	108.33±13.22^{efg}	68.33±23.45^{bcde}	32.00±6.55^{abcde}	17.50±3.96^{cdef}	2.30±0.26^{bcdef}	473.87±20.9^{bc}
14.	1292	135.67±7.228^{g}	109.67±17.50^{gh}	40.00±4.35^{e}	17.67±1.52^{cdef}	3.13±0.11^{fg}	559.40±43^{cde}
15.	1294	98.33±23.76^{cdef}	83.00±18.52^{cdefg}	37.00±3.00^{de}	16.17±1.25^{bcdef}	2.67±0.72^{efg}	423.41±27.1^{abc}
16.	1296	127.00±19.03^{efg}	77.00±20.03^{bcdef}	35.33±3.78^{cde}	14.67±3.32^{bcde}	2.73±0.68^{efg}	875.58±44.7^{gh}
17.	1298	100.67±12.67^{cdef}	104.33±16.44^{fgh}	30.67±8.32^{abcde}	18.33±4.04^{def}	3.10±0.52^{fg}	411.15±18.2^{abc}
18.	1300	126.00±21.97^{efg}	126.00±27.00^{h}	34.33±3.51^{cde}	16.83±3.01^{bcdef}	3.33±0.15^{g}	685.60±43.6^{def}
19.	1301	79.33±18.30^{abcde}	46.67±9.71^{ab}	26.00±4.35^{abcd}	13.33±0.28^{bcd}	1.50±0.15^{ab}	474.70±160^{bc}
20.	1315	106.33±10.01^{defg}	74.66±23.71^{bcdef}	33.00±6.24^{bcde}	14.83±2.46^{bcde}	2.57±0.56^{defg}	479.74±60.7^{bc}
21.	1320	73.00±18.55^{abc}	53.50±20.00^{abc}	26.00±4.00^{abcd}	14.33±3.05^{bcde}	2.13±0.55^{abcde}	354.05±40.8^{ab}
22.	1321	114.67±13.72^{efg}	81.67±7.63^{cdefg}	35.33±3.78^{cde}	18.00±1.73^{def}	2.63±0.51^{efg}	454.63±55.2^{abc}
23.	1326	101.00±6.39^{cdef}	65.00±26.05^{bcd}	28.67±2.51^{abcde}	15.00±1.80^{bcde}	2.73±0.40^{efg}	903.10±14.8^{h}

Note: *The different letter(s) in each column shows values are significantly different ($P<0.05$) as evaluated by the DMRT. ± shows the standard deviation of mean values of three replicates.*

Table 5: Proximate and pigment constituents in cladode of *Opuntia* accessions (on fresh weight basis)

Sl. No.	Accession No.	Moisture (%)	pH	Ash (%) (D. Wt.)	Total chlorophyll (mg g^{-1})	Carotenoids (mg g^{-1})
1.	Wild	94.18±0.02^{egf}	4.87±0.03^{defg}	4.10±0.98^{de}	0.245±0.003^{fg}	0.147±0.001^{g}
2.	1258	94.49±0.99^{g}	5.01±0.06^{h}	2.16±0.06^{ab}	0.267±0.004^{i}	0.149±0.002^{g}
3.	1267	93.91±0.60^{cdefg}	4.94±0.06^{fgh}	3.50±0.41^{bcde}	0.292±0.001^{k}	0.142±0.002^{f}
4.	1269	93.36±0.65^{abcdefg}	4.93±0.04^{fgh}	4.05±1.32^{de}	0.193±0.06^{a}	0.103±0.001^{a}
5.	1270	93.41±0.33^{abcdefg}	4.91±0.04^{efgh}	4.73±1.55^{e}	0.231±0.002^{d}	0.142±0.003^{f}
6.	1271	92.81±0.24^{abcd}	4.86±0.11^{defg}	2.39±0.34^{abc}	0.236±0.004^{de}	0.137±0.002^{e}
7.	1278	92.83±0.35^{abcd}	4.86±0.04^{defg}	1.90±0.48^{a}	0.249±0.003^{gh}	0.147±0.003^{g}
8.	1279	93.30±0.23^{abcdef}	4.79±0.08^{de}	3.61±1.15^{bcde}	0.231±0.004^{d}	0.148±0.004^{g}
9.	1280	93.36±0.71^{abcdefg}	4.76±0.13^{cd}	3.75±1.41^{cde}	0.241±0.006^{ef}	0.126±0.001^{c}
10.	1281	93.88±0.69^{cdefg}	4.97±0.03^{gh}	2.77±0.35^{abcd}	0.249±0.002^{h}	0.149±0.002^{g}
11.	1282	94.38±0.52^{fg}	4.79±0.09^{de}	4.95±1.48^{e}	0.236±0.006^{de}	0.122±0.002^{b}
12.	1283	92.96±0.42^{abcd}	4.77±0.05^{cd}	2.38±0.63^{abc}	0.275±0.003^{j}	0.164±0.002^{h}
13.	1288	92.45±0.20^{a}	4.83±0.02^{def}	3.07±0.63^{abcd}	0.288±0.004^{k}	0.163±0.002^{h}
14.	1292	93.28±0.99^{abcdef}	4.66±0.01^{bc}	3.46±0.32^{bcde}	0.329±0.004^{n}	0.200±0.002^{m}
15.	1294	92.54±0.31^{a}	4.63±0.06^{c}	2.14±0.23^{ab}	0.215±0.004^{b}	0.135±0.002^{de}
16.	1296	93.96±0.44^{defg}	4.90±0.05^{efgh}	2.63±0.66^{abcd}	0.270±0.002^{ij}	0.164±0.002^{h}
17.	1298	93.23±0.71^{abcdef}	4.85±0.03^{defg}	2.47±0.35^{abc}	0.254±0.006^{h}	0.128±0.003^{c}
18.	1300	92.49±0.64^{a}	4.87±0.08^{defg}	2.13±0.16^{ab}	0.305±0.003^{l}	0.177±0.002^{j}
19.	1301	93.92±1.07^{cdefg}	4.68±0.04^{bc}	1.72±0.69^{a}	0.319±0.004^{m}	0.193±0.003^{l}
20.	1315	93.79±0.45^{bcdefg}	4.59±0.05^{ab}	1.53±0.08^{a}	0.234±0.005^{d}	0.141±0.001^{f}
21.	1320	92.75±0.80^{abc}	4.58±0.07^{ab}	3.09±0.66^{abcd}	0.248±0.003^{gh}	0.184±0.001^{K}
22.	1321	93.14±0.25^{abcde}	4.51±0.02^{a}	2.76±1.18^{abcd}	0.224±0.002^{c}	0.132±0.002^{d}
23.	1326	92.61±0.21^{ab}	4.48±0.02^{a}	2.11±0.07^{ab}	0.305±0.003^{l}	0.174±0.002^{i}

