Characteristics of *Chamaerops humilis* L. var. *humilis* seed oil and study of the oxidative stability by blending with soybean oil

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Abstract Herein we examine the characteristics of date seed oil extracted from *Chamaerops humilis* L. var. *humilis* seeds (HSO) cultivated in a gardening zone in Tunisia. Its physicochemical properties, fatty acid composition, and thermal and antioxidant properties were evaluated and compared with those of seed oil from another variety of *Chamaerops humilis*. The results showed that HSO possessed higher contents of oleic (44%) and linoleic (20%) acids than the other seed oil. The total tocopherol and tocotrienol content was 88 mg/100 g oil, where α -tocotrienol (64%) was the major isomer. The total phenolic (91 μ g/g oil) and flavonoid contents (18 μ g/g oil) of the HSO were determined, and its antioxidant capacities, measured in terms of ABTS and DPPH radical-scavenging capacities, were 210 μ M TEAC/g DW and 4.3 mM TEAC/g DW, respectively. The oxidative stability index (OSI) of the oil was 16 h at 110 °C. Furthermore, the OSI of soybean oil was significantly enhanced upon blending with

HSO. HSO exhibited higher thermal stability than the other oils and significantly different thermal behavior. The determination of fatty acid composition, physicochemical properties, bioactive content, oxidative stability, and thermal behavior of HSO demonstrated that this renewable resource can be used for edible purposes.

Keywords *Chamaerops humilis* L. var. *humilis* seed oil · Fatty acids · Antioxidant properties · Oxidative stability · Blending

Introduction

Vegetable oil has become increasingly popular over the past several decades, resulting in growing global oil crop production (O'Brien 2009). Oil crops have been increasingly used as raw materials for food, livestock feed, and in non-food industrial applications.

Oils occur naturally in a wide range of sources, with each source providing a distinct type of oil. Many seeds and fruits contain oil, but only a few of these sources are of economic importance. Thus, considerable efforts have been made to identify and characterize oil crops that produce oils suitable for industrial and fuel uses. When these crops can be grown in arid environments, they offer an especially attractive alternative to both edible oils and petroleum (Azeem et al. 2016). Furthermore, wild plant species are typically been used in traditional medicines (Eromosele and Eromosele 2002).

Date seeds are produced in many regions, and are a waste product of the production of pitted dates, date syrup, and date confectioneries from date palms (Abdul Afiq et al. 2013; Habib et al. 2013). Therefore, utilizing this waste product has important implications for date cultivation and for increasing income in this field.

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Chamaerops humilis L., more commonly referred to as the dwarf fan palm, is a medicinal plant that belongs to the Arecaceae family. It is naturally found in southern Europe (Italy, Sardinia, and Spain) and North Africa (Tunisia, Algeria, and Morocco), but is also widely used in horticulture and landscaping in many regions preferentially over other non-indigenous palms (Giovino et al. 2014). These factors, along with the possible benefits of *Chamaerops humilis* L. products to Mediterranean ecosystems, account for its widespread cultivation (Siles et al. 2015; Giovino et al. 2015). *Chamaerops humilis* grows to an average height of 1.0–1.5 m, and in protected areas it can reach up to 9–10 m in height. All varieties produce a single inflorescence consisting of a spadix surrounded by a long and slender greenish-yellow spathe.

Despite the great variability in its location and appearance, this species has only two varieties: *Chamaerops humilis* var. *humilis* and *Chamaerops humilis* var. *argentea* André, which have green and gray leaves, respectively (Siles et al. 2015). Few studies have investigated the oil extracted from *Chamaerops humilis* L. seeds. However, studies regarding the oils extracted from the seeds of *Phoenix dactylifera* L. (Abdul Afiq et al. 2013; Habib et al. 2013), or the fruit pulp instead than the seed of the fruit (Tan and Man 2002; Neo et al. 2010) have been widely reported.

Anwar et al. (2007) reported that oleic acid (C18:1) shows a high resistance towards oxidation compared with other unsaturated fatty acids. Fatty acid oxidation occurs primarily at double bonds, and a high content of polyunsaturated fatty acids increases the rate of oxidation. It has been shown that blending oils with high saturated fatty acid content reduces the degree of unsaturation, and therefore increases oxidative stability (Chu and Kung 1998). Conventional vegetable oils, such as soybean and sunflower oils, are used for cooking and salad dressing (Gunstone 2002) but cannot be used for high-temperature applications due to their low oxidative stability (Anwar et al. 2007). Consequently, a suitable equilibrium between saturated and polysaturated fatty acids must be achieved by blending to use vegetable oil as a base stock for industrial applications.

