International Journal of Food Sciences and Nutrition

ISSN: 0963-7486 (Print) 1465-3478 (Online) Journal homepage: www.tandfonline.com/journals/iijf20

Cladodes from prickly pear as a functional ingredient: effect on fat retention, oxidative stability, nutritional and sensory properties of cookies

Lotfi Msaddak, Rayda Siala, Nahed Fakhfakh, M. A. Ayadi, Moncef Nasri & Nacim Zouari

To cite this article: Lotfi Msaddak, Rayda Siala, Nahed Fakhfakh, M. A. Ayadi, Moncef Nasri & Nacim Zouari (2015) Cladodes from prickly pear as a functional ingredient: effect on fat retention, oxidative stability, nutritional and sensory properties of cookies, International Journal of Food Sciences and Nutrition, 66:8, 851-857, DOI: 10.3109/09637486.2015.1095862

To link to this article: https://doi.org/10.3109/09637486.2015.1095862

Published online: 12 Oct 2015.

INTERNATIONAL JOURNAL OF FOOD SCIENCES and NUTRITION

http://informahealthcare.com/ijf
ISSN: 0963-7486 (print), 1465-3478 (electronic)

Int J Food Sci Nutr, 2015; 66(8): 851–857
 DOI: 10.3109/09637486.2015.1095862

Taylor & Francis
Taylor & Francis Group

FOOD COMPOSITION AND ANALYSIS

Cladodes from prickly pear as a functional ingredient: effect on fat retention, oxidative stability, nutritional and sensory properties of cookies

Lotfi Msaddak[1], Rayda Siala[1], Nahed Fakhfakh[1], M. A. Ayadi[2], Moncef Nasri[1], and Nacim Zouari[3]

[1]Laboratory of Enzyme Engineering and Microbiology, ENIS, University of Sfax, Sfax, Tunisia, [2]Laboratory of Food Analysis, ENIS, University of Sfax, Sfax, Tunisia, and [3]High Institute of Applied Biology of Medenine, University of Gabes, Medenine, Tunisia

Abstract

The stems of *Opuntia ficus-indica* known as cladodes are rich source of bioactive and functional substances, which make them important candidate for the production of health-promoting food. Cladodes powder was incorporated at different levels of substitution (2.5%, 5% and 7.5%) in cookies (butter/wheat flour: 55/100 m/m). Substitution of wheat flour by cladodes powder improved dietary fiber, ash, potassium, magnesium and calcium contents of enriched cookies. The results also revealed that cladodes supplementation increased hardness; however, it decreased *a** and *b** values and reduced exudate loss of cookies during storage. Moreover, rising levels of cladodes powder contribute to the increase of antioxidant activity of cookies and decreased their oxidative degradation. Sensory evaluation showed that cladodes supplementation at 5% level remained acceptable at 5-point hedonic scale. The present study suggested that cladodes supplementation in high-fat cookies not only added nutritional value to food, but also improved its functional characteristics.

Keywords

Dietary fiber, fat retention, functional cookies, *Opuntia* cladodes, oxidative stability

History

Received 22 April 2015
Revised 13 June 2015
Accepted 15 September 2015
Published online 13 October 2015

Introduction

Lipid auto-oxidation produced during the manufacturing process and food storage leads to an increase in reactive radicals initiating further reactions whose products cause changes in taste, smell and colour and therefore a loss of food quality. The rate of lipid auto-oxidation may be influenced by many factors, such as exposure to air, light and temperature and content of unsaturated fatty acids (Mau et al., 2004). Bakery products, such as cookies containing high amount of butter, are widely distributed among consumers in many countries. Refined wheat flour being the base material of cookies may lack appreciable concentrations of fiber, minerals and antioxidants, which become highly required for their interest to human health. In fact, the regular intake of natural antioxidants can decrease the risk of various diseases by reducing oxidative stress (Kris-Etherton et al., 2002). Moreover, the addition of dietary fiber to food gives the following three different types of benefits: first, their nutritional value which is advised by nutritionists; second, their technofunctional properties that are of great interest to food manufacturers; finally, dietary fiber may also be used to upgrade agricultural products and by-products for use as food ingredients (Thebaudin et al., 1997). Several studies reported on the use of green leafy vegetables in biscuits in order to improve their nutritional properties, such as *Moringa oleifera*, *Murraya koenigii* and *Tinospora cordifolia* dried leaves. Indeed, the contents of protein, dietary fiber, minerals, β-carotene and radical-scavenging activity in biscuits increased with the incorporation of high levels of these leaves (Dachana et al., 2010; Drisya et al., 2015; Sharma et al., 2013). Furthermore, Ismail et al. (2014) studied the effect of pomegranate peel supplementation on nutritional and organoleptic properties of cookies. Thus, they show an increase in total phenolics and antioxidant potential and a reduction in oxidative degradation during the storage of supplemented cookies.