Table 6: Mucilage in *Opuntia* accessions and their water and oil holding capacity (on dry weight basis)

Sl. No.	Accession No.	Mucilage content (%)	Water holding capacity (g g^{-1})	Oil holding capacity (g g^{-1})
1.	Wild	11.07±0.290^{g}	0.82±0.099^{abc}	2.29±0.064^{bcd}
2.	1258	5.32±0.087^{cdef}	1.46±0.237^{cd}	1.27±0.075^{a}
3.	1267	9.82±3.089^{g}	6.01±0.532^{i}	1.38±0.193^{ab}
4.	1269	4.79±0.200^{bcdef}	3.14±0.513^{f}	2.17±0.594^{abcd}
5.	1270	5.40±0.598^{cdef}	0.58±0.235^{a}	1.97±0.506^{abcd}
6.	1271	6.26±0.664^{ef}	0.75±0.588^{ab}	1.88±0.381^{abcd}
7.	1278	5.05±1.281^{bcdef}	1.76±0.318^{de}	1.78±0.387^{abcd}
8.	1279	4.94±1.360^{bcdef}	1.93±0.907^{de}	3.24±0.305^{efg}
9.	1280	4.45±0.104^{bcde}	1.80±0.237^{de}	1.93±0.021^{abcd}
10.	1281	3.36±0.695^{bc}	1.91±0.151^{de}	2.37±0.210^{cde}
11.	1282	6.71±1.064^{f}	1.25±0.172^{bcd}	3.62±1.757^{gh}
12.	1283	3.05±0.686^{b}	2.42±0.497^{e}	1.93±0.478^{abcd}
13.	1288	3.78±0.283^{bcd}	4.43±0.265^{g}	2.12±0.147^{abcd}
14.	1292	3.72±0.436^{bcd}	1.58±0.611^{d}	2.19±0.502^{abcd}
15.	1294	4.85±0.476^{bcdef}	1.47±0.121^{cd}	1.49±0.326^{abc}
16.	1296	5.10±0.516^{bcdef}	1.59±0.021^{d}	2.03±0.090^{abcd}
17.	1298	3.63±1.403^{bcd}	1.52±0.240^{d}	2.37±0.145^{cde}
18.	1300	5.38±0.421^{cdef}	1.67±0.291^{d}	2.29±0.472^{bcd}
19.	1301	4.56±0.955^{bcdef}	1.43±0.177^{cd}	4.02±0.273^{gh}
20.	1315	5.18±2.133^{bcdef}	1.53±0.061^{d}	4.23±0.081^{h}
21.	1320	5.71±0.641^{def}	1.53±0.420^{d}	4.22±0.191^{h}
22.	1321	1.21±0.196^{a}	5.18±0.426^{h}	3.42±0.485^{fgh}
23.	1326	5.57±1.646^{cdef}	1.47±0.090^{cd}	2.72±0.640^{def}

