Plant Foods for Human Nutrition 38: 83–93 (1988)

Developmental changes in composition and quality of prickly pear cactus cladodes (nopalitos)

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Received 11 June 1987; accepted in revised form 14 August 1987

Key words: *Opuntia* spp, nopalitos, prickly pear cladodes, cactus stems, cactus leaves, composition during development

Abstract. The composition and quality of edible tender stems or cladodes of 3 Prickly Pear Cactus species (*Opuntia amyclaea, O. ficus-indica, and O. inermis*) were studied at different stages of development. This traditional Mexican vegetable is called "nopalitos" in Spanish and "cactus leaves" in English. Cladodes harvested when 20 cm in length have the following average composition per 100 g: 91.7 g of water, 1.1 g of protein, 0.2 g of lipid, 1.3 g of ash, 1.1 g of crude fiber, 4.6 g of complex carbohydrates and 0.82 g of simple sugars, 12.7 mg of ascorbic acid and 28.9 μg of carotenes. The cladode's juice has an average pH of 4.6, 0.45% titratable acidity and 6.9% soluble solids. The components which varied most during development of the cladodes were: carotenes, acidity and total carbohydrates which increased, and protein and crude fiber (acid-detergent) which decreased. The nutritive value of the tender cladodes in the stages of growth at which they are commonly harvested and consumed (15 to 25 cm long weighing 50 to 80 g per stem), was similar for the 3 species.

Introduction

More than half of the Mexican terrain is arid and semiarid. In these areas the landscape is dominated by a great diversity of plants which are well adapted to the extreme climatological and edaphic conditions. The flat-stemmed prickly pear cactus (*Opuntia* subgenus *Opuntia*) is one such plant, with a representation of over 100 species in Mexico [6]. Some of these prickly pear species have been utilized by man for hundreds of years in many different ways: for animal feed, especially in times of drought; for the production of natural dyes such as cochineal red; and for human consumption. The juicy ripe fruits are consumed fresh and the young tender cladodes are utilized as a fresh or cooked vegetable in a variety of dishes [2, 4].

The edible cladodes or nopalitos are formed in a special meristematic area

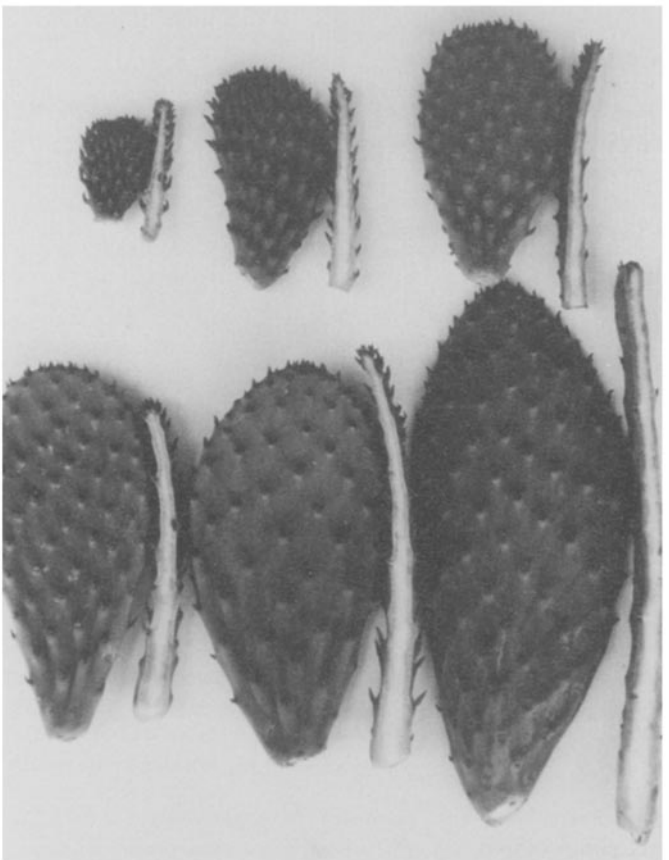

Fig. 1. Developmental stages of nopalitos of *Opuntia inermis*. Top row from the left: Stages 1, 2 and 3. Bottom row from the left: Stages 4, 5 and 6.

(areole) on the "mother" or mature cladode. Botanically, cladodes are flattened photosynthetic stems, which in early stages of development, are covered by small leaves. These abscise as the cladode develops and matures (Fig. 1). Depending upon the weather, the nopalitos require from 20 to 30 days to develop to a harvestable size (20 cm) [15]. To be consumed as a fresh or cooked vegetable, good quality nopalitos must be fresh looking, turgid, tender and have a brilliant green color.

