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Research Article

Phenolic Profile, Sugar Composition, and Antioxidant Capacities of Some Common Date Palm (*Phoenix dactylifera* L.) Cultivars as a Potential Nutraceutical and Functional Food Ingredients

Imen Bettaieb,[1] **Ahlem Kilani**,[1] **Khadija Ben Othman**,[1] **Mohamed Ali Benabderrahim**,[2,3] **and Walid Elfalleh**[1]

[1]*Energy Water Environment and Process Laboratory (LR18ES35), National Engineering School of Gabes, University of Gabes, Gabes 6072, Tunisia*
[2]*Arid and Oases Cropping Laboratory, Arid Lands Institute, Medenine 4119, Tunisia*
[3]*Faculty of Sciences of Tunis, University of Tunis El Manar, El Manar 2092, Tunisia*

Correspondence should be addressed to Walid Elfalleh; walid.elfalleh@fst.rnu.tn

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Date palm (*Phoenix dactylifera* L.), a strategic oasian species in most Mediterranean regions, is often known by the commercialized Deglet Nour variety. However, many other common varieties that might have high importance are neglected. The current study aims to evaluate the nutraceutical and functional properties of six common date palm cultivars, collected from three Tunisian oasian regions. The biochemical composition and antioxidant potential of these date cultivars were investigated. Total polyphenols (TPP), total flavonoids (TF), and condensed tannins (CT) contents varied significantly between varieties. In particular, the Ftimi cultivar had the highest amounts of TPP, TF, and CT (204.04 ± 12.85 mg·GAE/100 g·FW, 117.35 ± 7.49 mg·RE/100 g·FW, and 147.93 ± 7.65 mg·CTE/100 g·FW, respectively). Similarly, this cultivar exhibited the highest antioxidant activity with 131.59 ± 11.54 mg·TE/100 g·FW and 106.57 ± 2.33 mg·TE/100 g·FW, respectively, for DPPH and $ABTS^+$ assays. Contrary to the Deglet Nour variety, the six common dates contain a high amount of fructose and glucose (reducing sugars) and a low content of sucrose. LC-ESI-MS analysis showed that "Kenta" had the highest number of polyphenolic compounds (19 compounds) followed by "Ftimi" with 18 compounds, whereas "Deglet Nour" has only 15. Six major compounds (quinic acid, epicatechin, rutin, hyperoside, luteolin 7-O-glucoside, and kaempferol) were omnipresent. These findings highlight the high potential of neglected date palm varieties and confirm their richness with nutraceuticals and natural antioxidants.

1. Introduction

In recent years, with the noticeable change in dietary habits toward healthier foods, there has been a significant demand for plant-based bioactive compounds as sustainable alternatives to synthetic products. Hence, plant-based foods are regarded as the basis of good human health [1] due to their high contents of phytochemicals and nutritional components that protect against several chronic diseases [2] through antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and anticancer activities [3]. Thus, there is a surge of interest in identifying and quantifying the various classes of bioactive substances found in different plant tissues.

Date palm (*Phoenix dactylifera* L.) fruits have been reported to provide several health benefits attributed to their abundance of bioactive components like polyphenols, carotenoids, tocopherols, and flavonoids [4]. Also, dates are rich in carbohydrates; they are considered sugar-packed but have a low glycemic index, dispelling the illusion that dates are comparable to candies [5]. They are considered as a good source of proteins, lipids, fiber, and vitamins [6, 7]. Several studies on the nutritional value of date fruits have been done,

focusing especially on the commercialized cultivars [8, 9]. Although not all date cultivars have been approved for their nutritional significance and potential health benefits, there are a few feedbacks on other common local cultivars or secondary cultivars.

In Tunisia, more than 250 date cultivars are identified based on the phenotypic traits of their fruits [10]. Nevertheless, the current mode of cultivation has encouraged monovarietal cultivation, threatening the palm's genetic heritage [11]. This tendency has even aided in the gradual extinction of many varieties and the poor management of the Phoenician genetic potential. Hence, elite cultivars known as Deglet Nour are increasing at the expense of other common cultivars that may be very important. These secondary cultivars are frequently incorporated into animal feeds or discarded, resulting in a significant biomass loss. Thus, there is an urgent need to valorize them and highlight their health promoting effects. For that, only analyses and well-developed knowledge of raw materials can detect these materials' potential qualities and guide their exploitation [12].

Herein, the present research aims to evaluate the nutritional value of six common cultivars of date fruits and the elite cultivar (Deglet Nour) collected from Tunisian oases by analyzing their sugar contents, phenolic profiles, and antioxidant potentials.