Note: *The different letter(s) in each column shows values are significantly different ($P<0.05$) as evaluated by the DMRT. ± shows the standard deviation of mean values of three replicates.*

Table 7: Proximate constituents in cladode of *Opuntia* accessions

Sl. No.	Accession No.	True protein (mg g^{-1}) (F. Wt.)	Total carbohydrates (mg g^{-1}) (D. Wt.)	Crude fat (%) (D. Wt.)	Crude fibre (%) (D. Wt.)
1.	Wild	3.66±0.205^{l}	14.68±1.464^{mn}	1.66±0.007^{abc}	21.82±0.262^{bcd}
2.	1258	2.38±0.120^{g}	12.57±0.392^{fghi}	2.18±0.435^{bcdef}	20.90±2.090^{abc}
3.	1267	1.54±0.025^{c}	22.00±0.081^{o}	1.26±0.026^{a}	20.90±3.477^{abc}
4.	1269	1.77±0.031^{d}	15.58±0.455^{n}	2.06±0.655^{bcdef}	24.58±1.965^{efg}
5.	1270	2.40±0.029^{g}	12.87±0.420^{fghij}	1.75±0.100^{abcd}	19.28±2.044^{ab}
6.	1271	1.54±0.026^{c}	1.35±0.172^{a}	2.02±0.211^{bcdef}	24.13±1.825^{defg}
7.	1278	1.75±0.059^{d}	13.69±0.135^{ijklm}	3.67±1.056^{g}	20.31±1.072^{abc}
8.	1279	3.29±0.075^{k}	14.27±1.160^{lm}	2.12±0.572^{bcdef}	24.62±0.660^{efg}
9.	1280	1.71±0.040^{d}	14.080.146^{klm}	1.62±0.025^{ab}	19.14±0.550^{ab}
10.	1281	1.16±0.052^{a}	12.07±0.697^{efg}	2.31±0.105^{def}	23.91±0.525^{def}
11.	1282	1.92±0.045^{e}	6.63±0.310^{b}	1.99±0.020^{bcdef}	24.19±0.280^{defg}
12.	1283	2.34±0.053^{g}	13.35±0.546^{hijkl}	1.60±0.085^{ab}	18.99±0.178^{a}
13.	1288	1.73±0.055^{d}	9.96±0.349^{c}	2.31±0.045^{def}	23.00±0.820^{cdef}
14.	1292	2.11±0.038^{f}	12.41±0.142^{fgh}	2.23±0.105^{cdef}	21.59±0.293^{abcd}
15.	1294	1.18±0.064^{a}	14.04±0.070^{jklm}	2.31±0.070^{def}	22.69±0.461^{cdef}
16.	1296	1.39±0.085^{b}	11.24±1.344^{de}	2.44±0.225^{f}	21.75±0.223^{bcd}
17.	1298	1.78±0.040^{d}	13.10±1.038^{ghijkl}	2.07±0.055^{bcdef}	21.78±0.248^{bcd}
18.	1300	1.22±0.075^{a}	11.88±0.140^{ef}	2.24±0.360^{cdef}	22.15±0.105^{cde}
19.	1301	3.41±0.093^{k}	23.38±1.164^{p}	2.29±0.110^{def}	21.63±0.246^{abcd}
20.	1315	3.31±0.091^{k}	13.01±0.764^{fghijk}	2.34±0.010^{def}	21.85±0.217^{bcd}
21.	1320	2.66±0.023^{i}	16.72±0.299^{n}	2.40±0.135^{ef}	25.36±0.330^{fg}
22.	1321	2.82±0.076^{j}	10.37±0.460^{cd}	1.81±0.009^{abcde}	26.65±0.256^{g}
23.	1326	2.53±0.076^{h}	14.15±0.669^{klm}	1.73±0.030^{abcd}	24.53±0.126^{efg}

Table 8: Macro and micro minerals in cladode of *Opuntia* accessions (on dry weight basis)

