Chemical composition, antioxidant capacity, and mineral extractability of Sudanese date palm (Phoenix dactylifera L.) fruits

Rania M. A. Mohamed, Aisha S. M. Fageer, Mohamed M. Eltayeb & Isam A. Mohamed Ahmed*

Department of Food Science and Technology, Faculty of Agriculture, University of Khartoum, Shambat 13314, Sudan

Abstract

The aim of the present work was to investigate the chemical composition, mineral extractability, and antioxidant capacity of six date palm varieties grown in Sudan. The results showed that Sudanese date varieties contained significantly different ($P < 0.05$) amounts of moisture, ash, fiber, oil, and carbohydrates, but have almost similar amounts of protein. Moreover, results revealed that date varieties contained significantly varied ($P < 0.05$) amounts of total polyphenols and total flavonoids, which ranged between 35.82 and 99.34 mg gallic acid equivalent/100 g and 1.74–3.39 mg catechin equivalent/100 g, respectively. The antioxidant activities of the studied date varieties were as follows: ferric-reducing antioxidant power (FRAP) was within the range of 2.82–27.5 mmol/100 g, chelation of Fe$^{2+}$ ion ranged from 54.31% to 94.98%, and scavenging of H$_2$O$_2$ ranged from 38.48% to 49.13%. There were many correlations (positive, negative, and weak) between antioxidant and mineral extractability of Sudanese date fruits.
reached about 119,048 metric tons of fruit in 2010, accounting for about 5.5% of total world production (FAOSTAT 2010). Date palms contribute to the livelihoods of people in northern Sudan, as well as playing an important role in the cultural heritage of the local population. It is the most important agricultural crop in the area and provides food and income to a majority of the inhabitants. It ranks first among all crops due to its high nutritional and economic value. The annual income gained from dates is estimated to be around $200 million in the Northern and River Nile States, representing not less than 26% and 20%, respectively, of total agricultural income (Osman 2001). As by-products, wood is made from the stems, and fronds are widely used for thatching, buildings, braiding, and basketry (household utensils). Although dates have a great importance for the people of Sudan, there have been few studies on the nutritional quality (Sulieman et al. 2012) and functional properties of Sudanese dates.

In the past decade, there has been a growing interest in the chemotherapeutic and preservative properties of natural plant antioxidants to prevent oxidative reactions in food, cosmetics, and in biological systems (Molyneux 2004). Regular consumption of bioactive compounds from plants and fruit may be associated with protection against oxidative damage and lowered risk of chronic diseases, such as cancer, heart disease, and cerebrovascular disease (Hung et al. 2004). Polyphenols and flavonoids are of considerable interest to scientists, manufacturers and consumers due to their antioxidant properties (Haminiuk et al. 2012; Barbosa-Pereira et al. 2013). Although, polyphenolics and flavonoids constitute an important class of secondary metabolites that act as free radical scavengers and inhibitors of low-density lipoprotein, of cholesterol oxidation and of DNA breakage, they can also form complex with minerals and hence, reduce mineral bioavailability (Galleano et al. 2010; Rehecho et al. 2011). Thus, to understand the positive and negative effects of antioxidants on mineral bioavailability, studies on the correlation between the antioxidant capacity and mineral extractability are of great importance.

Despite the large amount of information available on the antioxidant properties and phenolic compounds of dates from various countries (Mansouri et al. 2005; Al-Farsi et al. 2007; Biglari et al. 2008; Benneddour et al. 2013), information regarding the antioxidant potential of Sudanese dates is scarce. To the best of our knowledge, limited data are available on the chemical composition of dates grown in Sudan (Sulieman et al. 2012). To date, there has been no data published on the antioxidant capacity, polyphenols, flavonoids, and mineral extractability of Sudanese date fruits. Detailed information on the nutritional composition and health-promoting components of dates will enhance our knowledge and appreciation for the use of dates and their products in a variety of food and specialty products, including their use as functional foods and ingredients in nutraceuticals, pharmaceuticals, and medicine. Given this, the objectives of the present research were to investigate the chemical composition, mineral content and extractability, and antioxidant capacity of Sudanese date fruits.

Materials and Methods

Materials

The dates acquired were Barakawi, Gondaila, Jaw, Mishrig, Bittamoda, and Madini. These six varieties are the most common varieties locally grown and utilized in Sudan. The fruits of these varieties were purchased from a well-known date’s market in Khartoum State, Khartoum, Sudan, at the beginning of the 2010 harvest season. The origin of these fruits is a date farm in Dongola region, northern Sudan. They had been subjected to uniform harvest, postharvest, and handling practices. In these processes, the fruits were harvested manually on a clean plastic sheets, sun dried, packed, and transported to the market. The date fruits selected and used were of uniform size and free of physical damage, insects, injury, and fungal infection. Samples were manually cleaned, pitted, and blended with a blender and kept in polyethylene bags at 4°C for further investigations. The experiment was designed as a completely randomized design with three replicates. Ten dates were used for each replication for each type of date. Unless otherwise stated, all chemicals used in the study were of analytical grade.

