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Effects of thermal processing on physicochemical properties and oxidative stability of *Balanities aegyptiaca* kernels and extracted oil

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SUMMARY: In the present study, the effects of roasting and boiling on the proximate composition of the kernels as well as the physicochemical properties and oxidative stabilities of the extracted oils of *Balanites aegyptiaca* were investigated. Roasting was performed at 180 ˚C for 15 minutes, whereas boiling of the kernels was carried out in tap water for one hour. The oils from raw and thermally processed samples were extracted using n-hexane in a Soxhlet extraction apparatus and characterized. The roasting significantly ($p < 0.05$) influenced the peroxide value and the oxidative stability of the extracted oil in a positive way; whereas boiling had the opposite effect. The oils were composed of linoleic, oleic, stearic, and palmitic acids as the major fatty acids (96%) and contained predominantly α- and γ-tocopherols (ca. 400mg/kg). The study suggests that the oil from roasted kernels could be used as a natural antioxidant for enhancing the characteristics of other edible oils via blending.

KEYWORDS: Balanities aegyptiaca; *Boiling; Fatty acids; Oxidative Stability; Roasting; Tocols*

RESUMEN: ***Efecto de tratamientos térmicos sobre las propiedades fisicoquímicas y estabilidad oxidativa de semillas de* Balanities aegyptiaca *y de los aceites extraídos.*** En el presente estudio se investigaron los efectos del tostado y ebullición sobre la composición proximal de las semillas, así como las propiedades fisicoquímicas y estabilidad oxidativa de los aceites extraídos de *Balanites aegyptiaca*. La torrefacción se realizó a 180 ºC durante 15 minutos mientras que la ebullición de los granos se realizó en agua durante una hora. Los aceites de las muestras crudas y térmicamente procesadas se extrajeron utilizando n-hexano mediante Soxhlet y fueron caracterizados. La torrefacción influyó significativamente ($p < 0,05$) en el valor del peróxido y en la estabilidad oxidativa del aceite extraído, de manera positiva, mientras que la ebullición tiene el efecto opuesto. Los aceites contenían linoleico, oleico, esteárico y palmítico como principales ácidos grasos (96%) y contenían predominantemente α- y γ-tocoferoles (aprox. 400 mg/kg). El estudio sugiere que el aceite de granos tostados podría ser utilizado como un antioxidante natural para mejorar las características de otros aceites comestibles a través de la mezcla.

PALABRAS CLAVE*: Ácidos grasos;* Balanities aegyptiaca*; Ebullición; Estabilidad oxidativa; Tocols; Tostado*

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1. INTRODUCTION

Exploring new sources of oil has been of growing interest due to the rapid increase in consumption by the ever-growing human population, economic purposes, and diverse industrial applications (Chenga, *et al.* 2016; Vermaak, *et al.* 2011; Mariod, *et al.* 2004). *Balanites aegyptiaca* which is also known as "desert date" belongs to the family of *Balanitaceae* and species of the genus *Balanites aegyptiaca (L) Delile*. It is widespread in most arid, semi-arid to sub-humid tropical savannas in Africa, all over the Sahel, extending from the Atlantic coastline of Senegal to the Red Sea, Indian Ocean, and the Arabian Peninsula (Maydell, 1990). In Sudan, it is commonly found in the dark cracking clays of central Sudan, often associated with *Acacia seyal* on the short grass savanna (El Amine, 1990).

Few articles have been published on the characteristics and potential applications of *Balanites aegyptiaca* oil. The findings have revealed interesting characteristics of this oil which makes it applicable in many areas including food, biodiesel, antimicrobial, and anti-ulcer (Al Ashaal, *et al.* 2010; Chapagain, 2009; Nour, *et al.* 1985). Al Ashaal *et al*. [2010] have studied the chemical composition and the biological activities of the fixed oil of *Balanites aegyptiaca*. Their results have shown that the oil has anticancer, antimutagenic, antiviral and antimicrobial activities. Despite the wide distribution of the *Balanites aegyptiaca* tree among almost all regions of Sudan and the amazing characteristics of its oil, limited attention has been given to this multi-purpose tree and its products, especially the oil. Thermal processing (roasting and boiling) is commonly used by local communities to obtain the oil. To the best of our knowledge, this is the first article to report on the influence of these treatments on the chemical composition of the kernels and the extracted oils as well as the fatty acid composition, and oxidative stability of the oil.