To the best of our knowledge studies on fatty acid composition, physicochemical properties, antioxidant activities, and thermal behavior of *Chamaerops humilis* var. *humilis* seed oil have not been reported to date. Moreover, studies aiming to improve the oxidative stability of edible oils have focused on the addition of natural or synthetic antioxidants and few researchers have examined blending oils. The oxidative stability of edible oils is vital for oil selection by manufacturers.

In a previous study, the fatty acid composition and physicochemical properties of *Chamaerops humilis* var. *argentea* seed oil (ASO) were investigated (Nehdi et al.

2014). In this study, the fatty acid composition, physicochemical properties, bioactive compound (tocopherols and tocotrienols) content, and thermal behavior of oils extracted from *Chamaerops humilis* var. *humilis* seeds were examined. We also compare these properties with those of date palm oil from the same variety (var. *argentea*) but different family (*Phoenix dactylifera* L.). Moreover, the effect of blending HSO with soybean oil (SSO) on the oxidative stability of the resulting blended oils at different temperatures was determined.

The results of this investigation should stimulate interest in date seed oils for use in food and other industries, and increase the utilization of renewable vegetable oils whether as pure oils or as blends.

Materials and methods

Seed material and oil extraction

Fruits of *C. humilis* L. var. *humilis* were collected from palms located on Carthage Street (latitude 36°47'N; longitude 10°10'E; altitude 0 m) in Tunis (Tunisia) in August 2015. The identification of the plant was performed by Dr. Jacob Thomas Pandalayil of the Biochemistry Department, Science College, King Saud University. The seeds were removed from the fruit and placed in an oven at 60 °C for 24 h, then air-dried at room temperature. The seeds were milled using an IKA-M20 universal mill (tungsten cutter, hardness 9). The resulting fine powders were divided into three proportions of approximately equal mass ($n = 3$) and placed in cellulose paper and then subjected to Soxhlet extraction in n-hexane for 8 h. The hexane was removed via rotary evaporation (R-210 BUCHI, Flawil, Switzerland) at 80 °C under atmospheric pressure and subsequently at 40 °C under vacuum. Soybean oil was purchased from a local market and the blended oils (B1, B2, B3, and B4) were prepared by blending HSO with SSO in proportions of 10:90, 20:80, 30:70, and 40:60% (w/w).

Statistical analysis

Samples of pure and blended oils were examined in triplicate. Statistical analyses were performed using one-way ANOVA (Bonferroni test) and linear regression tests at a 95% confidence level using Sigmaplot software (version 13.0). Values with differences at a level of $P < 0.05$ were considered significant.

Fatty acid composition

The fatty acid composition of the oils was determined using a gas chromatography mass spectrometer (GC–MS,

QP2010 Ultra, Shimadzu, Japan) equipped with a flame ionization detector (FID) and a Rxi-5Sil MS column (30 m × 0.25 mm i.d., 0.25 µm film thickness; Bellefonte, Restek, Pennsylvania, USA). Triacylglycerols were transesterified to convert them into fatty acid methyl esters (FAMES) (Nehdi et al. 2013). The GC conditions for FAME separation were as follows: injector and detector temperatures, 220 and 275 °C, respectively; injection volume, 1 µL; oven temperature, ramped from 150 to 180 °C at 15 °C/min followed by an increase to 210 °C at 1 °C/min; carrier gas He at a flow rate of 1.50 mL/min.

The MS was operated in electron ionization (EI) mode at 70 eV. The FAMES were identified by matching their mass spectra to those of standards deposited in the Wiley library database and by comparison of retention times to known standards.

Physicochemical properties

Free fatty acid (oleic acid) and peroxide contents were determined using standard procedures (ISO 660 and ISO 3960). An Abbe refractometer (Bellingham and Stanley, Ltd., Kent, England) was used to measure the refractive index of the oils at 21 °C. UV spectra of 0.01, 1, and 10% (v/v) oil in hexane were measured at 200–290, 290–400, and 400–800 nm, respectively, using a UV-1800 UV-Vis spectrophotometer (Shimadzu, Kyoto, Japan). The chlorophyll and carotenoid contents of the oils were determined according to the method described by Allalout et al. (2009). The theoretical iodine value was calculated using the method reported by Sbihi et al. (2014) based on the areas of the olefinic and four glyceryl methylene proton signals in the ¹H NMR spectra of the seed oils. Spectral data were recorded on a JEOL Eclipse 400 MHz NMR spectrometer (JEOL, Peabody, MA, USA) operating at 9.39 T and 400 MHz. For NMR analysis, an aliquot of approximately 40 mg of the oil sample was diluted with 0.5 mL of CDCl₃. The solution was filtered and then transferred into a 5 mm NMR tube containing a small amount of tetramethylsilane.