The major production area of nopalitos in Mexico is centered around the town of Milpa Alta, where an annual production of 30,000 ton is estimated [7]. Although data are not available for production at the national level, production of nopalitos has been increasing in recent years, both in Mexico and the southwest U.S.

Although nopalitos have been important in the traditional Mexican diet, few studies have been carried out which consider the factors that affect their quality and nutrient composition as a vegetable. Hernandez et al. [13] reported an average proximate composition (vitamins, calcium, iron, lipid, protein and carbohydrate) of an unspecified type of nopalito. Villarreal et al. [20] studied compositional differences (soluble and total solids, acidity, ash and pectins) among 5 species of *Opuntia*. However, the cladodes used in the study were much larger than those which are commonly consumed as a vegetable. That is also the case in a more recent study on cladode composition [5]. Feitosa-Teles [8] and Feitosa-Teles et al. [9] carried out a detailed qualitative and quantitative study on the amino acid, organic acid, sugar, vitamin and mineral composition of *O. ficus-indica* cladodes categorized as "young" and "mature". Camarillo and Grajeda [7] showed differences in some nopalito components (water, soluble solids and titratable acidity) in relation to winter production under plastic. Most recently, Robles-Contreras [15] reported small increases in acidity and soluble solids in nopalitos from plants of *O. ficus-indica* receiving differing amounts of irrigation water.

The study summarized here complements the information reported previously. Its objective was to determine some physical and compositional characteristics of vegetable cladodes as affected by species of *Opuntia* and stage of development.

Materials and methods

Young cladodes were harvested from 3 species of *Opuntia* from plantings of 3 to 4 years of age at the School of Agriculture of the University of Sonora near Hermosillo. Cladodes from two species used for commercial production of nopalitos (*O. ficus-indica* and *O. inermis*) and 1 species of the *Opuntia* used in fruit production (*O. amyclaea*) were studied [4]. This species was included because plantations for fruit production may occasionally be managed for nopalito production. The experimental plots were on a sandy soil and had been irrigated sporadically during the first two years of growth. They were not pruned or irrigated in the year prior to the study, during which time they received about 20 cm of rain.

Cladodes at different stages of development were randomly harvested between 7:30 and 8:30 A.M. from the spring growth flush. A total of over 40 cladodes from stages 1, 2, 3 and 4 and 10 of stages 5 and 6 were harvested. The stages designated 2, 3 and 4 corresponded to the range of sizes for commercially harvested cladodes. The cladodes were classified into 6 catego-

ries based on size, presence or absence of small leaves, and thickness of the stem base, after which three replicates for each category were composed. Without removing the small leaves and spines, the cladodes were cut into pieces 1 cm square, divided into two portions, one of which was frozen at − 12 °C and the other was dried in a forced-air oven at 70 °C. Determinations of water content, protein, ash, crude fiber (acid-detergent), lipid and total carbohydrate were made on the dried material ground to pass a 60 mesh screen [3]. Titratable acidity, pH, soluble solids, carotenes and ascorbic acid were determined on the frozen tissue [3, 10, 17, 18]. For the determination of diurnal changes in acid content, cladodes of *O. ficus-indica* of commercially acceptable size (Stage 3) were harvested (3 replicates with 3 cladodes each), transported to the laboratory on ice, and handled as previously mentioned. The results were analyzed statistically by Bartlet's Test for Homogeneous Variances, Analysis of Variance and Duncan's Multiple Range Test [14].

Results and discussions

The young cladodes of the 3 *Opuntia* species studied are quite distinct in appearance. Those of *O. ficus-indica* are long and thin with few spines, whereas those of *O. inermis* are disc-shaped with few spines, and those of *O. amyclaea* are disc-shaped with many spines. These physical characteristics are reflected in differences in weight and length during development of the cladodes (Fig. 1 and Table 1). In addition to an increase in size, the major differences between Stages 4 and 5 are the abscission of the small leaves on the cladodes and a noticeable thickening of the cuticle. Both characteristics are undesirable for good quality nopalitos. The cladodes also begin to increase in thickness by Stage 5, due to development of water-storing parenchyma, an undesirable quality characteristic.

The water content increased slightly with development of the cladodes, from an average for the 3 species of 91.0 in Stage 1 to 92.7% in Stage 5. These values are within the range reported by Bravo-Hollis [6], but less than the 94 to 95% reported by Camarillo and Grajeda [7], Feitosa-Teles [8], and Robles-Contreras [15]. The water content of the cladodes can vary greatly depending upon water availability to the plant [1, 15].