2. MATERIALS AND METHODS

2.1. Sample collection and pretreatment

A *Balanites aegyptiaca* sample was purchased from an Omdurman market (Souk Omdurman), Sudan, on January 2015. The epicarps of the *Balanites aegyptiaca* fruit were removed manually and the remaining edible flesh (mesocarp) plus the endocarps were soaked in tap water overnight. After complete removal of the edible flesh the endocarps were dried in sunlight for two days. Finally, the endocarps were removed manually using a hammer and the kernels were stored at 10 °C for the next steps.

2.2. Pretreatment of the kernels

2.2.1. Boiling

The kernels were immersed in boiling tap water at 100 °C at a ratio of 1:4 kernel/water for one hour in a 500 mL beaker with continuous heating and stirring until the pieces were well cooked. The cooked sample was dried and ground in a grinder (Ndidi, *et al.* 2014).

2.2.2. Roasting

Kernels were arranged in a single layer on an aluminium tray and placed in a KUMTEL electric oven (LX3520 T-INOX (with adjustable thermostat 80–320 °C, homogeneous heat distribution, timer function), Turkey) at 180 °C for 15 minutes and finally the sample was allowed to cool to ambient temperature, and stored at 10 °C (Mariod, *et al.* 2012).

2.3. Proximate analysis

Moisture, ash, protein, and lipids were determined following the standard methods of the Association of Official Analytical Chemists (AOAC) [1990]. In each case triplicate analyses were done and the mean and the standard deviation were calculated (mean ± SD). Total carbohydrates were determined by difference and the standard deviation was calculated using propagation of error.

2.4. The physical properties of the oil

2.4.1. Determination of specific gravity

An empty and a dry pycnometer were weighed and filled with distilled water at 25 °C and weighed again. The dry pycnometer was re-filled with oil at the same temperature and weighed. The experiment was repeated three times and the mean and standard deviation were calculated. The density was determined using the following equations:

$$W_o = W_{o+p} - W_p$$
$$W_w = W_{w+p} - W_p$$
$$\text{Density} = W_o/W_w$$

Where W_o = weight of oil, W_w = weight of water, W_p = weight of empty pycnometer, W_{o+p} = weight of empty of pycnometer + weigh of oil, W_{w+p}= weight of the empty pycnometer + weight of water (AOCS, 2011).

2.4.2. Determination refractive index

The refractive index of the oil was measured using an Abbe refractometer. Three drops of oil were placed on the surface a lower prism. The prism

and mirror were adjusted until it gave the sharpest reading. The experiment was repeated twice and the mean and standard deviation were calculated (AOCS, 2011).

2.4.3. Determination of viscosity

The viscosity of the oil was measured using Thermo Scientific HAAKE viscotester 6 plus. About 40 ml of oil sample were placed in a beaker and the rotor was immersed in the oil. The velocity of the instrument was adjusted to 200 rounds per min. The viscosity was read directly from the screen of the instrument. The experiment was repeated twice and the mean and standard deviation were calculated (AOCS, 2011).

2.4.4. Determination of color

The color of the oil was determined using a Lovibond Tintometer type 4D. Oil was placed in a standard sized glass cell and visually compared with red, yellow and natural color standards. Results were expressed in terms of numbers associated with the color of standards (AOCS, 2011).

2.5. Chemical properties of the oils

Acid, peroxide, and saponification values were determined following the standard methods of the AOCS Official Methods [AOCS, 2011]. In each case triplicate analyses were carried out and the mean and the standard deviation were calculated (mean ± SD).

2.5.1. Fatty acid composition of the oils

The fatty acid composition was confirmed according to the ISO standard ISO 5509 (ISO, 2000). Briefly, one drop of the oil was broken down in 1 ml of n-heptane, 50 µg of sodium methylate (Merck, Darmstadt, Germany) were added, and the closed tube was agitated vigorously for 1 min at room temperature. After the addition of 100 µL of water, the tube was centrifuged at 4500 rpm for 10 min and the lower aqueous phase was removed. Then 50 µL of HCl (1 mol with methyl orange (Merck, Darmstadt, Germany)) were added, the solution was briefly mixed, and the lower aqueous phase was rejected. About 20 mg of sodium hydrogen sulphate (monohydrate, extra pure; Merck, Darmstadt, Germany) were added, and after centrifugation at 4500 rpm for 10 min, the top n-heptane phase was transferred to a vial and injected into a HP5890 gas chromatograph (Agilent Technologies Sales & Services GmbH & Co. KG, Waldbronn, Germany), with a capillary column, CP-Sil 88 (100 m long, 0.25 mm ID, film thickness 0.2 µm). The temperature program was as follows: From 155 °C; heated to 220 °C (1.5 °C/min), 10 min isotherm; injector 250 °C, detector 250 °C; carrier gas 36 cm/s hydrogen; split ratio 1:50; detector gas 30 ml/min hydrogen; 300 ml/min air and 30 ml/min nitrogen; manual injection volume less than 1 µl. The peak areas were computed by the integration software, and percentages of fatty acid methyl esters (FAME) were obtained as weight percent by direct internal normalization.