Oxidative stability index

The oxidative stability index of pure oils and oil blends were determined using a Professional Rancimat apparatus Model 892 (Metrohm, Switzerland). First, 3.0 g of HSO was weighed into a glass reaction vessel and the conductivity cell was filled with 60 mL of deionized water. The sample was heated to three different temperatures (100, 110, and 120 °C), and air was passed through the heated oil at a rate of 20 L/h. The oxidative stability index was determined by the Professional Rancimat instrument and expressed in hours.

The shelf-life (SL) of HSO, B1, B2, B3, B4, and SSO were determined by extrapolating parameters using the Arrhenius equation:

$$t = A \exp\left(\frac{B}{T}\right)$$

where A is the pre-exponential factor and B is the Arrhenius coefficient.

Tocol (tocopherols and tocotrienols) composition

The vitamin E content in the extracted oil was determined by high-performance liquid chromatography (HPLC, LC-20AT pump, Shimadzu, Kyoto, Japan) using a Hypersil silica column (15 cm × 3.0 mm i.d., 3.0 µm particle size, Thermo scientific). The fluorescence detector (Shimadzu, Kyoto, Japan) operated at an excitation wavelength of 295 nm and an emission wavelength of 330 nm and the ISO 9936 (2006) standard method was applied. Briefly, 0.5 g of the extracted oil was dissolved in 25 mL of hexane, and 20 µL of the prepared mixture was injected into the GC–MS. The mobile phase used was hexane/2-propanol (99.5:0.5, v/v) at a constant flow rate of 0.5 mL/min.

The concentrations of tocopherol and tocotrienol isomers in the extracted oil were calculated based on the response factors of their respective standards (Sigma Chemical Co., St. Louis, MO, USA) measured under identical conditions using the following equation:

$$\text{tocol content} = \frac{\rho \cdot \bar{A}_t \cdot V}{\bar{A}_s \cdot m}$$

where ρ is the concentration, in µg/mL, of the standard solution; $\bar{A}_s$ is the average of the peak areas of the standard; $\bar{A}_t$ is the average of the peak areas of the test sample; m is the mass, in g, of the sample; and V is the volume of test solution prepared (25 mL).

Antioxidant assays

DPPH assay

Antioxidant capacity was determined based on the methods developed by Thoo et al. (2010) and Tay et al. (2014), with slight modification. Briefly, the oil sample was dissolved in acetone at a 1:1 (v/v) ratio. An aliquot of the dissolved oil sample (0.1 mL) was then added to 3.9 mL of ethanolic DPPH (60 µM). The mixture was vortexed and placed in the dark at room temperature. After 30 min, the absorbance was measured at 517 nm. A negative control was prepared by replacing the dissolved oil sample with 0.1 mL of acetone. The DPPH radical-scavenging activity was calculated based on the following expression:

$$\left[1 - \left(\frac{A_s}{A_c}\right)\right] \times 100\% (A_s = A_{517} \text{ of sample}; \\ A_c = A_{517} \text{ of negative control}).$$

Measurements were calibrated using a standard curve of the prepared Trolox and expressed as millimoles of Trolox equivalent antioxidant capacity (TEAC) per g dry weight (mM TEAC/g DW).

Total phenolic content (TPC), total flavonoid content (TFC), and ABTS assays

Prior to the assays, the oil samples were extracted using the method described by Fuentes et al. (2012), with slight modification. Briefly, the oil sample (2 g) was dissolved in 4 mL of hexane, and the compounds of interest were extracted with 3 mL of methanol/water (60:40, v/v) by vortexing for 2 min. Both phases were separated using centrifugation at 3500 rpm for 10 min and the hexane phase was re-extracted using the same steps described above. The methanolic extracts were then used for the determination of TPC and TFC, and for the ABTS assay.

Determination of TPC

The TPC was determined using the Folin-Ciocalteu (FC) assay described by Tay et al. (2014). The methanolic extract (0.32 mL) obtained from the oil samples were mixed with 1.6 mL of FC reagent (diluted tenfold). After 5 min, 1.28 mL of sodium carbonate (7.5% w/v) was added and the mixture was vortexed and allowed to stand in the dark at room temperature for 30 min. A blank was prepared by replacing the methanolic extract with a pure methanolic phase (methanol/water, 60:40, v/v). The absorbance was measured against the blank at 765 nm. TPC was calculated based on the gallic acid calibration curve and expressed as gallic acid equivalent (GAE) in μg per g of oil (μg GAE/g oil).