The actual trend to find new sources of functional ingredients in agroresources that have traditionally been undervalued is more important. In this context, the various potentially active nutrients and their multifunctional properties make cladodes (stems) from prickly pear (*Opuntia ficus-indica*) important candidates for the production of health-promoting food and food supplements. The prickly pear cactus is endemic to America and it is widely distributed in Africa and the Mediterranean basin. In Mexico, freshly harvested cladodes (nopalitos) are widely consumed as vegetables. Moreover in folk medicine, the prickly pear cactus stems are used to treat diabetes, hyperlipidemia, obesity and gastrointestinal disorders (Kaur et al., 2012). The *Opuntia* cladodes are known as a source of a varied number of nutritional compounds, such as dietary fiber, minerals, vitamins and antioxidant compounds (Feugang et al., 2006). Lee et al. (2002) reported that ethanol extract of the prickly pear cladodes is characterized by a high amount of phenolics and important antioxidant potential evaluated by various complementary methods. Ayadi et al. (2009) characterized cactus cladodes in terms of technological properties. In fact, cladodes flower presents important hydration properties described by swelling, water solubility index and water-holding capacity. López-Cervantes et al. (2011) reported that the application of high

Correspondence: Dr Nacim Zouari, High Institute of Applied Biology of Medenine, 4119 Medenine, University of Gabes, Medenine, Tunisia. Tel: + (216) 75633919. Fax: + (216) 75633918. E-mail: znacim2002@yahoo.fr

thermal treatments during the preparation of cactus pear cladodes flours affects the water absorption capacity and the green colour negatively. Thus, the cladodes flours prepared at 60 °C presented higher techno-functional properties and are considered the most adequate for the formulation of dietary supplements. Furthermore, it was mentioned that unpeeled whole cladodes and dried in air-forced tunnel provides powders with higher dietary fiber and bioactive compounds contents (Sepúlveda et al., 2013).

Few reports have been published on the industrial uses of cactus cladodes as a source of antioxidants and dietary fiber. A dried powder of spineless cladodes from the Mediterranean *Opuntia ficus-indica* f. *inermis* was prepared and characterized in terms of chemical and technological properties. The objective of the study was to evaluate the effect of cladodes powder substitution to wheat flour on the nutritional characteristics (i.e. minerals, dietary fiber and antioxidant activities), colour, hardness and sensory properties of cookies containing high amount of butter. Moreover, exudate loss and lipid oxidative stability of cookies during storage were assessed.

Materials and methods

Plant material and cladodes powder preparation

Cladodes from *Opuntia ficus-indica* f. *inermis* (spineless cladodes) were collected on March 2014 from the area of Sfax (Tunisia) characterized by a mean rainfall of 200–300 mm/year (Latitude 34°45′32″N; Longitude 10°41′50″E). The mass of collected cladodes ranged between 400 and 600 g. Cladodes were washed, cut lengthwise into a rectangular shape and dried in convection oven at 50 °C during 6 h (Polin A511088/AL/3125, Verona, Italy). The dried products were ground in a spice grinder (Black & Decker CBG100S Smartgrind, MD), sieved through 250 µm sieve and the obtained powder (Figure 1A) was stored at 25 °C before use.

Chemical analysis

Moisture, protein, fat, total carbohydrates and ash contents were determined according to A.O.A.C. (1995). Dietary fiber content was determined according to the gravimetric enzymatic method as previously described by Prosky et al. (1988). Minerals concentrations were determined after an acid digest of each sample with a nitric/perchloric acid (2:1, v/v) mixture. Potassium [K], magnesium [Mg], calcium [Ca], sodium [Na], zinc [Zn] and iron [Fe] were analyzed separately using an atomic absorption spectrophotometer (Hitachi Z6100, Tokyo, Japan). Total chlorophyll and β-carotene contents were determined according to the methods previously described (Ayadi et al., 2009). Total phenolics, flavonoids and tannins were measured in ethanolic extract of cladodes powder as previously described (Dewanto et al., 2002; Sun et al., 1998). The cladodes powder (25 g) was soxhlet-extracted using 300 ml of ethanol during 6 h. The solvent was then evaporated under vacuum and the residual solvent was removed by flushing with nitrogen. Finally, the obtained ethanolic extract was kept in the dark at 4 °C until further analysis. Total phenolics content was expressed as milligram gallic acid equivalent/100 g of dry matter. Flavonoids content was expressed as milligram quercetin equivalent/100 g of dry matter. Tannins content was expressed as milligram catechin equivalent/100 g of dry matter.

Functional characteristics of cladodes powder

Cladodes powder swelling (volume/g of cladodes dry matter) was measured as previously described (Ayadi et al., 2009). The water-holding capacity (WHC) was expressed as gram of water bound per gram of cladodes dry matter and fat absorption capacity (FAC) was expressed as gram of oil bound per gram of cladodes dry matter (Ayadi et al., 2009).

Colour measurement

Colour measurement parameters (Lightness L^*, redness a^* and yellowness b^*) were carried out using a colour flex spectro-colorimeter (Hunter Associates Laboratory Inc., Reston, VA). L^* value indicates the lightness, 0–100 representing dark to light, a^* value gives the degree of the green–red colour, with a higher positive a^* value indicating more red. The b^* value indicates the degree of the blue–yellow colour, with a higher positive b^* value indicating more yellow.