The protein content of nopalitos (calculated from nitrogen content using a factor of 6.25) varied significantly among species of *Opuntia* and with stage of development (Table 2). Nopalitos of *O. amyclaea* had the highest protein content in all stages of development. The protein content of cladodes of *O. ficus-indica* and *O. inermis* decreased about 50% between Stages 1 and 6.

Table 1. Developmental changes in weight and length of nopalitos from 3 species of *Opuntia*

Stage of development	*O. amyclaea*		*O. ficus-indica*		*O. inermis*	
	Range	Average	Range	Average	Range	Average
Length (cm)						
1	7–12	9	7–12	10	8–12	10
2	11–18	14	12–18	15	12–15	13
3	15–19	17	15–21	19	14–17	15
4	17–22	20	20–26	23	18–23	20
5	22–30	26	31–37	33	19–24	21
6	32–36	34	31–40	36	21–34	31
Weight (g)						
1	12–37	23	10–26	15	20–37	27
2	38–71	50	31–47	40	42–55	49
3	72–97	86	57–75	66	60–95	75
4	103–141	124	87–130	102	116–158	112
5	175–251	229	152–219	189	182–225	199
6	357–380	368	293–422	336	274–583	388

Cladodes were classified on the basis of color, glossiness, small leaf development and thickness, as shown in Fig. 1. Data are based on 40 cladodes for stages 1 through 4 and 10 cladodes for stages 5 and 6.

The values obtained in this study were higher than the 11.0% reported by Feitosa-Teles [8] using the same Kjeldahl procedure and less than the 21% calculated from data of Hernandez et al. [13]. Nopalitos, like most fresh vegetables, are relatively low in protein [11].

Lipid content (ether-soluble extract) was low (1.3 to 3.0%) in the cladodes of the 3 species, with no consistent changes as the cladodes developed (data not shown). The lipid content was found to be similar to that of other photosynthetic tissues, in which the lipids are mostly structural [8, 11].

Table 2. Protein content ($N \times 6.25$) of cladodes from 3 species of *Opuntia*

Stage of development	Protein (% dry wt.)		
	O. amyclaea	*O. ficus-indica*	*O. inermis*
1	19.7a[1]	16.0a	13.9a
2	16.8b	13.0b	13.7a
3	16.3c	12.8b	12.0b
4	14.4d	10.3c	11.0c
5	12.7e	10.4c	8.3d
6	13.9d	9.0d	7.1e

[1] Data within a column followed by different letters are significantly different at the 5% level.

Table 3. Crude fiber (acid-detergent) content of cladodes from 3 species of *Opuntia*

Stage of development	Crude fiber (% dry wt.)		
	O. amyclaea	*O. ficus-indica*	*O. inermis*
1	17.6a[1]	16.3a	16.1a
2	15.1b	12.7c	15.4b
3	14.1c	13.7b	14.1c
4	13.9c	12.2d	11.8e
5	11.5d	13.1bc	12.8d
6	12.9e	12.1d	12.8d

[1] Data within a given column followed by different letters are significantly different at the 5% level.

The ash content of the dried cladode samples increased from an average of 14.8 in Stage 1 to 17.0% in Stage 6. The cladodes of *O. inermis* had a significantly higher ash content throughout development. These results agree with those reported by Villarreal et al. [20] who found a 12 to 17% ash content for the 5 *Opuntia* species they studied. They are, however, much lower than the 23.5% determined by Feitosa-Teles [8] in young cladodes of *O. ficus-indica*. Bacalho and Penteado [5] found that about 60% of the mineral content of young cladodes was calcium, and Tractenberg and Mayer [19] have reported large deposits of calcium as oxalate crystals in mature cladodes.

Cladodes of *O. ficus-indica* have the lowest content of acid-detergent crude fiber (principally lignin and cellulose) (Table 3). Fiber content was always higher, however, than the 8.9% reported by Feitosa-Teles [8] for the same species. The content of acid-detergent crude fiber decreased significantly as the cladodes developed. This decrease may be due to the increased proportion of water-storing parenchyma in relation to the outer photosynthetic parenchyma tissues. It has been reported that total fiber content may exceed 30% in mature cladodes [6]. The difference between the total and the acid-detergent soluble fiber, reportedly represents the hemicellulose fraction, part of which, in the case of the *Opuntia*, is a mucilage which varies with stage of development of the cladode [19]. The content of complex carbohydrates, other than acid-detergent crude fiber, was estimated by difference (data not shown). This varied from an average for the 3 species of 48.5 in Stage 1 to 58.3% in Stage 6. There were no significant differences in content between the species. Feitosa-Teles [8] estimated the complex carbohydrate content to be 65% in young dried cladodes.