Approximate analysis

The determination of moisture, crude fiber, crude fat, crude protein, and ash were carried out according to the official standard method (AOAC 2003). The total carbohydrate of the samples was calculated by subtracting the value of protein, oil, fiber, ash, and moisture content from 100.

Determination of minerals content and extractability

Minerals content were determined by the dry ashing method (Chapman and Pratt 1982). Calcium and magnesium (Mg) were measured by titration. Phosphorus was determined spectrophotometrically using the molybdenum-vanadate method. All other minerals were determined by atomic absorption spectrophotometer (Shimadzu AA-680, Shimadzu, Japan).

HCl extractability of minerals (in vitro bioavailability) was determined by the method of Chauhan and Mahjan...
Mineral extractable in HCl (mg/100 g) of 0.03 mol/L HCl for 3 h at 37°C and then filtered. The clear extract obtained was oven dried at 100°C and then acid digested. The amount of extractable minerals was determined by the above described methods. HCl extractability of minerals (%) was determined as follows:

$$\text{HCl extractability of minerals (\%)} = \frac{\text{Mineral extractable in HCl (mg/100 g)}}{\text{Total minerals (mg/100 g)}} \times 100$$

**Extraction**

One hundred grams of the edible part of the date palm fruit was extracted with 300 mL methanol–water (4:1, v/v) at room temperature (20°C) for 5 h using an orbital shaker. The extracts were then filtered and centrifuged (Hettich Zentrifugen, Tuttingen, Germany) at 4000g for 10 min. The supernatant was concentrated under reduced pressure at 40°C for 3 h using a rotary evaporator (IKA-WERKE-RV06ML; Staufen, Germany) to obtain the date palm fruit methanolic crude extract. The crude extract was kept in dark glass bottles inside the freezer until use. The storage conditions (time and temperature) were the same for all types of fruit.

**Determination of polyphenols**

Total polyphenols were determined as described by Al-Farsi et al. (2005a). The results were expressed as milligram gallic acid equivalents per 100 g of dry weight (mg GAE/100 g DW).

**Determination of total flavonoids content**

Total flavonoids content (TFC) of the date extracts were measured according to the colorimetric assay of Kim et al. (2003). One milliliter of the methanolic extract was added to 300 μL sodium nitrite solution (5%) followed by 300 μL aluminum chloride (10%). Test tubes were incubated at room temperature for 5 min, and then 2 mL of 1 mol/L sodium hydroxide was added. Immediately, the volume of reaction mixture was made to 10 mL with distilled water and the mixture was thoroughly vortexed. The absorbance of the mixture was determined at 510 nm. Total flavonoid content was reported as milligrams of catechin equivalents per 100 g (mg CE/100 g DW).

**Determination of antioxidant capacities**

**Ferric-reducing antioxidant power**

The FRAP of samples was determined according to the method described by Oyaizu (1986). A stock solution of each date variety in methanol (1 mg/mL) was prepared and different volumes (125, 250, 500, and 1000 μL) from each stock solution were transferred to different test tubes. The volume in each test tube was adjusted to 1 mL with the same solvent. Then, 2.5 mL of 200 mmol/L sodium phosphate buffer (pH 6.6), and 2.5 mL of 1% potassium ferricyanide were added to each test tube and incubated at 50°C for 20 min. After incubation, 2.5 mL of 10% trichloroacetic acid was added and centrifuged at 2000g for 10 min. The upper layer (2.5 mL) was mixed with 2.5 mL of deionized water and 0.5 mL of 0.1% ferric chloride. The absorbance was measured at 700 nm against a blank. The FRAP of each date sample at different concentrations was compared to ascorbic acid as a positive control and the results were expressed as ascorbic acid equivalent.

**Chelation of Fe²⁺ ions**

Concentration of free iron ions (Fe²⁺) was estimated using chelating agent 2,2-dipyridyl as described by Harris and Livingstone (1964). Briefly, a stock solution of each date variety containing 1 mg/mL in methanol was prepared and different amounts (125, 250, 500, and 1000 μL) from each stock solution were transferred to different test tubes. The volume in each test tube was adjusted to 1 mL with the same solvent. To each tube, 1 mL of a solution containing 50 mmol/L FeSO₄ and 50 mmol/L NaCl (pH 7.0) was added. A blank solution was prepared using 1 mL of methanol instead of the sample. Samples were incubated for 30 min at room temperature and then 2 mL of 2,2-dipyridyl (1 mmol/L) was added. Absorbance of ferrous–dipyridyl complex was measured at 525 nm against a solution devoid of ferrous sulfate. The results were expressed as a percentage of inhibition of 2,2-dipyridyl–Fe²⁺ complex formations.

