Evaluation of date seeds for oil extraction: effect of roasting on physico-chemical characteristics, antioxidant properties, oxidative stability, fatty acid profiles, and tocopherol compounds

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This study aims to investigate the effect of roasting on the quality of oils from three date seeds (*Degla Beida*, *Tantebouchet*, and *Deglet Nour*). To achieve this, unroasted and roasted (200°C for 22 min) date seeds were subjected to Soxhlet extraction, and the quality of the oils obtained was assessed by physico-chemical characterization (moisture, free fatty acids, peroxide value, K232, K270, colour, refractive index, and induction time), carotenoids and total phenolic contents (TPC), antioxidant activity (DPPH and ABTS), and fatty acid profile. The results showed that the roasting process significantly increased the oil yield, colour, and carotenoid and TPC compared to unroasted seeds. Furthermore, roasted seed oils also showed better antioxidant activity and revealed an elongation of the induction time by 1.5 to 3 times. However, the roasting led to a significant decrease in the total tocopherol contents, while the level of γ-tocopherol was strongly improved, with an increase of more than 80% for all roasted seed oils. In addition, the fatty acid profiles of oils were modified only slightly by the roasting process. These data demonstrate that the roasting of date seeds improves the nutritional value, antioxidant capacity, and thermo-resistance of their extracted oils.

Keywords: Date seed oil, Roasting, Quality parameter, Antioxidant property, Physico-chemical characteristic.

1. INTRODUCTION

The date palm (*Phoenix dactylifera* L.) represents an important fruiting plant for many countries and is renowned for its delicious and healthy date fruits [1,2]. The world production of date fruit was estimated to be 7715380 tonnes in 2021, from about twenty-five countries, of which Egypt was the leading producer, followed by Saudi Arabia and Iran [3].

In addition to the consumption of fresh dates, this fruit can be transformed into various processed forms, such as powders, date paste, syrup, juice, chocolate-coated dates, and date-based confectionery [4]. Most of the by-product resulting from these various transformations is made up of date pits or seeds and represent about 10 to 15% of the total weight of the date [5]. This by-product contains sugars (10.6-5.6%), of which 2.6-2.8% are ash, and proteins (5.4-4.0%), as well as numerous other bioactive compounds, particularly phenolic compounds recognized for their elevated antioxidant activity. It's also a very useful ingredient for preparing fibre-based foods due to the large amounts of dietary fibre, which represents about 15% [6].

Date seeds, containing 10 to 15% lipids, are the source of excellent oil [7], characterized by its high oxidative stability compared to numerous other vegetable oils [8]. As regards fatty acids composition, date seed oil is rich in oleic acid (25.89 to 55.10%) [9], which allows for better protection and resistance against deterioration in addition to the production of toxic products, such as

aldehydes, compared to other oils rich in linoleic and linolenic acids [10].
Date seed oil is a lucrative source of economic profit for the food industry, which has developed several fields in the formulation of added-value products. This oil is used in the production of mayonnaise [11], as natural antioxidants in oil blending, contributing to the enhanced stability of edible oil compared to synthetic substances [12], and can be added as a substitute for hydrogenated vegetable fats in the preparation of industrial products [13]. In addition, date seed oil is used in several non-food applications, such as cosmetic and pharmaceutical products [5].
Roasting is one of the thermal processes that treats food materials at high temperatures for a short period of time in order to enhance the quality of the products. The roasting process of oilseeds could improve the quality of oil by reducing moisture and increasing oil yield, bioactive compounds, antioxidant activity, and oxidative stability [14-16].
In this regard, this work seeks to evaluate the effect of roasting on the seed oils of three date varieties (*Degla Beida*, *Tantebouchit*, and *Deglet Nour*). The analyses were assessed by physico-chemical properties (moisture content, refractive index, acidity, UV absorption coefficient, peroxide value, and colour), bioactive compounds (total carotenoids, total phenolic contents), tocopherol and fatty acid compounds, oxidative stability, and antioxidant activity.

2. MATERIALS AND METHODS

2.1. DATE SEED SAMPLES

The fruits of three varieties of date palm, namely Dagla Beida, Tantebouchit, and Deglet Nour, were collected in 2021 from the Tolga region in the Biskra department, located in southeastern Algeria (34°43'18.5'' N, 5°22'42.2'' E). About 2 kg of pitted seeds were separated from date fruits. The seeds were soaked in water to eliminate any adhered date flesh and then wiped with absorbent paper.

2.2. DATE SEED ROASTING

The sample of each variety was divided into two parts, of which one portion was kept unroasted (control), and the other was subjected to roasting. The seeds were spread in a thin layer on trays and roasted at 200°C for 22 minutes [17] in a ventilated oven (Memmert UF110, Schwabach, Germany), then cooled to room temperature. The roasted and unroasted date seeds were ground into a fine powder (particle size < 250 µm) using a Fritsch Pulverisette 9 planetary ball mill (Pulverisette 5, Fritsch, Germany) and stored at –20°C in plastic sample bags until use.
The moisture content was determined by drying 5 g of powdered date seeds (roasted and unroasted) at 105°C in a ventilated oven until a constant weight was achieved [18]. The results were expressed as percentages.

