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Cladodes from *Opuntia ficus indica* as a source of dietary fiber: Effect on dough characteristics and cake making

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ABSTRACT

Chemical composition and physical properties of Mediterranean (Tunisian) spiny (*Opuntia ficus indica* f. *amylocea*) and spineless cladodes (*O. ficus indica* f. *inermis*) were studied. Chemical characterization of the two cladodes varieties showed a high fiber, minerals, especially potassium and calcium, and phenols contents. Powders obtained from spiny and spineless cladodes showed a great technological potentiality as water binding capacity (WBC) and fat absorption capacity (FAC). Cladodes powders were incorporated in wheat flours at 5%, 10%, 15% and 20% levels. Obtained results showed that cladodes flours had a significant effect in wheat dough properties ($P < 0.05$). In deed, with the increase of cladodes flours levels, an increase of tenacity, energy, adhesion, stickiness, and hardness of dough was observed whereas dough elasticity decreased. A significant difference in physical characteristic between cakes fortified with cladodes flours and control was showed ($P < 0.05$). With the increase of cladodes flours levels in formulation, cakes hardness increased whereas L^* and a^* crust and crumb color values decreased. Increasing levels of cladodes flours caused decreases in total sensory scores. The overall acceptability rate showed that a maximum of 5% cladodes flours can be incorporated to prepare acceptable quality cakes.

1. Introduction

Nowadays, consumers prefer ready to eat foods and a diet that is low in calories, low in cholesterol, low in fat or in other words 'healthy foods'. In accordance with this trend, consumers also want to eat foods with higher fiber content. Romo et al. (2008) reported that the recommended amount of dietary fibers (DF) intake per adult is of 25–38 g. Dietary fiber refers to parts of fruits, vegetables, crops, nuts and legumes that cannot be digested by humans. It is a well-established fact that the consumption of adequate amounts of dietary fiber reduces significantly the risk of degenerative diseases, including diabetes, obesity, coronary heart disease, bowl cancer and gallstones (Ahmad, 1995; Horn, 1997). Dietary fibers also have technological properties that can be used in the formulation of foods, resulting in texture modification and enhancement of the stability of the food during production and storage (Thebaudin et al., 1997). Both the nutritional value and technological properties of dietary fibers are important in the potential development of a wide range of fiber-enriched foods (e.g. bakery products, snacks, sauces, drinks, cereals, biscuits, dairy products, meat products).

In the last fives decades there is a trend to find new sources of dietary fiber, such as agronomic by-products that have traditionally been undervalued. Dietary fibers from different sources have been used to replace wheat flour in the preparation of bakery products. Pomeranz et al. (1977) used cellulose, wheat bran and oat bran in bread making. Potato peel, a by-product from potato industry, rich in dietary fiber, was used as a source of dietary fiber in bread making (Toma et al., 1979). Recently, Valencia et al. (2007) tested fiber concentrate from mango fruit as a bakery product ingredient. Anil (2007), used hazelnut as a source of dietary fiber in bread making. Sudha et al. (2007a) studied the influence of fiber from different cereals on the rheological characteristics of wheat flour dough and on biscuit quality. Sudha et al. (2007b) studied the effect of apple pomace by-product, as a source of dietary fiber and polyphenols, on cake making.

Actually in Tunisia and in other Mediterranean countries, cactus pear plant grows spontaneously and consumed exclusively as fresh fruit and cladodes as an animal feed complement. Only a small quantity is being used for processing; so, there is need to create a better outlet for seasonally surplus production which used in animal feeds or otherwise go to waste. The actual trend to find new sources of dietary fiber and natural antioxidant such as agronomic by-products that have traditionally been undervalued was more important. In this context cladodes from *Opuntia ficus indica* f. plant could be a great source of bio-molecule such as dietary fiber, mineral and natural antioxidant compounds. In the literature the available data have been especially concerned general physicochemical composition and processing of pulp and seeds (Ennouri et al., 2005, 2006).

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Traditionally and still today, cladodes serve as sources for vegetables, for medicinal and cosmetic purposes, as forage, building material. Few reports have been published on the industrial uses of vegetative part of cactus plants (cladodes) as a source of dietary fiber or natural antioxidants.

The objective of the present study was to assess nutritional potential of cladodes from Mediterranean *O. ficus indica* f. *amyloceae* (spiny cladodes) and *O. ficus indica* f. *inermis* (spineless cladodes) by evaluating the physico-chemical properties and technological parameters. The second part of this paper was dedicated to studying the influence of cladodes powders addition on dough characteristics and cake making.

2. Materials and methods

2.1. Materials

Cladodes (2–3 years) from *O. ficus indica* f. *amyclaea* (spiny cladodes) and *O. ficus indica* f. *inermis* (spineless cladodes) were collected in the area of Sfax (Tunisia) between March and June 2007. After spines removal for spiny form, cladodes were washed and homogenized with a Warring blender (Philips, France). Blended cladodes were used as raw materials for the determination of chemical characteristics. For physical characteristics determination, cladodes were washed, cutted, dried at 60 °C and then were milled using a laboratory grinder to obtain cladodes powders.

2.2. Chemical analysis

Cladodes were analyzed for moisture, ash, protein and fat contents as per the standard AACC methods (2000). Nitrogen content was estimated by Kjeldhal method and was converted to protein using factor 6.25.

The amount of soluble dietary fiber (SDF), insoluble dietary fiber (IDF) and total dietary fiber (TDF) was determined according to the gravimetric enzymatic method as previously described by Prosky et al. (1988). Starch content was evaluated by an enzymatic-colorimetric method. Soluble sugars concentration was determined by the phenol-sulphuric acid method (Dubois et al., 1956) after ethanol extraction. Proportion of saccharose, glucose and fructose in soluble sugar was measured using a HPLC apparatus (High Performance Liquid Chromatography, Schumadzo, 10 AT, Japan). A sample of extracted soluble sugars was filtered (0.45 μm diameter). 20 μl of filtered sample was injected and separated with an ionic exchange column (Polypore CA, 250 mm, 4.6 mm thickness). Temperature and pressure was fixed at 80 °C and 1000 psi respectively. Flow rate of elution phase was maintained at 0.3 ml/min.