**Hydrogen peroxide scavenging capacity**

The hydrogen peroxide (H₂O₂) scavenging ability of palm dates was measured using the method described by Jayarakasha et al. (2004). A solution of H₂O₂ (40 mmol/L) was prepared in phosphate buffer (pH 7.4). Various concentrations (125, 250, 500, and 1000 μL) of date extract were prepared in 40 mmol/L phosphate buffer saline (pH 7.4). Then, 1 mL of H₂O₂ solution (40 mmol/L) was added and the reaction mixtures were incubated for 10 min at room temperature. Absorbance of H₂O₂ at 230 nm was determined after 10 min against a blank solution containing phosphate buffer without hydrogen peroxide. The scavenging capacity was calculated using the following formula:
Scavenging capacity (%) = \left(\frac{A_0 - A_1}{A_0}\right) \times 100

where \(A_0\) is the absorbance of the control and \(A_1\) is the absorbance of the sample extracts.

### Statistical analysis

For all the experiments, three samples of each date were analyzed and the entire assay was carried out in triplicate. Results were analyzed using one way analysis of variance (ANOVA) and Tukey's multiple comparison tests were used to compare between treatment means. The significance level was accepted at \(P < 0.05\). The correlation between antioxidant and mineral extractability was assessed using the Pearson criteria \((P < 0.05\) and \(0.01\)) using the Statistical Analysis System (SAS, v. 8.1; SAS Institute Inc., Cary, NC).

### Results and Discussion

#### Approximate composition

The chemical composition of the six Sudanese date varieties studied is shown in Table 1. With the exception of protein, ANOVA showed significant \((P < 0.05)\) varietal differences of chemical components in all Sudanese date fruits. The moisture, ash, fiber, protein, fat, and carbohydrate content were within the ranges of 8.78–10.68, 1.96–2.50, 2.37–3.14, 1.71–2.06, and 78.73–80.41 g/100 g, respectively. These results were in general agreement with those reported previously (Ahmed et al. 1995; Al-Farsi et al. 2007; Amira et al. 2011; Baliga et al. 2011; Tang et al. 2013). However, in contrast, different amounts of these chemical components in dates from various countries have also been reported (Al-Shahib and Marshal 2003; Al-Farsi et al. 2005a). These variations could be attributed to differences in cultivar, harvest/postharvest practices, and growing environment such as soil fertility, temperature, humidity, etc. Our data revealed that Sudanese date fruits contained sufficient amounts of most essential nutrients, and thus could be recommended for regular consumption. The low level of lipid content compared with the high sugar content of dates is a good indicator for its potential uses. Interestingly, date fruits are usually characterized by high carbohydrate content (up to 88%), most of which is in the form of digestible sugar such as glucose, fructose, and sucrose (Baliga et al. 2011).

Because of this, sugars in dates are the most important constituent as they provide a rich source of energy to the human system. Approximately 100 g of flesh can provide 314 kcal of energy (Al-Farsi et al. 2005a; Al-Farsi and Lee 2008). This could also elevate blood sugar after rapid digestion of reducing sugars such as glucose. Beside their value as an energy source, date sugars are also used as sweeteners of foods especially in the preparation of beers (Al-Farsi et al. 2005a; Al-Farsi and Lee 2008). Although the sugar types of Sudanese dates were not investigated in this study, it can be assumed from the higher concentration of total carbohydrate and/or appreciable amounts of fiber and protein that Sudanese date fruits have good nutritional and health potential.

#### Total and extractable macrominerals

Significant varietal \((P < 0.05)\) differences existed in macromineral composition and extractability of Sudanese date varieties (Table 2). The calcium content of different date varieties was within a range of 222.2–293.04 mg/100 g and was significantly \((P < 0.05)\) different between date varieties. These findings were within the wide range 140–385 mg/100 g reported for some Iranian dates at the Tamr stage (Rastegar et al. 2012). However, our results were much higher than those reported by many investigators (Ahmed et al. 1995; Al-Shahib and Marshal 2003; Al-Farsi et al. 2005a; Baliga et al. 2011; Tang et al. 2013). Despite the high calcium content of Sudanese date varieties, only 20–37.5% of the total calcium was extractable. Madini cultivar has shown the highest extractability of calcium, whereas Bittamoda has the lowest. Mineral extractability of Sudanese date cultivars varied significantly \((P < 0.05)\). Barakawi exhibited high calcium content and a good degree of calcium extractability. Although many studies have described the mineral contents of date fruits from

