Changes in physical and chemical properties of *Opuntia dillenii* fruits during the growing stages

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Received: December 15, 2015; Accepted: May 6, 2016.

ABSTRACT

This study was conducted to enlarge the knowledge about the changes in physical and chemical properties of *Opuntia dillenii* fruits during the growing stages. Significant increases were observed in weight of ten fruits, ratio of pulp/peel, seeds percentage, firmness, width and length. In addition, the levels of total soluble solids, total sugars, reducing sugars, ascorbic acid, total phenolic compounds and antioxidant activity significantly increased, but the pH decreased. In addition, the maximum values of the properties were observed at 210 DAFB (Days After Full Bloom). The content of betalains significantly increased and the maximum value was 100.47 mg /100 g at 210 DAFB. However, the content of total chlorophylls significantly decreased and the lowest level was 1.65 mg / L at 210 DAFB. Also, the highest level of (a^*) and the lowest level of (b^*) were recorded at 210 DAFB. Therefore, the *Opuntia dillenii* fruits should be harvested at 210 DAFB under the Egyptian conditions.

Keywords: Cactus pear, ascorbic acid, betalains, total phenolic compounds, color attributes.

INTRODUCTION

The genus *Opuntia* grows in arid and semi-arid climates and embraces different species of cactus, many of them produce sweet (cactus pear) or acid fruits (xoconostle) (Álvarez-Castro *et al*. 2014). The cactus fruits offer a wide spectrum of colors from white, yellow, orange, red, and purple based on betalains and antioxidant compounds. The thick pericarp is covered with small-barbed spines hosting a juicy pulp with non-edible seeds (Stintzing *et al.* 2005; Martinez *et al*. 2015). The pulp is a good source of vitamin C, calcium, magnesium, in addition to pectin and mucilaginous components (complex polysaccharides) which serve as thicking agents (El-Samahy *et al*. 2007). In addition, the fruits have multiple functional properties and could be an excellent source of natural constituents such as phenolics, betalains and taurine that may improve human health and nutrition (Kuti, 2004). Moreover, cactus pears are best suited to be betalains sources for coloring food (Azeredo, 2009).

In Egypt, cactus pear has been grown in sandy areas in various parts of Egypt because it is extremely drought tolerant. The trees are grown not only for their fruits but also to protect the soil from the risk of desertification. It is cultivated in many areas, such as Belbis, Sinai, Abo-Zabal and the reclaimed areas at El-Nubaria, El-Bostan, and El-Banger (Abdel-Nabey, 2001). Many species of cactus pear are cultivated in Egypt one of them is *Opuntia dillenii* (a new fruit in Egypt). *Opuntia dillenii* originates from southeastern parts of North America, the East coast of Mexico, and from the North of South America. The juicy flesh of fruits is purple in color and contains many rounded seeds that are about 4 mm in diameter, and total betalains are the most characteristic substances of *O. dillenii* (Böhm, 2008). Although, there are many studies on the physical and chemical properties of different species of cactus pear, the investigations on *O. dillenii* are scanty.

In general, for most fruits, advancing maturity corresponds to a number of coordinated physiological, biochemical, and structural processes, making the fruit desirable for consumption (Wilson and Downs, 2012). Fruit maturity can be assessed at harvest using different parameters such as skin color, flesh firmness, soluble solids content (SSC) and acidity (TA) (Pinillos *et al.* 2011). For cactus fruits, the color changes in the skin and pulp are related to modifications in the composition of the major pigments including chlorophylls and betalains during the ripening. Chlorophylls, responsible for the immature green fruit color, were degraded whilst betalains were biosynthesized during the ripening. In both yellow and orange cactus immature fruits, the total chlorophyll concentration was remarkably higher in the skin than in the pulp (Coria-Cayupan *et al.* 2011). Cactus pear fruits are non-climacteric fruits and present a low respiration rate, thus, their nutrient concentration does not change considerably after harvest (Nazareno *et al.* 2009**)**. Hence, the commercial maturity for cactus fruits is close to the point in the fruit development defined as physiological maturity when reaching to the maximum growth. Therefore the main aim of this study was to determine the optimum maturity of the *Opuntia dillenii* fruits by analyzing the physical and chemical changes at several development stages during the growing period.