2.3. OIL EXTRACTION

Twenty grams of each unroasted or roasted seed powder were subjected to oil extraction using a Soxhlet apparatus with n-hexane as solvent for 4 hours at a temperature of 68 ± 3°C [14]. The same procedure was repeated using 20 g of powder in each extraction until a volume of 50 mL of oil had been collected. The solvent was removed under vacuum using a rotary evaporator (Rotavapor R-210/215, Büchi, Switzerland) at 40°C, and the oils obtained were duly stored in darkness at 4°C until analysis. The yield was calculated using the following formula and expressed as a percentage of the initial dry weight of the seed powder.

$$\text{Oil yield (\%)} = (W1/(W2))\times 100$$

where W_1 is the weight of the extracted oil and W_2 is the weight of the date seed powder (dry basis).

2.4. PHYSICO-CHEMICAL ANALYSIS

2.4.1 Refractive index

The refractive index (RI) was measured using an Anton Paar refractometer (Abbemat 3100, Germany). The measurements were taken at a temperature of 20°C, and the results were displayed directly by the apparatus.

2.4.2 Free fatty acids

The free fatty acids (FFA) were determined according to Kiritsakis and Markakis [19]. An aliquot of oil (5 g) was dissolved in previously neutralized ethanol and gently warmed. The resulting solution was titrated with NaOH solution (0.1 N) using phenolphthalein as a colouring indicator until a permanent light pink colour appeared. The content of FFA, expressed as a percentage of oleic acid, was calculated using the following formula:

$$\text{FFA (\%)} = (V\times N\times 282)/(10\times m)$$

V: volume of NaOH titrant (mL), *N*: Normality of NaOH (0.1 N), *282*: Molecular weight of oleic acid (g/mol), *m*: Sample mass in grams.

2.4.3 UV absorption coefficient

The UV absorption coefficients (K232 and K270) were determined on the basis of the absorption of a 1% solution of oil in cyclohexane (w/v) at 232 and 270 nm [14].

2.4.4 Peroxide value

The peroxide value (PV) was determined using the

method described by Novidzro et al. [20]. A 5g aliquot of sample was mixed with 18 mL of acetic acid and 12 mL of chloroform. Then, 1 mL of a saturated solution of potassium iodide (KI) was added to this mixture. After 5 min in the dark, 75 mL of distilled water was added and vigorously stirred with the addition of a few drops of starch solution as a colouring indicator. The resulting solution was titrated with sodium thiosulfate solution (0.01 N) until the colour disappeared. The PV was calculated using the following formula:

$$PV\ (meq\ g/\ kg)=(N\times(V-V0)\times1000)/m$$

Pv: Peroxide value expressed as milliequivalent grams O2 per kilogram of oil (meq O2/Kg),
N: Normality of Na2S2O3 solution, *V*: Volume of Na2S2O3 used in titration, *V0*: Volume of Na2S2O3 used in blank titration, *m*: Sample mass in grams.

2.4.5 Carotenoids

The concentration of carotenoids was determined using the method described by Isabel Minguez-Mosquera et al. [21]. For 0.6 g of oil sample, 2 mL of cyclohexane was added, and the resulting mixture was thoroughly agitated. The absorbance was measured at 470 nm using UV/Vis spectroscopy according to the following formula.

$$\text{Carotenoid (mg/kg)} = \frac{A \times 10^6}{2000 \times 100 \times d}$$

A: absorbance at 470 nm; *2000*: specific extinction of lutein, the predominant compound in the carotenoids fraction; *d*: the thickness of the spectrophotometer cell. The concentration of carotenoids was expressed as milligrams per kilogram of oil (mg/kg).

2.4.6 Colour

The colour of the oils was measured according to ISO 15305 (1998) using Lovibond (Tintometer, PFX 880 Series). Results were expressed in terms of red and yellow values.

2.4.7 Fatty acids composition

The fatty acids of the unroasted and roasted date seed oils were identified and quantified according to Mohd Jaih et al. [23] with certain modifications. Initially, methyl esters were prepared using methanolic boron trifluoride (13-15%), then a volume of 1 µl was injected into a gas chromatography system (6890 Network GC System, Agilent Technologies, USA) equipped with a Flame Ionization Detector (FID). The system was equipped with a capillary column (60 m × 0.25 mm internal diameter × 0.25 µm film thickness) and an injector spraying at a temperature of 250°C. The temperature gradient was programmed to increase by 6.5°C/min from 130°C to 170°C and then by 40°C/min from 170°C to 230°C. Hydrogen was used as the carrier gas, and the fatty acids were identified and quantified as a relative percentage by correlating the retention time and peak area with the FA methyl ester standards.

2.5. DETERMINATION OF TOTAL PHENOLIC CONTENT

The TPC was measured using the method described by Mohd Jaih et al. [23]. First, the oils were diluted in dimethyl sulfoxide (DMSO). Then, 0.5 mL of the diluted oil was mixed with 2.5 mL of 10% Folin-Ciocalteu reagent and 2 mL of 7.5% sodium carbonate. The resulting mixture was incubated for one hour at 40°C. The absorbance was read at 765 nm. Gallic acid was used as a reference and the results were given as milligrams of gallic acid equivalent per 100 g of oil (mg GAE/100 g).