### Table 1. Chemical composition (g/100 g) of different Sudanese date varieties.

| Varieties | Moisture | Ash | Fiber | Protein | Fat | Carbohydrate |
|-----------|----------|-----|-------|---------|-----|--------------|
| Gondaila  | 8.78 ± 0.10<sup>d</sup> | 2.20 ± 0.03<sup>e</sup> | 2.53 ± 0.12<sup>b</sup> | 4.09 ± 0.15<sup>a</sup> | 2.00 ± 0.08<sup>ab</sup> | 80.41 ± 0.01<sup>a</sup> |
| Barakawi  | 9.38 ± 0.09<sup>c</sup> | 2.50 ± 0.13<sup>a</sup> | 2.67 ± 0.09<sup>a</sup> | 4.03 ± 0.12<sup>a</sup> | 1.87 ± 0.05<sup>abc</sup> | 79.55 ± 0.03<sup>abc</sup> |
| Jaw       | 10.68 ± 0.19<sup>a</sup> | 2.38 ± 0.11<sup>ab</sup> | 2.74 ± 0.13<sup>ab</sup> | 3.69 ± 0.08<sup>b</sup> | 1.79 ± 0.04<sup>cd</sup> | 78.73 ± 0.71<sup>b</sup> |
| Mishrig   | 8.81 ± 0.07<sup>d</sup> | 2.19 ± 0.05<sup>c</sup> | 2.78 ± 0.19<sup>ab</sup> | 3.92 ± 0.10<sup>ab</sup> | 2.06 ± 0.05<sup>a</sup> | 80.27 ± 0.27<sup>a</sup> |
| Bittamoda | 10.03 ± 0.13<sup>b</sup> | 1.96 ± 0.09<sup>df</sup> | 2.37 ± 0.16<sup>b</sup> | 3.72 ± 0.09<sup>ab</sup> | 1.81 ± 0.03<sup>c</sup> | 80.11 ± 0.44<sup>a</sup> |
| Madini    | 9.90 ± 0.12<sup>b</sup> | 2.27 ± 0.05<sup>b</sup> | 3.14 ± 0.11<sup>c</sup> | 3.94 ± 0.04<sup>ab</sup> | 1.71 ± 0.01<sup>d</sup> | 79.04 ± 0.43<sup>b</sup> |

Means (±SD, \(n = 3\)) in the same column sharing the same letter(s) are not significantly different at \(P < 0.05\).
Mineral Extractability of Sudanese Dates

R. M. A. Mohamed et al.

Table 2. Total (mg/100 g) and extractability (%) of macrominerals of different Sudanese date varieties.

| Varieties   | Ca (mg/100 g) | P (mg/100 g) | Mg (mg/100 g) | Na (mg/100 g) | K (mg/100 g) |
|-------------|---------------|--------------|---------------|---------------|--------------|
| Gondaila    | 282.10 ± 12.65 | 131.87 ± 8.76 | 29.8 ± 1.91   | 41.10 ± 1.37  | 73.17 ± 2.09 |
| Barakawi    | 276.74 ± 10.98 | 135.36 ± 7.64 | 25.98 ± 2.01  | 41.10 ± 1.87  | 73.17 ± 2.09 |
| Jaw         | 234.04 ± 15.26 | 139.11 ± 7.64 | 23.76 ± 2.01  | 46.42 ± 2.01  | 73.17 ± 2.09 |
| Mishrig     | 283.04 ± 15.26 | 139.11 ± 7.64 | 23.76 ± 2.01  | 46.42 ± 2.01  | 73.17 ± 2.09 |
| Bittamoda   | 277.78 ± 15.26 | 139.11 ± 7.64 | 23.76 ± 2.01  | 46.42 ± 2.01  | 73.17 ± 2.09 |
| Madini      | 222.20 ± 6.22  | 139.11 ± 7.64 | 23.76 ± 2.01  | 46.42 ± 2.01  | 73.17 ± 2.09 |

Means (+SD, n = 3) in the same column sharing the same letter(s) are not significantly different at P < 0.05.
Total and extractable microminerals

Micronutrients are involved in a high numbers of biological processes, as a component of proteins or as essential components of numerous enzymes required for oxidative, amino acids, lipids or carbohydrate metabolism. The results presented in Table 3 showed significant varietal \((P < 0.05)\) differences in micromineral content and extractability. The concentration of iron (Fe) in Sudanese dates ranged from 4.06 mg/100 g in Barakawi to 7.06 mg/100 g in Jaw. ANOVA showed a significant \((P < 0.05)\) difference in Fe content between all date varieties. Our results on Fe content fell within the range of 0.3–1.5 mg/100 g reported previously for date varieties from different countries (Al-Shahib and Marshal 2003). The current findings were higher than the range 0.3–1.5 mg/100 g \((\text{Ahmed et al. 1995})\), 0.58–1.09 mg/100 g \((\text{Al-Farsi et al. 2005a})\), 0.1–1.5 mg/100 g \((\text{Baliga et al. 2011})\), 0.83–1.76 mg/100 g \((\text{Ismail et al. 2006})\), and 1.6–1.8 mg/100 g \((\text{Rastegar et al. 2012; Tang et al. 2013})\) reported for dates from various countries. On the other hand, Fe extractability of Sudanese date fruits varied significantly \((P < 0.05)\) and ranged between 8.67% and 37.0%. Although the variety Barakawi had the lowest Fe content it showed higher extractability. In contrast, the variety Jaw, which had the highest Fe value, showed lower extractability. This finding demonstrates that Fe content and extractability of Sudanese date fruits are variety-dependent factors.