2. Materials and Methods

2.1. Chemicals and Reagents. Trolox: 6-hydroxy2,5,7,8-tetramethylchroman-2-carboxylic acid was procured from Fluka Chemical Co. (Ronkonkoma, USA- NY); DPPH: 2,2-diphenyl-1-picrylhydrazyl; ABTS: 2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid); gallic acid; catechin; rutin; and Folin Ciocalteu's phenol reagent were purchased from Sigma Chemical Co. (St. Louis, USA-MO). Fructose and glucose were procured from Carlo Erba (France-Val de Reuil). All analyses in this study were performed using high-grade chemicals.

2.2. Date Samples. Six common date cultivars (Ftimi, Kenta, Fezzeni, Bouhattam, Hessa, and Ghars) and one commercialized cultivar (Deglet Nour) were randomly collected at the full maturity ("Tamar") stage of the 2021 campaign from three oasian regions of southern Tunisia: the continental oases (Tozeur and Kebili) and the littoral oases (Gabes). Fruit samples were gathered from their local regions with the optimal environmental conditions to produce a significant yield of secondary metabolites [13]. Fruits were then pitted and reserved in a refrigerator (4°C) in sealed bags of polyethylene until further analysis. Table 1 presents more information about the principal characteristics and geographical origin of each cultivar.

Date palm fruit is classified as dry date (DD), semi-dry date (SDD), and soft date (SD) based on texture, pliability, and the ratio between the contents of total sugar and moisture [14]. The different cultivars used in this study were SD, namely, Hessa and Fezzeni (moisture content 38–35%), SDD, namely, Ftimi, Ghars, and Deglet Nour (moisture content 22–27%), and DD, which were Kenta and Bouhattam (moisture content 13–15%).

2.3. Determination of Sugars' Contents

2.3.1. Preparation of the Juice Extract. Sugar extraction from date pulp is more complex, especially when the dates are "common" or "soft," low in sucrose, and high in reducing sugars. Notably, the abundance of sugar is related to the relatively low humidity of the variety. Dates cannot be pressed directly, as is done with grapes or apples. The diffusion method was used to recover 100% of the soluble material in hot water [15]. Therefore, 20 g of each cultivar was homogenized with distilled water (60°C, 1 : 3), filtred using Whatman filter paper, and centrifuged (4000 rpm, 15 min), as reported by Reynes et al. [14]. The resultant supernatants were then filtered with a 0.45 μm membrane filter and stored in dark glass vials at 4°C until sugar analysis.

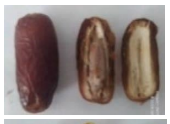
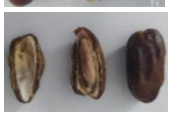
2.3.2. HPLC Analyses of Sugar Content. Sucrose, glucose, and fructose concentrations were determined by HPLC-RID (Agilent HP 1100), equipped with a C18 ZORBAX Eclipse plus column (250 mm × 4.6 mm i.d., 5 μm) for the separation. For the detection of various picks, a RID-10 detector was employed. The column's temperature was maintained constant at 40°C. The flow rate of the mobile phase (75% water and 25% acetonitrile) was carried out at 1.5 ml/min. Sugar amounts in date juices were determined using a standard prepared with acetonitrile and water, and the calibration curves ranged from 25 to 300 g/ml. Shimadzu LabSolutions software (version.5.42) was used to measure the area under the curve.

2.4. Phenolic Compounds Analyses

2.4.1. Preparation of the Date Extract. To extract phenolic compounds, maceration at room temperature was used with an aqueous ethanol solvent (50 : 50 v/v). Twenty grams of each sample were added to 60 ml of the solvent for 24 hours in a covered container with constant agitation. The mixture was then filtered with Whatman filter paper and centrifuged (4000 g, 10 min). The obtained supernatant was collected. Different extracts were kept in darkness and stored at 4°C until analysis.

2.4.2. Total Polyphenols Content (TPP). TPP in each extract was evaluated using the Folin–Ciocalteu method previously described in [16], with slight modifications. The aqueous ethanol extract (100 μl) was added to 500 μl of Folin–Ciocalteu reagent and 4 ml of a 1 M solution of sodium carbonate. The mixtures were incubated at ambient temperature in darkness for 90 minutes before being measured for absorbance at 765 nm with a T60 UV-VIS spectrophotometer. Results were expressed as mg of gallic acid equivalent per 100 g of fresh weight (mgGAE/100 g·FW).

Table 1: Main characteristic and geographical areas of the seven studied cultivars.

Cultivars	Codes	Fruit photos	Quality*	Region and oasis types	Latitude and longitude
Ghars	K1		SDD	Kebili-continental oasis	33°42′15″N
Hessa	K2		SD		8°58′08″E
DegletNour	DN		SDD		
Ftimi	T1		SDD	Tozeur-continental oasis	33°55′10.85″N
Fezzeni	T2		SD		8°8′0.67″E
Kenta	G1		DD	Gabes-coastal oasis	33°52′53″N
Bouhattam	G2		DD		10°05′53″E

*DD, dry date; SDD, semi-dry date; SD, soft date.