Determination of TFC

The TFC was estimated according to the procedure described by Thoo et al. (2010). The methanolic extract (0.25 mL) was added to 1.25 mL of deionized water and 75 μL of 5% sodium nitrite. After 6 min, 150 μL of 10% aluminum chloride was added. After 5 min, 0.5 mL of 1 M sodium hydroxide and 275 μL of deionized water were added and vortexed. Subsequently, the absorbance of the mixture was measured at 510 nm against a blank. The TFC was calculated based on a calibration curve using catechin as a standard and expressed as catechin equivalent (CE) in μg per g of oil (μg CE/g oil).

ABTS assay

The ABTS radical-scavenging capacity was determined according to the method described by Thoo et al. (2010). First, the ABTS radical solution was prepared by mixing 10 mL of 7 mM ABTS solution with 10 mL of 2.45 mM potassium persulfate solution and allowed to stand in the dark at room temperature for 16 h. The prepared ABTS radical solution was adjusted with ethanol to achieve an absorbance of 0.7 (± 0.01) at 734 nm. The methanolic extract (0.1 mL) was added to 3.9 mL of the adjusted ABTS radical solution and allowed to react for 6 min. A negative control was prepared by replacing the methanolic extract with the methanolic phase (methanol/water, 60:40, v/v). The ABTS radical-scavenging activity was calculated based on the following expression:

$$\left[1 - \left(\frac{A_s}{A_c}\right)\right] \times 100\% (A_s = A_{734} \text{ of sample}; \\ A_c = A_{734} \text{ of negative control}).$$

Measurements were calibrated using a standard curve of prepared Trolox and expressed as μM of Trolox equivalent antioxidant capacity (TEAC) per g of dry weight (μM TEAC/g DW).

Thermal analysis

Simultaneous thermogravimetric and first derivative thermogravimetric (TG/DTG) curves as well as differential scanning calorimetry (DSC) curves were obtained using a thermal balance (TGA-50, Shimadzu, Kyoto, Japan) and a Shimadzu DSC-60 differential scanning calorimeter (Shimadzu, Kyoto, Japan), respectively.

The TG/DTG curves were obtained using a sample mass of 5.0 ± 0.5 mg under synthetic air flow of 100 mL/min and a heating rate of 10 $^{\circ}\text{C}/\text{min}$. The temperature range was 25–600 $^{\circ}\text{C}$ and Shimadzu TA-60 WS (2.20) software was used to analyze the data from the three independent measurements and to obtain TG/DTG curves. The DSC curves were collected using nitrogen (99.999% purity) as a purge gas at a flow rate of 20 mL/min. In the first step, 10–12 mg of the sample was weighed into an aluminum pan and sealed with a cover. The sealed pan was heated to 100 $^{\circ}\text{C}$ for 1 min, cooled to -100 $^{\circ}\text{C}$ at 20 $^{\circ}\text{C}/\text{min}$, and held isothermally for 1 min. Subsequently, the sample was heated to 100 $^{\circ}\text{C}$ at 10 $^{\circ}\text{C}/\text{min}$, held isothermally for 1 min, and cooled to -100 $^{\circ}\text{C}$ at 10 $^{\circ}\text{C}/\text{min}$. The melting/crystallization point of the sample was defined as the temperature at which the sample was entirely melted/solidified and was determined from the heating/cooling program data.

Results and discussion

Fatty acid composition

The fatty acid profile of the extracted HSO is shown in Table 1. The major fatty acid components of HSO are oleic acid (44%) and linoleic acid (20%), followed by lauric acid (13%) and myristic acid (6.2%). However, in ASO the major fatty acid is oleic acid (39%), followed by lauric (21%) and linoleic acids (15%). Roughly the same compositional profile was observed in *Phoenix canariensis* L. seed oil (PSO).

Human studies have suggested that lauric acid can raise total serum cholesterol and low-density lipoprotein cholesterol concentrations beyond the levels induced by oleic acid. However, lauric acid is not as effective at increasing cholesterol concentration as palmitic acid. The cholesterol-raising properties of saturated fatty acids can be

attributed solely to lauric, myristic, and palmitic acids (Mensink et al. 1994).