ANOVA showed significant \((P < 0.05)\) differences in copper (Cu) content and extractability of Sudanese date varieties (Table 3). The Cu content of Sudanese dates ranged from 0.71 mg/100 g in the variety Gondaila to 1.86 mg/100 g in the cultivar Madini. These results were within the range of 0.1–2.9 mg/100 g reported for some date varieties from other countries \((\text{Al-Shahib and Marshal 2003})\). However, our results were higher than those reported for Cu concentration in dates from several countries \((\text{Ahmed et al. 1995; Al-Farsi et al. 2005a; Baliga et al. 2011})\). This variation could be due to variation in date genotypes, cultivation practices, ripening stage, and soil

Table 3. Total (mg/100 g) and extractability (%) of microminerals of different Sudanese date varieties.

| Varieties | Fe mg/100 g | % | Cu mg/100 g | % | Zn mg/100 g | % | Mn mg/100 g | % |
|-----------|-------------|---|-------------|---|-------------|---|-------------|---|
| Gondaila  | 6.48 ± 0.28b | 23.04 ± 0.10c | 0.71 ± 0.01c | 86.92 ± 0.86c | 0.75 ± 0.02d | 89.34 ± 3.53c | 0.78 ± 0.04a | 85.89 ± 5.89b |
| Barakawi  | 4.06 ± 0.21b | 37.00 ± 0.54c | 1.27 ± 0.08b | 44.10 ± 2.23c | 0.72 ± 0.01c | 72.17 ± 1.69b | 0.59 ± 0.01a | 100.00 ± 6.35b |
| Jaw       | 7.06 ± 0.10a | 8.67 ± 0.68c | 0.89 ± 0.06d | 79.11 ± 0.95c | 0.78 ± 0.06e | 77.76 ± 3.11c | 0.74 ± 0.02h | 66.81 ± 7.01c |
| Mishrig   | 5.50 ± 0.13d | 17.51 ± 0.19c | 1.04 ± 0.05c | 87.29 ± 1.10b | 0.66 ± 0.01i | 99.60 ± 4.32b | 0.71 ± 0.04e | 45.02 ± 1.61b |
| Bittamoda | 5.09 ± 0.11e | 29.58 ± 0.40c | 1.09 ± 0.03e | 76.65 ± 0.37c | 0.83 ± 0.04b | 71.66 ± 2.45c | 0.68 ± 0.03b | 13.69 ± 3.02b |
| Madini    | 6.91 ± 0.04b | 36.18 ± 0.83c | 1.86 ± 0.12c | 33.50 ± 1.03c | 1.00 ± 0.07a | 55.55 ± 4.17c | 0.54 ± 0.01d | 25.51 ± 2.23c |

Means (±SD, n = 3) in the same columns sharing the same letter(s) are not significantly different at \(P < 0.05\).
fertility. On the other hand, extractability of Cu varied \((P < 0.05)\) between date varieties and showed a wide percentage range \((33.50–87.93\%\)). Surprisingly, more than 77\% of Cu in the four date varieties (Mishrig, Gondaila, Jaw, and Bittamoda) of this study was extractable and available for absorption. In contrast, the other cultivars (Barakawi and Madini) showed more than 33\% bioavailability of Cu in Sudanese dates. A higher extractability of Cu in date fruits is an indication of better utilization by the human body.

Significant \((P < 0.05)\) varietal differences in zinc (Zn) concentration and extractability of six Sudanese date varieties were also evident from the results in Table 3. The concentration of Zn in Sudanese dates varied from 0.66 mg/100 g in Mishrig to 1.0 mg/100 g in Madini. In agreement with our results, Al-Shahib and Marshal (2003) reported a wide range of Zn concentration \((0.1–1.8 \text{ mg/100 g})\) in dates from various countries. In contrast, significantly lower concentrations of Zn in date fruits from various countries was reported (Ahmed et al. 1995; Al-Farsi et al. 2005a; Ismail et al. 2006; Baliga et al. 2011). However, a higher content of Zn at the Tamr stage of ripening in three Iranian dates was recently reported (Rastegar et al. 2012; Tang et al. 2013). The variation in Zn content between these studies could be attributed to differences in varieties, agronomical practices, ripening stage, soil fertility, and environmental conditions. On the other hand, an in vitro extractability study revealed that more than 50\% of the total Zn of Sudanese date varieties studied was available for absorption in the digestive tract. The varieties Mishrig \((99.60\%)\) and Gondaila \((89.34\%)\) presented the first and second highest levels of Zn extractability, respectively.