2.5.2. Determination of tocol contents of the oil

For determination of vitamin-E-active compounds, a solution of 250 mg of oil in 25 mL of n-heptane was directly used for the HPLC. The HPLC analysis was conducted using a Merck-Hitachi low-pressure gradient system, fitted with a L-6000 pump (Merck-Hitachi, Darmstadt, Germany), a Merck-Hitachi F-1000 fluorescence spectrophotometer (Darmstadt, Germany; detector wavelengths for excitation 295 nm, for emission 330 nm), and a ChemStation integration system (Agilent Technologies Deutschland GmbH, Böblingen, Germany). The samples in the amount of 20 µL were injected by a Merck 655-A40 autosampler (Merck-Hitachi, Darmstadt, Germany) onto a Diol phase HPLC column 25 cm × 4.6 mm ID (Merck, Darmstadt, Germany) used with a flow rate of 1.3 mL/min. The mobile phase used was 99 mL n-heptane + 1 mL tert-butyl methyl ether (Balz, *et al.* 1992).

2.5.3. Rancimat test

Rancimat test Induction time was determined using the International Standard Organization method (ISO 6886, 2006). The oxidative stability of each sample was determined as the induction period (IP, h) recorded by a 743 Rancimat (Metrohm, Herisau, Switzerland) apparatus using 3 g of oil sample. The samples placed in Rancimat standard tubes were subjected to the normal operation conditions of the test by heating at 110°C with an air flow of 20 L/h.

2.6. Statistical analysis

The values reported in Tables 1 to 3 are the means ± the standard deviations (SD) of three replicates (two replicates for viscosity and refractive index). The statistical analysis was done with SPSS 20.0. Analysis of variance (ANOVA) was used to evaluate the significance between the raw and thermally processed samples. The variant means were separated using the least significant difference method (LSD). The level of significance was set at $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1. Proximate composition

The results of the proximate analysis of the kernel seeds of raw and thermally processed samples are given in Table 1. As can be seen from the table,

Table 1. Proximate composition of the kernels as well as the physical and chemical properties of Balanities aegyptiaca oils extracted from raw and processed kernels

	Sample		
Component	**Raw**	**Boiled**	**Roasted**
Moisture (%)	3.74[a] ± 0.69	3.35[a] ± 0.21	2.18[b] ± 0.22
Ash (%)	2.88[a] ± 0.13	2.32[b] ± 0.11	2.92[a] ± 0.01
Protein (%)	42.41[a] ± 0.03	41.80[a] ± 0.06	38.52[a] ± 0.11
Lipid (%)	39.98[a] ± 1.24	38.28[a] ± 2.20	46.23[a] ± 1.38
Total carbohydrate (%)*	10.99[a] ± 1.4*	14.25[a] ± 2.2*	10.15[a] ± 1.4*
Specific gravity	0.9132[a] ± 0.0006	0.9138[a] ± 0.0005	0.9118[a] ± 0.0008
Viscosity (Poise)	63.5[a] ± 0.73	67[a] ± 1.4	66[a] ± 3.5*
RI	1.468 ± 0.0028	1.468 ± 0.0007	1.465 ± 0.0014
Color	13.2y, 0.4r	20.1y, 1.2r	20.2y, 1.5r
Peroxide value (meq/kg)	13.34[a] ± 0.28	18.06[b] ± 0.46	4.56[c] ± 0.28
Acid value (mg KOH/g)	0.30[a] ± 0.02	0.34[a] ± 0.03	0.34[a] ± 0.00
Saponification value (mg KOH/g)	200.31[a] ± 2.42	200.47[a] ± 5.54	203.55[a] ± 6.31

* *Values are means (± SD). The standard deviation was calculated using propagation of error.*
** Means followed by different letters within a row are significantly ($p < 0.05$) different (All comparisons were made between the raw and the thermally processed samples only).