2.4.3. Total Flavonoids Content (TF). To quantify flavonoids, the colorimetric technique indicated in [17] was adopted, with minor modifications. In brief, 1 ml of each extract was added to 1 ml of a 10% aluminum chloride solution. The tube's contents were agitated and incubated for 30 min at ambient condition. The absorbance was measured at 430 nm. The amount of TF was calculated as mg of rutin equivalent per 100 g of fresh weight (mgRE/100 g·FW).

2.4.4. Condensed Tannins Content (CT). The vanillin test [18] was employed to measure the content of condensed tannins. Each extract (250 μl) was added to 1.5 ml of a 4% vanillin solution. After 2 min of vortexing, 750 μl of concentrated HCl was added. The resulting mixture was kept at room temperature for 15 min, and the absorbance was measured at 550 nm. The CT amount was presented as mg of catechin equivalent per 100 g of fresh weight (mgCTE/100 g·FW).

2.5. Liquid Chromatography-Electrospray Ionization-Tandem Mass Spectrometry (LC-ESI–MS) Analysis. Each extract was dissolved in methanol (10%) and filtered with a membrane filter (0.45 m) before being injected into the column. An analysis was carried out on a (Shimadzu, Kyoto, Japan) LC-MS-2020 equipped with an ESI ionization source operated in negative mode. The MS was connected with an ultra-fast LC system with a binary pump system (LC-20 AD XR) for high-speed separation, a degasser (DGU-20 A 3R), an auto-sampler (SIL-20 AC XR), and a column oven (CTO-20 AC). To improve selectivity and compound retention, Aquasil C18 column (150 mm, 3 mm, 3 m, Thermo Electron, Dreieich, Germany) and Aquasil C18 guard column (10 mm, 3 mm, 3 m, Thermo Electron) were used. The mobile phase combined A (0.1%, v/v, formic acid blending with water) and B (0.1%, v/v formic acid blending with methanol), with a linear gradient elution (0–45 min, 10–100% B; 45–55 min, 100% B) and with a 0.4 ml/min of flow rate. The equilibration time was performed for 5 min. Samples were injected with a volume of 5 μl, and the temperature of the column was maintained at 40°C. Spectra were monitored in mode SIM (selected ion monitoring) and analyzed with Shimadzu LabSolutions LC–MS software. The MS was set at −3.5 V and operated in full scan spectra (50 to 2000 Da). Negative mode with the following conditions: 12 l/min of a dry gas flow rate, 400°C of a block source temperature, 250°C of a dissolving line temperature, 1.5 l/min of a nebulizer gas flow, and 1.2 V of a voltage detector. The identified phenolic compounds

were determined by comparing their retention times and their spectra to those of standard compounds, and the final results were presented as mg per kg of fresh weight (mg/kg·FW).

2.6. Antioxidant Activities

2.6.1. DPPH Radical Scavenging Activity. The DPPH free radical scavenging activity was measured using a calorimetric technique, as previously described in [19]. One hundred and eighty μl of 0.2 mM DPPH solution was mixed with 20 μl of each extract. After 30 minutes of incubation time in the dark, sample absorbances were evaluated at 517 nm. The standard used as a reference was Trolox, and the final results were expressed as mg of Trolox equivalent (TE) per 100 g of fresh weight (mg·TE/100 g·FW).

2.6.2. ABTS Radical Scavenging Activity. The ABTS assay was evaluated following the method [20]. Before analysis, the radical monocation ($ABTS^{\bullet+}$) was prepared by mixing ABTS solution (7 mM) with potassium persulfate (2.45 mM) and incubating at room temperature for 16 hours. Each extract (20 μl) was mixed with 180 μl of the ABTS solution previously prepared. The Trolox was employed as a reference standard. The results were presented in mg of Trolox equivalent (TE) per 100 g of fresh weight (mg·TE/100 g·FW).

2.7. Statistical Analyses. All measures were done in triplicate. Statistical analyses were done using Xlstat software Ver. 2019 (https://www.xlstat.com). The data were subjected to a one-way analysis of variance (ANOVA). Results were averaged as a means of ± standard deviation (± SD). The heatmap was drawn using Xlstat software Ver. 2019 (https://www.xlstat.com) based on the predominant polyphenolic compounds and antioxidant capacities. The Pearson's correlations between chemical composition and antioxidant activities were presented with a correlogram using Minitab v20.

3. Results and Discussion

3.1. Identification of Individual Sugar by HPLC. High-performance liquid chromatography (HPLC) has been used for both the qualification and quantification of the reducing and nonreducing sugars present in the juices of various date palm cultivars, and the resulting amounts are shown in Table 2.