2.6. ANTIOXIDANT ACTIVITY

Antioxidant activity was evaluated using two methods: the DPPH (1,1-diphenyl-2-picrylhydrazyl) and ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) assays. The DPPH assay was carried out according to Bondet et al. [24]. Various concentrations of date seed oil solutions were prepared using dimethyl sulfoxide (DMSO). Then, 0.2 mL of each extract was mixed with 2 mL of a methanolic DPPH radical solution (0.025 mg/mL), and the mixture was shaken vigorously before being left to stand at room temperature for 30 min. The absorbance was measured at 517 nm. The results were given as a half-efficient concentration (IC50) and expressed as mg/g.
The ABTS radical scavenging activity evaluation was described by Re et al. [25]. A mixture of aqueous solutions of potassium persulfate (2.45 mM) and ABTS (7 mM) was stored for 16 h in the dark to create the stock solution composed of ABTS radical cations (ABTS°+). Then, the solution was diluted with ethanol to obtain an absorbance of 0.7±0.03 at 765 nm. The unroasted and roasted seed oils of the three date varieties were diluted with DMSO at different concentrations. Subsequently, 100 µL of each oil dilution was mixed with 2.9 mL of the prepared ABTS°+ solution. The results were given as half-efficient concentrations (IC50) and expressed as mg/g.
Additionally, butylated hydroxytoluene (BHT) and ascorbic acid were used as reference antioxidants in both DPPH and ABTS assays to evaluate and compare the antioxidant activity of the oils. Their IC50 values were determined under the same experimental conditions as the samples to ensure consistent comparison.

2.7. TOCOPHEROL ANALYSIS

Tocopherols were analyzed by high-performance liquid

chromatography (HPLC) aided by a fluorescence detector (Jasco, Japan) [26]. An aliquot of oil was mixed with 10 µL of tocols as internal standards in hexane. The solution was centrifuged at 3500 rpm/5 min, and the supernatant was analyzed by HPLC. The column used for separation was Supelcosil™ LC-SI. For the elution, a 97:3 hexane:dioxane mixture was used at a flow rate of 1.0 mL/min for 12 min. The results were analyzed with the ChromNAV Control Center - JASCO Chromatography Data Station (Japan). Authentic standards were used for comparison, identification, and quantification. The results were expressed in mg/kg of oil.

2.8. OXIDATIVE STABILITY

The seed oils were analyzed by the 743 Rancimat analyzer (Metrohm AG, Herisau, Switzerland) according to the procedure of Benbouriche et al. [27]. A 3 g aliquot of date seed oil was tested at a temperature of 100°C at an airflow rate of 15 L/hour. The data were expressed in hours as an induction time (IT).

Statistical analysis

The results were expressed as the mean ± standard deviation of the three replicates. The data were compared statistically by analysis of variance following the LSD (Least Significant Difference) test using Statistica 5.5. The comparison of means before and after roasting was carried out by the Student t-test. The level of significance was taken at $p < 0.05$. The graphs were generated using Microsoft Excel.

3. RESULTS AND DISCUSSION

This study was conducted to evaluate the effect of roasting on the quality and antioxidant properties of seed oils of three date varieties (*Degla Beida*, *Tantebouchet*, and *Deglet Nour*). The photographs of date seeds and their corresponding powders and extracted oils before and after roasting are shown in Figure 1.

3.1. MOISTURE OF DATE SEEDS

The results of moisture contents of the three varieties before and after roasting are indicated in Table I. The moisture contents of unroasted date seeds were higher (6.21-6.87%) than of roasted ones (1.03-1.49%). These values were in agreement with those of many unroasted seed varieties of Saudi Arabia [11] Tunisia [28,29], and United Arab Emirates [30], which were between 3.66 and 10.3%. The difference in moisture content depends on several factors, including the growing region, variety [31], as well as pretreatments such as drying and roasting. The moisture content of seeds was significantly reduced by approximately 5 times for all varieties after the roasting process. These results were similar to those reported by Rahman et al. [4] for Tamr variety roasted at 220°C for 15-20 min.

3.2. OIL YIELD

The oil yield could be dependent on different growth conditions, harvest stages, and raw material sources

Figure 1 - Photographs of seeds, powders, and oils of unroasted and roasted date seeds.

such as the region and the variety. Date seeds may contain between 3 and 16.5% oil [9].

The results of the oil yields of the studied varieties are presented in Table I. It was observed that oil yields were very close for the three unroasted date seeds, with an average of 9.65%, and also for the roasted seed oils, with about 10.23%. The roasting induced a significant increase in oil yield for all varieties, with 10% for *Degla Beida* and 4% for *Tantebouchet* and *Deglet Nour*.

These results were higher than those for Algerian unroasted seed varieties with 4.1-4.93% [32], and similar to the results obtained in some other investigations into unroasted date seeds with yields ranging from 7 to 10% [33,34]. The increase in the oil yield after roasting was supported by other studies. It was found that roasting increased the yield by 75% with an increment in roasting temperature [35]. This positive effect of roasting on oil yield was related to the release of oil by breaking down the cell structure through the heating process and to the generation of pores in the oilseed structures, facilitating the movement of oil from the seed to the outside [36].

3.3. REFRACTIVE INDEX

The refractive index provides information on the quality and purity of oils and fats, which increase with the length of the chain and the amount of unsaturated fatty acids. RI depends on the type of oil, its origin, the technological treatments, and the oxidative status [37]. Table I presents the refractive index results of the unroasted and roasted oils studied. The unroasted seed oils have a RI ranging from 1.4502 to 1.4612. The roasting did not affect the RI of the seed oils of the three varieties. These findings were in agreement with unroasted seed oil from Tunisian date varieties [8]. Nor were any effects observed of roasting of coconut (*Cocos nucifera*) seed oil and Soxhlet and cold press extraction oils from chia seeds [38,39], but the RI slightly decreased for sunflower oils with the roasting time of sunflower seeds and gradually decreased for sesame oils with the increase in roasting temperature of sesame seeds [40,41].

3.4. FREE FATTY ACIDS

The amounts of the FFA of unroasted and roasted date seed oils are given in Table I. The results before roasting elucidated regular FFA contents for UDB, UT, and UDN (0.11-0.15%) and didn't show significant differences. Low acidity levels were also obtained from date seed oils of Saudi Arabia cultivars (0.360-0.676%) [11,42].

