JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

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pubs.acs.org/JAFC

Dietary Fiber from Tunisian Common Date Cultivars (*Phoenix dactylifera* L.): Chemical Composition, Functional Properties, and Antioxidant Capacity

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ABSTRACT: The dietary fibers (DF) of 10 date varieties from Tunisian oases have been investigated. Further knowledge on the content, composition, and technological applications of those fibers could support their genetic variability and promote the socioeconomical development of growing areas. The composition, water- and oil-holding capacities, solubility, and antiradical activity have been determined. The DF content ranged from 4.7% (Matteta, Rochdi) to >7% (Deglé Nour, Garen Gaze, Smeti). Composition varied significantly among cultivars, and the results evidenced that uronic acids and lignin determine to a great extent the organoleptic quality of dates. Many of the varieties that have been studied (Garen Gaze, Matteta, Kenta, Rochdi, Mermella, Korkobbi, Eguwa) were selected because of great interest from technological and functional points of view. Among their physicochemical characteristics, these samples presented water- and oil-holding capacities of higher than 17 and 4 mL/g fiber, respectively, which make them suitable for use as additives in fiber-enriched foods. Also, DF of Garen Gaze, Smeti, Mermella, and Eguwa had a high antiradical capacity (>230 Trolox equiv/kg fiber). It was concluded that some of these varieties could be grown as potential sources of DF, which could be included in the formulation of fiber- and antioxidant-enriched foods.

KEYWORDS: *dietary fiber, date palm fruits, chemical composition, functional characteristics, antioxidant capacity*

■ INTRODUCTION

The date (*Phoenix dactylifera* L.) is an important crop in arid and semiarid regions of the world. Nearly 2000 cultivars of date palm are known in the world, but only some of them are evaluated for their performance and fruit quality. Date production has tripled from 1 915 615 tons in 1975 to 6 002 040 tons in 2005.[1] In Tunisia, the mean annual production of date fruits has remarkably improved and reached an average of 120 000 tons/year, dominated by the Deglé Nour variety (60% of total production), which has a highly appreciated sensory quality and high marketing value. This progress in production, at the national and international scales, is unfortunately accompanied by a considerable increased loss in secondary or common-variety dates (approximately 30 000 tons for Tunisia and 2 000 000 tons worldwide). These dates are generally rejected or in some limited cases used for animal feed. It is by this selective orientation that we are currently witnessing a progressive disappearance of secondary cultivars and therefore a reduction in genetic variability. Among the threatened cultivars are those of the coastline oasis of Gabès. To fight this ecological and economic problem, several studies on the valorization of common dates have been conducted. The literature mentions certain technological transformations, for example, the production of jams, frosts, juices, and syrups of dates.[2,3] The chemical composition of the date shows that the flesh is an important source of sugar (81−88%, mainly fructose, glucose, and sucrose), dietary fiber (DF, 5−8.5%), and small amounts of protein, fat, ash, and polyphenol.[4,5] Thus, dates provide a good source of rapid energy (sugars) and good nutritional value, based on their DF contents.

The demand for byproducts from fruits and vegetables as sources of DF has been increasing because these sources offer higher nutritional quality, higher amounts of total and soluble fiber, lower caloric content, stronger antioxidant capacity, water- and oil-holding capacities, and colonic fermentability, as well as a lower phytic acid content[6,7] than cereal byproducts. DF plays an important role in human health and has shown beneficial effects in the prevention of several diseases, such as cardiovascular diseases, diverticulosis, coronary heart disease, constipation, irritable colon, colon cancer, atherosclerosis, obesity, and diabetes.[5,7,8]

To date, limited data are available regarding the compositional and functional characteristics of common dates grown in Tunisia.[9] The common date may possess high-value components that may be used in value-added applications, including their use as functional foods and ingredients in nutraceuticals.[5,10]

The objective of this study was to isolate common date dietary fibers and evaluate their chemical composition and functional properties. This is the first time that a complete study on the chemical composition of date DF has been done. Nowadays, the antioxidant capacity is one of the most valuable among the functional properties. We have studied this capacity in the DF of common dates, especially the one linked to fiber. This is the characteristic that could ultimately promote the use

Received: September 6, 2011
Revised: March 9, 2012
Accepted: March 23, 2012
Published: March 23, 2012

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of dates and their corresponding fibers as "antioxidant fibers" in the market of healthy ingredients for functional food formulation.