MATERIALS AND METHODS

Chemicals

Folin–Ciocalteau phenol reagent and 2,2-diphenyl-1-picrylhydrazyl (DPPH) were purchased from Sigma Chemical Corporate. Solvents (analytical grade) were purchased from El-Salam for Chemical Industrious, Egypt.

Plant material

An upright or spreading, fleshy plant usually is growing to 50-100 cm tall. Its stems are much-branched and consist of a series of flattened, fleshy segments which are longer than they are broad and sparsely covered in groups of 1-7 sharp spines (2-4 cm long). Its showy yellow flowers (6-8 cm across) are borne along the margins of the stem segments. Its fleshy fruits have several tufts of small barbed bristles on their surface and turn reddish-purple as they mature (Photograph 1).

Photograph 1. *Opuntia dillenii* (family Cactaceae) is commonly known as pear bush, prickly pear, mal rachette or tuna.

Stems:

The stems are much branched and consist of a series of flattened fleshy (*i.e*. succulent) segments, which are sometimes confused for leaves. These segments (10-40 cm long, 5-20 cm wide and 1-2 cm thick) are green or bluish-green in color and longer than they are broad (*i.e*. elliptic or egg in shape). They are hairless (*i.e*. glabrous) and covered in small raised bumps (*i.e*. areoles) which bear tiny spiny bristles (*i.e*. glochids). Most of these small raised bumps (*i.e*. areoles) also have 1-7 larger sharp spines (2-4 cm long). The leaves are reduced to small, slightly curved, cone-shaped (*i.e*. conical) structures (up to 6 mm long) and are quickly shed (*i.e*. they are caduceus).

Flowers and Fruit

The flowers (up to 7 cm long and 6-8 cm across) are bright yellow and sometimes have greenish or pinkish colored markings on the outer 'petals'. Flowering occurs mostly during spring and summer. The immature fruit are green, but they turn reddish-purple in color as they mature. These fruit (4-9 cm long and 3-4 cm wide) are fleshy (*i.e*. succulent), pear-shaped (*i.e*. pyriform) or almost rounded (*i.e*. globose), berries. They may have a shallow depression at the top, especially when they are young, and always have several tufts of small barbed bristles (*i.e*. glochids) on their surface. The reddish or purplish colored pulp in the center of the fruit contains large numbers of seeds. These seeds (4-5 mm long and 4-4.5 mm wide) are generally yellow or pale brown in color and somewhat rounded (*i.e*. sub-globose) in shape (Photograph 2).

Photograph 2. Flowers and fruits of *Opuntia dillenii*.

Sampling

Cactus pear (*Opuntia dillenii*) fruits were harvested from the farm of Faculty of Agriculture, Suez Canal University, Ismailia (30° 36´ North Latitude, 32° 16´ East Longitude). The fruits were sampled randomly every month during the development stages (for eight months; from June to January) after the full bloom stage (DAFB). Temperature and relative humidity during study period ranged between 15-30° and 5-19%, respectively.

Preparation of samples

The samples of fruits (1.5 kg for each sample) were harvested randomly during the development stages every month; starting from the full bloom stage (FBS) for eight months (from June to January, DAFB). The fruits were immediately washed with running tap water, drained and left to dry on a cheese cloth for 15 min at room temperature before the physical

measurements, after that, fruits were peeled and cut for two pieces to remove the seeds then the pulp was homogenized in a Warning blender for chemical analyses.