The free fatty acid content of oils significantly increased from an average of 0.13% before roasting to 0.66% after roasting, but these values remained relatively weak and were included in the recommended standards. Edible oils typically have FFA values below 0.5% for refined oils, while higher FFA content (up to 5% or more) may be acceptable in crude or unrefined oils [43]. Significantly, RDN (0.60%) was the least affected and showed the least content compared to RDB and RT. The increase of acidity with roasting was due to the release of fatty acids due to hydrolysis of triglycerides caused by heating (200°C). Similar findings were seen in different studies into the effect of seeds roasting on oil acidity, including chia and argan seeds [39,44].

Table I – Physico-chemical parameters of unroasted and roasted date seeds and seed oils

Varieties	***Degla Beida***		***Tantebouchet***		***Deglet Nour***	
Parameter	UDB	RDB	UT	RT	UDN	RDN
Seeds						
Moisture	6.34 ± 0.15^{b}	$1.32 \pm 0.11^{a}\downarrow$	6.87 ± 0.09^{a}	$1.49 \pm 0.10^{a}\downarrow$	6.21 ± 0.08^{b}	$1.03 \pm 0.07^{b}\downarrow$
Oil yield	9.52 ± 0.41^{a}	$10.49 \pm 0.38^{a}\uparrow$	9.79 ± 0.19^{a}	$10.17 \pm 0.13^{a}\uparrow$	9.65 ± 0.19^{a}	$10.03 \pm 0.11^{a}\uparrow$
Oils						
RI	1.450 ± 0.05^{a}	1.460 ± 0.10^{a} /	1.461 ± 0.04^{a}	1.463 ± 0.07^{a} /	1.453 ± 0.08^{a}	1.461 ± 0.06^{a} /
FFA	0.15 ± 0.03^{a}	$0.71 \pm 0.03^{a}\uparrow$	0.13 ± 0.02^{a}	$0.72 \pm 0.02^{a}\uparrow$	0.11 ± 0.05^{a}	$0.60 \pm 0.04^{b}\uparrow$
K232	1.62 ± 0.10^{a}	$1.98 \pm 0.08^{a}\uparrow$	1.55 ± 0.08^{ab}	$1.89 \pm 0.04^{ab}\uparrow$	1.45 ± 0.06^{b}	$1.81 \pm 0.09^{b}\uparrow$
K270	0.34 ± 0.04^{b}	$1.03 \pm 0.05^{a}\uparrow$	0.66 ± 0.06^{a}	$1.05 \pm 0.08^{a}\uparrow$	0.59 ± 0.03^{a}	$1.09 \pm 0.07^{a}\uparrow$
PV	3.97 ± 0.12^{b}	$4.79 \pm 0.10^{a}\uparrow$	4.43 ± 0.10^{a}	$3.70 \pm 0.22^{b}\downarrow$	3.92 ± 0.07^{b}	$3.68 \pm 0.13^{b}\downarrow$
Carotenoids	1.24 ± 0.03^{c}	$7.66 \pm 0.08^{a}\uparrow$	1.95 ± 0.02^{a}	$5.10 \pm 0.05^{c}\uparrow$	1.50 ± 0.01^{b}	$7.40 \pm 0.04^{b}\uparrow$
Color						
Red unit	3.40 ± 0.17^{a}	$5.50 \pm 0.16^{a}\uparrow$	3.20 ± 0.10^{a}	$4.40 \pm 0.21^{b}\uparrow$	3.40 ± 0.12^{a}	$4.40 \pm 0.11^{b}\uparrow$
Yellow unit	7.30 ± 0.15^{b}	$24.00 \pm 0.97^{b}\uparrow$	6.70 ± 0.27^{b}	$28.00 \pm 1.17^{a}\uparrow$	14.00 ± 1.37^{a}	$26.10 \pm 1.39^{ab}\uparrow$

U, unroasted; R, roasted; DB, *Degla Beida*; T, *Tantebouchit*; DN, *Deglet Nour*; The results are expressed as the mean ± SD; The results in the same row for roasted or unroasted seeds with different letters are statistically different (ANOVA, LSD test, $P<0.05$); The results of roasted seeds with the signs ↑, /, or ↓ are statistically higher, similar, or lower compared to unroasted seeds of the same variety (Student t-test, $P<0.05$).

3.5. UV ABSORPTION COEFFICIENT

The oxidation of unsaturated fatty acids leads to the formation of peroxides, which are the primary oxidation products associated with the formation of conjugated dienes. The increase in these products indicates an increase in ultraviolet absorption at 232 nm. UV absorption at 270 nm indicates the generation of conjugated trienes and secondary oxidation products [45].

The results of K232 showed a significant difference only between DB and DN before and after roasting (Table I). The results of K270 revealed a lower value for UDB compared to UT and UDN, while the results for roasted varieties were similar. The roasting affected the absorptivity of oils, where significant increases in UV absorption at both 232 and 270nm were found, with increases of 22.22, 202.94, and 21.94% for K232 and 59.09, 24.83, and 84.75% for K270 for seed oils of the *Degla Beida*, *Tantebouchi*, and *Deglet Nour*, respectively. Similar studies demonstrated that roasting leads to an increase in the formation of conjugated dienes and trienes in peanut oil [46], argan oil [44], and rapeseed oil [47].