The main sugars found in date fruits are sucrose (S), glucose (G), and fructose (F). DN is the only variety that contains a large amount of sucrose. All other cultivars have a high reducing sugar content (fructose and glucose) and a low sucrose content. In fact, the sucrose level was significantly higher in DN juice (13.44 ± 0.06 g/100 g FW) in comparison to all other varieties. In particular, the lowest amounts of this type of sugar were observed in G1 and G2 cultivars (0.14 ± 0.00 g/100 g·FW and 0.13 ± 0.01 g/100 g·FW, respectively). On the contrary, glucose and fructose levels were 4.07 to 4.85 folds and 2.73 to 4.07 folds, respectively, much higher in common cultivars than in DN. The high reducing sugars' content suggests the presence of significant invertase that metabolizes the sucrose [21]. Furthermore, Malek et al. [22] found that the activity of the invertase enzyme is higher in soft dates that retain more water, while in most dry and semi-dry dates, the sugar conversion is partial. Such differences in enzymatic activity might explain our findings. Dates' sugar composition and moisture content are inextricably linked. Soft dates typically have a high reducing sugar content and a low sucrose level. The situation is reversed for dry dates [23]. Also, there were almost no significant differences in the glucose/fructose (G/F) ratio in all varieties, which can be in corroboration with the results of Rastegar et al. [24] in some Iranian dates and with those of Amira et al. [25] in some Tunisian cultivars. Even so, the glucose-to-fructose ratio is of specific importance and is considered scientifically valid as a determinant for food intake. Fructose does not stimulate insulin production to the same degree that glucose or sucrose do [26]. Herein, the commercial cultivar Deglet Nour (DN) has the lowest ratio (1.17), so it has the highest proportion of fructose and hence may be considered the best for healthy consumption.

Table 2: Sugar composition of the Tunisian date palm cultivars.

Cultivars	Sucrose (S) (g/100 g·FW)	Glucose (G) (g/100 g·FW)	Fructose (F) (g/100 g·FW)	G/F ratio
T1	0.18 ± 0.01^{CD}	6.16 ± 0.03^{D}	4.56 ± 0.04^{D}	1.35
T2	0.27 ± 0.04^{B}	6.94 ± 0.04^{B}	5.18 ± 0.01^{C}	1.34
G1	0.14 ± 0.00^{D}	6.73 ± 0.07^{C}	5.34 ± 0.04^{B}	1.26
G2	0.13 ± 0.01^{D}	7.52 ± 0.01^{A}	5.85 ± 0.05^{A}	1.29
K1	0.19 ± 0.01^{CD}	6.80 ± 0.03^{C}	5.32 ± 0.01^{B}	1.28
K2	0.22 ± 0.02^{BC}	6.25 ± 0.04^{D}	4.51 ± 0.01^{D}	1.38
DN	13.44 ± 0.06^{A}	2.09 ± 0.07^{E}	1.78 ± 0.10^{E}	1.17

Results are given as mean values ± SD ($n = 3$); data with different superscript letters in the same column are significant ($P < 0.05$); FW, fresh weight.

3.2. Total Polyphenols, Flavonoids, and Condensed Tannins Contents. Table 3 represents the total phenolics, flavonoids, and condensed tannins contents extracted from each date palm fruit cultivar. The amount of total phenol (TPP) varied widely alongside date palms' cultivars. The highest levels were found in Deglet Nour, Bouhattam, and Ftimi (297.42 ± 29.09 mg·GAE/100 g·FW, 229.15 ± 10.07 mgGAE/100 g·FW, and 204.04 ± 12.85 mg·GAE/100 g·FW, respectively), while the lowest amount was found in Hessa (10.35 ± 2.51 mg·GAE/100 g·FW). The highest concentrations of flavonoids were found in Ftimi and Deglet Nour, with 117.35 ± 7.49 mg·RE/100 g·FW and 107.24 ± 7.5 mg·RE/100 g·FW, respectively. The condensed tannin levels are similarly highest in these cultivars (147.93 ± 7.65 mg·CTE/100 g·FW for Ftimi and 124.55 ± 7.79 mg·CTE/100 g·FW for Deglet Nour). The lowest one, on the other hand, was found in Ghars with 40.16 ± 2.41 mg·CTE/100 g·FW.

Previous research based on the biochemical composition of some Tunisian date palms also revealed significant differences between cultivars [27]. The total phenolic concentration in this study differed from that of the Saoudian cultivars, which ranged from 50.64 ± 0.03 mg·GAE/100 g to

Table 3: Total polyphenols (TPP), flavonoids (TF), and condensed tannins (CT) contents of the studied date palm cultivars.