Table 2. Fatty acid composition of Balanities aegyptiaca oil extracted from raw and processed kernels

	% (mean±SD)		
Fatty acid	**Raw**	**Boiled**	**Roasted**
C16:0	12.97[a] ± 0.23	12.47[a] ± 0.00	12.58[a] ± 0.10
C16:1Δ7	-	-	0.03 ± 0.00
C16:1Δ9	0.18 ± 0.01	0.20 ± 0.00	0.17 ± 0.00
C17:0	0.12 ± 0.01	0.11 ± 0.00	0.11 ± 0.00
C17:1	-	0.06 ± 0.00	0.06 ± 0.00
C18:0	13.64[a] ± 0.08	14.07[a] ± 0.00	12.98[a] ± 0.15
C18:1Δ9	31.44[a] ± 0.07	32.51[a] ± 0.01	31.80[a] ± 0.02
C18:1Δ11	0.80 ± 0.00	0.88 ± 0.01	0.82 ± 0.01
C18:2Δ9,12	39.43[a] ± 0.06	38.20[a] ± 0.01	39.88[a] ± 0.09
C18:3Δ9,12,15	-	0.06 ± 0.00	0.06 ± 0.01
C20:0	0.37 ± 0.01	0.38 ± 0.01	0.35 ± 0.01
C20:1	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00
C22:0	-	0.06 ± 0.00	0.06 ± 0.01
Saturated	27.1	27.09	26.08
Monounsaturated	32.52	33.75	32.98
Polyunsaturated	39.43	38.32	39.94

* *Values are means (± SD).*
** Statistical analysis was performed for the major fatty acids only. Means followed by different letters within a row are significantly ($p < 0.05$) different (All comparisons were made between the raw and the thermally processed samples only).

Table 3. Tocopherol and tocotrienol (tocols) composition of Balanities aegyptiaca oil extracted from raw and processed kernels*

	mg/100g		
Tocols	**Raw**	**Boiled**	**Roasted**
α-T	23.1[a] ± 0.2	21.2[a] ± 0.1	21.4[a] ± 0.4
β-T	0.1 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
γ-T	18.4[a] ± 0.2	17.95[a] ± 0.07	17.85[a] ± 0.4
δ-T	0.6 ± 0.0	0.5 ± 0.0	0.6 ± 0.0
Total tocopherols	42.2	39.85	40.05
α-T3	0.2 ± 0.1	0.2 ± 0.0	0.1 ± 0.1
β-T3	nd**	nd**	nd**
γ-T3	0.1 ± 0.0	nd**	nd**
δ-T3	nd**	nd**	nd**
Plastochromanol-8 (P8)	nd**	nd**	nd**

**Values are means (± SD).*
**Not detectable.
** Statistical analysis was performed for the major tocols only. Means followed by different letters within a row are significantly ($p < 0.05$) different (All comparisons were made between the raw and the thermally processed samples only).

the raw sample contained 3.72% moisture, 2.88% ash, 42.41% crude protein, 39.98% crude fat, and 10.99% total carbohydrates (obtained by difference). These results fall within the range of previously reported values of the chemical composition of *Balanites aegyptiaca* kernel seeds (Hussain, *et al.* 1949; Nour *et al.* 1985; Mohamed, *et al.* 2002; Chapagain *et al.* 2009; Manji *et al.* 2013). In conclusion, the findings of these studies have revealed considerable variations in the chemical composition based on various genotypes of *Balanites aegyptiaca* and the different origins of the analyzed samples. The lowest and the highest values reported for crude fat were 39–49.9%, crude

protein 26.1–50.37%, ash 3.3–6.3%, and moisture 3.1–5.7%. Compared to a raw sample, thermally processed kernel seeds did not show significant ($p > 0.05$) changes in crude protein, crude fat, or total carbohydrates. On the other hand, the findings of the study have shown a significant difference ($p < 0.05$) in the ash content between raw and boiled samples (2.88% for raw sample and 2.32% for boiled one). The leaching of minerals by water during the boiling process was reported by some authors (Arinola and Adesina, 2014; Hefnawy, 2011) as the main cause of this decrease in ash content. Furthermore, the moisture content of the roasted kernels changed significantly ($p < 0.05$) in comparison with the raw ones (Table 1). This variation in moisture content could be attributed to the effect of roasting which facilitates oil extraction by decreasing its viscosity, releasing oil from intact cells and removing moisture (Alenyorege, 2015).