Minerals concentrations were determined after an acid digest of each sample with a nitric/perchloric acid (2:1, v/v) mixture. Aliquots were used to estimate Phosphor concentration by spectrophotometeric methods and Ca, Mg, K, Na, Fe, Cu and Zn by atomic absorption spectrophotometry (Hitachi Z6100, Tokyo, Japan) (AOAC, 1990).

Total phenols contents were determined by the Folin-Ciocalteu method and measured at 675 nm (Singleton et al., 1999). Chlorophyll content was determined according to the method described by Mencarelli and Saltveit (1988). Fresh cladodes (10 g) was homogenized with three aliquots of 15 ml of cold acetone (800 g/l) and vacuum-filtered through a Whatman No. 2 filter paper. Chlorophyll content (total, *a*, *b*) (mg/100 g) was calculated as follows:

Total chlorophyll = 7.12 (A665) + 1 6.8 (A649).
Chlorophyll *a* = 9.93 (A660) − 0.777 (A642.5).
Chlorophyll *b* = 17.6 (A642.5) − 2.81 (A660).

β-Carotene content was determined according to the method described by Rodriguez-Amaya (1999). 2 g of cladodes were extracted with 10 ml of hexane/acetone/ethanol (50:25:25, v/v) before being centrifuged for 5 min at 6500 rpm at 5 °C. The top layer of hexane, containing the color, was recovered and transferred to a 25-ml volumetric flask. The volume of recovered hexane was then adjusted to 25 ml with hexane. β-Carotene determination was carried out on an aliquot of hexane extract by measuring absorbance at 450 nm. β-Carotene was calculated using an extinction coefficient of β-carotene $E^{1\%} = 2505$.

2.3. Physical characteristics of cladodes powders

2.3.1. Bulk density measurement

Cladodes powders samples were gently filled into 10 ml graduated cylinders, previously tarred. The bottom of the cylinder was gently tapped on a laboratory bench several times until there was no further diminution of the sample level after filling to the 10 ml mark. Bulk density was calculated as weight of sample per unit volume of sample (g/ml) (Kaur and Singh, 2005).

2.3.2. Color measurement

Color measurements of cladodes powders samples were carried out using a Hunter Lab system with a colorimeter (Minolta CR-300, Japan) on the basis of L^*, a^* and b^* values. L^* value indicates the lightness, 0–100 representing dark to light, a^* value gives the degree of the red–green color, with a higher positive a^* value indicating more red. The b^* value indicates the degree of the yellow–blue color, with a higher positive b^* value indicating more yellow.

2.3.3. Cladodes powders swelling

Cladodes powders (100 mg) were hydrated with 10 ml of distilled water, containing 0.02% azide as a bacteriostat, in a calibrated cylinder (1.5 cm diameter) at room temperature. After equilibration (18 h), the bed volume was recorded and expressed as volume/g original cladodes dry weight (Robertson et al., 2000).

2.3.4. Water solubility index

Water solubility index (WSI) of cladodes powder was determined by slightly modifying the method of Anderson et al. (1969). Powders sample (2.5 g) was dispersed in 30 ml of distilled water, using a glass rod, and cooked at 90 °C for 15 min in a water bath. The cooked paste was cooled at room temperature and centrifuged at 3000 × *g* for 10 min. The supernatant was decanted for determination of its solid content into a tarred evaporating dish. The weight of dry solids was recovered by evaporating the supernatant overnight at 110 °C. WSI was calculated by the following equation:

$$\mathrm{WSI}(\%) = \frac{W_S}{W_{DS}} \times 100$$

where W_s: weight of dissolved solids in supernatant and W_{DS}: weight of dry solids.

2.3.5. Water holding capacity (WHC)

For water holding capacity (WHC) determination, 1 g of cladodes powder was mixed with 50 ml of distilled water vigorously for 1 min and then centrifuged for 15 min at 10,000 × *g* at 20 °C. The supernatant was discarded and the tube was kept inverted for 25 min at 50 °C. The WHC was expressed as g of water bound per gram of the sample on dray basis (Chen et al., 1988).

2.3.6. Fat absorption capacity

Fat absorption capacity was calculated according to the method described by Lin et al. (1974). Cladodes powders samples (0.5 g) were mixed with 6 ml of corn oil in pre-weighed centrifuge tubes.

The contents were stirred for 1 min with a thin brass wire to disperse the sample in the oil. After a holding period of 30 min, the tubes were centrifuged for 25 min at 3000 × g. The separated oil was then removed with a pipette and the tubes were inverted for 25 min to drain the oil prior to reweighing. Fat absorption capacity was expressed as g of oil bound per g of sample on a dry basis.

2.4. Dough properties

Dough's were prepared from blends containing 0%, 5%, 10%, 15% and 20% levels of spiny or spineless cladodes flours by replacing wheat flour.

2.4.1. Alveograph and texture properties

Effect of cladodes powders addition on alveographic and textural properties of dough was studied using an Alveograph (MA 82, Tripette et Renaud, France) and a Texture Analyzer (LLOYD instruments, England). Dough's were prepared from blends wheat flours by hand-mixing of 100 g of blinded wheat flour with 60 ml distilled water and 0.25 g of salt (NaCl).

The following Alveograph parameters were automatically recorded by a computer software program developed by R-Design, Pullman, WA: the maximum overpressure (P) needed to blow the dough bubble, which is an index of resistance to extension; the average abscissa (L) at bubble rupture, an index of dough extensibility, the deformation energy, W, an index of dough strength and P/L ratio which indicate dough quality.

A Texture Procedure Analysis (TPA) test was performed using a Texture Analyser (Texture Analyser: LLOYD instruments, England) equipped with a 1000 (N) load cell, 0.05 (N) detection range. Sample of dough was transferred into a moulded Nalgene polypropylene tube (5 cm height) that was placed in a fixture to hold it in place under the Texture Analyzer. An acrylic cylindrical probe was used to compress the semolina sample by 50% of its original height (40 mm) at a speed of 10 mm/s. The Texture Analyzer was interfaced with a computer, which controls the instruments and analyses the data, using the software supplied by Texture Technologies Corp. Hardness (peak force of first compression cycle), stickiness (distance of the detected height of the product on the second compression divided by the original compression distance), cohesiveness (ratio of positive areas of second cycle to area of first cycle), adhesiveness (negative force area of the first byte represented the work necessary to pull the compressing plunger away from the sample), were determined.