Cultivars	TPP (mg·GAE/100 g·FW)	TF (mg·RE/100 g·FW)	CT (mg·CTE/100 g·FW)
T1	204.04 ± 12.85^{C}	117.35 ± 7.49^{A}	147.93 ± 7.65^{A}
T2	98.17 ± 3.59^{E}	75.71 ± 1.48^{B}	$42.07 \pm 1.46^{E.F}$
G1	162.02 ± 1.78^{D}	67.53 ± 4.11^{B}	89.89 ± 4.82^{C}
G2	229.15 ± 10.07^{B}	68.02 ± 6.93^{B}	$50.60 \pm 0.74^{D.E}$
K1	104.98 ± 0.89^{E}	46.29 ± 7.00^{C}	40.16 ± 2.41^{F}
K2	10.35 ± 2.51^{F}	45.02 ± 7.42^{C}	58.65 ± 4.10^{D}
DN	297.42 ± 29.09^{A}	107.24 ± 7.50^{A}	124.55 ± 7.79^{B}

The results are given as the mean values ± SD ($n = 3$); data with different superscript letters in the same column are significant ($P < 0.05$); GAE, gallic acid equivalent; RE, rutin equivalent.; CTE, catechin equivalent; FW, fresh weight.

98.61 ± 0.03 mg·GAE/100 g [28] and differed also from those observed by Chaira et al. [29] who showed that the phenol amount in some Tunisian date cultivars was lower than 9.70 mgGAE/100 g·FW. These findings were in line with those reported by Alam et al. [30], who found that the phenol content varied from 46 to 397 mg·GAE/100 g·FW using the Folin–Ciocalteu technique. Accordingly, the variations observed between cultivars may be due to their variety, growth stage, and environmental conditions [6]. These findings confirm the several biological activities of common date palm fruits and their interest as functional foods and sources for pharmaceutical and medicinal substances.

3.3. Identification of Phenolic Compounds in the Seven Fruit Extracts. Table 4 shows the concentration of the individual phenolic components in the different date fruits obtained by LC-ESI–MS. The seven varieties were found to be high in phenolic compounds, with amounts varying between cultivars. Hessa has the highest amount of total compound concentration (87.70 ± 4.62 mg/kg·FW), followed by Deglet Nour and Fezzeni (70.94 ± 3.20 mg/kg·FW and 66.23 ± 6.42 mg/kg·FW, respectively). The lowest content in the total phenolic compounds was observed in Ghars variety (13.25 ± 0.46 mg/kg·FW). In total, nineteen compounds were identified (seven phenolic acids and twelve flavonoids). Six of them predominated (quinic acid, epicatechin, luteolin-7-o-glucoside, rutin, kaempferol, and hyperoside). Quinic acid is the most abundant of the identified phenolic acids (except for Ghars and Bouhattam), with a concentration varying between 12,80 ± 1.65 mg/kg·FW (in Ftimi) and 62,21 ± 4.63 mg/kg·FW (in Hissa). This compound is characterized by its water solubility, low cytotoxicity, and nondegradability in the gastrointestinal tract by bacterial enzymes [31]. These properties encourage the use of quinic acid as an alternative medicine against cancer since it exerts a potent antiproliferative effect against cancerous cells [32]. Accordingly, Kchaou et al. [33] supported the nutraceutical and pharmaceutical use of several palm date cultivars, such as Ftimi, Deglet Nour, and Bejo.

In general, the abundance of phenolic compounds in *Phoenix dactylifera* subspecies greatly changes within cultivars, geographic locations, and the extraction methods. Gallic acid, for example, was found to be the most prevalent metabolite in overall date cultivars including Smeti, Garen Gazel, and Eguwa [34]. This is also true for other metabolites. Herein, the analyses also revealed that the detected flavonoids and their amounts significantly varied depending on varieties. Indeed, epicatechin, hyperoside, luteolin-7-o-glucoside, rutin, and kaempferol were identified as major substances among the twelve detected flavonoids. Rutin is the most abundant flavonoid with the highest amounts in Ftimi, Kenta, Bouhattam, and Deglet Nour (14.50 ± 2.27 mg/kg·FW, 10.89 ± 0.81 mg/kg·FW, 9.70 ± 0.72 mg/kg·FW, and 20.89 ± 1.55 mg/kg·FW respectively). Rutin (known as vitamin P) is omnipresent in many plants such as tea and apple. It possesses a wide range of medicinal virtues and was approved to exert antioxidative, neuroprotective, antidiabetic, hepatoprotective, and gastroprotective effects, as well as anti-inflammatory and other pharmacological benefits [35, 36]. Kaempferol is present in all varieties with a concentration varying between 3.20 ± 0.26 mg/kg·FW (in Ftimi) and 10.59 ± 0.85 mg/kg·FW (in Deglet Nour). According to Kowalski et al. [37], kaempferol reduces the effects of oxidative stress and inflammation and has been shown to be beneficial in the treatment of cancer and cardiovascular disease. As a result, these varieties could be used for several medicinal and pharmacological purposes.

3.4. Assessment of Antioxidant Potential. Because antioxidant activities are affected by several factors, it may be necessary to use more than one method to estimate them. Here, the antioxidant ability of the different aqueous-ethanolic extracts was screened by the DPPH and $ABTS^{+\cdot}$ assays (Table 5).