Proximate Chemical Analysis

Moisture content, total sugars, reducing sugars and ascorbic acid were determined according to the methods described in the AOAC (2000). The pH value was measured using a pH-meter (Jenway Ltd., UK) at 25°C. Total acidity (%, as citric acid) was calculated after titration of 10 g of seedless pulp with 0.01 *N* NaOH to end point (pH 8.2) according to AOAC (2000). Total soluble solids content was measured using a refractometer (Abbe Hergestellt in der DDR, Germany) at 20°C with values being expressed as Brix.

Determination of chlorophyll

The chlorophylls *a* and *b* were extracted and determined by the method of Wrolstad *et al.* (2005). Half gram of the sample was mixed with 20 mL acetone and pigments were extracted by homogenization. The extract was filtered through cotton in a 50 mL volumetric flask and made up to the mark by acetone. The absorbance of the extract was measured at 645 and 662 nm against blank (acetone). The concentrations of chlorophylls *a* and *b* were calculated by using the following equations:

Chlorophyll *a* (µg/g fresh sample) = $11.75 \times A_{662} - 2.23 \times A_{645}$ (Eq. 1)

Chlorophyll *b* (µg/g fresh sample) = $18.61 \times A_{645} - 3.96 \times A_{662}$ (Eq. 2)

The total chlorophyll content was calculated through summation *a* and *b*.

Extraction and determination of total phenolic compounds

The total phenolic compounds (TPC) were extracted and determined according to the method of Jaramillo-Flores *et al.* (2003). The phenolic compounds were extracted using 80% methanol containing 0.1% HCl for 20 min at room temperature. The mixture was centrifuged and the supernatant was analyzed immediately by using Folin-Ciocalteu phenol reagent. The absorbance was measured at 725 nm using a spectrophotometer (6505 UV/VIS, Jenway LTD., Felsted, Dunmow, UK) and the calibration curve was prepared by using gallic acid.

Extraction and determination of betalains and antioxidant compounds

Betalains and antioxidant compounds were extracted using 50% ethanol with centrifugation as described by Ravichandran *et al.* (2013). The collected supernatants were used for the determination of betalains and antioxidant activity. The content of betalain compounds including betaxanthins and betacyanins in the ethanol extract, was determined according to Stintzing *et al.* (2003) using a spectrophotometer at 538 and 480 nm, respectively. The antioxidant activity was determined by 2,2-diphenyl-1-picrylhydrazyl (DPPH) method, according to Lee *et al*. (2003). After adding the extract to the DPPH solution (react for 30 min) the absorbance at 515 nm was recorded. A control with no added extract was also analyzed. Scavenging activity was calculated as follows:

DPPH radical−scavenging activity (%) = $(A_{control} - A_{sample}) / A_{control}) \times 100$ (Eq. 3)

Where, A refers to the absorbance at 515 nm.

Physical analyses

The diameters and lengths (polar diameter) of the fruits were measured using a digital caliper (Mitutoyo Corp., Japan) and the mean weight of individual fruits pulp, peel and seeds were recorded. The changes of fruits growth were recorded in terms of length, width and weight. The fruit firmness was measured using a penetrometer (Fruit Tester) and the results were expressed as kg/cm^2. The colors of the samples were measured with a Minolta colorimeter (Minolta Co. Ltd., Osaka, Japan). The measurements were expressed in L^*, a^*, and b^* values which represent light-dark spectrum with a range from 0 (black) to 100 (white), the green-red spectrum with a range from -60 (green) to +60 (red), and the blue-yellow spectrum with a range from -60 (blue) to +60 (yellow), respectively.

Statistical analysis

All measurements were done in triplicate and data were reported as means ± standard deviation (SD). The analysis of variance (ANOVA) accompanied with Duncan test using SPSS software (version 16.0 for Windows, SPSS Inc., Chicago) was conducted to identify the significant differences between samples (P<0.05).