2.5. Baking test

Cakes were prepared from blends containing 0%, 5%, 10%, 15% and 20% of spiny or spineless cladodes flours.

2.5.1. Cake preparation

The formula included 100 g flour blend, 100 g sugar, 120 g egg, 25 g shortening, 40 g refined vegetable oil, 0.5 g baking powder and 1.5 g salt. Cake batter was prepared in a Hobart mixer (N-50) using flour batter method, wherein, the flour, shortening, salt and baking powder were creamed together to get a fluffy cream; eggs and sugar were whipped together until semi-firm foam resulted. The sugar–egg foam was mixed with the creamed flour and shortening, after which the vegetable oil was added in small portions. Cake batter was poured into a wooden pan and baked at 160 °C for 1 h. Cakes were cooled to room temperature (Sudha et al., 2007a).

2.5.2. Physical characteristics of cakes

Volume (V, cc) of cakes was measured using rapeseed displacement method. Weight of the cakes was measured (W, g) and density (W/V, g/cc) was calculated. Hardness of cakes was measured using a Texture Analyzer (LLOYD instruments, England). Cakes slices (2.5 cm in thickness) were placed on the platform. An acrylic cylindrical probe was used to compress cake sample 50% of its original height at a speed of 10 mm/s. Colors of crust and crumb were measured using the Hunter Lab system with a colorimeter (Minolta CR-300, Japan).

Table 1
Approximate composition of cladodes from *Opuntia ficus indica* f. *amyloceae* (spiny cladodes) and *Opuntia ficus indica* f. *inermis* (spineless cladodes).

Parameters	Spiny cladodes	Spineless cladodes
Moisture[b] (%)	90.67 ± 0.75	91.04 ± 0.53
aw[b]	0.762 ± 0.002	0.767 ± 0.003
pH[a]	4.02 ± 0.4	3.84 ± 0.1
Titrable acidity[a] (% of malic acid)	0.724 ± 0.07	0.652 ± 006
Total protein[b,*]	8.74 ± 0.51	8.88 ± 0.74
Total fat[a,*]	3.95 ± 0.22	4.69 ± 0.31
Total ash[a,*]	25.65 ± 0.94	23.3 ± 0.78
Total carbohydrates[b,*]	60.36 ± 1.13	60.93 ± 0.99
Total dietry fiber (TDF)[a,**]	51.24 ± 2.12	41.83 ± 2.98
Insoluble dietry fiber (IDF)[a,**]	34.58 ± 0.99	30.36 ± 0.98
Soluble dietry fiber (SDF)[a,**]	12.98 ± 0.32	8.78 ± 0.28
Starch[a,*]	7.63 ± 1.12	13.09 ± 1.15
Soluble sugars[a,*]	2.49 ± 0.95	6.01 ± 0.88
Saccharose[a,***]	29.95 ± 1.95	2.2 ± 0.95
Glucose [a,***]	24.9 ± 1.55	7.47 ± 0.85
Fructose [a,***]	54.15 ± 2.15	90.33 ± 3.05
Starch[a,*]	7.63 ± 1.12	13.09 ± 1.15

[a] Significant difference was showed between samples ($P < 0.05$).
[b] No significant difference was showed between samples ($P < 0.05$).
[*] g/100 g of dry matter.
[**] % of Total carbohydrates.
[***] % of soluble sugar.

2.5.3. Sensory analysis

The organoleptic characteristics of cakes were carried out by 45 panelists. The panelists were asked to evaluate the products for crust color, crumb color, grain, texture, eating quality and overall quality (Sudha et al., 2007a). The ratings were on 5-point hedonic scale ranging from 5 (like extremely) to 1 (dislike extremely) for each organoleptic characteristic.

2.6. Statistical analysis

At least three replicates were made for each analysis. Results were presented as $x \pm$ SD with x the mean of at least three replications and SD the standard deviation. Ducan's test was used to detect significance of differences among means. Confidence levels were set at 95% ($P < 0.05$). SPSS for windows (version 11.0, USA) was used to perform these tests.

3. Results and discussion

3.1. Chemical characteristics of cladodes powders

Table 1 summarized the general composition of spiny and spineless cladodes. High moisture, ash and carbohydrates contents were observed for the two varieties of cladodes. However, a low fat and protein contents were observed. The two varieties of cladodes exhibit a low pH value. This low pH could be explained by the presence of many organic acids as malic, citric and oxalic acids (Stintzing and Carle, 2005). Indeed, Rodriguez-Felix and Cantwell (1988) reported a pH value of 4.6 for cladodes of *O. ficus indica* f. *amylocea* and *O. ficus indica* f. *inermis* cultivated in Mexico. Water activity of fresh cladodes was about 0.76 for the two varieties. pH and aw value of cladodes could prevent bacteria development but could not prevent moulds and yeast development (El Gersifi, 1998).

No significant difference ($P < 0.05$) was observed between proteins contents for the two cladodes varieties. In deed, Gebremariam et al. (2006) reported that protein level in cactus cladodes was about 8% of dry matter. This value is in agreement with value obtained in this study. However, Rodrigyez-Felix et al. (1988) and Ben Salem et al. (2005) reported that cladodes protein amounts were 13.25/100 g of dry weight and 3.3/100 g of dry weight, respectively.

Significant difference ($P < 0.05$) was observed between fat content for spiny and spineless cladodes. Rodriguez-Felix et al. (1988) and Malainine et al. (2003) reported that cladodes fat content of 2.4/100 g of dry weight and 7.2/100 g of dry weight, respectively.

Ash contents observed in this study were higher than value reported by Rodriguez-Felix et al. (1988) and Malainine et al. (2003).