Preparation of cookies

Cookies were prepared in a local pastry industry (Société Pâtisserie-Masmoudi, Sfax, Tunisia) and the standard cookies formulation consisted of: 100 g wheat flour, 55 g butter, 40 g sugar, 20 g egg white and 1.2 g sodium chloride. Cookies with variable concentrations of cladodes powder were made from blends containing a mixture of wheat flour and cladodes powder in the ratios of 100/0 (control), 97.5/2.5, 95/5 and 92.5/7.5 m/m. The formulations containing cladodes powder were made without sodium chloride addition. The butter was beaten in a mixer for 15 min at medium speed. Then, the homogeneous mixture of wheat flour along with preweighed proportions of cladodes powder were added and mixed for further 15 min. After that, the ground sugar and egg whites were added to butter flour mass and the mixture was homogenized using medium speed for 5 min. The resulting dough passes through the Bench-top dropping machine with wire cut (FBM Boscolo, Legnano, Italy) and the obtained cookies were placed in stainless steel trays. Baking was done at 170 °C for 17 min. Finally, cookies were cooled to room temperature and stored in airtight glass jars for further analysis.

Exudate loss and hardness of cookies

Cookies (almost 100 g) were placed in an enclosed area on several layers of whatman papers, which absorb oil. Temperature (28.3 °C) and humidity (56.6% RH) were measured by a Kistock datalogger (Kimo, Montpon, France) and they were constant during the storage period. Exudate loss was measured as

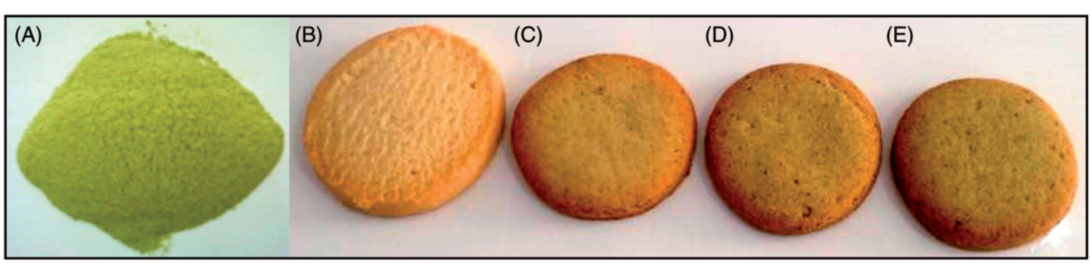

Figure 1. Photograph of cladodes powder from *Opuntia ficus indica* (A) and cookies prepared with 2.5% (C), 5% (D) and 7.5% (E) of cladodes powder. (B) represents the control product without cladodes powder.

the percentage loss of cookies in comparison with the initial mass, during 30 days of storage. Hardness of cookies was measured using a texturometer (Lloyd Instruments Ltd., West Sussex, UK) as previously described by Ayadi et al. (2009).

Peroxide value determination, antioxidant activity and hardness of cookies

Fat was extracted from cookies and oxidation was evaluated by determining the peroxide value (PV) at 1 and 30 days of storage, as previously described (Zouari et al., 2010). Antioxidant activity was also determined in ethanol extract of cookies at 1 and 30 days of storage. Cookies samples were converted into fine powder by using pestle and mortar. Then, about 5 g of powdered sample were homogenized with 25 ml ethanol for 2 h at ambient temperature using an orbital shaker at stirring speed of 250 rpm. After centrifugation at 8000 rpm for 30 min, the supernatant (ethanolic extract) was recovered and kept in the dark at 4 °C until further analysis. The DPPH● radical-scavenging activity (%) and the reducing power (absorbance at 700 nm) of cookies were measured as previously described (Kirby & Schmidt, 1997; Yildirim et al., 2001). In the reducing power assay, the presence of antioxidants in the sample would result in the reducing of Fe^{3+}–Fe^{2+} by donating an electron. An amount of Fe^{2+} complex can then be monitored by measuring the formation of Perl's Prussian blue ($Fe_4[Fe(CN)_6]3$) at 700 nm. Increasing absorbance at 700 nm indicates an increase in reductive ability.

Sensory evaluation

The sensory properties (colour, odour, taste, crispiness, chewiness and overall acceptability) were evaluated according to the method of Murray et al. (2001) by 60 panelists. A five-point hedonic scales were used, where 5 = like very much, 4 = like moderately, 3 = like slightly, 2 = dislike moderately, 1 = dislike very much for each organoleptic characteristic.

Statistical analysis

All analytical determinations were performed in triplicate. One-way analysis of variance (ANOVA) was conducted using SPSS software, 17.0. A difference was considered statistically significant when $p < 0.05$.

Results and discussion

Cladodes powder characteristics

The results for the cladodes powder chemical characteristics were presented in Table 1. Protein (7.43%), fat (3.02%) and total carbohydrates (59.16%) contents of cladodes powder reported in this investigation were within the values described by Ayadi et al. (2009). However, ash content (27.78%) observed in this study was higher than the value reported by Ayadi et al. (2009) for cladodes of the same species. Cladodes powder was a good source of dietary fiber being 28.84%. Administration of *Opuntia* lyophilized cladodes in rats revealed a protective action against ethanol-induced ulcer. In fact, cladodes fiber probably may affect the gastrointestinal mucosa regeneration (Galati et al., 2003). Table 1 showed that total chlorophyl (802 mg/100 g), β-carotene (2.75 mg/100 g) and total phenolics (2485 mg/100 g) contents were higher as compared to the findings of Ayadi et al. (2009) for cladodes of the same species; differences may be associated with the collecting season and the geographic regions. Phenolic compounds are mainly responsible for the antioxidant properties and several studies were devoted to find natural antioxidants in cheap raw materials (Dziki et al., 2014). Compared to other agro-resources, *Opuntia* cladodes could be considered as an important source of natural antioxidants. It was reported that quercetin 3-methyl ether, a flavonoid isolated from *Opuntia* cladodes, exhibits potent neuroprotective action in primary cultured rat cortical cells through antioxidant actions (Dok-Go et al., 2003).