HSO contains a higher percentage of oleic and linoleic acids when compared to ASO. The high percentage of oleic acid in HSO is medicinally beneficial because oleic acid plays a crucial role in neural tissue synthesis and cardiovascular remediation (Sbihi et al. 2014). Because of its high unsaturated fatty acid content, particularly C18:1 (oleic) and C18:2 (linoleic), HSO is considered an edible oil. Moreover, linoleic acid is an essential fatty acid and serves as a substrate to produce polyunsaturated fatty acids that are found in cellular structures and as a precursor in the synthesis of many regulatory biochemicals (Shahidi 2005). HSO is also low in lauric acid (C12:0), myristic acid (C14:0), and stearic acid (C18:0), but slightly higher in palmitic acid (C16:0).

Canola and peanut oils have higher oleic acid (61 and 46%, respectively) and linoleic acid contents (22 and 31%,

Table 1 Fatty acid profile (% of total fatty acid) of HSO, ASO, PSO and SSO

Fatty acid	HSO	ASO ^a	PSO ^b	SSO
C8:0	*	*	0.08	*
C10:0	1.3 ± 0.05	2.4 ± 0.05	0.1	*
C11:0	0.01 ± 0.01	*		*
C12:0	13 ± 0.4	21 ± 0.1	10	*
C13:0	0.01 ± 0.01	*		*
C14:0	6.2 ± 0.3	7.2 ± 0.08	7.5	0.04 ± 0.01
C15:0	0.06 ± 0.01	0.07 ± 0.05	0.07	*
C16:1Δ6c	0.05 ± 0.01	0.05 ± 0.03	0.07	*
C16:1Δ9c	0.04 ± 0.01	0.04 ± 0.03	0.06	0.06 ± 0.01
C16:0	12 ± 0.4	10 ± 0.2	9.8	10 ± 0.5
C17:1Δ10c	0.02 ± 0.01	0.06 ± 0.04	0.08	*
C17:0	0.08 ± 0.01	0.1 ± 0.03	0.15	0.09 ± 0.01
C18:2Δ9c,12c	20 ± 0.8	15 ± 0.4	19	55 ± 0.9
C18: 3Δ9c,12c,15c	*	0.1 ± 0.02	0.1	7.9 ± 0.1
C18:1Δ9c	44 ± 0.9	39 ± 0.65	50	20 ± 0.3
C18:1Δ11c	0.4 ± 0.01	0.3 ± 0.06	0.1	1.3 ± 0.05
C18:0	3.1 ± 0.3	3.6 ± 0.08	1.7	4.4 ± 0.08
C20:1Δ11c	0.2 ± 0.01	0.4 ± 0.05	0.3	*
C20:0	0.01 ± 0.01	0.2 ± 0.03	0.2	0.3 ± 0.02
C22:0	*	0.04 ± 0.01	0.09	0.2 ± 0.01
C23:0	*	*	0.02	0.04 ± 0.01
C24:0	*	*	0.02	0.1 ± 0.01
SFA	36	45	30	16
MUFA	44	40	51	22
PUFA	20	15	19	62
UFA	64	55	70	84
U/S	1.8	1.2	2.3	5.4
Molecular weight	830	800 ± 0.9		870

Values are mean ± standard deviation of 3 samples

^aNehdi et al. (2014); ^bNehdi et al. (2010); *not detected

respectively). Canola is used primarily as a cooking oil as well as in salad dressings and soft margarine. However, peanut oil has been associated with cardiovascular disease and food allergies (Gunstone 2002). The fatty acid composition of HSO determined in this study indicates that this new oilseed crop could be used in edible oil products.

The physicochemical properties of seed oil

Relevant physicochemical properties of HSO are listed in Table 2. The oil content of the seeds is 9.9% (w/w) and is slightly higher than that obtained for ASO (9.8%) and similar to that found in PSO (10%). The iodine value of HSO was determined to be 61 g/100 g oil, which is higher than that of ASO (56 g/100 g oil) and lower than that of PSO (77 g/100 g oil). This higher iodine value is a results of the high unsaturated fatty acid content, mainly caused by the higher abundance of oleic and linoleic acids (Table 1). Palm oil with an iodine value of > 60 is used for the production of palm olein, which is used in fried foods and other consumer products without the need for hydrogenation. Moreover, HSO is a non-drying oil (iodine value: < 125) (Shahidi 2005), and unlike conventional oils such as corn (iodine value: 127–133) and safflower oils (iodine value: 141–147) (Gunstone 2002), the more saturated character of HSO results in strong resistance to oxidative rancidity. The peroxide value of HSO was determined to be 7.1 meq O₂/kg, which is slightly lower than that of ASO (7.9 meq O₂/kg). Therefore, HSO is acceptable for edible applications because its peroxide value is lower than the recommended 10 meq O₂/kg (Sbihi et al. 2015). The free fatty acid value of crude HSO is 1.6%, slightly higher than the preferred value of 1%, but lower than the value of ASO (4.9%).