No significant difference was showed between spiny and spineless total carbohydrates contents ($P < 0.05$). Dietary fiber was the important carbohydrate fraction followed by starch and soluble sugars. Spineless cladodes showed the highest starch (13.09 g vs. 7.63/100 g of dry weight) and soluble sugars (6.01 g vs. 2.99/100 g of dry weight) contents. Sutton et al. (1981) reported that starch content of *O. ficus indica* cladodes fluctuated with seasons and reached mean values of 85–171 mg/g of dry weight. Rodrigyez-Felix et al. (1988) reported a soluble sugars content of 9.87% for cladodes of *O. ficus indica* f. *amylocea* and *O. ficus indica* f. *inermis* cultivated in Mexico. Soluble sugars contents shows a significant difference ($P < 0.05$) between spiny and spineless cladodes and show that fructose is the major soluble sugars for the two cladodes varieties.

Total dietary fiber, soluble dietary fiber and insoluble dietary fiber were calculates according to the method described by Prosky et al. (1988). Spiny cladodes were richer in TDF, IDF and SDF than spineless cladodes. TDF content of 46.31/100 g of dry weight with 30.65 g being insoluble fiber and 15.66 g being soluble fiber were reported by Sàenz (1997) for Mexican cladodes. For the two Tunisian varieties of cladodes, IDF amount was higher than SDF amount. The ratio of SDF/IDF was 1:3. Sàenz (1997) reported a SDF/IDF ratio of 1:2 in Mexican cladodes.

Chlorophyll, β-carotene and total phenol contents of spiny and spineless cladodes were showed in Table 2. β-Carotene and total phenols contents show a significant difference between spiny and spineless cladodes ($P < 0.05$). Guevara et al. (2001) reported that total chlorophyll of cladodes was 12.5 mg/100 g fresh weight (9.5 mg/100 g fresh weight of chlorophyll *a* and 3.0 mg/100 g fresh weight of chlorophyll *b*). According to Stintzing and Carle (2005), *Opuntia* sp. Cladodes β-carotene amount ranged from 11.3 from 53.5 μg/100 g fresh weight.

Polyphenols are mainly responsible for an antioxidant activity. Several studies were devoted to find natural antioxidant in cheap raw material such as olive leaves, by-product of pomace juice, lemon, etc. With a content of 10.16 mg/g DW, apple pomace was considered as a great source of natural polyphenols Comparing to others conventional source of natural antioxidant cladodes contain 900 mg/100 of dry matter witch could be a great source of natural antioxidant.

Table 2
Chlorophylle, β-carotene and total phenol contents in cladodes from *Opuntia ficus indica* f. *amyloceae* (spiny cladodes) and *Opuntia ficus indica* f. *inermis* (spineless cladodes).

Parameters (mg/100 g of dry matter)	Spiny cladodes	Spineless cladodes
Total chlorophylle [a]	131.08 ± 9.36	151.78 ± 8.84
Chlorophyll *a*[a]	73.63 ± 6.66	82.59 ± 5.32
Chlorophyll *b*[a]	35.34 ± 2.82	39.84 ± 1.13
β-Carotene[b]	0.649 ± 0.12	1.01 ± 0.17
Total phenol[b]	975.82 ± 36.12	825.81 ± 24.13

[a] Significant difference was showed between samples ($P < 0.05$).
[b] No significant difference was showed between samples ($P < 0.05$).

Mineral composition of spiny and spineless cladodes was showed in Fig. 1. K, Mg, Na, P, Zn determination showed no significant difference between spiny and spineless cladodes ($P < 0.05$). However, Ca, Fe and Cu contents were statistically different ($P < 0.05$). Potassium is the most abundant mineral in cladodes. According to De Chavez et al. (1995), potassium was also the abundant mineral in Mexican cladodes. Spiny cladodes were richer in calcium than spineless cladodes (3.03 g vs. 1.4/100 g of dry weight, respectively). These values were lower than those cited by Ben Salem et al. (2005) (5.64/100 g of dry weight). The others minerals (Mg, Na, P, Zn, Cu, Fe) were also presents but in low content. Mineral composition was reported to be 0.19%, 0.15%, and 0.4% of dry weight for Mg, P and Na, respectively, in cladodes cultivated in Tunisia (Ben Salem et al., 2005). Ben Salem et al. (2005) showed that Fe, Cu and Zn content of 0.14 mg, 0.55 mg and 0.35 mg in 100 g dry weight cladodes, respectively. According to Stinzing et al. (2005), Cu and Zn content ranged from 0.8 to 0.9 mg and from 2.2 to 2.7 mg in 100 g dry weight, respectively.

3.2. Physical characterization of cladodes flours

Physical characteristics of powders obtained from spiny and spineless cladodes were presented in Table 3. Bulk density of spiny and spineless cladodes powders was 0.703 and 0.647 g/cc, respectively. These value shows that powders obtained from spiny cladodes are denser then flours obtained from spineless cladodes. CiaLab coordinates (L^*, a^* and b^*) of spiny and spineless cladodes powders show a high lightness value and a plate green aspect. These results are comparable to those reported by Sàenz (1997). In deed this author report that cladodes color is not very intense and therefore is easy to add to others products.

Hydration properties described by swelling, water solubility index and water holding capacity was presented in Table 3. Except

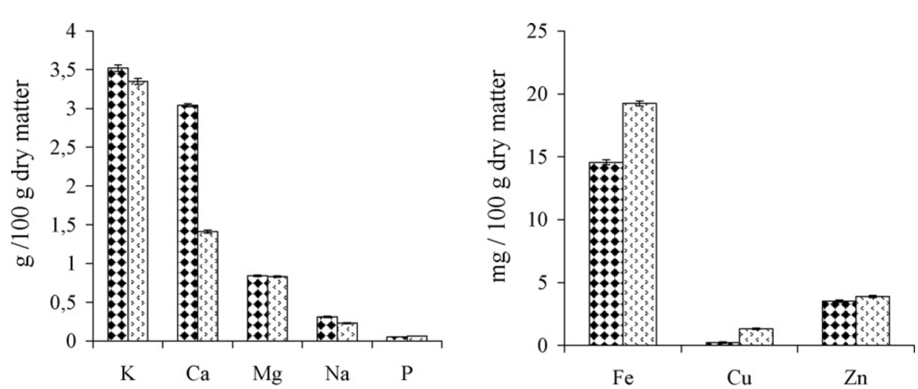

Fig. 1. Mineral composition of cladodes from *Opuntia ficus indica* f. *amyloceae* (spiny cladodes) and *Opuntia ficus indica* f. *inermis* (spineless cladodes). Error-bar represents standard deviation of the mean.