■ MATERIALS AND METHODS

Chemicals. 4-Morpholinoethanesulfonic acid (MES), protease from *Bacillus licheniformis*, amyloglucosidase solution from *Aspergillus niger*, tris(hydroxymethyl)aminomethane (Tris), trifluoroacetic acid, 3-phenylphenol, anthrone, Folin−Ciocalteu phenol reagent, and 2,2-diphenyl-1-picrylhydrazyl (DPPH• free radical) were purchased from Sigma-Aldrich Química (Madrid, Spain). Amylase thermostable Thermamyl 120 L was from Novo Nordisk Pharma (Madrid, Spain). Na_2CO_3, sodium hydroxide, and acetic acid were from Panreac Química S.A. (Barcelona, Spain). Standards of gallic acid (GA), *myo*-inositol, and *trans*-cinnamic acid were purchased from Sigma-Aldrich Quimica. Ethyl acetate and acetonitrile were of HPLC grade purity (Romyl, Teknokroma, Barcelona, Spain). Sulfuric acid and acetone were from Sharlau (Barcelona, Spain). Ethanol was purchased from Alcoholes del Sur (Córdoba, Spain).

Samples. Ten varieties of dates (Bouhattam, Matteta, Kenta, Eguwa, Garen Gaze, Limsi, Rochdi, Smeti, Mermella, and Korkobbi) from the Gabès littoral oasis (southern Tunisia) were picked at commercial maturity (Tarm stage) during the 2010 harvest season (September−October). Identification of each cultivar was visually verified by experienced farmers. The study included a total of 200 fresh samples consisting of 20 palm trees per variety, nearly 600 fruits per variety. Sample from the Deglé Nour cultivar were collected from the continental oasis of Tozeur. This variety was also picked at Tarm stage, and it was used as a reference sample. All dates were stored in a refrigerator at approximately 4 °C (1−2 months) until all samples were collected for analysis and extraction.

Dietary Fiber Extraction. The amount of DF was determined using the protocol described by Lee et al.,[11] with slight modifications. As samples contained a high level of sugar, they were previously extracted with 80% ethanol to remove most of the sugars. Triplicate dry and desugared samples (1 g each) were suspended in 40 mL of MES-Tris buffer and treated with 50 μL of Thermamyl (heat-stable α-amylase) at 100 °C for 15 min and then digested with 100 μL of a 50 mg/mL protease solution (60 °C, 30 min), followed by incubation with 100 μL of amyloglucosidase (60 °C, 1 h) to remove protein and starch. Four volumes of 96% hot ethanol was then added to precipitate soluble DF. Total DF was recovered by filtration on a sintered glass crucible (no. 2) using the Fibertec E system consisting of the 1023 filtration module. The residue was then washed with 80% ethanol and 96% ethanol, dried overnight at 105 °C in an air oven, and then weighed. The dried fibers were ground in a hammer mill to a particle size of <1 mm and stored at 4 °C until analysis.

Composition of Dietary Fiber. Neutral sugars, uronic acids, proteins, and Klason lignin were determined as described previously.[12] For neutral sugars, fibers were hydrolyzed with trifluoroacetic acid at 121 °C for 1 h, and the released sugars were quantified as alditol acetates by gas chromatography. A HP 6890 Plus+ gas chromatograph (Hewlett-Packard, Palo Alto, CA, USA) fitted with a 30 m × 250 μm × 0.20 mm capillary column (SP-2330, Supelco, Bellefonte, PA, USA) was used. The carrier gas was helium with a constant flow = 2.2 mL/min and pressure = 21.5 psi (148.24 kPa). Injection was performed in splitless mode. The oven temperature was held at 50 °C for 2 min after injection, then programmed to 180 °C at 35 °C/min, held at 180 °C for 5 min, and then immediately increased to 220 °C at 5 °C/min and held at 220 °C for 22 min. Total run was 40.7 min. The injector temperature was 250 °C and flame ionization detector (FID), 300 °C. *myo*-Inositol was used as internal standard.

Uronic acids were quantified using the phenyl−phenol method after sulfuric acid hydrolysis;[13] proteins (for DF corrections) were analyzed according to the Kjeldahl method using a Büchi Digestion Unit, K-424, and a Büchi Distillation Unit, K-314, and applying a factor of 6.25 to convert the total nitrogen into protein content; Klason lignin levels were determined gravimetrically as the amount of acid-insoluble material remaining after a two-stage sulfuric acid hydrolysis. Cellulose was quantified from the trifluoroacetic acid-insoluble residue after 72% sulfuric acid hydrolysis according to the anthrone method.

Water-Holding Capacity (WHC). The WHC was determined using the method described by Jiménez et al.[14] Samples (250 mg × 3) were suspended in 15 mL of water. After 24 h of stirring at room temperature, the suspension was centrifuged at 14000*g* for 1 h. Supernatants were carefully eliminated, and the hydrated fibers were weighed. WHC was expressed as milliliters of water per gram of fiber. Hydrated pellets were freeze-dried, and their solubility in water was determined by the difference in weight between before and after the WHC assay, which was expressed as a percent.

Oil-Holding Capacity (OHC). The OHC was determined using the method described by Jimenez et al.[14] OHC was measured by adding 15 mL of sunflower oil (1.0054 g/mL density) to a concentrate of date fibers (250 mg × 3) in a 50 mL centrifuge tube. The content was stirred for 24 h at room temperature; then, the tubes were centrifuged at 14000*g* for 1 h. Supernatants were carefully eliminated, and the oil-embedded fibers were weighed. Oil-holding capacity was expressed as milliliters of oil per gram of fiber.