These two tests revealed that the antioxidant activity showed significant variation between varieties. Ftimi date presented the highest antioxidant activity according to the results of the ABTS test (106.57 ± 2.33 mg·TE/100 g·FM) and DPPH assay (131.59 ± 11.54 mgTE/100 g·FM). Hessa date exhibited the lowest ABTS inhibiting level (28.05 ± 4.28 mg·TE/100 g·FM), whereas Ghars showed the lowest one for DPPH scavenging (21.06 ± 9.97 mg·TE/100 g·FM). These variations are thought to be related to qualitative and quantitative variations in the phenolic composition between varieties [38]. Also, it was revealed that the amount of moisture has an important effect on antioxidant ability. In fact, it was proven that both dry and semi-dry dates have higher antioxidant activities compared to soft dates based on ABTS and FRAP assays [39]. Our results confirm those reported in the literature [40, 41], highlighting that the fruits of "common" palm date cultivars present a great ability to scavenge and neutralize free radicals. Our

Table 4: Phenolic profile obtained by chromatographic analysis (HPLC) of seven Tunisian date palm cultivars.

Compounds	RT (min)	T1	T2	K1	K2	G1	G2	DN
Quinic acid	2.087	12.80 ± 1.65^{C}	45.04 ± 7.08^{B}	ND	62.21 ± 4.63^{A}	14.16 ± 2.22^{C}	ND	15.17 ± 1.13^{C}
1.3-Dicafenoyquinic acid	1.682	0.90 ± 0.18^{C}	1.39 ± 0.18^{B}	2.01 ± 0.16^{A}	1.90 ± 0.15^{A}	1.01 ± 0.16^{C}	1.87 ± 0.14^{A}	ND
Gallic acid	1.588	0.19 ± 0.05^{CD}	0.62 ± 0.05^{B}	0.23 ± 0.03^{C}	0.82 ± 0.06^{A}	0.16 ± 0.01^{CD}	0.13 ± 0.01^{DE}	0.08 ± 0.01^{E}
Protocatechuic acid	4.61	1.23 ± 0.01^{A}	0.16 ± 0.01^{D}	0.66 ± 0.05^{B}	0.34 ± 0.04^{C}	1.30 ± 0.10^{A}	0.32 ± 0.02^{C}	0.71 ± 0.06^{B}
Catechin (+)	7.726	0.98 ± 0.07^{B}	ND	ND	ND	0.65 ± 0.05^{C}	ND	1.94 ± 0.16^{A}
Epicatechin	12.649	5.23 ± 0.82^{B}	0.60 ± 0.09^{D}	0.23 ± 0.03^{D}	0.23 ± 0.04^{D}	2.60 ± 0.41^{C}	0.25 ± 0.03^{D}	6.57 ± 0.49^{A}
P-coumaric acid	16.246	0.52 ± 0.04^{B}	0.90 ± 0.07^{A}	0.31 ± 0.02^{C}	0.63 ± 0.10^{B}	0.55 ± 0.09^{B}	0.49 ± 0.06^{B}	0.33 ± 0.05^{C}
Trans ferulic acid	19.483	0.78 ± 0.12^{C}	1.87 ± 0.14^{A}	0.45 ± 0.07^{D}	1.13 ± 0.09^{B}	0.60 ± 0.09^{CD}	0.83 ± 0.10^{C}	0.66 ± 0.08^{CD}
Rutin	21.571	14.50 ± 2.27^{B}	5.17 ± 0.35^{D}	1.68 ± 0.11^{E}	3.22 ± 0.24^{DE}	10.89 ± 0.81^{C}	9.70 ± 0.72^{C}	20.89 ± 1.55^{A}
Hyperoside	22.08	5.82 ± 0.39^{B}	2.26 ± 0.17^{D}	0.50 ± 0.08^{E}	1.99 ± 0.16^{D}	4.44 ± 0.70^{C}	5.04 ± 0.58^{BC}	8.47 ± 0.63^{A}
Luteolin-7-o-glucoside	22.28	0.80 ± 0.06^{E}	0.96 ± 0.11^{DE}	1.18 ± 0.19^{DE}	4.32 ± 0.32^{B}	7.16 ± 1.13^{A}	2.09 ± 0.24^{CD}	3.06 ± 0.23^{C}
Quercetin-3-o-rhamonoside	24.054	2.14 ± 0.16^{A}	0.44 ± 0.03^{C}	0.11 ± 0.01^{D}	0.72 ± 0.11^{C}	2.13 ± 0.16^{A}	1.70 ± 0.13^{B}	1.52 ± 0.17^{B}
Apigenin-7-o-glucoside	24.56	ND	ND	ND	0.10 ± 0.01^{A}	0.04 ± 0.00^{B}	ND	ND
Quercetin	29.033	0.05 ± 0.00^{A}	ND	0.02 ± 0.00^{D}	0.04 ± 0.00^{B}	0.03 ± 0.00^{C}	ND	0.04 ± 0.00^{B}
Trans cinnamic	29.135	0.59 ± 0.04^{C}	0.45 ± 0.07^{C}	1.48 ± 0.12^{A}	1.30 ± 0.20^{A}	0.54 ± 0.04^{C}	0.99 ± 0.07^{B}	0.91 ± 0.07^{B}
Kaempferol	29.178	3.20 ± 0.26^{B}	6.35 ± 0.63^{AB}	4.35 ± 0.43^{B}	8.56 ± 0.84^{AB}	10.46 ± 0.84^{A}	8.76 ± 5.59^{AB}	10.59 ± 0.85^{A}
Naringenin	31.346	0.09 ± 0.01^{A}	ND	ND	0.10 ± 0.01^{A}	0.06 ± 0.01^{B}	0.10 ± 0.01^{A}	ND
Apigenin	31.964	4.76 ± 6.72^{A}	0.02 ± 0.00^{B}	0.04 ± 0.00^{B}	0.04 ± 0.00^{B}	0.02 ± 0.00^{B}	0.03 ± 0.00^{B}	0.01 ± 0.00^{B}
Luteolin	32.269	0.15 ± 0.01^{A}	0.14 ± 0.02^{A}	ND	ND	ND	ND	ND
$\sum$ (mg/kg·FW)		54.72 ± 5.37^{D}	66.23 ± 6.42^{BC}	13.25 ± 0.46^{F}	87.70 ± 4.62^{A}	56.91 ± 5.15^{CD}	32.31 ± 3.58^{E}	70.94 ± 3.20^{B}
Number of compounds		18	15	14	17	18	14	15