Table 3
Physical characteristics of cladodes powders from *O. ficus indica* (spiny cladodes) and *O. inermis* (spineless cladodes).

Parameters	Spiny cladodes	Spineless cladodes
Bulk density (g/cc)	0.703 ± 0.01	0.647 ± 0.01
L^*	67.49 ± 0.98	73.53 ± 1.13
a^*	−8.17 ± 0.74	−8.45 ± 0.84
b^*	25.15 ± 0.61	25.53 ± 0.54
Swelling (cm^3/g)	7.36 ± 0.07	7.78 ± 0.05
WSI (%)	5.23 ± 0.02	27.84 ± 0.09
WHC (g water/g DM)	6.85 ± 0.03	3.15 ± 0.01
FAC (g fat/g DM)	1.29 ± 0.01	1.31 ± 0.01

swelling value, spiny and spineless cladodes powders showed significant difference for WSI and WHC ($P < 0.05$). WSI are related to the presence of soluble molecules. Spiny and spineless cladodes powders presented WSI index of 4.78% and 25.54%, respectively. This index was five times higher for spineless cladodes than for spiny cladodes powder. High soluble sugars and starch contents in spineless cladodes could be responsible for this difference. Flour's swelling is attributes to its content on polysaccharides. Table 3 shows that flours obtained from spiny and spineless cladodes present the same swelling value (≈7.5 cm^3/g). This value were similar to swelling of flours obtained from others vegetable source such as wheat and carrot (Thebaudin, 1997). WHC represents the ability of a product to associate with water (Singh, 2001). Spiny cladodes flours showed the highest WHC (6.74 g/g vs. 2.97 g/g dry weight). Spiny cladodes powder WHC was twice times higher than spineless cladodes powder WHC. Difference in fiber content could explain this difference in WHC value. According to Hodge and Osman (1976), flours with high water holding capacity have more hydrophilic constituents such as fibers. Apple, wheat, sugar beet, pea and carrot fibers represented a WHC ranged from 2.5 to 10 g/g dry weight.

Fat absorption capacity of cladodes powders were presented in Table 2. The two varieties of cladodes powder showed no significant difference for fat absorption capacity ($P < 0.05$). Hydrophobic constituents are the main responsible of FAC (Kinsella, 1976). With 1.15 g fat/g dry weight, raw cladodes powder present a comparable FAC then flours obtained from fibers of others vegetables sources such as wheat, apple, pea and carrot (Thebaudin et al., 1997).

3.3. Dough properties

Incorporation of cladodes powders at 0%, 10%, 15% and 20% levels showed differences on the dough properties as measured by the alveographe and texture parameters. The effect of cladodes powders addition on the alveograph parameters of wheat flour dough is shown in Fig. 2. Cladodes powders addition showed a significant effect on alveograph parameters of fortified samples and control dough ($P < 0.05$). Dough resistance to deformation or tenacity (P) is a predictor of the ability of dough to retain gas. This parameter increased with the addition of cladodes flours (Fig. 2a). The highest effect was exhibited with spiny cladodes powders at a level of 20% (P = 153 mm vs. 52 mm in control). Likewise, the extensibility of dough (L), an indicator of the handling characteristics of the dough, was greatly reduced by cladodes powders addition (Fig. 2b). Dough prepared from spiny cladodes powders at a level of 20% showed the lowest extensibility value (L = 25 mm vs. 102 mm in control). As resulting of the cladodes flours action on both dough resistance and dough extensibility, the P/L ratio (which gives information about the elastic resistance and extensibility balance of a flour dough) was augmented in dough containing cladodes flours (Fig. 2c). Powders from spiny cladodes yielded dough with the highest P/L ratio (6.12 vs. 0.51 in the control). The deformation energy (W) increased with the addition of cladodes flours (Fig. 2d). The highest effect was observed with spiny cladodes flours at a level of 20% ($W = 225 \times 10^{-4}$ J vs. 170×10^{-4} J in control). These results could be due to the high content of fiber in cladodes, so a great number of hydroxyl groups existing in the fiber structure, which allow more water interactions through hydrogen bonding as was