Extraction of Soluble Phenols. Ten grams (by duplicate) of fresh pulp was homogenized in an Ultraturax at top speed for 1 min with 50 mL of a 70:30 mixture of acetone/water. The suspension was extracted over 30 min by sonication in an ice bath. After filtration, the slurry was extracted again under the same conditions. Both filtrates were collected. The solvent was evaporated under vacuum, and the extracts were redissolved in 10 mL of the same solvent. These concentrated extracts were used to determine soluble phenols and soluble antiradical activity. The dry pellet was used to determine the antioxidant activity of the fiber portion. The yield of this extraction step was used to generate results for antioxidant activity on a fresh weight (FW) basis.

Determination of Soluble Phenols. The total polyphenol content was quantified for each date extract according to the Folin−Ciocalteu spectrophotometric method, using gallic acid as a reference standard. Aliquots of 0.2 mL of each sample were dosified in triplicate, and 0.5 mL of Folin−Ciocalteu phenol reagent (0.2 M) was added to each tube and mixed. Afterward, 0.4 mL of Na_2CO_3 (75 g/L) was added and mixed well. A microplate reader was set at 630 nm, and the absorbance was measured after 60 min. Results are expressed as gallic acid (GA) equivalents (mg/100 g FW).

Determination of the Antiradical Activity. Soluble antioxidant activity was determined from the soluble phenol extracts by the DPPH• method.[15] Fiber antioxidant activity was evaluated as described by Fuentes-Alventosa et al.[16] Between 3 and 20 mg of soluble phenol-free fibers was transferred to an eppendorf tube (for weights of <3 mg, fibers had to be diluted with cellulose as an inert material), and the reaction was started by adding 1 mL of the DPPH• reagent (3.8 mg/50 mL methanol). After 30 min of continuous stirring, samples were centrifuged, and the absorbance of the cleared supernatants was measured (in triplicate) at 480 nm. Both antioxidant activities were expressed as millimoles of Trolox equivalent antioxidant capacity per kilogram of sample by means of a dose−response curve for Trolox.

Extraction and Quantification of Ester-Linked Phenolics. Ester-linked phenolics present in fiber samples were extracted and quantified as previously described.[17] Briefly, soluble phenol-free samples (in duplicate) were treated with 2 N NaOH for 24 h at room temperature under nitrogen and in the dark. After filtration, *trans*-cinnamic acid was added as an internal standard. Solutions were acidified and extracted three times with ethyl acetate. Ethyl acetate extracts were evaporated under nitrogen, redissolved in 50% methanol, and analyzed by HPLC. Phenolic compounds were quantified using a Synergy 4 μ Hydro-RP80A reverse-phase column (25 cm × 4.6 mm i.d., 4 μm; Phenomenex, Macclesfield, Cheshire, U.K.). The gradient profile was formed using solvent A (10% aqueous acetonitrile plus 2 mL/L acetic acid) and solvent B (40% methanol, 40% acetonitrile, and 20% water plus 2 mL/L acetic acid) according to the following program: the proportion of B was increased from 10 to 42.5% for the first 17 min, was held isocratically at 42.5% for a further 6 min, was increased to 100% over the next 17 min, and was finally returned to

Table 1. Dietary Fiber Content (Expressed as Percent Fresh Pulp) and Composition (Grams per 100 g Fiber) of Different Date Fruit Cultivars[a]

cultivar	dietary fiber	neutral sugars	uronic acids	cellulose	lignin
Rochdi	4.76 ± 0.02 a	20.23 ± 1.45 b	16.60 ± 1.60 f	21.81 ± 1.91 de	35.03 ± 1.82 ab
Matteta	4.79 ± 0.09 a	25.06 ± 1.89 de	14.88 ± 1.62 de	24.82 ± 1.59 e	33.35 ± 1.27 a
Korkobbi	5.11 ± 0.06 b	20.38 ± 0.49 b	13.25 ± 0.73 bc	21.63 ± 1.41 cd	42.27 ± 0.33 de
Eguwa	5.85 ± 0.07 c	15.56 ± 0.39 a	13.40 ± 0.85 bc	17.01 ± 1.51 a	50.17 ± 0.44 g
Bouhattam	6.05 ± 0.16 d	20.44 ± 1.35 b	14.12 ± 1.01 cd	19.12 ± 1.21 bc	38.67 ± 0.28 c
Mermella	6.53 ± 0.02 e	20.50 ± 0.04 b	16.71 ± 0.87 f	19.80 ± 1.39 bc	39.19 ± 0.46 c
Limsi	6.62 ± 0.16 ef	25.71 ± 2.75 e	13.04 ± 0.85 b	18.16 ± 1.16 a	42.95 ± 0.09 e
Kenta	6.71 ± 0.03 ef	22.23 ± 0.60 bcd	15.50 ± 1.34 e	20.86 ± 2.41 cd	35.92 ± 2.02 b
Deglé Nour	7.23 ± 0.10 g	16.22 ± 0.16 a	10.74 ± 0.90 a	19.67 ± 1.66 c	50.37 ± 1.28 g
Garen Gaze	7.24 ± 0.11 g	24.89 ± 2.34 cde	12.90 ± 1.05 b	22.38 ± 1.86 de	46.08 ± 1.65 f
Smeti	7.26 ± 0.03 g	21.78 ± 1.50 bc	13.44 ± 0.90 bc	18.20 ± 1.33 b	40.58 ± 0.23 cd