Table 2 Physico-chemical properties of HSO, ASO and PSO

Parameters	HSO	ASO ^a	PSO ^b
Oil yield % (w/w)	9.9 ± 0.2	9.8	10
Color (visual)	Yellow	Yellow	Yellow
State at ambient temperature	Liquid	Liquid	Liquid
Free fatty acid (oleic %)	1.6 ± 0.05	4.9	0.6
Iodine number (g/100 g oil)	61 ± 2.1	56	77
Peroxide value (meq O ₂ /kg)	7.1 ± 0.20	7.9	3.6
Refractive index	1.5 ± 0.0	1.5	*
Carotenoid content (mg/kg oil)	7.4 ± 0.3	1.7	5.5
Chlorophyll content (mg/kg oil)	5.4 ± 0.2	2.4	0.1

Values are mean ± standard deviation of 3 samples

^aNehdi et al. (2014); ^bNehdi et al. (2010); *not found in the article

Oxidative stability

The oxidative stability index (OSI) values of HSO and HSO blended with SSO were measured at three temperatures: 100, 110, and 120 °C and the results listed in Table 3. Table 3 shows that HSO exhibits a higher OSI at three different temperatures (33, 16, and 7.4 h) than SSO (11, 5.2, and 2.4 h). SSO has a higher polyunsaturated fatty acid (PUFA) (62%) compared to that of HSO (20%), whereas SSO has a higher total tocopherol content (180 mg/100 g oil) than HSO (88 mg/100 g oil). Moreover, HSO exhibits a higher OSI at 110 °C (16 h) than canola (4.3 h) and peanut oils (6.5 h) (O'Brien 2009). Shahidi (2005) reported that the higher content of polyunsaturated fatty acids results in this lower oxidative stability.

The OSI data obtained for the blended HSO and SSO (B1, B2, B3, and B4) are listed in Table 3. The results showed that the OSI of SSO significantly increased ($P < 0.05$) upon blending with HSO from 2.4 to 4.4 h (at 120 °C), from 5.2 to 9.6 h (at 110 °C), and from 11 to 21 h (at 100 °C). Figure 1 shows that the OSI was strongly correlated with the weight percentage of HSO (X) in the oil blends. The correlations were obtained as follows:

$$\text{OSI} = 2.4 + 5.1 * X \quad (\text{at } 120^\circ\text{C}, 0 < X < 0.4) \quad (1)$$

$$\text{OSI} = 5.2 + 11 * X \quad (\text{at } 110^\circ\text{C}, 0 < X < 0.4) \quad (2)$$

$$\text{OSI} = 11.4 + 24.3 * X \quad (\text{at } 100^\circ\text{C}, 0 < X < 0.4) \quad (3)$$

For Eqs. (1), (2), and (3), the coefficient of determination (R^2) was 0.99. Removing lauric (C12:0) and myristic (C14:0) acids by adding HSO and reducing linoleic (C18:2) and linolenic acids (C18:3) significantly increased the OSI of the blended oils. Palmitic (C16:0) and stearic (C18:0) acid contents were similar in HSO and SSO.

Bhatnagar and Krishna (2015) reported that seed oil, which contains a large amount of saturated fatty acids (SFAs) (coconut) or monounsaturated fatty acids (MUFAs) such as oleic acid (olive oil), remarkably enhances the OSI when blended with niger seed oil containing a large amount of PUFA (linoleic: 69.2%). HSO contains a large amount of SFA (36%) and MUFA (44%), and Siddeeg and Xia (2015) found that peanut oil did not significantly enhance the OSI of senat oil although its contained large amounts of tocopherol. The PUFA content of peanut and senat oils were determined to be 36 and 61%, respectively.