Textural and stabilizing properties of cladodes powder result from the hydration properties of its fiber. Therefore, hydration properties described by swelling and water holding capacity (WHC) were presented in Table 1. Cladodes powder prepared in this study showed swelling value (6.31 cm^3/g) similar to the finding of Ayadi et al. (2009) for cactus cladodes or to other vegetable sources, such as wheat and carrot fiber (Thebaudin et al., 1997). However, a higher WHC (795 g water/100 g dry sample) was obtained as compared to the value (315 g water/100 g dry sample) reported for cladodes of the same species (Ayadi et al., 2009). Apple, pea, wheat, sugar beet and carrot fiber presented WHC values ranging from 250 to 1000 g water/100 g dry sample (Thebaudin et al., 1997). Flours with high WHC have more hydrophilic constituents. Moreover, López-Cervantes et al. (2011) reported that drying conditions affect the functional properties of dehydrated powders. Owing to its high water retention ability and swelling properties, cactus pear cladodes powder could be appropriate to improve texture and stability of a variety of foods such as bakery products. Table 1 also shows that fat absorption capacity (FAC) of cladodes powder (177.5 g oil/100 g dry sample) was comparable to the value reported by Ayadi et al. (2009) for cladodes flour from the same species or fiber of others vegetables, such as apple, pea, wheat, sugar beet and carrot (Thebaudin et al., 1997). Hydrophobic constituents, such as insoluble fiber, are the main responsible for FAC. This property could be exploited in some foods to enhance their retention of fat and flavor and to increase the technological yield (Thebaudin et al., 1997).

Colour parameters of cladodes powder were also presented in Table 1. The prepared powder showed a high lightness value (L^*: 65.27), a yellow colour (b^*: 26.17) and a low intensity of the green colour (a^*: −9.37) (Figure 1A). Ayadi et al. (2009) reported that cladodes flour from the same species has comparable colour parameters with regard to green (a*: −8.45) and yellow (b*: 25.53) colours, but with higher luminosity (L^*: 73.53). The drying

Table 1. Chemical, colour and functional characteristics of cladodes powder from *Opuntia ficus-indica*.

Parameters	
Moisture	8.10 ± 0.25
Protein[a]	7.43 ± 0.60
Fat[a]	3.02 ± 0.13
Ash[a]	27.78 ± 0.53
Total carbohydrates[a]	59.16 ± 1.12
Dietary fiber[a]	28.84 ± 0.76
Total chlorophyll[b]	802 ± 10
β-Carotene[b]	2.75 ± 0.15
Total phenolics[c]	2485 ± 61
Flavonoids[d]	1063 ± 32
Tannins[e]	921 ± 43
L^*	65.27 ± 0.58
a^*	−9.37 ± 0.44
b^*	26.17 ± 0.61
Swelling index (cm^3/g)	6.31 ± 0.09
Water holding capacity[a]	795 ± 40
Fat absorption capacity[a]	177.5 ± 10

[a]g/100 g of dry matter.
[b]mg/100 g of dry matter.
[c]mg gallic acid equivalents/100 g of dry matter.
[d]mg quercetin equivalents/g extract.
[e]mg catechin equivalent/100 g of dry matter.

Table 2. Chemical composition (g/100 g of dry matter) of cookies prepared with wheat flour substituted with cladodes powder.

Substitution level (g/100 g of wheat flour)	Moisture	Fat	Protein	Ash	Total carbohydrates	Dietary fiber
0 (control)	2.89 ± 0.05^a	24.22 ± 0.08^a	9.26 ± 0.10^a	1.19 ± 0.02^a	63.91 ± 0.98^a	0.40 ± 0.02^a
2.5	2.91 ± 0.02^a	24.25 ± 0.10^a	9.20 ± 0.08^a	1.80 ± 0.05^b	63.31 ± 0.74^a	0.95 ± 0.04^b
5	2.92 ± 0.02^a	24.33 ± 0.09^a	9.14 ± 0.09^a	2.54 ± 0.03^c	62.78 ± 0.91^a	1.76 ± 0.02^c
7.5	2.91 ± 0.03^a	24.30 ± 0.08^a	9.08 ± 0.08^a	3.21 ± 0.02^d	62.36 ± 0.98^a	2.42 ± 0.03^d

Values with same superscript letters in the same column are non-significant at $p < 0.05$.

Table 3. Minerals (mg/100 g of dry matter) of cladodes powder and cladodes supplemented cookies.