Manganese (Mn) concentrations of Sudanese date fruits ranged between 0.54 and 0.78 mg/100 g with slight significant differences between date varieties (Table 3). The highest Mn content was found in Gondaila, whereas the lowest was observed in Madini. Compared with previous reports on Mn content of date fruits from different origins, our results fell within the ranges 0.3–5.9 mg/100 g (Al-Shahib and Marshal 2003) and 0.4–1.6 mg/100 g (Rastegar et al. 2012; Tang et al. 2013). In contrast, other studies reported lower concentrations of Mn in dates from various countries (Ahmed et al. 1995; Al-Farsi et al. 2005a; Ismail et al. 2006; Baliga et al. 2011). On the other hand, ANOVA showed significant \((P < 0.05)\) varietal differences in the in vitro extractability of Mn. A wide range of Mn extractability was also observed with a maximum extractability of 100\% in Barakawi and a minimum extractability of 13.69\% in Bittamoda. Taken together, the micromineral concentrations of Sudanese date varieties were generally higher than those reported previously for other date varieties. With the exception of iron, the extractability of all micronutrients in this study was found to be good.

Overall, the values of minerals assessed in date palm fruits were generally high compared with other fruits (Rastegar et al. 2012). It has been reported that the percentages of potassium, phosphorus, and iron in dates were much higher than in other fruits (Al-Shahib and Marshal 2003). The amount of these three minerals in dates was three to five times more than their amount in grapes, apples, oranges, and bananas (Al-Showiman 1990). With few exceptions, concentration and in vitro extractability of both macro- and microminerals of Sudanese date varieties was generally good. Thus, it can be assumed that the consumption of these dates could efficiently supply the body with the recommended dietary allowance of these minerals.

### Total polyphenol content

A comparison of total polyphenol content (TPC) data of the Sudanese date varieties tested is presented in Table 4. The TPC of different date varieties varied considerably \((P < 0.05)\) and ranged from 35.82 to 199.34 mg GAE/100 g DW. The order of TPC of Sudanese date varieties was as follows: Madini > Bittamoda > Mishrig > Jaw > Gondaila > Barakawi. The results were within the range 3.91–661 mg/100 g reported for dates from different origins (Baliga et al. 2011). The results were also higher compared to those reported by Mansouri et al. (2005) who found that TPC of methanolic extract of ripe Algerian date fruits varied from 2.49 to 8.36 mg GAE/100 g FW. Furthermore, the results were slightly higher than the range 2.89–141.35 mg GAE/100 g DW reported for some Iranian soft, semidry and dry dates (Biglari et al. 2008). In contrast, higher TPC of date fruits from different countries has been reported by a number of authors (Al-Farsi et al. 2005b; Benmeddour et al. 2013). The observed differences among these studies may be related to the cultivars, environmental conditions, fruit maturity, fruit moisture content, and extraction conditions such as solvent and ratio of material/solvent (Al-Farsi et al. 2005b; Benmeddour et al. 2013). Comparative studies with fresh and dried dates

### Table 4. Total polyphenols content (TPC) and total flavonoids content (TFC) for different Sudanese date varieties.

| Varieties | TPC (mg GAE/100 g DW) | TFC (mg CE/100 g) |
|-----------|----------------------|------------------|
| Gondaila  | 55.82 ± 3.68*        | 3.39 ± 0.09*     |
| Barakawi  | 35.82 ± 0.01\(\text{**}\) | 1.85 ± 0.01\(\text{**}\) |
| Jaw       | 63.24 ± 5.07\(\text{**}\) | 1.81 ± 0.01\(\text{**}\) |
| Mishrig   | 111.65 ± 9.22\(\text{**}\) | 1.74 ± 0.00*      |
| Bittamoda | 124.89 ± 7.48\(\text{**}\) | 3.27 ± 0.07*      |
| Madini    | 199.34 ± 9.51\(\text{**}\) | 1.74 ± 0.04*      |

Means \((±SD, n = 3)\) in the same column sharing the same letters(s) are not significantly different at \(P < 0.05\).
The FRAP significantly (P < 0.05) increased with increases in the concentration (15-100 µg) of Sudanese date palm fruits extracts (Table 4). The results also revealed that FRAP of all date palm fruits showed significant (P < 0.05) antioxidant power.

The differences in TFC between these studies could be due to the cultivars, environmental conditions, fruit maturity, fruit moisture content, and extraction conditions. It is well known that flavonoids present in plants possess diverse health benefits, which include antioxidant and radical scavenging activities, reduction in certain chronic diseases, prevention of some cardiovascular disorders, and of certain kinds of cancerous processes (Tapas et al. 2008). Although it is established that flavonoids are important phenolic compounds that contribute to the antioxidant activity of date palm fruits, it is possible that other phenolic compounds could also contribute to the antioxidant properties of these types of dates.

The FRAP significantly (P < 0.05) increased with increases in the concentration (15-100 µg) of Sudanese date palm fruits extracts (Table 4). The results also revealed that FRAP of all date palm fruits showed significant (P < 0.05) antioxidant power.