The results are given as the mean values ± SD ($n = 3$); data with different superscript letters in the same line are significant ($P < 0.05$); ND, not detected; RT, retention time.

Table 5: DPPH and ABTS$^+$ radical scavenging activities of seven Tunisian date palm cultivars.

Cultivars	DPPH (mg·TE/100 g·FW)	ABTS$^+$ (mg TE/100 g·FW)
T1	131.59 ± 11.54^{A}	106.57 ± 2.33^{A}
T2	51.62 ± 16^{C}	46.42 ± 2.68^{E}
G1	79.89 ± 1.69^{B}	92.29 ± 3.21^{B}
G2	46.67 ± 6.05^{CD}	54.53 ± 0.42^{D}
K1	21.06 ± 9.97^{E}	45.51 ± 1.23^{E}
K2	30.47 ± 5.94^{DE}	28.05 ± 4.28^{F}
DN	64.16 ± 13.22^{BC}	70.92 ± 3.79^{C}

The results are given as the mean values ± SD ($n = 3$); data with different superscript letters in the same column are significant ($P < 0.05$); TE, trolox equivalent; FW, fresh weight.

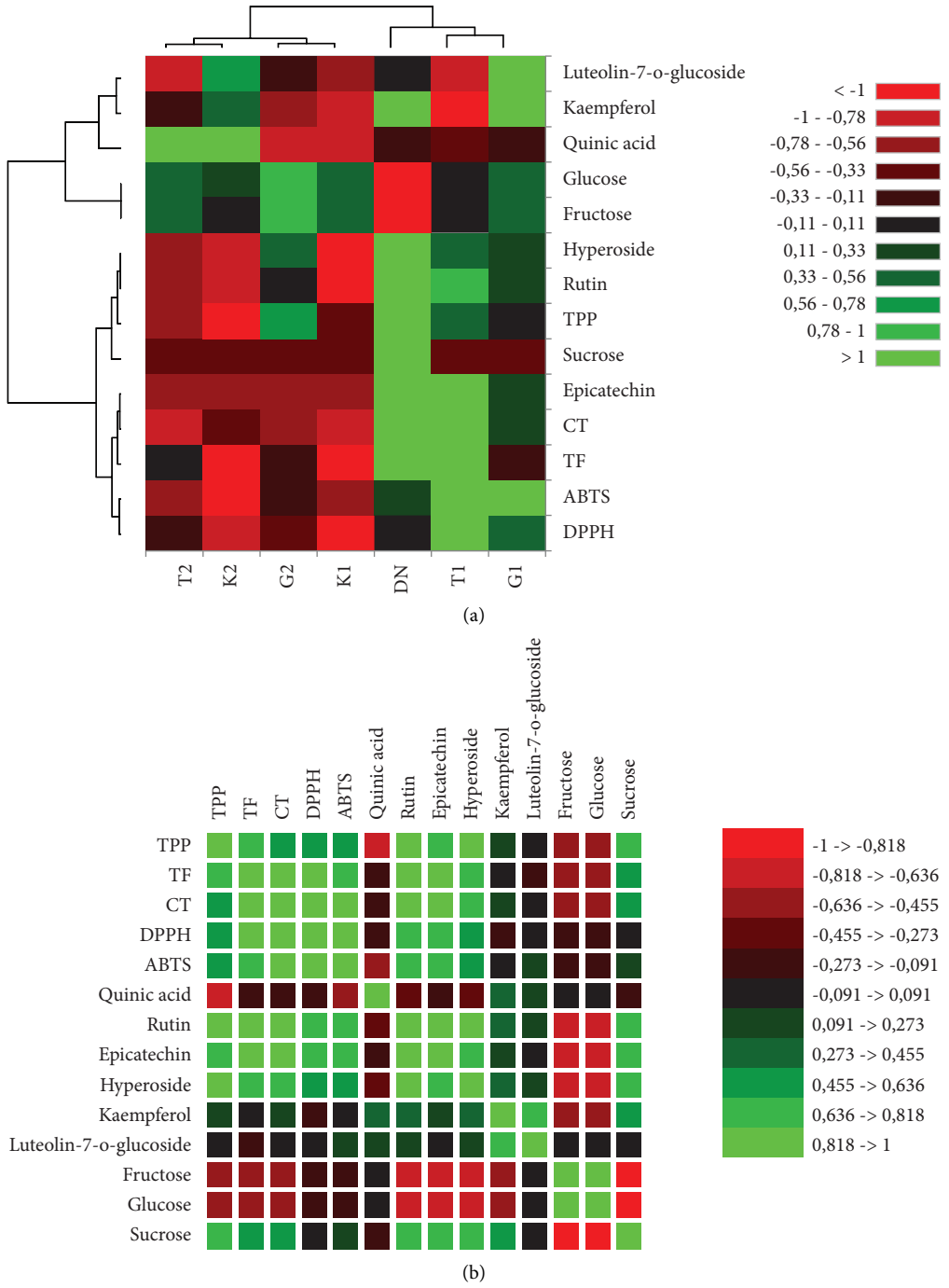


Figure 1: Heatmap (a) and Pearson's correlation (b) of the predominant phenolic compounds, sugar compositions, and antioxidant activities of seven date palm fruits. The mean values are displayed by colors ranging from red to green, with the minimum represented by red and the maximum represented by green. CT: condensed tannin; TF: total flavonoids; TPP: total polyphenols.

main findings highlight the particular importance of Ftimi and Kenta, which have high free radical scavenging activity, as good sources of natural antioxidant substances.

3.5. Heatmap Clustering and Pearson's Correlation. The heatmap visualization based on the main phenolic profile (predominant compounds), sugar composition, and antioxidant activities of the seven cultivars is presented in Figure 1(a). It allows the distinction of two groups: the first, represented by T2, K2, G2, and K1, contains the highest amounts of reducing sugar and the lowest antioxidant potential and phenolic contents. The second cluster, gathered DN, T1, and G1, is identified by the highest levels of phenolic contents and rutin, epicatechin, and hyperoside as predominant polyphenolic compounds, as well as high antioxidant activity and a moderated content in reducing sugar when compared to the other cultivars. The reduced sugar content has a negative correlation with phenolic compounds (Figure 1(b)), which could be attributed to the