Substitution level (g/100 g of wheat flour)	K	Mg	Ca	Na	Zn	Fe
Cladodes powder	2266.50 ± 2.20^a	586.89 ± 1.29^a	446.20 ± 1.14^a	146.92 ± 1.18^a	4.87 ± 0.04^a	14.02 ± 0.12^a
0 (control)	139.48 ± 1.03^e	24.02 ± 0.10^e	2.93 ± 0.03^e	32.95 ± 0.07^e	0.27 ± 0.01^e	0.95 ± 0.08^e
2.5	176.02 ± 0.63^d	32.32 ± 0.15^d	10.27 ± 0.06^d	35.64 ± 0.08^d	0.46 ± 0.01^d	1.13 ± 0.04^d
5	215.45 ± 1.11^c	40.19 ± 0.81^c	19.12 ± 0.05^c	37.83 ± 0.08^c	0.55 ± 0.01^c	1.73 ± 0.07^c
7.5	260.07 ± 1.40^b	52.85 ± 0.60^b	30.16 ± 0.05^b	38.68 ± 0.03^b	0.69 ± 0.01^b	2.14 ± 0.01^b

Values with same superscript letters in the same column are non-significant at $p < 0.05$.

Table 4. Colour characteristics and hardness of cookies prepared with wheat flour substituted with cladodes powder.

Substitution level (g/100 g of wheat flour)	*L**	*a**	*b**	Hardness (*N*)
0 (control)	73.30 ± 0.57^a	6.11 ± 0.03^a	24.69 ± 0.51^a	59.28 ± 1.56^a
2.5	69.56 ± 0.61^b	4.32 ± 0.02^b	22.45 ± 0.50^b	67.07 ± 0.92^b
5	68.16 ± 0.49^c	2.01 ± 0.03^c	21.72 ± 0.40^c	82.08 ± 0.88^c
7.5	67.50 ± 0.41^c	1.20 ± 0.03^d	20.42 ± 0.30^d	91.85 ± 0.69^d

Values with same superscript letters in the same column are non-significant at $p < 0.05$.

temperature and the maturity of the cladodes play an important role in the determination of the colour of the resulted powder (López-Cervantes et al., 2011).

Nutritional composition of cookies

Table 2 shows the chemical composition of cookies prepared with wheat flour substituted by cladodes powder of 2.5 to 7.5%. Relatively slight but not significant changes ($p > 0.05$) in moisture, protein, fat and total carbohydrates contents of control and supplemented cookies were observed. A significant ($p < 0.05$) increase in ash and dietary fiber contents was observed in cookies made with cladodes powder compared to the control product. As a matter of fact, the dietary fiber content increased from 0.40 to 0.95, 1.76 and 2.42% with the addition of 2.5, 5 and 7.5% cladodes powder, respectively. The ash content of control and cookies with different levels of cladodes powder ranged between 1.19 and 3.21%. These changes were due to the elevated levels of these nutrients within the prickly pear cladodes. Improvement in the nutritional characteristics, such as dietary fiber, minerals, proteins, antioxidant potential and shelf life with the use of vegetables flours in bakery products have also been reported (Dachana et al., 2010; Drisya et al., 2015; Ismail et al., 2014; Sharma et al., 2013).

Table 3 showed that potassium (2266.50 mg/100 g) was the most abundant mineral in cladodes, followed by magnesium (586.89 mg/100 g), calcium (446.20 mg/100 g) and sodium (146.92 mg/100 g). Potassium was also the abundant mineral in Mexican cladodes (Ayadi et al., 2009). Thus, the cladodes powder can be considered as a good source of most dietary minerals especially calcium, magnesium and potassium. Consequently, a significant ($p < 0.05$) improvement in minerals contents was observed for cladodes-supplemented cookies (Table 3). In fact, cladodes powder was found to improve essentially potassium, magnesium, and calcium concentrations of control by 139.48–260.07 mg/100 g, 24.02–52.85 mg/100 g and 2.93–30.16 mg/100 g, respectively at 7.5% level of substitution.

Quality characteristics and antioxidant activity of cookies

The effect of cladodes powder addition on the cookies colour characteristics was presented in Table 4. Cookies were found to be darker than control, as shown by lower *L** value, with different levels of cladodes powder ($p < 0.05$). The obtained results showed a decrease in *L** value from 73.3 (control product) to 67.5 in cookies prepared with 7.5% level of cladodes powder. Moreover, as cladodes powder substitution level increased *a** and *b** values decreased, which indicates that yellow colour decreased toward a greenish colour (Figure 1). This could be explained mainly by the richness of cladodes powder in chlorophyll. The results presented in Table 4 also showed that addition of increasing levels of cladodes powder from 0% to 7.5% caused an increase in the cookies hardness from 59.28 to 91.85 N. Indeed, improvement of dietary fiber contents in cladodes-supplemented cookies, that is, 0.40–2.42% resulted in harder product. Sharma et al. (2013) also reported an increase in cookies hardness from 68.5 to 88.7 N with the addition of *Tinospora cordifolia* leaf powder.

Lee et al. (2002) reported that prickly pear cladodes are characterized by a high amount of phenolics, which might be the

Table 5. Antioxidant activity, oxidation and exudates loss of cookies enriched with cladodes powder during storage.