RESULTS AND DISCUSSION

Changes in physical properties

The changes in physical properties during growing are given in (Table1). The results show that physical properties of *Opuntia dillenii* increased significantly during growing development stages of the fruits. During ripening period, weight of ten fruits increased significantly from 85.15 g at 30 (DAFB) to 112 g at 150 (DAFB). At 180 (DAFB) the weight reached to the peak (147.76 g) then decreased with non-significant difference at 210 (DAFB), followed by a significant decrease (115.9 g) at 240 (DAFB), indicating that the full ripening was at 180 and 210 (DAFB). Also, the decrease of the weight at 240 (DAFB) may be due to the over-ripening accompanied with the loss of moisture and other components. Regarding to the ratio of pulp/peel, it increased to 2.81 and 2.61 at 180 and 210 DAFB, respectively, then decreased significantly to 2.45 at 240 DAFB. Also, a significant increase was occurred in the seeds percentage starting with 7.40% at 30 DAFB to 39.66% at 240 of DAFB. With respect to the width and length, significant increases were observed and the values increased from 2.04 and 0.47 cm (at 30 DAFB) to 3.77 and 2.10 cm (at 240 DAFB), respectively. The results are in a good agreement with those found by Duru and Turker (2005) for O*punia ficus-indica* fruits. It was found that whole fruits, pulp/peel (%), seeds and fruits length increased during the growing development of O*punia ficus-indica* fruits in Turkey. Also the same trend was noticed in other fruits, for instance, Fawole and Opara (2013a) observed that pomegranate fruit length, diameter and volume increased at each maturity stage until the last maturity stage along the DAFB of each growing season.

Table 1. Changes in some physical properties (mean ± SD) of O*puntia dillenii* fruits during growing stages.

Parameter	Growing period (DAFB)							
	30	60	90	120	150	180	210	240
Weight of ten fruits (g)	85.15^{f} ±2.7	99.09^{e} ±4.6	103^{d} ±7.6	104.98^{dc} ±1.2	112.53^{cb} ±8.0	147.76^{a} ±1.6	141.30^{a} ±0.5	115.90^{b} ±1.2
Pulp/peel (%)	2.23^{e} ±0.07	2.28^{d} ±0.07	2.31^{d} ±0.04	2.39^{c} ±0.07	2.69^{a} ±0.16	2.81^{a} ±0.09	2.61^{ab} ±0.03	2.45^{bc} ±0.26
Seeds (%)	7.40^{h} ±1.4	10.95^{g} ±0.1	13.41^{f} ±0.7	15.58^{e} ±0.9	21.70^{d} ±0.6	30.26^{c} ±1.2	32.46^{b} ±0.8	39.66^{a} ±0.7
Length (cm)	2.04^{e} ±0.2	2.19^{e} ±0.1	2.94^{d} ±0.1	3.07^{cd} ±0.1	3.50^{bc} ±0.4	3.82^{b} ±0.1	4.65^{a} ±0.6	3.77^{b} ±0.1
Width (cm)	0.47^{d} ±0.1	0.92^{c} ±0.2	0.97^{c} ±0.01	1.08^{c} ±0.1	1.64^{b} ±0.03	2.28^{a} ±0.2	2.31^{a} ±0.1	2.10^{a} ±0.1

Means in the same row with different superscripts are significantly different at $P<0.05$. (DAFB) days after full bloom.

Changes in chemical properties

The changes in chemical properties during growing period are presented in (Table 2). The pH values decreased to 3.35 at 210 DAFB but insignificantly increased to 3.39 at 240 DAFB. This result confirmed the findings of Kader (2002) that all *xoconostle* pear varieties are acidic fruits (pH <4). Also, the total titratable acidity (TA) increased during the growing period to 1.41% (as citric acid) at 210 DAFB and the decrease in acidity observed at 240 DAFB was insignificant. Similarly, most of fruits species showed decreases in pH values during ripping. Mazur *et al*. (2014) and Ornelas-Paz *et al*. (2013) found decreases in pH values during the ripeness for strawberry and pomegranate respectively. Also, Montero *et al*. (1996) reported a decrease of pH in strawberry fruits during the early stages of fruit development followed by an increase during the latest stages. The results also, show that the total soluble solids (TSS) increased significantly from 0.83 to 8.75° Brix during the growing period. Although,TSS showed a different trend in strawberry during ripening the highest TSS content was found in fully ripe fruits (Mazur *et al*. 2014). Furthermore, the total sugars content increased significantly to 27.67% at 120 DAFB and then decreased to 21.85% at 240 DAFB and the same trend was found for the reducing sugars. These results are in a good agreement with those found by Silos-Espino *et al.* (2003) and Duru and Turker (2005) for *O. ficus-indica* fruits but with lower values. The increases in TSS, total sugar and reducing sugar may be attributed to the hydrolysis of starch into simple sugars.