The FRAP significantly (P < 0.05) increased with increases in the concentration (15-100 µg) of Sudanese date palm fruits extracts (Table 4). The results also revealed that FRAP of all date palm fruits showed significant (P < 0.05) antioxidant power.

### Table 5. Ferric reducing antioxidant power (FRAP), chelation of Fe²⁺ (Fe²⁺chel), and scavenging of H₂O₂ (SA of H₂O₂) at different concentrations of methanolic extracts of six Sudanese date varieties.

| Varieties   | Date extract concentration (µg/mL) | FRAP (mmol/100 g) | Fe²⁺chel (%) | SA of H₂O₂ (%) |
|-------------|------------------------------------|-------------------|--------------|----------------|
|             |                                    |                   | 125          | 250            | 500            | 1000           | 125          | 250          | 500          | 1000          |
| Gondila     |                                    | 3.91 ± 0.08       | 5.44 ± 0.01    | 10.75 ± 0.09 | 71.71 ± 0.44   | 75.39 ± 0.09   | 76.02 ± 0.18   | 79.31 ± 0.33  | 80.47 ± 0.60  | 44.91 ± 0.21  | 47.74 ± 0.14  | 48.25 ± 0.13   |
| Barakawi    |                                    | 2.82 ± 0.03       | 5.31 ± 0.05    | 10.16 ± 0.00 | 64.73 ± 0.13   | 65.55 ± 0.25   | 65.83 ± 0.01   | 73.59 ± 0.75   | 74.78 ± 0.14  | 40.70 ± 0.13  | 45.27 ± 0.10  | 48.56 ± 0.09   |
| Jaw         |                                    | 4.16 ± 0.11       | 7.79 ± 0.14    | 14.25 ± 0.13  | 64.50 ± 0.00   | 66.31 ± 0.17   | 79.78 ± 0.29   | 94.98 ± 0.24   | 40.28 ± 0.08  | 45.47 ± 0.01  | 48.58 ± 0.10   | 49.13 ± 0.10   |
| Mishrig     |                                    | 3.38 ± 0.02       | 6.00 ± 0.11    | 11.88 ± 0.05  | 54.30 ± 0.38   | 56.35 ± 0.37   | 60.19 ± 0.07   | 75.47 ± 0.22   | 41.51 ± 0.00  | 44.14 ± 0.01  | 47.27 ± 0.02   | 47.33 ± 0.03   |
| Bittamoda   |                                    | 5.06 ± 0.05       | 8.38 ± 0.17    | 13.73 ± 0.02  | 55.41 ± 0.00   | 57.52 ± 0.46   | 59.33 ± 0.01   | 79.94 ± 0.14   | 43.98 ± 0.26  | 47.02 ± 0.10  | 48.25 ± 0.07   | 48.87 ± 0.21   |
| Madini      |                                    | 3.59 ± 0.10       | 6.94 ± 0.09    | 13.75 ± 0.03  | 27.25 ± 0.06   | 60.42 ± 0.10   | 61.29 ± 0.20   | 78.76 ± 0.50   | 38.48 ± 0.33  | 46.19 ± 0.12  | 46.55 ± 0.09   | 47.94 ± 0.11   |

Means (±SD, n = 3) within rows and columns sharing the same letters(s) are not significantly different at P < 0.05.
varietal differences and ranged between 2.82 and 27.50 mmol/100 g. The cultivar Bittamoda showed greater FRAP at extract concentrations of 125, 250, and 500 µg/mL. In contrast, Jaw cultivar showed the highest FRAP at an extract concentration of 1000 µg/mL. On the other hand, Barakawi cultivar had the lowest FRAP values at an extract concentration of 125–500 µg/mL. With regard to FRAP, the cultivar Bittamoda was found superior as compared to other cultivars. These results were also constituent with those of total polyphenol and total flavonoid contents of the same date variety. In agreement with our results, previous reports on date fruits from different countries showed significant varietal differences in FRAP (Biglari et al. 2008; Al-Mamary et al. 2010; Benmeddour et al. 2013). Furthermore, similar to our observations, the FRAP of date palm fruits from different origins appeared in a dose-dependent fashion (Biglari et al. 2008; Al-Mamary et al. 2010). In addition, this study revealed that Sudanese date varieties have high FRAP as compared with many other fruits (Fu et al. 2011). The FRAP of date fruits measured by the method used in this study could be related to phenolic and polyphenolic compounds, which reduced ferrocyanide ion ([Fe (CN)₆]³⁻) to ferrocyanide ions ([Fe (CN)₆]⁺⁻), which reacts with Fe³⁺ ions to give the compound called Prussian blue-colored complex (i.e., ferric ferrocyanide, Fe₄[Fe (CN)₆]₃). This reduction occurs due to the electron (or ‘H) donating ability of palm date fruits containing phenolic and polyphenolic compounds having more OH groups. These OH groups act as more powerful reducing agents, because they have more electron-donating abilities that result in the cessation of free radical chain reactions.