[a]Values are the means of triplicate assays. Means bearing the same letter are not significantly different at the 5% level as determined by the Duncan multiple-range test.

the initial conditions. The flow rate was 1 mL/min. Phenols were detected using a Jasco-LC-Net II ADC liquid chromatograph system equipped with DAD and a Rheodyne injection valve (20 μL loop). Quantification was performed by integrating the peak areas at 280 nm with reference to calibrations performed while using known amounts of pure compounds.

Statistical Analysis. The results are expressed as the mean value ± standard deviation. To assess the differences in composition, functional characteristics, and antiradical activity between the different date varieties, a multiple-sample comparison was performed using the Statgraphics Plus program version 2.1. Multivariate analysis of variance (ANOVA), followed by Duncan's multiple-comparison test, was performed to differentiate the groups. The level of significance was $P < 0.05$. Correlation coefficients (R) were determined using regression analysis at the same confidence level.

RESULTS AND DISCUSSION

Chemical Composition of Date Dietary Fiber. Ten different varieties of dates from the coastline oases of Gabès were analyzed to characterize their DF content. The Deglé Nour variety was also studied as a standard for comparison. The percentage of DF in each variety is presented in Table 1. Deglé Nour, Garen Gaze, and Smeti had the highest DF content: >7% in fresh weight. Matteta and Rochdi had the lowest. These percentages were consistent with those found in the bibliography for these fruits: 5.9−8.7% for Omani dates.[5,18] In other studies, the percentage of fiber was much higher: 6.39−11.35%,[4] 10.88−13.45%,[9] or 6.99−17.67%.[19] Besides being attributed to variety, these differences could be also related to the stage of maturation, as during the ripening process enzymes gradually break down polysaccharides to more soluble compounds,[18] decreasing the fiber content. The analytical method used to quantify the fiber content is also a factor because some authors do not desugar the samples before analysis, so the total DF content would have been over-estimated.[5] The DF contents of a number of fresh fruits, such as apple, banana, cherry, mango, muskmelon, and peach, were reported by Punna and Paruchuri.[20] The values obtained ranged from 0.8 g/100 g for muskmelon to 2 g/100 g for mango. In addition, the DF contents of other dried fruits, such as raisins (3.7%), plums (7.1%) or figs (9.8%),[21] are similar to those observed for dates. Thus, date flesh could be considered a good source of DF compared with most fresh and dried fruits.

After DF hydrolysis, the content in neutral sugars, uronic acids, cellulose, and Klason lignin was quantified (Table 1). These values ranged from 15.56 to 25.71 g/100 g DF for neutral sugars, from 10.74 to 16.71 g/100 g DF for uronic acids, from 17.01 to 24.82 g/100 g DF for cellulose, and from 33.35 to 50.37 g/100 g DF for Klason lignin. The last one was the major component in all of the samples, as was the case for other date varieties.[9,22] Deglé Nour and Eguwa had a very similar composition. Both varieties had the highest amount of Klason lignin and the lowest of neutral sugars. The DF composition of some varieties was different with respect to those previously described. Elleuch et al.[9] analyzed Deglé Nour and Allig varieties from the Déguech region (Tunisia). They found that Deglé Nour had a lower amount of lignin (26% for lignin, cellulose, and uronic acids and 21% for neutral sugars), although Allig was similar to Matteta, Kenta, and Rochdi in our study. The compositional differences of the Deglé Nour variety could be due to the growth zone, as the Déguech zone is a mountain oasis. The Iranian variety Dalaki has been studied as a source of fiber and juice for fermentation.[22] This variety is a waste date due to its harder texture and higher fiber density compared to commercial edible-grade fruit. The composition of Dalaki date flesh fiber is approximately 70% lignin, 15% cellulose, 15% neutral sugars, and a negligible amount of uronic acids. It seems that lignin and uronic acids could be the key compounds in determining the quality of dates: high lignin and low pectin contents could indicate inedibility.[22] On the contrary, low lignin and high pectin contents are indicators of good quality. The varieties researched in this study exhibited intermediate contents, with Matteta, Kenta, and Rochdi possessing a valuable composition (the highest in uronic acids and the lowest in Klason lignin).