Table 2. Changes in chemical properties (mean ± SD) of O*puntia dillenii* fruits during growing stages.

Parameter	Growing period (DAFB)							
	30	60	90	120	150	180	210	240
pH value	5.35^{a} ±0.3	4.59^{b} ±0.1	4.18^{c} ±0.1	3.63^{d} ±0.3	3.51^{de} ±0.1	3.45^{de} ±0.2	3.35^{de} ±0.1	3.39^{e} ±0.2
Acidity (%, as citric acid)	0.01^{f} ±0.1	0.14^{ef} ±0.02	0.22^{e} ±0.1	0.58^{c} ±0.01	0.83^{d} ±0.1	1.18^{b} ±0.03	1.41^{a} ±0.1	1.31^{ab} ±0.1
TSS (^{o}Brix)	0.83^{d} ±0.3	1.66^{cd} ±0.3	2.05^{c} ±0.1	8.16^{b} ±0.8	8.50^{ab} ±0.5	9.41^{a} ±0.1	8.66^{ab} ±0.8	8.75^{ab} ±0.7
Moisture (%)	91.30^{a} ±0.1	90.86^{a} ±0.2	89.40^{bc} ±0.3	89.30^{b} ±0.3	88.39^{b} ±0.4	88.11^{c} ±0.4	87.0^{d} ±1.3	85.6^{d} ±0.8
*Total sugars (%)	12.84^{f} ±0.3	19.01^{e} ±0.2	23.25^{cd} ±0.8	27.67^{a} ±0.9	26.20^{ab} ±2.3	24.68^{cb} ±0.6	22.6^{d} ±0.7	21.8^{d} ±0.6
*Reducing sugars (%)	5.86^{f} ±0.1	14.12^{e} ±0.4	17.02^{cd} ±0.5	20.23^{a} ±0.8	19.41^{ab} ±1.8	18.02^{cb} ±0.1	16.27^{d} ±0.6	15.91^{d} ±0.4

Mean in the same row with different superscripts are significantly different at $P<0.05$. *Estimated on dry weight. DAFB (days after full bloom).

Changes in pigments

The fruit ripening is related to the initiation and the development of pigmentation of the fruits. Also, changes in the color of the skin and pulp of the fruits are related to modifications in the composition of the pigments during the ripening (Coria-Cayupan *et al*. 2011). The changes in fruits pulp pigments during the growing period are displayed in (Table 3). The results show that the total betalains content increased insignificantly to 5.09 ± 0.4 mg/100 g at 150 DAFB then increased significantly to the maximum value (100.47 mg/100g) at 210 DAFB, then a significant decrease was occurred at 240 DAFB. The fractions of betalains (betacyanins and betaxanthine) had the same trend and the highest levels were 42.49 and 57.97 mg/100 g, respectively, at 210 DAFB. The results indicate that *Opuntia dillenii* fruits could be used as a new source for food colorant because they contained high levels of betalains. Moreover, total betalains reached to the peak at 210 DAFB during the growing period, hence, it is recommended to harvest the fruits at this stage (210 DAFB). These results are similar to those found in *Opuntia ficus-indica* during the growing stages (Duru and Turker 2005; Coria-Cayupan *et al*. 2011). On the other hand, total chlorophylls decreased significantly during the growing period and the lowest level was 1.65 mg/L at 210 DAFB, then the total chlorophylls

decreased insignificantly to 1.33 mg/L at 240 DAFB. Moreover, the chlorophyll *b* had the same trend, but the chlorophyll *a* significantly decreased to the lowest level at 240 DAFB.