3.2. The physical properties of the oils

The physical properties of the extracted oils from raw, boiled and roasted kernels are displayed in Table 1. As can be seen from the table, the crude oil of *Balanites aegyptiaca* is a liquid which has a light yellow color, a specific gravity of 0.9132, a viscosity of 63.4 cpoise, and a refractive index of 1.468. The values of the specific gravity, the color, and the refractive index of the oil are in good agreement with the reported values in the literature [Hussain, *et al.* 1949; Nour *et al.*1985; Manji *et al.* 2013; Chapagain *et al.*, 2009]. However, only Chapagain *et al.* [2009] have reported the value of the viscosity and it was observably different from the present study; 49 cp aganist 63.5 cp repectively. Additionaly, the results demonstrated that both roasting and boiling did not have considerable effects ($p > 0.05$) on viscosities, refractive indices, and specific gravities of the extracted oils when compared to raw one. On the other hand, boiling has intensified the color (color changes from light yellow to deep yellow) as shown in Table 1. This could probably be due to the increase in α-carotene content as a result of thermal processing (boiling) which facilitates the distribution or extraction of α-carotene from kernels to oils. This was clearly observed from the color of the defatted cakes of the raw (yellowish) and the boiled (off white) samples. Previous study by Hussain *et al.* (1949) has shown that *Balanites aegyptiaca* oil contains α-carotene.

In the case of the roasted sample, the color of the oil has changed from light yellow to brownish yellow. Moreover, the color of the defatted cake was also changed to brown. The formation of brown color during roasting was noticed by some researchers (Akinoso, *et al.* 2011; Anjum, *et al.* 2006) and was explained by the formation of browning substance which results from Maillard-type non-enzymatic reactions, caramelization, and phospholipid degradation.

3.3. The chemical properties of the oils

The chemical properties of the oils of *Balanites aegyptiaca* are presented in Table 1. As can be seen from the table, with the exception of peroxide value, the chemical properties of the oil extracted from the raw kernels compare well with the previous studies (Hussain, *et al.* 1949; Nour *et al.* 1985; Manji *et al.* 2013). Nour *et al.* (1985) have analyzed the oils of two different samples of *Balanites aegyptiaca* seeds originating from Sudan. They have found that the saponification values were 190.05 and 176.97, peroxide values 3.7 and 2.7, and acid values 0.40 and 0.50, respectively. Similarly, Manji *et al.* (2013) reported that the saponification and the peroxide values for *Balanites aegyptiaca* oil were 168.6 and 6.0, respectively.

The results also showed that the peroxide values of the oil from thermally processed seeds changed significantly ($p < 0.05$). Compared to the oil from the raw sample, the peroxide value of the oil from the roasted sample decreased drastically ($p < 0.05$); whereas a considerable increase ($p < 0.05$) in the peroxide value of the oil from the boiled sample was noticed. The drastic change in peroxide value in the boiled sample is probably due to the increase in oxidation of the oil caused by heating (boiling) which accelerates the oxidation processes as well as the hydrolysis in an aqueous medium which also increases the rate of rancidity. In contrast to boiling, the considerable decrease in peroxide value for the oil of the roasted seeds could be due to the formation of some materials which inhibit the oxidation of the oil. Roasting of seeds prior to oil extraction has been reported in some articles (Wijesundera, *et al.* 2008; Abou-Gharbia, *et al.* 1996) to enhance the oxidative stability of oils. In contrast, some authors have found that roasting has a negative effect on the oxidative stability of oils extracted from roasted seeds (Mariod, *et al.* 2012; Anjum, *et al.* 2006). Wijesundera *et al.* (2008) have reported that the roasting (at 165 °C for 5 min) of canola and mustard seeds increased the oxidative stability of the extracted oils and did not affect the content of tocopherols. The enhancement in oxidative stability of canola oil was attributed to the formation of 2,6-dimethoxy-4-vinyl phenol (DMVP) during roasting.