3.6. PEROXIDE VALUE

The unroasted seed oils of the three varieties showed a low peroxide value (3.92-4.43 meq O2/kg) with the highest value found for the *Tantebouchi* variety (Table I). Regarding the results of the effect of roasting seeds on oils, the PV was slightly increased for *Degla Beida* seed oil (from 3.97 to 4.79), whereas it was reduced for *Tantebouchi* (from 4.43 to 3.70) and *Deglet Nour* (from 3.92 to 3.68) seed oils. The increase observed in PV is due to the oxidation of unsaturated fatty acids, while the decrease can be attributed to its decomposition into secondary products of oxidation under high temperature. Several studies have reported that the PV of roasted seed oils first increases at low temperatures and then decreases at high temperatures [48,49]. Overall, the results of the peroxide value for all varieties were below the maximum recommended value of 15 meq/kg [50].

3.7. CAROTENOID CONTENTS

Carotenoids are beneficial components due to their important physiological properties, and they play an important role in oxidative stability due to their antioxidant capacity. They are commonly used in industry as colouring additives [51,52].

The carotenoid contents before and after heat treatment of the three date seed oils are presented in Table I. The level of carotenoid in unroasted seed oils ranged from 1.24 to 1.95 mg/kg. In other works on the oils of unroasted date seeds, the carotenoid contents were 11.24 mg/kg for the Tunisian date of Kentichi variety [53], from 11.8 to 26.8 mg/kg for United Arab Emirates date varieties [54], and from 17.57 to 12.35 mg/kg for Moroccan varieties [55].

Table II - Fatty acid composition of unroasted and roasted date seed oils

Varieties	*Degla Beida*		*Tantebouchi*		*Deglet Nour*	
Fatty acid	UDB (%)	RDB (%)	UT (%)	RT (%)	UDN (%)	RDN (%)
C8:0	0.38 ± 0.08^{b}	$0.39 \pm 0.05^{a/}$	0.5 ± 0.02^{a}	$0.41 \pm 0.01^{a/}$	0.40 ± 0.04^{b}	$0.49 \pm 0.02^{a/}$
C10:0	0.40 ± 0.08^{b}	$0.42 \pm 0.05^{b/}$	0.58 ± 0.02^{a}	$0.50 \pm 0.02^{ab/}$	0.48 ± 0.04^{b}	$0.58 \pm 0.02^{a/}$
C12:0	21.47 ± 2.63^{c}	$21.92 \pm 2.16^{c\uparrow}$	24.70 ± 0.39^{a}	$23.89 \pm 0.41^{b\uparrow}$	23.78 ± 1.06^{b}	$24.45 \pm 0.19^{a\uparrow}$
C14:0	11.75 ± 0.5^{a}	$11.74 \pm 0.64^{a/}$	10.75 ± 0.06^{c}	$11.21 \pm 0.07^{b\uparrow}$	11.52 ± 0.02^{b}	$10.46 \pm 0.03^{c\downarrow}$
C16:0	11.18 ± 0.34^{a}	$11.01 \pm 0.05^{a\downarrow}$	9.21 ± 0.05^{c}	$9.33 \pm 0.09^{b\uparrow}$	9.40 ± 0.36^{b}	$9.24 \pm 0.01^{b/}$
C18:0	3.6 ± 0.29^{a}	$3.68 \pm 0.2^{a/}$	3.29 ± 0.05^{b}	$2.90 \pm 0.04^{c\downarrow}$	2.89 ± 0.23^{c}	$3.41 \pm 0.02^{b\downarrow}$
C20:0	0.46 ± 0.04^{a}	$0.46 \pm 0.05^{a/}$	0.47 ± 0.01^{a}	$0.40 \pm 0.04^{a/}$	0.39 ± 0.04^{a}	$0.49 \pm 0.01^{a/}$
C22:0	0.28 ± 0.02^{a}	$0.29 \pm 0.04^{a/}$	0.3 ± 0.02^{a}	$0.28 \pm 0.02^{a/}$	0.26 ± 0.08^{a}	$0.36 \pm 0^{a\uparrow}$
C18:1	42.81 ± 0.07^{b}	$42.19 \pm 1.71^{c\downarrow}$	42.55 ± 0.29^{c}	$43.48 \pm 0.41^{a\uparrow}$	43.75 ± 1.91^{a}	$42.83 \pm 0.2^{b\uparrow}$
C18:2	7.50 ± 0.2^{a}	$7.46 \pm 0.29^{a/}$	7.19 ± 0.03^{b}	$6.94 \pm 0.02^{c\downarrow}$	6.78 ± 0.16^{c}	$7.24 \pm 0.07^{b\downarrow}$
C18:3	0.35 ± 0.03^{b}	$0.35 \pm 0.03^{a/}$	0.42 ± 0.01^{ab}	$0.47 \pm 0.03^{a/}$	0.47 ± 0.03^{a}	$0.45 \pm 0.01^{a/}$
C22:2	0.15 ± 0.01	$0.17 \pm 0.01^{a/}$	/	0.17 ± 0.03^{a}	/	/
SFA	49.51 ± 2.6^{b}	$49.91 \pm 2.57^{a\uparrow}$	49.80 ± 0.36^{a}	$48.93 \pm 0.44^{c\downarrow}$	49.12 ± 0.59^{c}	$49.48 \pm 0.29^{b\downarrow}$
UFA	50.81 ± 0.31^{b}	$50.16 \pm 2.01^{c\downarrow}$	50.16 ± 0.33^{c}	$51.07 \pm 0.39^{a\uparrow}$	51.00 ± 2.1^{a}	$50.52 \pm 0.28^{b\uparrow}$
PUFA	8.00 ± 0.24^{a}	$7.97 \pm 0.3^{a/}$	7.61 ± 0.04^{b}	$7.58 \pm 0.15^{c/}$	7.25 ± 0.19^{c}	$7.69 \pm 0.08^{b\downarrow}$
MUFA	42.81 ± 0.07^{b}	$42.18 \pm 1.68^{c\downarrow}$	42.55 ± 0.29^{c}	$43.48 \pm 0.41^{a\uparrow}$	43.74 ± 1.95^{a}	$42.83 \pm 0.2^{b\uparrow}$
UFA/SFA	1.03 ± 0.06^{a}	$1.00 \pm 0.09^{a/}$	1.01 ± 0.01^{a}	$1.04 \pm 0.01^{a/}$	1.04 ± 0.05^{a}	$1.02 \pm 0.01^{a/}$