Substitution level (g/100 g of wheat flour)	Scavenging activity[e]		Reducing power[e]		PV (mEq/kg)		Exudate loss (%)
	Day 1	Day 30	Day 1	Day 30	Day 1	Day 30	Day 30
0 (control)	30.21 ± 0.31^{a}	23.02 ± 0.47^{a}	0.42 ± 0.03^{a}	0.29 ± 0.02^{a}	1.31 ± 0.12^{a}	8.25 ± 0.13^{a}	3.39 ± 0.08^{a}
2.5	35.05 ± 0.49^{b}	27.95 ± 0.59^{b}	0.51 ± 0.02^{b}	0.38 ± 0.01^{b}	1.18 ± 0.08^{a}	6.17 ± 0.12^{b}	2.28 ± 0.06^{b}
5	41.52 ± 0.39^{c}	32.05 ± 0.57^{c}	0.71 ± 0.02^{c}	0.58 ± 0.02^{c}	1.29 ± 0.10^{a}	5.21 ± 0.14^{c}	1.34 ± 0.02^{c}
7.5	53.29 ± 0.26^{d}	49.34 ± 0.38^{d}	0.87 ± 0.01^{d}	0.73 ± 0.02^{d}	1.10 ± 0.09^{a}	4.05 ± 0.11^{d}	1.07 ± 0.02^{d}

Values with same superscript letters (a–d) in the same column are non-significant at $P < 0.05$.
[e]DPPH● radical-scavenging activity (%) and reducing power (absorbance at 700 nm) were determined at a concentration of 50 mg of cookies/ml.

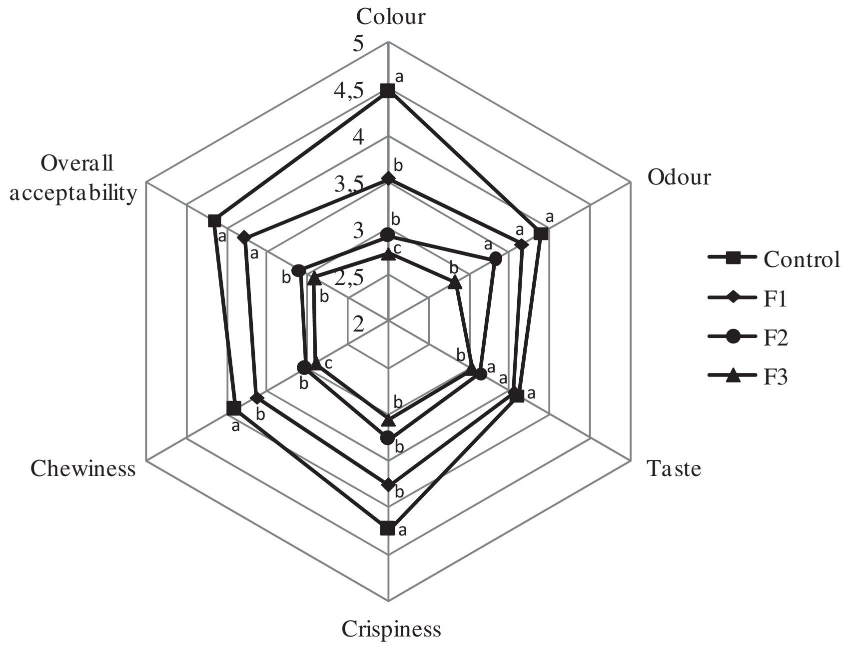

Figure 2. Sensory evaluation of cookies prepared with wheat flour fortified with cladodes powder. Control represents the product without cladodes powder. F1, F2 and F3 represent the formulations containing 2.5, 5 and 7.5% of cladodes powder, respectively. The average scores for an attribute with the same superscript letters are non-significant at $p < 0.05$.

active compounds responsible for the antioxidant properties of the cladodes powder. In addition, phenolics retain their antioxidant activity after the baking process, which has potential health benefits for consumers (Dziki et al., 2014). Thereby, antioxidant activity of cladodes-supplemented cookies was evaluated by DPPH● radical-scavenging activity and ferric reducing power at 1 and 30 days of storage (Table 5). Cookies prepared with 100% wheat flour were attributed to the lowest DPPH● radical-scavenging activity (30.21% on day 1 and 23.02% on day 30). Interestingly, at 7.5% level of cladodes supplementation, cookies exhibited the highest DPPH● radical-scavenging activity (53.29% on day 1 and 49.43% on day 30). Moreover, a comparable trend was also noticed for ferric-reducing power assay. In fact, ferric-reducing power for control cookies was (0.42 on day 1 and 0.29 on day 30) and it increased to (0.87 on day 1 and 0.73 on day 30) at 7.5% substitution level of cladodes powder. Table 5 also shows a reduction of antioxidant activity after 30 days of storage for all samples. The greatest reduction of antioxidant activity was obtained in control cookies, which could result in a negative effect on the storage stability of the product. Interestingly, cladodes-supplemented cookies could retain most of their antioxidants, since they showed relatively a small decrease in antioxidant activity after 30 days of storage. Further researches may be conducted to determine the types and amount of antioxidants present in these cladodes-supplemented cookies. Reddy et al. (2005) reported that addition of plant extracts from *Emblica officianalis*, *Moringa oleifera* and *Vitis vinifera* gave an excellent antioxidant effect on the biscuits as compared with the effect of synthetic butylhydroxyanisole (BHA). The obtained results suggest that the antioxidant potential of cladodes-supplemented cookies reinforces their nutritional quality in addition to their stabilization against oxidative damage.