Table 3. Changes in fruits pulp pigments contents (fresh weight, mean ± SD) of O*puntia dillenii* during growing stages.

Parameter	Growing period (DAFB)							
	30	60	90	120	150	180	210	240
Chlorophyll *a* (mg/L)	2.35^{a} ±0.1	1.92^{b} ±1.5	1.54^{c} ±0.01	1.43^{cd} ±0.3	1.29^{d} ±0.1	0.79^{e} ±0.2	0.70^{f} ±0.2	0.62^{g} ±0.1
Chlorophyll *b* (mg/L)	2.28^{a} ±0.02	2.03^{ab} ±0.3	1.74^{ab} ±0.8	1.66^{bc} ±0.3	1.10^{cd} ±0.1	1.08^{cd} ±0.1	0.95^{d} ±0.2	0.70^{d} ±0.2
Total chlorophylls (mg/L)	4.64^{a} ±0.2	3.96^{b} ±0.4	3.28^{c} ±0.8	3.10^{c} ±0.3	2.34^{d} ±0.1	1.88^{de} ±0.2	1.65^{e} ±0.4	1.33^{e} ±0.2
Betacyanin (mg/100g)	ND	0.58^{e} ±0.01	0.78^{e} ±0.1	0.75^{e} ±0.2	3.09^{d} ±0.4	25.02^{c} ±0.6	42.49^{a} ±1.4	34.83^{b} ±2.5
Betaxanthin (mg/100g)	ND	ND	0.49^{d} ±0.04	0.49^{d} ±0.1	1.99^{d} ±0.1	26.16^{c} ±0.6	57.97^{a} ±1.2	49.42^{b} ±4.6
Total betalains (mg/100g)	ND	0.58^{d} ±0.01	1.27^{d} ±0.1	1.25^{d} ±0.2	5.09^{d} ±0.4	51.19^{c} ±1.2	100.47^{a} ±2.6	84.26^{b} ±7.1

Means in the same row with different superscripts are significantly different at $P<0.05$. DAFB (days after full bloom). ND= not detected.

Changes in bioactive compounds and antioxidant activity

Changes in ascorbic acid, total phenolic compounds and antioxidant activity during the growing period are presented in Table 4. The results show that ascorbic acid began by 2.88 mg/100 g at 30 DAFB and ended by 52.04 mg/100 g at 240 DAFB. Ascorbic acid increased insignificantly during the growing stages from 60 to 120 DAFB then increased significantly from 150 to 210 DAFB. Also, the maximum value of ascorbic acid was 58.18/100 g at 210 DAFB. The total phenolic compounds contents increased insignificantly to 12.13 mg/100 g at 90 DAFB then increased significantly to the maximum level (178.9 mg/100 g) at 210 DAFB. During the growing period the antioxidant activity was measured by 1,1-diphenyl-2-pricklhydrazyl (DPPH) method. Antioxidant activity increased insignificantly to 4.27% at 90 DAFB then significantly increased to the maximum level (56.3%) at 210 DAFB, then decreased significantly at 240 DAFB. In general, the highest levels of the studied bioactive compounds and the antioxidant activity were observed at 210 DAFB. Similar trends for ascorbic acid, total phenolic compound and antioxidant activity were found in yellow and

orange *Opuntia megacantha* (Coria-Cayupan *et al*. 2011). On opposite, some fruits show different trends such as pomegranate for total phenolic compounds during the growing stages (Fawole and Opara, 2013b). In addition, total phenolic compounds and ascorbic acid contents in strawberry fruits were not significantly affected either by ripeness or by cultivar (Mazur *et al*. 2014).

Table 4. Changes in bioactive compounds content (mg/100 g FW) and antioxidant activity of *Opuntia dillenii* fruits during growing stages (mean ± SD).