U, unroasted; R, roasted; DB, Degla Beida; T, Tantebouchi; DN, Deglet Nour; SFA, saturated fatty acid; UFA, unsaturated fatty acid; PUFA, polyunsaturated fatty acid MUFA, monounsaturated fatty acid. The results in the same row for roasted or unroasted seeds with different letters are statistically different ($P<0.05$). The results of roasted seeds with the signs ↑, /, or ↓ are statistically higher, similar, or lower compared to unroasted seeds of the same variety ($P<0.05$).

The total carotenoid content in the oils of roasted seeds was significantly increased, reaching levels of between 5.10 and 7.66 mg/kg, with *Dagla Beida* seed oil displaying the highest amount. Previous studies showed comparable results in the case of nigella seed oil [49] and rapeseed oil [47]. Increased pigment levels may be due to the breakdown of complexes between proteins and pigments after protein denaturation with heating [56].

3.8. COLOUR

The colour results of oils extracted from unroasted and roasted date seeds are shown in Table I. According to the data, the roasting of seeds increased both the red and yellow colours of all seed oils. Some phenolics, chlorophylls, and carotenoids are the main compounds responsible for oil colouration; the increase in the latter after the roasting process may be attributed to release of these compounds as well as the compounds produced by the Maillard reaction, such as pyrazines and melanoidins, during the roasting process at high temperature [57].

3.9. FATTY ACID COMPOSITION

The fatty acid compositions of unroasted and roasted seed oils of the three varieties are summarized in Table II. Regarding unroasted seed oils, the most dominant fatty acid was oleic acid (C18:1), which ranged between 42.55 and 42.81%, followed by lauric (C12:0), myristic (C14:0), and then palmitic (C16:0) acid. The erucic acid (C22:1) was detected only in UDB seed oil; the remainder of the fatty acids were present only in low amounts. These oils were classified in the category of oleic-lauric oils, as established by previous investigations [28,32,58]. Other classifications were proposed by numerous investigators, such as the oleic-myristic oil type [54], and the oleic-linoleic category [59].

The unsaturated fatty acid/saturated fatty acid (UFA/SFA) ratios of seed oils ranged from 1.007 to 1.03, indicating an approximate equivalence between the amounts of saturated and unsaturated fatty acids. These results overall were in agreement with those reported previously [32,60,61]. However, this ratio was lower compared to other vegetable oils such as olive (3.00) and sesame (4.18) oils [62].

The fatty acid compositions of the three seed oils were slightly modified by the roasting process. According to other investigations, the fatty acid compositions of okra, rice germ, and peanut oils were not affected by roasting [63-65].

3.10. TOTAL PHENOLIC CONTENT

Phenolic compounds are bioactive substances with important antioxidant properties due to their ability to scavenge free radicals and reactive oxygen species [66]. The total phenolic content obtained from the unroasted and roasted date seed oils is presented in Figure 2. For the unroasted seed oils, the TPC of UDB oil (17.89 mg/100 g oil) was significantly higher, followed by UT oil and then UDN seed oil. The results obtained were lower than those found by Harkat et al. [32] for the same Algerian varieties, which ranged between 154.59 and 193.35 GAE mg/100 g, while the results of this study are higher than those reported by Rakhshanda et al. [67] for unroasted seeds oil of the Pakistan date variety (3.641 mg/100 g). Similarly, the seed oils of two Tunisian date cultivars, Deglet Nour and Allig, exhibited TPC levels of 52.6 mg/100 g and 21.5 mg/100 g, respectively [68].

For the roasted seeds, the TPC in RDB seed oil was significantly higher compared to RT seed oil, followed by RDN seed oil. The TPC of these oils were more than double that of unroasted seed oils. From the previous results, it can be seen that the roasting process positively affected the TPC of oils extracted from roasted seeds. It has been demonstrated that both the roasting temperature and duration significantly enhance the total phenolics of the extracted oil. Raising the roasting temperature from 160 to 200°C resulted in a 43% increase in oil phenolics after 30 minutes of date seed roasting. Moreover, extending the roasting time from 10 to 30 minutes led to a 39% increase in the oil's TPC [17]. This enhancement is mainly attributed to thermal processes such as the breakdown of lignocellulosic structures and protein denaturation, which improve the extractability of phenolic compounds. Furthermore, the Maillard reaction contributes to the formation of phenolic-type structures, including proanthocyanidins and gallic acid [69], thereby amplifying the phenolic content. Similar observations have also been reported during the roasting of other seeds, including gurum seed oil [15], cactus seed oil [70], and sesame seed oil [14].