3.4. Fatty acid composition of the oils

Table 2 displays the fatty acid composition of *Balanites aegyptiaca* oils. It is apparent that linoleic (average 31.92%), oleic (average 39.17%), stearic (average 13.56%), and palmitic

(average 12.68%) acids are the major fatty acids of the oils which collectively represent about 97% of the total acids. Moreover, the unsaturated fatty acids constitute about 71% of all the fatty acids present in the oils. The monounsaturated fatty acids represent an average value of 32.52%, whereas the polyunsaturated fatty acids reach an average value of 39.43%. The higher content of the unsaturated fatty acids is favorable from a nutritionist's point of view, although it is inferior with respect to oxidative stabilities of the oils because higher levels of unsaturation (level of polyunsaturated fatty acids specifically) is more susceptible to oxidation. Generally, the rate of oxidation was found to increase with the increase in the number of double bonds in the fatty acids (Kamal-Eldin, 2006; Savage, *et al.* 1999). Savage *et al.* (1999) have studied the oxidative stability of different samples of Walnut oil. The results revealed the presence of a correlation between the levels of C18:2 fatty acid in the oil and the reduction in the oxidative stabilities of the oil. Compared to the oil extracted from the raw sample, the fatty acid composition of the oil extracted from the processed samples remained roughly unchanged. The present results of the fatty acid composition of *Balanites aegyptiaca* oil are in good agreement with previous studies (Al Ashaal, *et al.* 2010; Chapagain, 2009; Hussain, *et al.* 1949; Mohamed, *et al.* 2002; Nour *et al.*1985) regarding the major fatty acids in the oil, however, except for Nour *et al.* (1985), significant variations in the percentages of these acids could be noticed. The noticeable variations in the percentages of fatty acids were clarified by Chapagain *et al*. (2009) who analyzed the fatty acid composition of six *Balanites aegyptiaca* genotypes. The percentage ranges of the four major fatty acids were found to be: palmitic acid 12.7–16.0%, stearic 10.2–12.1%, oleic acid 23.5–43.7%, and linoleic acid 31.50–51.6%. Moreover, the present study is the first study to report the presence of cis-vaccenic (0.80–0.88%), margaric (0.11–0.12%), and eicosenoic (gondoic) (0.1%) acids in *Balanites aegyptiaca* oil.

3.5. Tocol contents of the oil

The tocopherol and tocotrienol (tocols) compositions of the oil of *Balanites aegyptiaca* are given in Table 3. It is obvious that α- and γ-tocopherols represent the major constituents of tocols although traces or very little quantities of δ-tocopherols were also detected. The total tocopherol contents of the oil extracted from the raw, boiled, and roasted samples were found to be 42.2 mg/100g, 39.85 mg/100g, and 40.05 mg/100g, respectively. Tocopherols were reported in the literature (Kamal-Eldin, 2006) as one of the essential components of vegetable oil which have activity against oxidation or the development of rancidity. Compared to the values of tocopherol contents in vegetable oil and industrial fats investigated by Schwartz *et al*. (2008), the tocopherol content of *Balanites aegyptiaca* oil is higher than coconut oil, refined olive oil, and extra virgin olive oil and is comparable to sesame oil. In addition, it is observably lower than sunflower oil, rapeseed refined and cold pressed oil, camelina oil, and wheat germ. Furthermore, the results have revealed the absence of tocotrienols as well as plastochromanol–8 (P8) although trace quantities of α- and γ-tocotrienols were detected in some samples (Table 3).

3.6. Oxidative stability of Balanites aegyptiaca oil

The oxidative stability of the oil is expressed as the induction period (IP) and was determined by Rancimat at 110 °C. The oxidative stability of the oil extracted from the raw kernels was 10.64 h. The highest stability was shown by the oil from the roasted sample (14.50 h) whereas the lowest stability was displayed by the oil from the boiled sample (7.14h). It has been reported in the literature that the oxidative stability of vegetable oil depends on its fatty acid composition and the antioxidants (mainly tocopherols) (Kamal-Eldin, 2006). However, in the present study, these variations were not seen because of the differences in fatty acid compositions or tocol contents as their values remain fairly unchanged between the oil from the raw and the processed samples. Possibly these differences could be due to the presence of other antioxidants or might be due to the effect of boiling which accelerates the oxidation of the oil. The peroxide values for the oil confirm this assumption.

4. CONCLUSIONS

The present study reveals that the roasting of *Balanites aegyptiaca* kernels prior to oil extraction has positively improved the oxidative stability of the oil (from 10.64 hours for raw to 14.50 hours for roasted), and significantly ($p < 0.05$) reduced the peroxide value (from 13.34 meq/Kg for raw to 4.56 meq/Kg for roasted), and with the exception of color, did not change the other physical and chemical properties in a significant way ($p > 0.05$). In addition, the findings displayed that the oil contains significant levels of essential fatty acids and tocopherols. The observable higher levels of unsaturated fatty acids (71%) demonstrates the benefits of the oil for human consumption. Further study regarding the existence of phenolics, saponins, carotenoid compounds as well as the compounds formed or chemically modified as a result of roasting is required.

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