The ascorbic acid content (reduced and dehydro forms of ascorbic acid) varied from 7 to 18 mg/100 g, with cladodes of *O. inermis* having the highest

Table 4. Ascorbic acid content of cladodes from 3 species of *Opuntia*

Stage of development	Ascorbic acid (mg/100g fresh weight)		
	O. amyclaea	*O. ficus-indica*	*O. inermis*
1	9.9ab[1]	10.9a	11.7a
2	9.8ab	11.7a	12.1a
3	10.4a	8.8b	12.0a
4	10.9a	8.9b	12.2a
5	9.9ab	9.5b	13.0a
6	8.6b	7.1c	17.9b

[1] Data within a given column followed by different letters are significantly different at the 5% level.

content. No consistent pattern of change in ascorbic acid was associated with cladode development (Table 4). Nopalitos, therefore, have moderate amounts of Vitamin C in comparison to other vegetables [11]. Total carotene content was used as an estimate for beta-carotene. The content varied from an average of 18.8 to 44.6 μg/100 g for cladodes in Stage 1 and 6, respectively (Table 5). The lowest carotene content was found in cladodes of *O. amyclaea*. These results are within the range of 31.2 to 36.8 μg/100 g reported by Feitosa-Teles [8] and Hernandez et al. [13], and similar to that found in other green vegetables [11]. The increase in carotene content with cladode development coincided with an increase in chlorophyll content (data not shown).

The prickly pear cactus is one of many succulent plant genera which have Crassulacean Acid Metabolism (CAM) [1]. CAM is a modification of C3 photosynthesis which involves the initial fixation of carbon dioxide as organic acids during the night, and subsequent release and incorporation of the same carbon dioxide as sugars during the day [1]. This pattern results in

Table 5. Carotene content of cladodes from 3 species of *Opuntia*

Stage of development	Carotene content (μg/100g fresh weight)		
	O. amyclaea	*O. ficus-indica*	*O. inermis*
1	17.7ab[1]	25.8a	13.0a
2	11.3a	30.5a	–
3	19.3ab	30.9a	24.9b
4	24.7bc	27.9a	52.0c
5	33.6cd	36.7bc	49.7c
6	36.4d	44.0c	53.5c

[1] Data within a given column followed by different letters are significantly different at the 5% level.

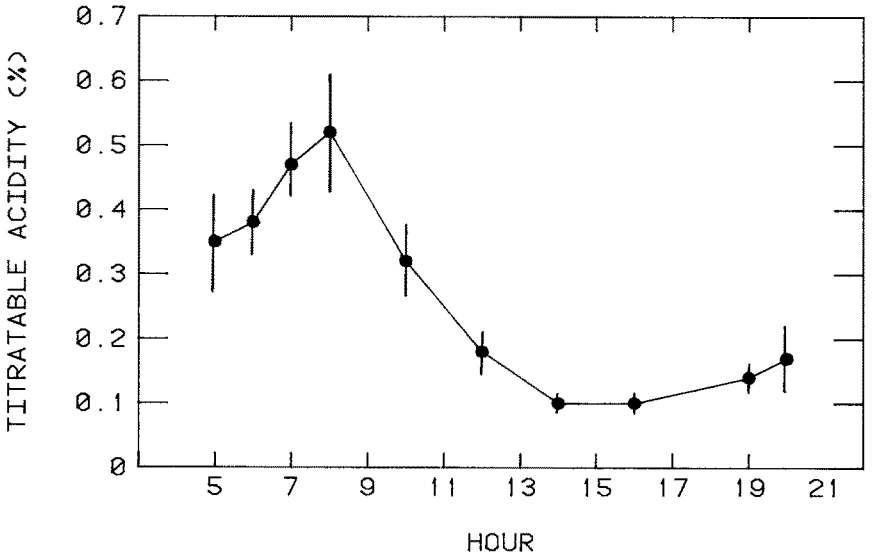

Fig. 2. Diurnal fluctuation in titratable acid content of nopalitos of *O. ficus-indica* (Stage 3) harvested from 5 A.M. to 10 P.M. Data and standard deviations are based on 3 replicates of 3 nopalitos each per sample period.

extreme diurnal variation in the acid content of the cladodes. Camarillo and Grajeda [7] have also shown that the acid content may vary from 0.87 to 0.55% in nopalitos of the same species produced during the winter under exposed and protected conditions.