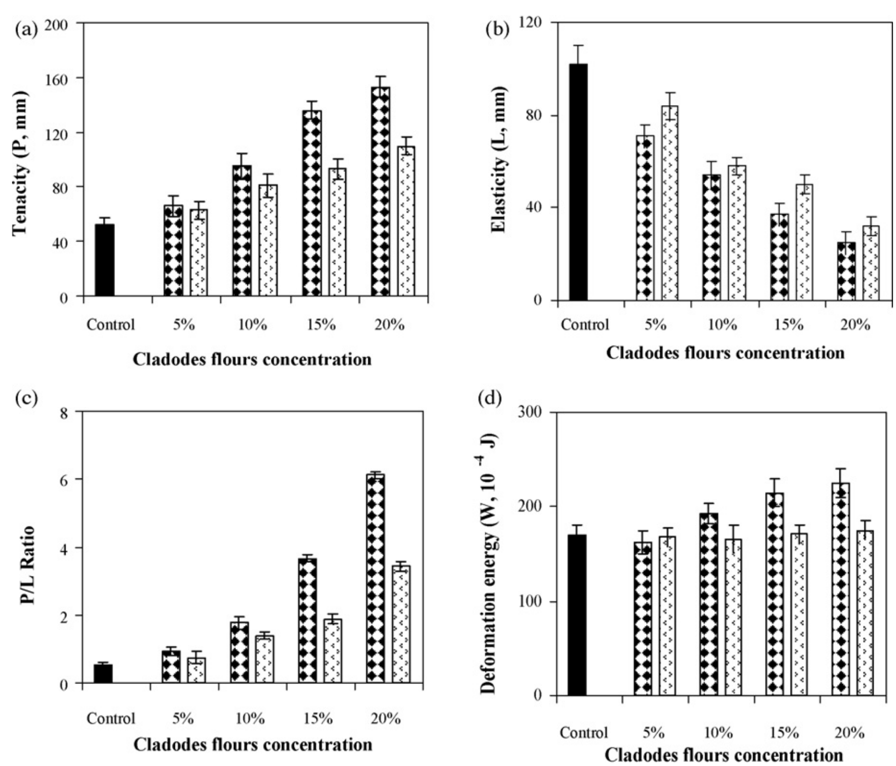

Fig. 2. Effect of spiny and spineless cladodes flours on the tenacity (a), elasticity (b), P/L ratio (c) and deformation energy (d) of dough. Error-bar represents standard deviation of the mean.

Table 4
Effect of spiny and spineless cladodes flours addition on textural properties (cohesion, adhesion, stickiness and hardness) of dough.

	Cohesion (mm)	Adhesion (N)	Stickiness (N)	Hardness (N)
Control	0.724 ± 0.09^{a}	4.056 ± 0.1^{a}	0.483 ± 0.06^{a}	5.379 ± 0.1^{a}
Spiny cladodes flours				
5%	0.713 ± 0.07^{a}	4.361 ± 0.09^{a}	0.661 ± 0.08^{b}	6.115 ± 0.16^{b}
10%	0.707 ± 0.04^{a}	5.402 ± 0.11^{d}	0.862 ± 0.03^{c}	7.634 ± 0.29^{d}
15%	0.674 ± 0.08^{ab}	5.621 ± 0.07^{d}	0.946 ± 0.09^{cd}	8.126 ± 0.11^{e}
20%	0.639 ± 0.05^{b}	5.922 ± 0.09^{e}	1.105 ± 0.1^{d}	9.129 ± 0.18^{g}
Spineless cladodes flours				
5%	0.721 ± 0.05^{a}	4.927 ± 0.08^{bc}	0.619 ± 0.09^{b}	6.249 ± 0.18^{b}
10%	0.704 ± 0.08^{a}	5.099 ± 0.12^{c}	1.065 ± 0.1^{d}	7.071 ± 0.11^{c}
15%	0.681 ± 0.06^{ab}	5.907 ± 0.06^{e}	1.101 ± 0.08^{d}	7.247 ± 0.2^{c}
20%	0.642 ± 0.04^{b}	6.016 ± 0.13^{e}	1.117 ± 0.03^{d}	8.528 ± 0.3^{f}
CD ($P < 0.05$)	0.06	0.41	0.44	0.89

Means followed by the same letter within column are non-significantly different ($P < 0.05$).

previously found by Rosell et al. (2001). Our findings are in line with the observations made by Sudha et al. (2007a) and Anil (2007) who reported a decrease on elasticity and an increase on resistance to extension of dough prepared by incorporating apple pomace and hazelta tested as sources of dietary fiber, respectively. The differences observed about the effect of spiny and spineless cladodes powders on the alveograph properties of dough can be attributed to the differences of water holding capacity of these two types of cladodes flours.

Textural evaluation of dough, containing 0%, 10%, 15% and 20% of cladodes powder, such as cohesion, adhesion, stickiness and hardness are presented in Table 4. There was a statistical difference in textural characteristic of dough between cladodes fortified samples and control. The dough cohesion property of the samples containing cladodes powders showed a very low CD value of 0.06 revealing a nearly insignificant effect of incorporation of cladodes powder on dough cohesion. However, CD of 0.41, 0.44 and 0.89 for the adhesion property, stickiness and hardness of dough, respectively, indicated a very significant difference, especially caused by the larger value of 20% incorporation cladodes powders.

Alveograph and textural evaluation of dough fortified with 0%, 10%, 15% and 20% of cladodes powder from *O. ficus indica* f shows that the dough became stiff and less elastic with increase cladodes in the blend. Sudha et al. (2007b) reported that dough became stiff with increase in apple pomace fraction in the blend. These authors reported that this result could be explained may be either due to the dilution of gluten proteins or interactions between polysaccharides and proteins from wheat flour. This rheological and textural change in dough properties may also be due to the interaction between fibrous materials and gluten, which affects the dough mixing properties as reported by Chen et al. (1988).

3.4. Baking test

3.4.1. Observations of cakes

Fig. 3 shows photos of cakes made with different level of cladodes powders incorporation. This figure shows a change in cakes quality with the incorporation of cladodes powders. In deed, with the increase of cladodes flours fraction, cakes crust became darker and greener especially at 20% concentration (Fig. 3a). Likewise, surface breakdowns were also observed with the increase of cladodes powders concentrations and especially with spineless cladodes powders (Fig. 3a). Cross-sections views are presented in Fig. 3b. A change in crumb cakes color was observed with cladodes powders incorporation. Cladodes powders addition made cakes greener.

3.4.2. Physical characteristic of cakes

Physical properties of cake are presented in Table 5. There was a significant difference in physical characteristic of cakes prepared

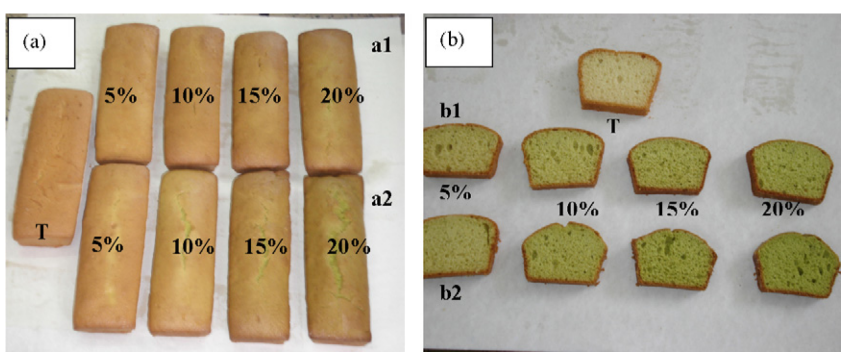

Fig. 3. Overall observations (a) and cross-section views (b) of cakes prepared with spiny (a1, b1) and spineless (a2, b2) cladodes flours.