evolution of the chemical structure of phenolic compounds during maturation, especially the formation of polyphenolic glycosides, which are more stable and easily assimilated by the organism [42, 43]. Nevertheless, antioxidant potential and polyphenol levels appear to be highly correlated. Bentrad and Hamida-Ferhat [44], in this context, pointed out that the antioxidant capacity of date palm fruit has been attributed to its high phenolic content, specifically flavanols [45]. Here, it appears that the combination of rutin, epicatechin, and hyperoside is a determinant of the role of date palm extracts in quenching and neutralizing free radicals (Figure 1(b), correlation more than 0.8). This phytochemical combination, in addition to being sought as evidence for the diversity of date palm cultivars from oasian regions, can be used as a biomarker to identify fruits with high antioxidant potential and a nutraceutical role [46].

4. Conclusions

To valorize the "common" date palm cultivars, secondary varieties collected from Tunisian oasian regions as well as the elite cultivar (Deglet Nour), were investigated. The phenolic and sugar profile analyses, as well as the radical scavenging assays, confirmed the potential value of all studied varieties as rich sources of sugars, bioactive components, and natural antioxidants in varying proportions. This variation directs their future applications. Hence, Ftimi, Deglet Nour, and Kenta offer the highest antioxidant capacity. They can be used to prepare new therapeutic formulations for medicinal and pharmaceutical purposes. Furthermore, Bouhattam, Ghars, Hessa, and Fezzeni have the highest reducing sugar content. They have a high nutritional value and can be applied to various transformation processes. These findings help to provide scientific proof for the potential benefits of neglected and noncommercialized date palm bioresources and point to their promising potential for isolating natural antioxidants for pharmaceutical and medical applications.

Data Availability

The data used to support the study's findings are accessible upon reasonable request to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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