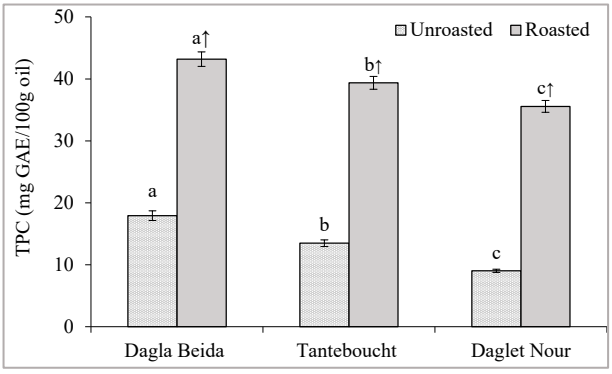

Figure 2 - TPC of unroasted and roasted seed oils.
The results for roasted or unroasted seeds with different letters are statistically different (P<0.05). The results of roasted seeds with the signs ↑, /, or ↓ are statistically higher, similar, or lower compared to unroasted seeds of the same variety (P<0.05).

3.11. ANTIOXIDANT ACTIVITY

In this study, the antioxidant activity was estimated by measuring the concentration of inhibition to scavenge 50% of free radicals, known as IC50, which was estimated through two methods based on the scavenging of DPPH (1,1-diphenyl-2-picrylhydrazyl) and ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) free radicals. A lower value of IC50 signifies the highest antioxidant capacity, and the opposite is true for a high value.

The results obtained for these analyses are given in Figure 3. The antioxidant activity of seed oils assessed by both DPPH and ABTS methods revealed significantly higher inhibition potential for UDB (165.65 and 244.54 mg/mL, respectively), followed by UT, then UDN. These results are roughly similar to those found for unroasted seed oils of Algerian date varieties, which were between 170 and 330 mg/mL for the DPPH method [71].

Moreover, the roasting of seeds had a positive effect on the antioxidant activity of the oils compared to unroasted seeds. RDB seed oil exhibited the highest anti-radical efficiency against DPPH and ABTS, with respective concentrations of 67.50 and 76.8 mg/mL, the latter recorded for RDN seed oil. It was noticed that the IC50 decreased by more than half compared to that of the unroasted seeds, and this can be attributed to the TPC, carotenoids, and other compounds formed during roasting. Similar enhancements in antioxidant activity following roasting have been reported for apricot kernel oil [72], peanut oil [73], and Sacha-Inchi oil [48].

However, compared to pure synthetic standards, the antioxidant activity of both oils remained lower than that of BHT and ascorbic acid, which exhibited IC50 values of 13.53 and 4.87 µg/mL, respectively, in the DPPH assay, and 7.26 and 2.18 µg/mL, respectively, in the ABTS assay. This difference can be attributed to the higher purity and reactivity of synthetic antioxidants, which are specifically designed to neutralize free radicals more efficiently than natural oil extracts.

Therefore, based on the previous findings, roasting date seeds not only increases the phenolic compound content in the oils but also significantly boosts their antioxidant activity. In particular, the antioxidant activity of date seed powder, assessed using the DPPH radical scavenging assay, nearly doubled when the roasting temperature increased from 160 to 200°C after 20 minutes of roasting [17]. This improvement was probably due to enhanced phenolic release resulting from cell wall degradation, as well as the formation of antioxidant Maillard reaction products such as melanoidins. Specifically, pyrazines are compounds formed during roasting through Maillard reactions, which involve the interaction between amino acids and reducing sugars. These compounds not only contribute to the characteristic roasted aroma but also exhibit antioxidant activity. Recent studies have confirmed that pyrazines are generated via these pathways and play a role in enhancing the antioxidant properties of roasted foods [74,75].

3.12. TOCOPHEROL CONTENT

Tocopherols include four types of isomers (α, β, γ, and δ). They are known as important dietary factors for some physiological processes and for their antioxidant properties in lipophilic media [76]. The individual and total tocopherol content of unroasted and roasted seed oils are reported in Table III. The three isomers of tocopherols detected in each date seed oil were α, γ and δ, while β-tocopherol was not detected. Oils obtained from unroasted seeds exhibited total tocopherol content ranging from 634.77 to 1939.6 mg/kg. α-tocopherol was the most abundant compared to the other isomers. *Deglet Nour* seed oil showed the highest amount of α-tocopherol (1679.25 mg/kg), which represents 86.25% of the total tocopherols, followed by *Tantebouchet* and *Degla Beida* seed oils with 56.93 and 68.14%, respectively. The γ-tocopherol contributed approximately 5% to 22% of total tocopherols, with the lowest value found in *Deglet Nour* seed oil (93.49 mg/kg). δ-tocopherol represented about 9

Table III - Tocopherol composition (mg/kg) and Rancimat induction time (h) of date seed oils before and after roasting process.

Varieties Parameters	*Degla Beida*		*Tantebouchet*		*Deglet Nour*	
	UDB	RDB	UT	RT	UDN	RDN
TTC	634.77 ± 4.23^{c}	590.91 ± 4.35$^{a\downarrow}$	914.9 ± 4.11^{b}	562.66 ± 4.73$^{b\downarrow}$	1939.6 ± 3.23^{a}	461.57 ± 4.23$^{c\downarrow}$
α-tocopherol	361.41 ± 3.60^{c}	263.10 ± 3.72$^{a\downarrow}$	623.5 ± 3.48^{b}	203.59 ± 5.24$^{c\downarrow}$	1679.25 ± 2.72^{a}	230.10 ± 3.60$^{b\downarrow}$
γ-tocopherol	138.90 ± 22.72^{b}	299.47 ± 6.72$^{a\uparrow}$	165.82 ± 5.48^{a}	302.72 ± 6.60$^{a\uparrow}$	93.49 ± 4.72^{c}	178.15 ± 2.48$^{b\uparrow}$
δ-tocopherol	152.5 ± 6.36^{b}	53.32 ± 2.61$^{a\downarrow}$	102.31 ± 3.36^{c}	56.35 ± 2.36$^{a\downarrow}$	166.86 ± 2.24^{a}	28.34 ± 6.60$^{b\downarrow}$
IT (h)	21.54^{b}	61.61$^{a\uparrow}$	29.68^{a}	47.42$^{b\uparrow}$	20.27^{c}	37.74$^{c\uparrow}$