In addition, Torres et al. (2011) found that every 20% addition of virgin oil to walnut oil increased the OSI values of the mixture by factor of 1.3. The factor was slightly higher (1.35) for each 20% addition of HSO to SSO. Rudzinska et al. (2016) indicated that the OSI of blended rapeseed oil (RO) with rice bran (RBO) or black cumin oils (BCO) increased by ≈ 1.05 folds for each 15% addition,

Table 3 OSI of HSO, SSO and oil blends at different temperatures

	SSO	B1	B2	B3	B4	HSO
OSI (h, 100 °C)	11 ^f ± 0.2	14 ^e ± 0.2	16 ^d ± 0.2	19 ^c ± 0.2	21 ^b ± 0.2	33 ^a ± 0.2
OSI (h, 110 °C)	5.2 ^f ± 0.1	6.3 ^e ± 0.1	7.4 ^d ± 0.2	8.5 ^c ± 0.1	9.6 ^b ± 0.1	16 ^a ± 0.1
OSI (h, 120 °C)	2.4 ^f ± 0.09	2.9 ^e ± 0.1	3.4 ^d ± 0.1	3.9 ^c ± 0.1	4.4 ^b ± 0.1	7.4 ^a ± 0.2
OSI (h, 25 °C)	1.4 × 10 ⁴	2.9 × 10 ⁴	3.2 × 10 ⁴	3.8 × 10 ⁴	4.5 × 10 ⁴	5.8 × 10 ⁴
OSI (year, 25 °C)	1.5 ^f ± 0.1	3.2 ^e ± 0.1	3.7 ^d ± 0.1	4.3 ^c ± 0.1	5.1 ^b ± 0.2	6.6 ^a ± 0.2

Values are mean ± standard deviation of 3 samples

Values having different superscripts in a row are significantly different at $P \leq 0.05$

Fig. 1 OSI of oil blends at 100, 110 and 120 °C

despite the high content of total tocopherols and tocotrienols in both RBO and BCO. The total of SFA in BCO and RBO was 16.3 and 23%, respectively, are they were found to contain high PUFA contents (BCO: 61.3% and RBO: 35.1%).

As shown in Table 3, the SLs of HSO and SSO at the target temperature (25 °C) are 58,000 h (6.6 years) and

Fig. 2 SL of oil blends at 25 °C

14,000 h (1.5 years), respectively. Figure 2 shows the SLs of the blended oils B1, B2, B3, and B4. A strong relationship was found between the SL and X as follows:

$$SL(\text{year}) = 2.2 + 6.3 * X \quad (4)$$

For Eq. (4), the coefficient of determination (R^2) is 0.98. The SL of the blended oils significantly increased ($P < 0.05$) with increasing HSO content from 1.5 to 5.1 h (40 wt % HSO). Many vegetable oils are not used as food oils because of their poor oxidative stability and must be partially hydrogenated for industrial applications (Gunstone 2002). The results presented here indicate that adding HSO to SSO has several advantages including enhancing oxidative stability and conserving essential fatty acids (linoleic and linolenic acids) which have good nutritional value.

Tocol composition

A number of tocopherol and tocotrienol isomers are present in HSO. The most abundant tocopherol was found to be γ -tocopherol (23%), and the most abundant tocotrienol was α -tocotrienol (64%). These two isomers are higher in abundance (20 and 56 mg/100 g for tocopherol and tocotrienol, respectively) than in ASO (15 and 22 mg/100 g, respectively; Table 4).

Saldeen et al. (1999) reported that γ -tocopherol is better than α -tocopherol at preventing the oxidation of low-density lipoproteins and delaying thrombus formation. In addition, tocotrienols are more effective at reducing the risk of breast cancer than tocopherols (Schwenke 2002). The consumption of tocotrienols capsules has been found to reduce cholesterol and low-density lipoprotein cholesterol in humans (Yuen et al. 2011). The tocol content of HSO (88 mg/100 g) was determined to be higher than that of both ASO (74 mg/100 g) and PSO (52 mg/100 g).

Tocopherols and tocotrienols are important fat-soluble vitamins that contribute to the stability of oils by stabilizing hydroperoxy and other free radicals, and their presence has a significant effect on oil flavor (O'Brien 2009). However, if the level of tocopherols and tocotrienols is

Table 4 Tocopherol compositions of HSO, ASO and PSP

Oil	HSO		ASO ^a		PSO ^b	
	mg/100 g	%	mg/100 g	%	mg/100 g	%
α -Tocopherol	1.8 $\pm$ 0.05	1.4	1.5	2	0.6	1.2
β -Tocopherol	2.6 $\pm$ 0.05	2.9	0.8	1.1	0.9	1.8
γ -Tocopherol	20 $\pm$ 0.4	23	15	20	10	20
δ -Tocopherol	0.4 $\pm$ 0.02	0.5	2.6	3.5	1.0	2
α -Tocotrienol	56 $\pm$ 0.1	64	22	29	34	66
γ -Tocotrienol	2.8 $\pm$ 0.05	3.2	8.8	12	4.6	9
δ -Tocotrienol	4.8 $\pm$ 0.08	5.4	24	32	0	0
Total	88	100	74	100	52	100
α -Tocol acetate	63		56			
TPC (μ g/g oil)	91 $\pm$ 2.4					
TFC (μ g/g oil)	18 $\pm$ 1.1					
ABTS (μ M/g oil)	210 $\pm$ 2.7					
DPPH (mM/g)	4.3 $\pm$ 0.01					