The studied cookies contained relatively high content of fat (almost 24% dry matter basis). Consequently, they are at higher risk of quality degradation in terms of oxidative changes and oil loss. The addition of natural ingredients bearing antioxidant properties or synthetic antioxidants can extend their shelf life by retarding or inhibiting oxidation reactions, which may be more attractive to the consumers. However, synthetic antioxidants have been reported as controversial with respect to their health safety for utilization in food products (Nanditha & Prabhasankar, 2008). Therefore, the antioxidant effect of the cladodes powder on oxidative stability of cookies was evaluated by peroxide value (PV) measurement at 1 and 30 days of storage (Table 5). PVs of both control and supplemented cookies were progressively increased with increasing storage time. PV at the end of storage study was 8.25 mEq/kg in control, but 4.05 mEq/kg in 7.5% cladodes-supplemented cookies, which indicate that addition of cladodes to the cookies significantly reduced their oxidation ($p < 0.05$). Similar findings have also been proposed by Ismail et al. (2014) suggesting that pomegranate peel reduce oxidative degradation of cookies during storage. It seems worthy to note that the studied cookies cause a loss of oil during storage when a paper is used in direct contact with them, which can be explained by their high fat content. Thus, exudate loss was measured as the percentage loss of cookies mass as compared to the initial mass. Table 5 shows that total loss of mass from the control cookies after 30 days of storage was 3.39%. Interestingly, exudate loss decreased significantly ($p < 0.05$) with the increasing level of cladodes powder. Indeed, at the highest substitution level, exudate loss was found to be 1.07%. This result can be explained by the fact that enrichment of cookies in cladodes fiber enhanced the fat retention. In addition, the antioxidant potential of phenolics with the fat retention by the cladodes fiber contributed to the enhancement of the oxidative stability during storage of cookies.

Sensory properties of cookies

Sensory analysis was carried out by checking colour, odour, taste, crispiness, chewiness and overall acceptability of formulated cookies. The current study highlighted significant effect ($p<0.05$) of cladodes powder supplementation on cookies colour (Figure 2). Cladodes powder gave greenish colour characteristic to finished products (Figure 1). Highest colour acceptability score was observed in control followed by cookies with 2.5% cladodes powder supplementation. A similar trend was also recorded by Sharma et al. (2013) and Ismail et al. (2014) reporting significant reduction in colour scores of cookies supplemented with guduchi leaf and pomegranate peel powders, respectively. The odour results also showed that there is a decreasing trend of the averages of scores when the incorporation of cladodes powder increased. Concerning the taste, slight likeness was attributed by the panelist at high supplementation level. Textural hardness features are important characteristics of cookies; nevertheless, a too hard structure could have a negative effect on sensory qualities of these products. Figure 2 shows a decline in crispiness and chewiness scores of supplemented cookies, which might be associated with the increase in their fiber contents (Uysal et al., 2007). Although consumer scores were reduced with increasing supplementation levels of cladodes powder, there was no significant difference ($p>0.05$) between the averages scores of overall acceptability for standard and 2.5% products. The product containing 5% of cladodes powder remained acceptable since the obtained mean score for the overall acceptability was 3.1 (Figure 2).

Conclusions

Chemical analysis of dried cladodes, collected from *Opuntia ficus indica* f. *inermis* (Tunisia, North Africa), showed richness in active and functional biomolecules. The substitution of wheat flour with *Opuntia* cladodes in the formulation of cookies, containing high content of butter, upgraded their functional characteristics. Indeed, addition of cladodes powder was found to be promising in terms of fat retention and reduction of oxidative damage, resulting in more stable product. Additionally, the yellow colour of cookies decreased toward a greenish colour. Sensory evaluation showed that cladodes supplementation at 5% level did not manifest any undesirable organoleptic response and the product remained acceptable. From the obtained results, it can be said that prickly pear cladodes could be commercially exploited by food manufacturing industries as potential source of dietary fiber, minerals, and antioxidants.

Acknowledgements

This study is part of a doctoral thesis by Lotfi Msaddak. Special thanks go to Miss Amina Gammoudi (ISBAM) for her kind help with English and Dr. Mourad Jridi (ENIS) for his fruitful discussions.

Declaration of interest

The authors declare no conflicts of interest. The authors alone are responsible for the content and writing of this paper. This work received financial support from *Ministère* de l'Enseignement Supérieur et de la *Recherche Scientifique*, Tunisia.

References

A.O.A.C. 1995. Official methods of analysis. Washington, DC: Association of Official Analytical Chemists (AOAC).

Ayadi MA, Abdelmaksoud W, Ennouri M, Attia H. 2009. Cladodes from *Opuntia ficus indica* as a source of dietary fiber: effect on dough characteristics and cake making. Ind Crop Prod 30:40–47.

Dachana KB, Jyotsna R, Indrani D, Prakash J. 2010. Effect of dried Moringa (*Moringa oleifera* Lam.) leaves on rheological, microstructural, nutritional, textural and organoleptic characteristics of cookies. J Food Qual 33:60–67.