Compared to other fruits, date fibers featured a neutral sugars content that is slightly higher than that found in other fruits or vegetables. In guava pulp,[23] neutral sugars accounted for approximately 16%, but lower levels (5−7%) were found in cocoa bean husks[24] and some citrus byproduct.[25] Uronic acid contents also showed high variability, depending on the product studied. The lowest level was found in guava pulp,[23] which was 2%. Lime peels had the highest level, around 25%.[26] Uronic acid levels similar to those in date were found in peach pulp.[27] The cellulose content of date fruit DF was also in the range of that of other fruits and vegetables, with the lowest level (around 10%) found in cocoa bean husks[24] and the highest (36−40%) in citrus.[25] The cellulose contents in date fibers were similar to those reported by Jiménez-Escrig et al.[23] for guava pulp and Fuentes-Alventosa et al.[12] for asparagus. The

dx.doi.org/10.1021/jf2035934 | J. Agric. Food Chem. 2012, 60, 3658−3664

Table 2. Neutral Sugar Composition of Date Fruit Dietary Fiber (Expressed as Molar Percentage)[a]

cultivar	Rha	Fuc	Ara	Xyl	Man	Gal	Glu
Rochdi	3.62 e	2.05 c	20.52 bcd	50.28 ab	4.47 abcd	14.12 cd	4.92 a
Matteta	1.97 ab	1.69 ab	20.44 bcd	55.22 bcd	6.07 d	9.42 ab	5.19 ab
Korkobbi	2.42 bc	1.66 ab	19.03 abc	52.46 abc	4.48 abc	13.97 c	5.98 abc
Eguwa	2.82 cd	1.74 b	17.2 a	51.35 abc	5.13 bcd	16.37 ef	5.32 a
Bouhattam	2.07 ab	1.40 a	22.80 d	48.34 a	3.83 abc	16.22 def	5.34 abc
Mermella	2.83 cd	1.71 ab	17.40 ab	52.78 abcd	3.75 abc	16.52 ef	5.02 a
Limsi	1.57 a	1.61 ab	17.68 a	54.64 cd	8.03 e	8.46 a	8.01 c
Kenta	2.59 bc	1.69 ab	17.8 ab	49.29 a	5.20 cd	15.31 cde	8.08 bc
Deglé Nour	2.58 bcda	1.63 ab	21.27 cd	54.78 bcd	4.50 abcd	10.63 b	4.61 a
Garen Gaze	3.33 de	2.04 c	21.42 cd	57.26 d	3.38 a	8.99 ab	3.57 a
Smeti	2.67 bcd	1.48 ab	16.9 a	53.89 abcd	3.62 ab	17.42 f	3.99 a

[a]Values are the means of triplicate assays. Means bearing the same letter are not significantly different at the 5% level as determined by the Duncan multiple-range test. Rha, rhamnose; Fuc, fucose; Ara, arabinose; Xyl, xylose; Man, mannose; Gal, galactose; Glu, glucose.

range of lignin content from other products was wide, varying from 6% for peach pulp[27] to 32% for cocoa bean husks.[24]

The neutral sugar composition of DF was also studied (Table 2). Xylose was the main sugar, accounting for nearly 50% of the molar percentage. Other sugars of interest were arabinose (between 17 and 22%) and galactose (8−16%). Mannose and glucose were near 5%, and rhamnose and fucose were found in lower amounts. Elleuch et al.[9] reported higher percentages of rhamnose and galactose than those found in our varieties. These differences could be related to higher amounts of uronic acids also quantified in those samples. Moreover, pectins, xylans, and arabinoxylans are the main noncellulosic polysaccharides present in date DF, representing approximately 75% of the total neutral sugars. This composition is very similar to that of other lignocellulosic agricultural byproduct. Some authors have compared it to hardwoods and straws rather than softwoods, which contain large amounts of mannose.[22]

Water- and Oil-Holding Capacities and Solubility of Date Fiber. The results obtained for WHC, solubility, and OHC are presented in Table 3. WHC is an important property of DF from both physiological and technological points of view. The WHC of date DF ranged from 12.65 to 17.22 mL water/g fiber. The Kenta variety had the highest value, and Deglé Nour, Mermella, Rochdi, and Matteta exhibited nonstatistical differences with respect to WHC. Other authors[9] reported a capacity of 15.5 mL water/g fiber for other varieties, a value that is in the range above cited. We can argue that these other common varieties could have the same physiologically beneficial effects as Deglé Nour. However, if we consider those varieties as not suitable for human consumption, they could be a good source of fiber for food formulations. The results found in this work are similar to or even higher than those reported for most described byproduct fibers, for example, 15.8 mL water/g for fiber from asparagus byproducts[12] and 12.6 mL water/g for peach pulp fiber.[27] Other agricultural byproducts have lower values than those mentioned above, for example, cocoa husks,[24] which have a WHC value of 5 mL water/g fiber. Dates fibers have very low solubility, from 0.11 to 0.23%. These results are related to the high rate of insoluble to soluble fibers in date flesh. In almost all of the reported data,[9,18] the percentage of insoluble fiber was >95%. The soluble and insoluble nature of DF involves differences in their technological functionality and physiological effects. Insoluble fibers are characterized by their porosity, their low density, and their ability to increase fecal bulk and decrease intestinal transit. On the basis of these values, date fiber could be used as a modifier of viscosity and texture of formulated products in addition to promoting the decrease in calories that this addition could imply.