Parameter	Growing period (DAFB)							
	30	60	90	120	150	180	210	240
Ascorbic acid	2.88^{f} ±1.0	5.49^{e} ±0.2	5.56^{e} ±1.1	6.43^{e} ±0.9	8.29^{d} ±0.2	29.23^{c} ±0.8	58.18^{a} ±1.5	52.04^{b} ±1.4
Total phenolic compounds	9.33^{e} ±1.7	9.43^{e} ±4.1	12.13^{e} ±4.8	23.73^{ed} ±11.7	33^{d} ±9.4	50.73^{c} ±6.3	178.90^{a} ±8.9	122.5^{b} ±9.8
Antioxidant activity (%, DPPH)	2.98^{f} ±0.5	3.97^{f} ±0.6	4.27^{f} ±3.8	8.92^{e} ±0.7	20.64^{d} ±0.3	36.58^{c} ±0.9	56.30^{a} ±0.5	50.14^{b} ±0.6

Means in the same row with different superscripts are significantly different at $P<0.05$. DAFB (days after full bloom). ND= not detected.

Changes in color attributes

The skin color of the cactus pear fruits is used as an indicator of the fruit growing and to the prediction of eating the fruits during the development. The data illustrated in Figure 1, display the color attributes: L^*, a^* and b^* of the fruit pulp. Lightness (L^*) values increased until reaching to 150 DAFB followed by decreases until the end of the growing period. This increase may be referring to biosynthesized betalain pigments during ripping. These results are in a good agreement with those found by Mazur *et al*. (2014) in strawberry during ripping. Regarding yellowness (b^*), the values increased until reaching to 90 DAFB, then decreased until the end of the growing period. However, redness (a^*) values decreased to the lowest level at 90 DAFB then increased until reaching to the end of the growing period. Moreover, the highest level of (a^*) and the lowest level of (b^*) were recorded at 210 DAFB. This could be due to the changes in the pigments, that betalains pigment were biosynthesized however, chlorophyll pigments degraded during ripping stages as observed in Table 3.

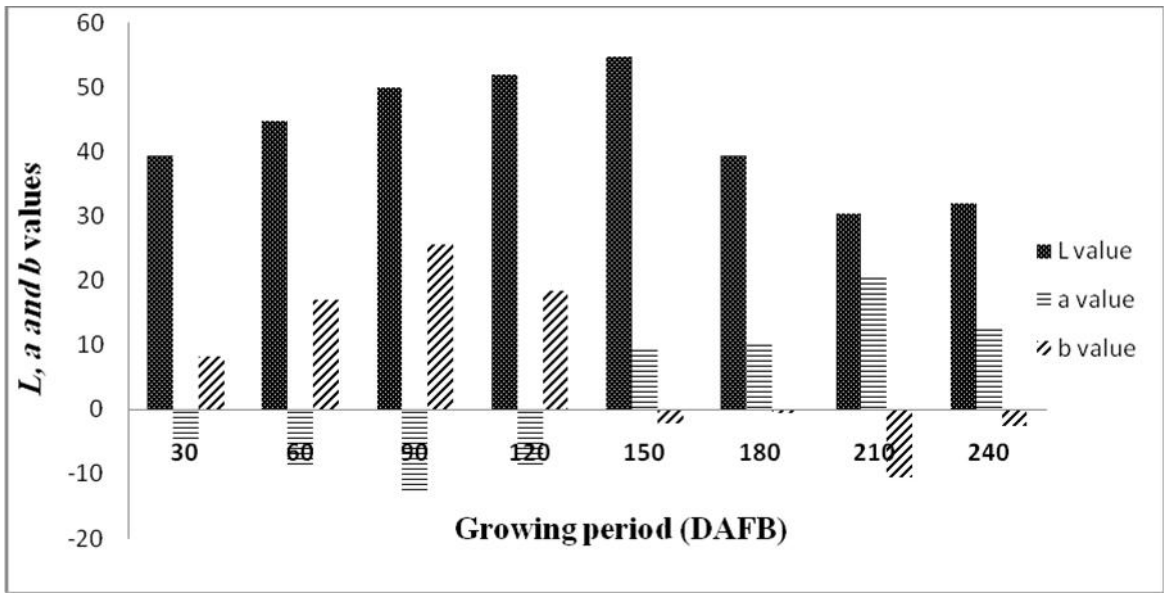

Figure 1. Changes in color attributes of O*puntia dillenii* fruits during growing stages.