Dewanto V, Wu X, Adom KK, Liu RH. 2002. Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. J Agric Food Chem 50:3010–3014.

Dok-Go H, Lee KH, Kim HJ, Lee EH, Lee J, Song YS, Lee YH, et al. 2003. Neuroprotective effects of antioxidative flavonoids, quercetin, (+)-dihydroquercetin and quercetin 3-methyl ether, isolated from *Opuntia ficus-indica* var. saboten. Brain Res 965:130–136.

Drisya CR, Swetha BG, Velu V, Indrani D, Singh RP. 2015. Effect of dried Murraya koenigii leaves on nutritional, textural and organoleptic characeteristics of cookies. J Food Sci Technol 52:500–506.

Dziki D, Różyło R, Gawlik-Dziki U, Świeca M. 2014. Current trends in the enhancement of antioxidant activity of wheat bread by the addition of plant materials rich in phenolic compounds. Trends Food Sci Tech 40:48–61.

Feugang JM, Konarski P, Zou D, Stintzing FC, Zou C. 2006. Nutritional and medicinal use of Cactus pear (*Opuntia* spp) cladodes and fruits. Front Biosci 11:2574–2589.

Galati EM, Mondello MR, Giufferida D, Dugo G, Miceli N, Pergolizzi S, Taviano MF. 2003. Chemical characterization and biological effects of Sicilian *Opuntia ficus indica* (L.) Mill. Fruit juice: antioxidant and antiulcerogenic activity. J Agric Food Chem 51:4903–4908.

Ismail T, Akhtar S, Riaz M, Ismail A. 2014. Effect of pomegranate peel supplementation on nutritional, organoleptic and stability properties of cookies. Int J Food Sci Nutr 65:661–666.

Kaur M, Kaur A, Sharma R. 2012. Pharmacological actions of *Opuntia ficus indica*: a review. J Appl Pharmaceutical Sc 2:15–18.

Kirby AJ, Schmidt RJ. 1997. The antioxidant activity of Chinese herbs for eczema and of placebo herbs-I. J Ethnopharmacol 56:103–108.

Kris-Etherton PM, Hecker KD, Bonanome A, Coval SM, Binkoski AE, Hilpert KF. 2002. Bioactive compounds in foods: their role in the prevention of cardiovascular disease and cancer. Am J Med 30:71–88.

Lee JC, Kim HR, Kim J, Jang YS. 2002. Antioxidant property of an ethanol extract of the stem of *Opuntia ficus-indica* var. Saboten. J Agric Food Chem 50:6490–6496.

López-Cervantes J, Sánchez-Machado DI, Campas-Baypoli ON, Bueno-Solano C. 2011. Functional properties and proximate composition of cactus pear cladodes flours. Cienc Technol Aliment 31: 654–659.

Mau JL, Huang PN, Huang SJ, Chen CC. 2004. Antioxidant properties of methanolic extracts from two kinds of *Antrodia camphorata* mycelia. Food Chem 86:25–31.

Murray JM, Delahunty CM, Baxter IA. 2001. Descriptive sensory analysis: past, present and future. Food Res Int 34:461–471.

Nanditha B, Prabhasankar P. 2009. Antioxidants in bakery products: a review. Crit Rev Food Sci Nutr 49:1–27.

Prosky L, Asp NG, Schweizer TF, DeVries JW, Furda I. 1988. Determination of insoluble, soluble, and total dietary fiber in foods and food products: interlaboratory study. J Assoc off Anal Chem 71: 1017–1023.

Reddy V, Urooj A, Kumar A. 2005. Evaluation of antioxidant activity of some plant extracts and their application in biscuits. Food Chem 90: 317–321.

Sepúlveda E, Gorena T, Chiffelle I, Sáenz C, Catalán E. 2013. Effect of the cactus cladodes peeling in the functional, technological and chemical characteristics and bioactive compounds in cactus cladodes powders. Acta Hort 995:269–272.

Sharma P, Velu V, Indrani D, Singh RP. 2013. Effect of dried guduchi (*Tinospora cordifolia*) leaf powder on rheological, organoleptic and nutritional characteristics of cookies. Food Res Int 50:704–709.

Sun B, Richardo-da-Silvia JM, Spranger I. 1998. Critical factors of vanillin assay for catechins and proanthocyanidins. J Agric Food Chem 46:4267–4274.

Thebaudin JY, Lefebvre AC, Harrington M, Bourgeois CM. 1997. Dietary fibres: nutritional and technological interest. Trends Food Sci Tech 8: 41–48.

Uysal H, Bilgiçli N, Elgün A, Ibanoğlu Ş, Herken EN Demir MK. 2007. Effect of dietary fiber and xylanase enzyme addition on the selected properties of wire-cut cookies. J Food Eng 78:1074–1078.

Yildirim A, Mavi A, Kara AA. 2001. Determination of antioxidant and antimicrobial activities of Rumex crispus L. extracts. J Agric Food Chem 49:4083–4089.

Zouari N, Elgharbi F, Fakhfakh N, Ben Bacha A, Gargouri Y, Miled N. 2010. Effect of dietary vitamin E supplementation on lipid and colour stability of chicken thigh meat. Afr J Biotechnol 9:2276–2283.