Sl. No.	Accession No.	Cu (μg g^{-1})	Fe (μg g^{-1})	Mn (μg g^{-1})	Zn (μg g^{-1})	Ca (mg g^{-1})	K (mg g^{-1})
1.	**Wild**	15.08±0.078^{o}	251.66±1.499^{p}	83.72±0.035^{fg}	24.85±0.021^{l}	39.51±0.049^{r}	4.83±0.042^{s}
2.	**1258**	5.52±0.127^{a}	268.39±0.259^{r}	4.74±0.299^{a}	4.35±0.067^{a}	40.32±0.408^{s}	4.30±0.076^{q}
3.	**1267**	12.66±0.494^{h}	256.46±1.220^{q}	108.38±0.145^{j}	56.90±0.959^{q}	21.72±0.444^{g}	4.53±0.053^{r}
4.	**1269**	9.88±0.091^{d}	337.98±0.359^{s}	96.72±0.860^{ij}	55.23±0.510^{p}	32.55±0.287^{k}	2.26±0.090^{h}
5.	**1270**	14.34±0.121^{m}	243.85±0.578^{o}	63.82±0.489^{c}	52.21±0.276^{o}	35.09±0.707^{o}	2.48±0.006^{i}
6.	**1271**	13.67±0.142^{jk}	159.13±0.609^{k}	76.69±0.340^{e}	10.63±0.371^{b}	33.93±0.015^{m}	3.26±0.047^{n}
7.	**1278**	16.94±0.171^{q}	210.45±1.013^{m}	91.72±0.204^{hi}	29.08±0.419^{m}	26.81±0.180^{i}	4.88±0.021^{s}
8.	**1279**	14.00±0.160^{l}	349.27±2.021^{t}	95.70±0.993^{ij}	18.80±0.206^{i}	26.66±0.350^{i}	3.47±0.010^{o}
9.	**1280**	8.70±0.146^{c}	235.56±1.328^{n}	55.42±0.217^{b}	14.97±0.320^{f}	13.69±0.066^{c}	4.15±0.032^{p}
10.	**1281**	16.04±0.282^{p}	166.30±0.556^{l}	65.52±0.568^{c}	42.78±0.635^{n}	31.86±0.195^{j}	3.47±0.021^{o}
11.	**1282**	16.03±0.176^{p}	101.30±0.159^{h}	93.00±0.466^{hi}	21.85±0.662^{k}	36.01±0.130^{pq}	3.20±0.006^{m}
12.	**1283**	13.95±0.105^{kl}	97.64±1.229^{g}	78.26±0.783^{ef}	21.02±0.208^{j}	35.60±0.170^{op}	2.70±0.006^{jk}
13.	**1288**	9.59±0.074^{d}	106.19±0.447^{i}	116.63±0.439^{k}	14.29±0.596^{ef}	1.64±0.006^{a}	1.18±0.006^{d}
14.	**1292**	8.28±0.057^{b}	75.28±0.365^{b}	55.53±0.183^{b}	13.55±0.634^{de}	10.52±0.040^{b}	0.82±0.006^{a}
15.	**1294**	10.47±0.099^{e}	105.53±0.442^{i}	63.82±1.507^{c}	15.93±0.550^{g}	19.96±0.320^{f}	1.01±0.006^{b}
16.	**1296**	11.62±0.284^{g}	111.97±0.355^{j}	56.78±0.125^{b}	13.52±0.070^{de}	21.32±0.365^{g}	1.27±0.006^{e}
17.	**1298**	12.35±0.421^{h}	87.89±0.401^{e}	74.16±0.341^{de}	11.97±0.734^{c}	15.91±0.085^{d}	0.98±0.006^{b}
18.	**1300**	12.99±0.195^{i}	102.43±0.694^{h}	77.28±0.325^{e}	17.41±0.142^{h}	25.76±0.300^{h}	1.35±0.006^{f}
19.	**1301**	11.49±0.225^{g}	91.44±0.576^{f}	68.79±0.185^{cd}	20.23±0.538^{j}	16.52±0.447^{e}	1.12±0.006^{c}
20.	**1315**	10.82±0.119^{f}	77.12±0.187^{c}	65.95±0.638^{c}	11.18±0.319^{b}	25.61±0.477^{h}	1.47±0.015^{g}
21.	**1320**	12.61±0.105^{h}	71.40±0.460^{a}	88.69±0.170^{gh}	13.14±0.573^{d}	34.49±0.283^{n}	2.74±0.010^{k}
22.	**1321**	13.41±0.112^{j}	78.70±0.324^{d}	109.91±0.607^{j}	20.67±0.643^{j}	33.33±0.263^{l}	2.65±0.012^{j}
23.	**1326**	14.65±0.078^{n}	77.97±0.465^{cd}	57.09±0.335^{b}	19.20±0.021^{i}	36.35±0.485^{q}	2.84±0.006^{l}

Note: *The different letter(s) in each column shows values are significantly different ($P<0.05$) as evaluated by the DMRT ± shows the standard deviation of mean values of three replicates.*

CONCLUSION

The biochemical components in *Opuntia* had wide variation in their content and also varied amongst the accessions. The cladodes showed an ample amount of moisture content ensuring its suitability for consumption as fodder and as vegetables in arid, semi-arid regions. The presence of micro and macronutrients will ensure its health-promoting effects. The high crude fibre content and low-fat level make good laxative and low-calorie food. There is a need to explore this plant with respect to the characterization of individual biochemical components and the promotion of the plant as a vegetable and fodder in Indian conditions by carrying out feed trials.

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