An example of the diurnal fluctuation (five-fold change) in acidity of 20 cm cladodes of *O. ficus-indica* is shown in Fig. 2. A high acid content in nopalitos causes an undesirable "sour" taste. Because of this, they are traditionally not harvested until midmorning when acidity has decreased. The acid content of cladodes of the 3 species studied, all harvested in early morning when differences would be greatest, varied from 0.28 to 0.95% (Table 6). Cladodes of *O. inermis* contained significantly more acid at all stages of development. The increase in acid content with development of the cladodes resulted in a decrease in pH, from an average of 5.0 in Stage 1 to 4.3 in Stage 6.

The content of reducing sugars also increased with the development of the nopalitos, varying from an average of 0.64 to 0.88% (data not shown). Nopalitos of *O. inermis* contained significantly less sugars than cladodes from the other 2 species. Feitosa-Teles [8] reported that young cladode juice of *O. ficus-indica* contained 0.49% reducing sugars and 0.27% sucrose. Analysis of the soluble solid content showed no consistent differences

Table 6. Titratable organic acid content of cladodes from 3 species of *Opuntia*

Stage of development	Titratable acidity (% fresh weight)		
	O. amyclaea	*O. ficus-indica*	*O. inermis*
1	0.36a[1]	0.28a	0.34a
2	0.43b	0.38b	0.35a
3	0.44b	0.42b	0.49b
4	0.49bc	0.41b	0.68c
5	0.54c	0.52c	0.72c
6	0.53c	0.47c	0.95d

[1] Data within a given column followed by different letters are significantly different at the 5% level.

among species and stage of development (data not shown). Soluble solids content averaged 6.9% for nopalitos of the 3 species. Camarillo and Grajeda [7] reported soluble solids contents of less than 4.0% for nopalitos of the same species. In most fruits and vegetables, acids and sugars are the major contributors to soluble solids [11]. That does not appear to be the case for nopalitos, in which these components account for less than half of the soluble solids content.

A summary of the components which contribute to the nutritive value of the nopalito is presented in Table 7. These values are the averages for developmental stages 2, 3 and 4, which encompass the sizes harvested in commercial vegetable cladode production. It is apparent from this summary that there are few notable differences in composition among the 3 species. Exceptions are the protein content which was significantly higher in *O. amyclaea*, and the ascorbic acid and carotene contents which were significantly higher in *O. inermis*. These summary results agree generally with

Table 7. Average chemical composition of cladodes from 3 species of *Opuntia* harvested at commercial maturity (stages of development 2, 3 and 4)

Component[1]	*O. amyclaea*	*O. ficus-indica*	*O. inermis*
Water (%)	92.0a[2]	91.5a	91.7a
Protein (%)	15.8a	12.0b	12.2b
Lipids (%)	2.2a	2.7b	2.3a
Ash (%)	15.0b	14.3c	16.8a
Crude Fiber (%)	14.3a	12.9c	13.8b
Carbohydrates (%)	52.6c	58.1a	55.5b
Ascorbic Acid (mg/100g)	10.4b	9.8b	17.9a
Carotenes (^{m}g/100g)	18.5c	29.8b	38.4a

[1] Data are calculated on a dry weight basis except for ascorbic acid and carotene.
[2] Data within a given row followed by different letters are significantly different at the 5% level.

those reported by Hernandez et al. [13] and Feitosa-Teles [8]. However in these previous studies, the stage of development was not clearly specified, making comparisons difficult.

Conclusions

The tender young stems or cladodes (nopalitos in Spanish) of the prickly pear cactus (*Opuntia* spp.) are consumed as a fresh or cooked vegetable in Mexico. This study compared the compositional and physical characteristics of cladodes of 3 *Opuntia* species during development. The components which varied most during development were: carotenes, titratable acidity and carbohydrates, which increased, and protein and crude fiber which decreased. The principal differences in composition among cladodes of the 3 species were in protein content, titratable acidity, and ascorbic acid. The acid content is an important quality factor since it affects the flavor and acceptability of the nopalitos in the marketplace. The acid content varied with time of harvest and with the stage of development of the cladodes. Nopalitos contain moderate amounts of Vitamin C and Vitamin A precursor.

The results obtained in the present study form a table of information useful as a basis for future horticultural, physiological, and biochemical studies on the edible cladodes of *Opuntia* species.

Acknowledgements

We thank Dr Michael Reid for his kind help and many useful criticisms in preparing this paper.

This study was supported by CONACYT (Mexico) Project No. 84/2238.

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