Table 3. Functional Properties of Date Fruit Fiber from Different Cultivars[a]

cultivar	WHC (mL water/g fiber)	% SOL	OHC (mL oil/g fiber)
Rochdi	16.23 ± 0.24 def	0.23 ± 0.01 f	3.84 ± 0.29 cd
Matteta	15.96 ± 1.25 def	0.15 ± 0.01 c	3.53 ± 0.07 bc
Korkobbi	14.77 ± 0.63 bcd	0.15 ± 0.00 c	4.21 ± 0.08 ef
Eguwa	12.65 ± 0.75 a	0.10 ± 0.01 a	4.46 ± 0.11 f
Bouhattam	14.56 ± 0.41 bc	0.18 ± 0.00 d	3.83 ± 0.38 cd
Mermella	16.45 ± 0.95 ef	0.20 ± 0.01 e	4.11 ± 0.18 de
Limsi	15.63 ± 0.49 cde	0.13 ± 0.02 b	3.72 ± 0.16 bc
Kenta	17.22 ± 0.92 f	0.14 ± 0.01 bc	3.38 ± 0.09 b
Deglé Nour	16.54 ± 1.47 ef	0.17 ± 0.01 d	3.64 ± 0.28 bc
Garen Gaze	13.01 ± 0.64 a	0.11 ± 0.01 a	4.25 ± 0.14 ef
Smeti	13.48 ± 1.05 ab	0.23 ± 0.00 f	3.01 ± 0.31 a

[a]Values are the means of triplicate assays. Means bearing the same letter are not significantly different at the 5% level as determined by the Duncan multiple-range test. WHC, water-holding capacity; SOL, solubility; OHC, oil-holding capacity.

The OHC results are presented in Table 3. Eguwa, Garen Gaze, and Korkobbi had the highest capacity (>4 mL/g fiber), which was much lower than that found in a previously cited work: approximately 9.7 g/g fiber.[9] These authors applied a force of 1500*g* to determinate the OHC instead of the 14000*g* we applied to our samples. The values found in the literature for other byproducts, for example, 0.6−1.8 g/g for apple pomace and citrus peel,[6] were much lower than those we reported for date fiber. Thus, the use of this fiber may be appropriate in products that require emulsifying properties.

Polyphenol Content and Antioxidant Activity of Date Fruits. The polyphenol content and antioxidant activity of both fractions, soluble and linked to fiber, are presented in Table 4. Deglé Nour was the variety that had the highest soluble polyphenol content (221 mg GA/100 g FW). From the coastal growth zone, Bouhattam, Korkobbi, and Eguwa were richer in these compounds than the other varieties, followed by Kenta, Limsi, Matteta, Garen Gaze, Smeti, Mermella, and Rochdi. Besides variety and growth zone, the soluble polyphenol content also depends on date humidity. There are important differences between soft, semidry, and dry dates. Biglari et al.,[28,29] who worked with Iranian dates, found that the polyphenol content in soft dates varies from 2 to 4 mg GA/

Table 4. Phenol Contents and Antioxidant Activities of Different Date Fruit Cultivars[a]

	soluble fraction		fiber fraction				
cultivar	phenol content (mg GA/100 g FW)	antiradical activity (mmol Trolox/kg FW)	vanillin (mg/100 g)	*p*-coumaric acid (mg/100 g)	ferulic acid (mg/100 g)	total phenols (mg/100 g)	antiradical activity (mmol Trolox/kg fiber)
Rochdi	28.96 ± 2.30 a	3.07 ± 0.63 a	39.57 ± 7.63	26.98 ± 11.11	49.27 ± 7.64	115.82 ± 11.10 h	104.32 ± 2.71 d
Matteta	84.72 ± 7.17 cd	11.58 ± 0.98 cd	10.39 ± 0.95	17.39 ± 1.33	56.35 ± 3.04	84.12 ± 0.77 ef	38.75 ± 4.13 a
Korkobbi	145.01 ± 8.17 f	28.68 ± 5.32 f	42.99 ± 1.08	5.62 ± 2.23	21.25 ± 0.82	69.86 ± 1.97 cd	73.98 ± 0.67 bc
Eguwa	146.65 ± 13.41 f	9.95 ± 2.13 bcd	50.74 ± 7.48	8.64 ± 0.99	35.51 ± 1.79	94.88 ± 8.28 g	232.30 ± 2.39 f
Bouhattam	164.50 ± 13.40 g	24.60 ± 1.51 e	25.83 ± 1.81	6.52 ± 1.04	31.43 ± 1.38	63.77 ± 4.23 bc	68.74 ± 0.23 b
Mermella	41.20 ± 3.79 a	3.18 ± 0.51 a	23.37 ± 0.96	24.10 ± 2.37	28.81 ± 1.53	76.28 ± 4.86 de	278.68 ± 3.03 g
Limsi	94.48 ± 11.70 de	8.82 ± 1.25 b	25.85 ± 1.46	15.90 ± 0.12	45.40 ± 0.46	87.15 ± 0.88 fg	71.94 ± 2.07 b
Kenta	96.62 ± 9.57 e	9.66 ± 1.13 bc	25.67 ± 0.15	12.01 ± 0.52	35.33 ± 0.88	73.01 ± 0.51 cd	79.45 ± 1.50 c
Deglé Nour	221.32 ± 18.35 h	50.82 ± 4.80 g	11.90 ± 0.43	8.11 ± 0.07	14.35 ± 0.63	34.36 ± 0.13 a	203.21 ± 0.81 e
Garen Gaze	79.40 ± 6.60 c	12.00 ± 2.81 d	25.23 ± 0.97	6.07 ± 1.32	33.16 ± 0.22	72.12 ± 1.95 cd	230.06 ± 6.25 f
Smeti	66.22 ± 3.23 b	8.04 ± 0.50 b	17.92 ± 0.83	13.89 ± 1.51	27.39 ± 0.29	59.19 ± 2.63 b	301.36 ± 10.23 h