Change in firmness

Changes in firmness are given in Figure 2. The firmness of the fruits increased significantly during the growing period starting with 1.33 kg/cm^2 at 30 DAFB and the highest level was 2.66 kg/cm^2 at 240 DAFB.

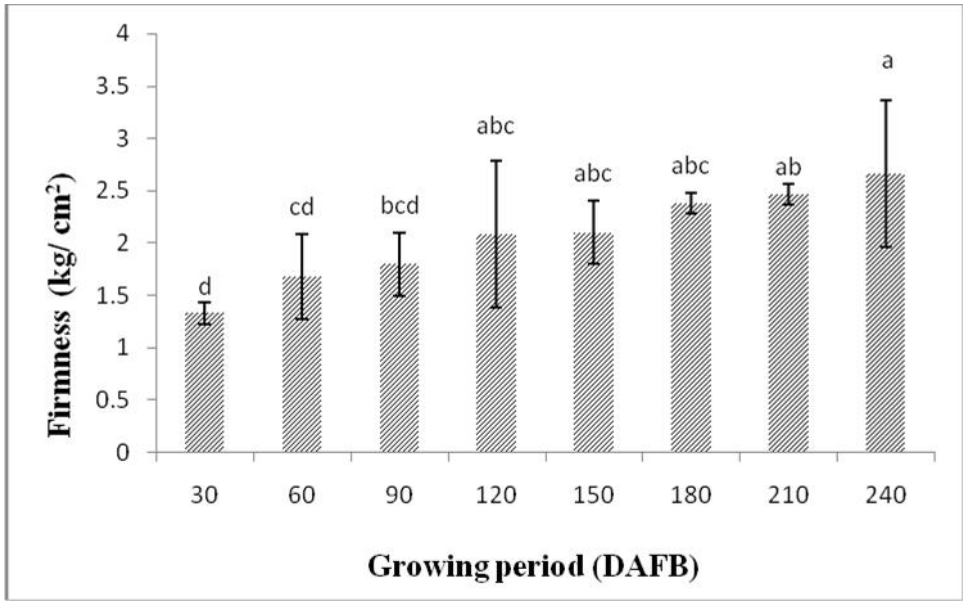

Figure 2. Changes in firmness of *Opuntia dillenii* fruits during growing stages.

The increase in firmness values may be due to the transfer of the texture of the skin from firm to leathery case; especially the texture was measured by the penetrometer. The obtained data are in compatible with those found by Woolf *et al.* (2000) for avocados fruits.

CONCLUSIONS

From the obtained results, *Opuntia dillenii* is acid fruit and the levels of physical properties (weight of ten fruits, ratio of pulp/peel, seeds percentage, firmness, width and length), antioxidant activity and betalains increased during the growing stages of the fruits. Also, the levels of total soluble solids, total sugars, reducing sugars, ascorbic acid and total phenolic compounds significantly increased but the level of chlorophylls and pH significantly decreased. Moreover, the maximum levels of the above mentioned properties (but the lowest level of chlorophylls) were occurred at 210 DAFB. Thus, it is recommended to harvest the *Opuntia dillenii* fruits at 210 DAFB under the Egyptian conditions. Moreover, the fruit contained high levels of betalains; therefore, it could be used for food colorant production. More studies should be conducted in the future to maximize the utilization of *Opuntia dillenii* fruits by incorporating them in some food products.

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