Table 5
Effect of cladodes flours additions in physical characteristic of cakes prepared with wheat flour fortified with cladodes powder at 5, 10, 15 and 20% level.

	Weight (g)	Volume (cc)	Density (g/cc)	Hardness (N)
Control	253.89 ± 10.13^{a}	500.76 ± 15.32^{a}	0.507	1.097 ± 0.16^{a}
Spiny cladodes				
5%	260.58 ± 9.56^{ab}	534.15 ± 13.56^{b}	0.487	0.945 ± 0.23^{b}
10%	274.55 ± 11.35^{bd}	588.4 ± 11.41^{c}	0.466	1.103 ± 0.19^{a}
15%	279.14 ± 8.96^{d}	436.3 ± 10.26^{d}	0.639	1.256 ± 0.11^{c}
20%	281.49 ± 10.06^{d}	420.35 ± 12.35^{e}	0.669	2.026 ± 0.21^{e}
Spineless cladodes				
5%	262.27 ± 12.56^{ab}	534.25 ± 9.98^{b}	0.491	0.919 ± 0.25^{b}
10%	262.22 ± 10.32^{ab}	618.35 ± 8.14^{f}	0.424	1.094 ± 0.11^{a}
15%	268.90 ± 9.63^{bd}	488.86 ± 10.49^{g}	0.550	1.104 ± 0.14^{a}
20%	274.07 ± 10.46^{bd}	454.87 ± 12.56^{h}	0.603	1.821 ± 0.18^{d}
CD ($P < 0.05$)	0.45	0.84	–	0.59

Means followed by the same letter within column are non-significantly different ($P < 0.05$).

Table 6
Effect of cladodes powders additions on the color characteristic of cakes prepared with wheat flour fortified with cladodes powder at 5, 10, 15 and 20% levels.

	L^*	a^*	b^*	ΔE^*
Crust				
Control	54.19 ± 0.52[a]	15.79 ± 0.09[a]	37.94 ± 0.52[a]	68.01 ± 0.81[a]
Spiny cladodes				
5%	49.4 ± 0.18[b]	13.35 ± 0.02[b]	33.77 ± 0.17[dc]	60.94 ± 0.22[bc]
10%	46.65 ± 0.1[c]	12.50 ± 0.01[c]	33.09 ± 0.06[ef]	58.93 ± 0.2[ef]
15%	44.77 ± 0.1[d]	9.12 ± 0.01[e]	30.70 ± 0.0[g]	54.24 ± 0.26[h]
20%	43.45 ± 0.1[d]	8.76 ± 0.02[f]	30.08 ± 0.0[g]	53.46 ± 0.2[g]
Spineless cladodes				
5%	50.1 ± 0.29[b]	12.54 ± 0.07[c]	34.76 ± 0.29[b]	62.17 ± 0.99[b]
10%	48.83 ± 0.25[b]	10.14 ± 0.05[d]	33.42 ± 0.25[de]	60.15 ± 0.19[ce]
15%	47.24 ± 0.26[c]	8.53 ± 0.1[g]	32.54 ± 0.26[f]	58.01 ± 0.25[fg]
20%	46.14 ± 0.19[c]	5.36 ± 0.05[h]	32.24 ± 0.25[f]	57.12 ± 0.9[g]
CD (P < 0.05)	0.466	0.955	0.469	0.748
Crumb				
Control	74.01 ± 1.73[a]	−3.98 ± 0.13[a]	27.05 ± 0.19[a]	81.14 ± 1.87[a]
Spiny cladodes				
5%	64.77 ± 0.93[b]	−5.21 ± 0.17[b]	33.91 ± 0.03[b]	77.68 ± 0.57[b]
10%	61.92 ± 0.99[d]	−6.76 ± 0.04[d]	34.77 ± 0.06[b]	74.64 ± 0.19[c]
15%	61.18 ± 0.55[d]	−8.43 ± 0.01[f]	37.05 ± 0.31[cd]	76.64 ± 1.06[b]
20%	60.87 ± 0.54[d]	−8.24 ± 0.05[f]	39.32 ± 0.19[e]	77.94 ± 0.6[b]
Spineless cladodes				
5%	69.23 ± 0.56[c]	−6.36 ± 0.04[c]	36.34 ± 0.09[c]	80.44 ± 1.02[a]
10%	60.38 ± 0.77[de]	−7.66 ± 0.09[e]	38.13 ± 0.22[d]	76.57 ± 0.50[b]
15%	59.7 ± 0.18[e]	−9.65 ± 0.0[g]	39.69 ± 0.99[e]	76.86 ± 0.52[b]
20%	58.9 ± 0.37[e]	−10.65 ± 0.33[h]	40.16 ± 0.51[e]	77.21 ± 1.6[b]
CD (P < 0.05)	0.635	0.902	0.305	0.401

Means followed by the same letter within column are non-significantly different (P < 0.05).

with fortified flours and control (P < 0.05) indicating by CD values. At 20% levels of cladodes powders, cakes density increased from 0.507 to 0.669 and 0.603 with spiny and spineless cladodes flours, respectively. These results are also reflected in the hardness measurement values. In deed at 20% levels of cladodes flours, cake hardness increased from 1.097 to 2.026 and 1.821 with spiny and spineless cladodes powders, respectively. Sudha et al. (2007a) reported an increase in cakes density prepared with apple pomace flours as a source of dietary fiber. They reported that the increase of cakes density due to the strong water holding capacity of apple pomace fiber.