[a]Values are the means of at least duplicate assays. Means bearing the same letter are not significantly different at the 5% level as determined by the Duncan multiple-range test.

100 g FW, that in semidry from 4 to 6 mg GA/100 g FW, and that in dry 141 mg GA/100 g FW. Similar results were published for Algerian soft dates,[30] between 2 and 8 mg GA/100 g FW, and for Omani dry dates,[5] from 172 to 246 mg GA/100 g FW. Chaira et al.,[31] who worked with Tunisian dates from some of the varieties presented in this study, found a smaller soluble polyphenol content (22−110 mg/100 g FW), most likely due to differences in the extraction and quantification methods. In agreement with our work, they found that Korkobbi, Bouhattam, and Kenta had the highest polyphenol content (they did not analyze the Eguwa cultivar).

The antiradical activity of the soluble fraction was studied, the results of which are presented in Table 4. As was the case with the polyphenol content, Deglé Nour had the highest activity (50 mmol Trolox/kg FW). Korkobbi and Bouhattam cultivars had nearly half that of the Deglé Nour activity (28.68 and 24.60 mmol Trolox/kg FW, respectively). The lowest values were those found for Rochdi and Mermella (3.07 and 3.18 mmol Trolox/kg FW, respectively). These results are also in agreement with those published by Chaira et al.[31] Although sugars and other compounds could have slight interference in the Folin−Ciocalteu quantification method, there was good correlation between the soluble polyphenol content and antiradical activity (R = 0.8451), as has been reported by other authors.[28,30,31]

In this work, we also studied the phenol composition and antiradical activity of the insoluble fraction. This fraction could be very important with regard to the total antioxidant activity of fruits and vegetables because, as Saura-Calixto[32] suggested, the transportation of antioxidants through the gastrointestinal tract is an essential physiological function of DF. This aspect has received very little attention so far. Bound phenolics were extracted from all samples and identified and quantified by HPLC. The results are presented in Table 4. Ferulic acid was the most abundant simple phenol in all of the samples, except for Korkobbi and Eguwa, in which vanillin was the major phenol. Ferulic acid ranged from 14.35 to 56.35 mg/100 g fiber in the Matteta and Deglé Nour varieties, respectively. The other phenolic acid identified, *p*-coumaric acid, was the minor component in almost all of the samples. The total amount and composition varied significantly among the samples, as reported by Al-Farsi et al.,[18] who worked with Omani dates.

Because we found that date pulp contained an interesting amount of phenols linked to fiber, we considered that these compounds could confer additional antioxidant activity that was not measured with the soluble extracts. In Figure 1, the antiradical activity of date fiber is presented. In this figure, the higher scope in the regression line indicates the higher antioxidant activity. The assayed fibers were soluble phenol-free, so their activities should be due exclusively to compounds present in the fiber fraction. There was a group of five varieties (Deglé Nour, Garen Gaze, Smeti, Mermella, and Eguwa) that had the highest activities. Bouhattam, Limsi, Kenta, Rochdi, and Korkobbi had an intermediate level of free radical scavenging activity, Matteta being the least active variety. In Table 4, these levels of activity are expressed as millimoles of Trolox per kilogram of fiber. The variety with the highest activity linked to fiber was Smeti; the order of the remaining samples with regard to this activity was as follows: Smeti > Mermella > Garen Gaze = Eguwa > Deglé Nour ≫ Rochdi > Kenta > Korkobbi > Limsi = Bouhattam ≫ Matteta. In the fiber fraction, there was no correlation between the polyphenol content and antiradical activity. In prepared food, which undergoes a thermal process, a nonenzymatic browning reaction takes place, leading to the formation of a complex series of compounds called Maillard