Values are mean $\pm$ standard deviation of 3 samples

^aNehdi et al. (2014); ^bNehdi et al. (2010)

excessive, the oxidation of unsaturated fatty acids is enhanced (O'Brien 2009).

The antioxidant capacity of HSO, measured in terms of ABTS and DPPH radical-scavenging capacities, are 210 and 4.3 mM/g, respectively. TPC and TFC of the HSO were determined to be 91 and 18 μ g/g, respectively (Table 4). TSO contains acceptable levels of phenolic compounds, which may contribute to its stability under accelerated oxidative conditions.

Thermal profiles

The TG and DTG curves of HSO in air are shown in Figure S1. The TGA curve indicates that HSO is more thermally stable (up to 278 °C) than ASO (up to 234 °C). Onset of thermal decomposition was indicated by the mass loss of 5%.

For HSO, a 90% mass loss occurs at 497 °C, whereas the same mass loss occurs at 481 °C for ASO. Therefore, it is clear that HSO can be used for high-temperature frying. The thermal stability of a frying oil mainly depends upon its initial acid value, peroxide value, and balance of saturated and unsaturated fatty acids.

The thermal decomposition of HSO occurs in three steps and is identical to ASO decomposition because both have a similar fatty acid composition.

The cooling curves of HSO exhibits three exothermic peaks at 7.8, -7.7 , and -14.7 °C (Figure S2). The major crystallization peak for HSO occurs at -7.7 °C, whereas the major peak for ASO occurs at -15.2 °C. The difference between the two cooling curves can be attributed to the difference in the triacylglycerol compositions of the

two oils. HSO has a high unsaturated fatty acid content (Table 1), whereas its triacylglycerol content is composed of a roughly equal mix of saturated and unsaturated fatty acids.

The melting curve of HSO exhibits a major transition at -16.4 °C with two smaller shoulder peaks at -9.7 and -41.4 °C. On the other hand, ASO shows only one melting peak at 9.3 °C. The first low-temperature endothermic peak at -41.4 °C likely corresponds to the transition between the α - and β -crystalline forms (Gunstone 2002). The melting point of ASO is higher than that of HSO because of the higher saturated fatty acid content of ASO (45%), particularly lauric acid, which makes up ca. 21% of the total (Table 1).

UV/visible spectroscopy

HSO exhibits absorbance peaks at 413, 440, 468, and 664 nm in its UV–visible spectrum (Figure S3). The absorbance at 400–470 nm indicates the presence of carotenoids, which impart yellow color to oil. The concentration of carotenoids is much higher in HSO (7.4 mg/kg) than in ASO (1.7 mg/kg). The low absorbance at 664 nm (0.182) indicates that HSO contains a small amount of chlorophyll, although the concentration is higher (5.4 mg/kg) than in ASO (2.4 mg/kg). These pigments have additional biological and health-related properties as they are involved in auto- and photo-oxidation mechanisms and can act as antioxidants in the dark. HSO exhibits some absorbance in the UV-C (100–290 nm) and UV-B (290–320 nm) regions (Figure S3). It absorbs more strongly in the UV-C region (1.9) than ASO (1.7). These

UV–visible absorption properties can protect against sunstroke in humans, which is caused by high dosages of solar UV rays. Thus, HSO may be a safe and effective oil for protecting skin from both UV-C and UV-B radiation.

Conclusion

This study provides a large amount of data regarding the oil extracted from *Chamaerops humilis* var. *humilis* seeds collected from palm trees grown in the wild in Tunisia. HSO has distinctive chemical and physical properties compared with oil from seeds of the same variety but different species. The high oleic and linoleic acid contents suggest that the oil may have applications in nutritional sciences. The high levels of tocopherols, carotenoids, and chlorophyll impart significant stability against oxidative deterioration and ensure a good shelf life of the oil. Blending with soybean oil remarkably improved its stability and the blended oils have the potential to meet nutritional needs for domestic cooking and deep-frying.

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