U, unroasted; R, roasted; DB, Degla Beida; T, Tantebouchet; DN, Deglet Nour. The results in the same row for roasted or unroasted seeds with different letters are statistically different (P<0.05). The results of roasted seeds with the signs ↑, /, or ↓ are statistically higher, similar, or lower compared to unroasted seeds of the same variety (P<0.05). IT, induction time; TTC, total tocopherol contents

to 24% of the total tocopherols. The results were within the range of those found for α and γ-tocopherols in the unroasted seed oil of ten date varieties, with 248.17-1584.57 mg/kg and 36.75-272.92 mg/kg, respectively [77]. Similar results were also recorded for total tocopherols ranging from 560.12 to 946.26 mg/kg compared to those of the *Degla Beida* and *Tantebouchi* in this study [32].
The results obtained indicated that the roasting process influenced date seed oils. The total, α- and δ-tocopherol contents were significantly decreased for all analyzed oils after roasting, while the level of γ-tocopherol was significantly increased by more than 80% for all roasted seed oils. The increase in the amount of γ-tocopherol can be explained by the rupture of bonds established with gamma-tocopherol with proteins of the membranes, phosphates, and/or phospholipids through the roasting treatment [78]. A reduction was displayed in the amount of α-tocopherol in peanut oils after the roasting process, while γ-tocopherol was not changed significantly [73]. γ-tocopherol content in sesame seed oil showed an increase after roasting up to a temperature of 200°C but decreased using a higher temperature (220°C) [79]. Additionally, the effect of the microwave after 15 minutes of roasting sunflower seeds induced a decrease in the amount of α-tocopherol, but the δ-tocopherol was completely degraded [40]. Other studies also reported a decrease in the level of total tocopherols in sesame oil with the duration of roasting [44,80]. Therefore, the choice of temperature and duration of seed roasting is important to preserve the tocopherols of the extracted oils from degradation.

3.13. RANCIMAT INDUCTION TIME

The oxidative stability of oils and lipids is an important quality indicator; it is related to the resistance to temperature and oxygen and depends on the composition of antioxidants such as tocopherols, polyphenols, carotenoids, and mainly on fatty acid and triglyceride profiles. Among the most widely used methods to determine oxidative stability, the Rancimat test is one of the methods that efficiently assesses oxidation by measuring induction time over high temperatures (50 to 220°C) [81].
The results of the Rancimat test of unroasted and roasted seed oils of the three varieties are represented in Table III. The induction time (hours) is measured at 100°C with an air supply of 15 L/h. The results of unroasted seed oils showed that the highest IT was recorded for *Tantebouchi*, followed by *Dagla Beida*, and finally Daglet Nour. Similar results were reported for unroasted dates seed oil from the Saudi Arabia variety [42]. However, in a previous study a higher IT was reported for unroasted seed oil of the *Deglet Nour* variety (45 h) [8].
The influence of roasting treatment on date seeds led to an enhanced induction time for the three varieties; the IT of *Dagla Beida* seeds oil increased up to 61.61 h, *Tantebouchi* seeds oil up to 47.42 h, and Daglet Nour up to 37.74 h. This significant increase can be explained by the high content of phenolic antioxidants responsible for the amelioration of IT after seed roasting, despite the degradation of tocopherols. Indeed, the IT of virgin olive oil presented a strong correlation with total polyphenols (r = 0.97), while no significant correlation was seen with tocopherol content (r = 0.05) [82]. In another study, only a weak correlation (r = 0.383) was observed between total tocopherol concentrations and IT in various types of edible oils [83]. The IT of oil is not only attributed to the fatty acid composition but also to the contents of antioxidant compounds, including phenolic compounds, carotenoids, and tocopherols [84].
Several studies corroborate the results obtained by demonstrating a positive effect of seed roasting on the oxidative stability of their oils, such as peanut seed oil [64], argan seed oil, gurum seed oil [15,85], sunflower, and rapeseed seed oils [86].

4. CONCLUSIONS

In this study, three date varieties (*Dagla Beida*, *Tantebouchi*, and *Deglet Nour*) were chosen in order to assess the effect of seed roasting on the quality of extracted oils. The roasting treatment significantly increased the oil yield and enhanced the levels of bioactive compounds (carotenoids and phenolic compounds). Moreover, this treatment improves antioxidant activity, the time of oxidation induction, with no effect on the fatty acid composition. Among the three varieties, the roasted *Degla Beida* seeds oil was selected since it had the best characteristics. This study demonstrated that roasting date seeds had a positive impact on the nutritional value and oxidative stability of the oils obtained. Unroasted date seed oils, rich in native phenolics and unsaturated fatty acids, may therefore be candidates for applications in nutraceutical or cosmetic formulations. Roasted date seed oils, benefitting from their enhanced antioxidant properties, could be used as natural stabilizers in functional foods and dietary supplements to improve shelf life and nutritional quality.

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Conflict of interest
The authors declare that they have no conflicts of interest.

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