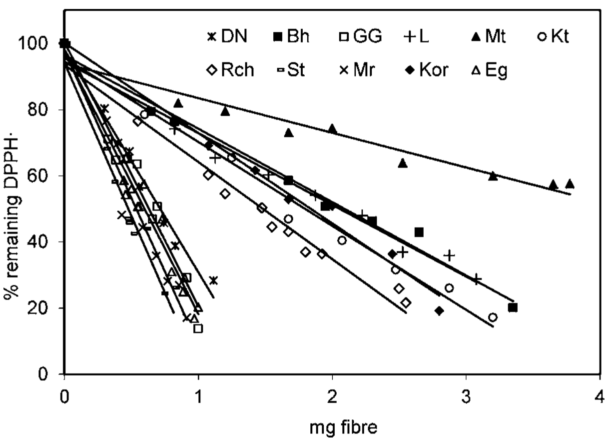

Figure 1. Dose−response lines of antiradical capacity of date fibers from different cultivars. Antiradical capacity is expressed as percent DPPH• remaining in solution after 30 min of reaction. Each individual point in the graph is the average value of three replicates. DN, Deglé Nour; Bh, Bouhattam; GG, Garen Gaze; L, Limsi; Mt, Matteta; Kt, Kenta; Rch, Rochdi; St, Smiti; Mr, Mermella; Kor, Korkobbi; Eg, Eguwa.

reaction products. The antioxidant activity of these compounds has been reported in several studies.[33] In date palm fruits, this reaction was mentioned by Barneveld.[34] In our work, these compounds could also contribute to the antioxidant activity of the fiber fraction; thus, a more detailed study on date Maillard reaction products should be conducted. The most interesting thing is that four Tunisian varieties had high antiradical activity, even higher than that of the Deglé Nour variety. The fiber from these date varieties could be considered "antioxidant DF", as defined by Saura-Calixto,[35] because they have a free radical scavenging capacity of >50 mg of vitamin E (measured by the DPPH• method), and this activity is derived from natural components of the material. Figure 2 shows the total antioxidant activity expressed on a fresh weight basis. It is clear that Deglé Nour is the best variety, with the highest activities (soluble and linked to fiber). However, fiber from Garen Gaze, Smeti, Mermella, and Eguwa cultivars had an activity similar to or even higher than that of Deglé Nour. These are the Tunisian secondary varieties that could be promising from a technological point of view.

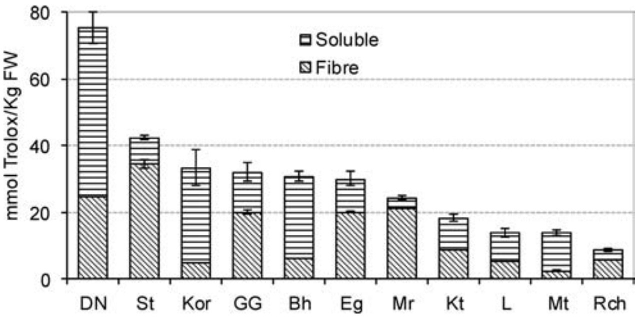

Figure 2. Total antiradical activity expressed as millimoles of Trolox per kilogram of fresh weight of date fruits from different cultivars. DN, Deglé Nour; Bh, Bouhattam; GG, Garen Gaze; L, Limsi; Mt, Matteta; Kt, Kenta; Rch, Rochdi; St, Smiti; Mr, Mermella; Kor, Korkobbi; Eg, Eguwa.

In summary, the DF contents of 10 Tunisian date varieties from Gabès coastal oases have been studied for the first time and compared to that of Deglé Nour, the most commercially accepted variety. Although Tunisian secondary varieties have similar DF content and composition, they are not very suitable for human consumption. Therefore, our study also focused on possible technological applications. The most important characteristic supporting the use of some of these varieties as food ingredients is their antioxidant activity. The level of activity found in the fiber of Garen Gaze, Smeti, Mermella, and Eguwa varieties makes them valuable as potential sources of antioxidant fiber. Further studies on the responsible compounds (maybe Maillard reaction products) for this characteristic are needed, as is a technological approach to obtaining this antioxidant DF from date fruit. The use of these secondary varieties in the food industry as healthy ingredients could help in the fight against the reduction in vegetal genetic variability. In addition, the growth of these cultivars for technological purposes may play an important role in the economic and social level of the people from this developing region.

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Funding

We are grateful to the Institut des Regions Arides (Medenine, Tunisia) for the financial support of travel expenses of A.M. for his stay with the Instituto de la Grasa (Sevilla, Spain).

Notes

The authors declare no competing financial interest.

ABBREVIATIONS USED

DF, dietary fiber; MES, 4-morpholineethanesulfonic acid; Tris, tris(hydroxymethyl)aminomethane; DPPH, 2,2-diphenyl-1-picrylhydrazyl free radical; GA, gallic acid; FW, fresh weight.

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