3.4.3. Cakes color

The effects of cladodes flours addition on the cakes color are shown in Table 6. Significant differences were observed between the crust and crumb of the control cake and the cake obtained with fortified dough. In terms of crust, significant differences were observed between the crusts of the control cake and those of cladodes powders supplemented cakes (P < 0.05). The control cake gave higher L^* values compared to the samples supplemented with cladodes flours. A decrease in L^* was showed with the addition of cladodes flours (54.19 in control to 43.45 and 46.14 in cakes prepared with spiny and spineless cladodes flours up to 20% level, respectively). This is mainly due to Maillard and caramelization reactions. Cakes formulated with 5% of cladodes powders gave higher a^* and b^* crust color values than cakes with 20% of cladodes flours. The cakes formulated with 20% cladodes flours were more affected by Maillard and caramelization reactions compared to the cakes with 5% cladodes flours due to their higher ratio of flour. For crumb color values, as cladodes powders substitution rate increased, L^* values changed from white to gray, a^* values changed from red to green and b^* values changed from blue to yellow. The increase in ratio of cladodes flours decreased crumb L^* and a^* values and increase b^* values. Sudha et al. (2007b) studied the effect of fiber addition from different cereals on the biscuit quality. These authors reported that the biscuits became darker with increasing level of

Table 7
Sensory evaluation of cakes prepared by incorporated spiny and spineless cladodes flours in wheat flours at levels of 5%, 10%, 15% and 20%.

	Color		Texture	Flavour	Taste	Grain	Overall acceptability
	Crust	Crumb					
Control	3.56 ± 0.84[a]	3.48 ± 1.08[a]	3 ± 0.95[a]	3.18 ± 0.91[a]	3.73 ± 0.96[a]	2.74 ± 1.09[a]	3.09 ± 0.87[a]
Spiny cladodes							
5%	3.21 ± 0.91[bc]	3.61 ± 0.89[a]	2.95 ± 0.97[a]	2.72 ± 0.55[b]	2.6 ± 1.03[b]	2.65 ± 0.71[ab]	3 ± 0.82[a]
10%	2.91 ± 0.94[bc]	3.43 ± 0.89[ab]	3.04 ± 0.76[a]	2.54 ± 0.8[b]	2.61 ± 0.72[b]	2.22 ± 0.79[bc]	2.27 ± 0.83[b]
15%	2.48 ± 1.08[cd]	2.95 ± 0.87[abcd]	2.87 ± 0.86[ab]	1.95 ± 0.84[bc]	2.30 ± 0.81[bc]	1.65 ± 0.77[de]	1.9 ± 0.68[b]
20%	2.17 ± 0.99[d]	2.74 ± 0.78[cd]	2.74 ± 0.89[ab]	1.72 ± 0.75[d]	2.26 ± 0.88[bc]	1.56 ± 0.81[e]	1.77 ± 0.77[b]
Spineless cladodes							
5%	3.3 ± 0.97[ab]	3.34 ± 0.93[abc]	2.86 ± 0.97[ab]	2.72 ± 0.45[b]	2.87 ± 1.1[b]	2.61 ± 0.78[ab]	2.82 ± 0.9[a]
10%	2.78 ± 0.95[bcd]	2.95 ± 0.93[abcd]	2.65 ± 0.88[ab]	2.36 ± 0.66[bc]	2.35 ± 0.77[bc]	2.08 ± 0.67[cd]	2.32 ± 0.72[b]
15%	2.55 ± 1.02[cd]	2.78 ± 0.99[bcd]	2.47 ± 0.89[ab]	1.91 ± 0.97[cd]	1.78 ± 0.9[c]	1.78 ± 0.9[cde]	1.94 ± 0.78[b]
20%	2.17 ± 0.89[d]	2.48 ± 1.01[d]	2.26 ± 0.77[b]	1.72 ± 0.54[d]	1.78 ± 0.56[c]	1.48 ± 0.81[e]	1.81 ± 0.76[b]
CD (P < 0.05)	0.165	0.086	0.077	0.393	0.371	0.229	0.176

Means followed by the same letter within column are non-significantly different (P < 0.05).

either of the bran except for barley bran incorporation where the percent whiteness was reduced marginally.

3.4.4. Sensorial analysis

The effects of cladodes powders supplementation on the sensory characteristics of cakes are presented in Table 7. Results from sensory evaluation indicated that cladodes flours had significant effects on cakes quality ($P < 0.05$). With the increase in the level of cladodes flours in formulation, the sensory scores for organoleptic characteristics of cakes decreased. The same observations are also found by Sudha et al. (2007a) for cake obtained from dough fortified with pomace fiber. The control samples had maximum overall acceptability, whereas cakes containing 15% and 20% of cladodes flours were found to be unacceptable to the panelists. The overall acceptability score for control was 3.09 on a 5-point hedonic scale. Cakes made from blends containing 5% level of cladodes flours did not differ significantly ($P < 0.05$) from the control. At 15% and 20% levels of substitution, the overall acceptability was rated as poor. From the overall acceptability rating, it was concluded that cladodes flour could be incorporated up to 5% level in the formulation of cakes. Sudha et al. (2007a) reported that apple pomace flours could be incorporated up to 10% level in the formulation of cakes.

4. Conclusion

Physico-chemical analysis of spiny (*O. ficus indica* f. *amylocea)* and spineless cladodes (*O. ficus indica* f. *inermis)* obtained from cactus plant growth in Mediterranean area (Tunisia) shows a great richness on bio-molecule witch could be valorized by including cladodes powders in food formulation to improve nutritional, technological and stability of formulated food stuffs. Fortification of wheat flours by cladodes powders as a source of dietary fiber leads to a change in dough properties. Cladodes like any other fiber source increase water absorption capacity of the flours and consequently the dough properties. Cladodes flours were found to affect quality parameters of dough and cakes significantly. Alveograph and textural properties results showed that addition of cladodes powders increase dough tenacity and decrease its elasticity. Baking test shows that cladodes incorporation cause a great change on cake aspect and quality especially for levels more than 10%. After cladodes flours addition the cake color become greener and the crust become darker. Cladodes addition in cake making can avoid the addition of other synthetic green color compounds as the cake prepared with cladodes flours had a nature color of pistachio. The sensory characteristics of cakes prepared with cladodes flours showed that control cakes had the highest total sensory evaluation scores. However, cakes with 5% cladodes flours had also acceptable results.

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