**Chelation of Fe²⁺ ions**

The results in Table 5 showed that all tested date fruit extracts exhibited metal-chelating activity at all concentrations. The metal-chelating activities of the Sudanese date fruit extracts were concentration dependent as evident from the increase in Fe chelating percentage with increasing concentrations (125–1000 µg/mL) of date fruit extracts. At the lower extract concentration (125, 250 µg/mL), the cultivar Gondaila exhibited the best chelating activity, whereas at higher concentrations (500, 1000 µg/mL), the cultivar Jaw had the highest value. The chelation of Fe²⁺ ions of palm date fruits at different concentrations differed significantly (P < 0.05) and were within the range of 54.31–94.98%. These findings demonstrate that Sudanese date fruits have intermediate to high iron binding capacity at the tested levels, which mean that these date fruits can act as peroxidation protectors. In agreement with our results, a concentration-dependent metal chelating ability has been reported for palm date syrups (Al-Mamary et al. 2010). In addition, Benmeddour et al. (2013) have investigated the antioxidant capacity of Algerian date fruits and found that the iron chelating ability of these dates ranged between 47.6% and 95.5%. In contrast, low to intermediate values (10.26–55.42%) of iron chelating capacity for Yemeni, Saudi, and Iraqi date syrups have also been reported (Al-Mamary et al. 2010). The differences between these results could be attributed to varietal difference, ripening stage, extraction, and environmental conditions.

**Scavenging of H₂O₂**

The H₂O₂ scavenging capacity of Sudanese date fruit extracts varied significantly (P < 0.05) having the range 38.48–49.13%. This significantly increased with an increase in the concentration (125–1000 µg/mL) of Sudanese date palm fruit extracts. The cultivar Bittamoda showed the greatest H₂O₂ scavenging activity at extract concentrations of 125, 250, and 500 µg/mL. In contrast, the cultivar Jaw showed the highest H₂O₂ scavenging activity at the extract concentration of 1000 µg/mL. In this regard, the cultivar Bittamoda is superior in H₂O₂ scavenging capacity as compared to other cultivars. The results of this study indicate that Sudanese date extracts have an intermediate H₂O₂ scavenging capacity. In agreement with our results, a concentration-dependent H₂O₂ scavenging ability has been reported for palm date syrups from various countries (Al-Mamary et al. 2010). Moreover, low to high values of H₂O₂ scavenging capacity for Yemeni, Saudi, and Iraqi date syrups (Al-Mamary et al. 2010) and for Algerian dates (Benmeddour et al. 2013) have been reported. H₂O₂ is a weak oxidizing agent and can inactivate a few enzymes directly by oxidation of essential thiol (-SH) groups. However, the H₂O₂ can penetrate cell membranes rapidly. Once inside the cell, it may react with Fe²⁺ and possibly Cu²⁺ ions to form hydroxyl radicals and this could be the source of its toxicity. Thus, it is important for cells to avoid an accumulation of H₂O₂. Therefore, consuming diets with high H₂O₂ scavenging capacity such as date fruits is highly recommended because this could possibly reduce and/or abolish the formation of H₂O₂, and hence save the body from oxidative damage.

**Correlation between antioxidant activity and mineral extractability**

The results in Table 6 present the correlations between antioxidants and mineral extractability of Sudanese date fruit extracts. Generally, our results showed that there were many correlations (positive, negative, weak) between antioxidant and mineral extractability. Significantly positive
correlations were observed between total flavonoids and extractability of both macro- and microminerals in date fruit extracts. Total flavonoid content showed extremely positive correlations (*P < 0.01) with K (r² = 0.889) and Mg (r² = 0.776) and significantly positive correlations (*P < 0.05) with Mn (r² = 0.485) as well as significantly (*P < 0.05) negative correlation with Ca (r² = -0.588). These findings suggest interaction between total flavonoids and mineral extractability, which could result in either reduction or enhancement of the bioavailability of these minerals. On the other hand, TPC was positively correlated (**P < 0.01) with Na (r² = 0.826) and P (r² = 0.598), but negatively correlated (**P < 0.01) with Zn (r² = -0.851). These results demonstrate that total polyphenol in date fruits has a significant impact on enhancing the extractability of both sodium and phosphorus, but they have no effect on the extractability of zinc. Moreover, these results are related with the ability to chelate ion metals by polyphenol compounds and to retain more effectively the complex into the macromolecular structure formed by condensed flavonoids as reported for extracts of some medicinal plants (Weber and Konieczynski 2003; Whittaker et al. 2009). Thus, the chelating role of these metals observed in Sudanese date fruit extracts could have potential interest as a dietary antioxidant in the food industry, preventing or delaying metal-catalyzed initiation and decomposition of lipid hydroperoxides.

In addition, a high correlation between antioxidant activities of date fruit extracts and mineral extractability was also observed (Table 6). The FRAP of date fruits extracted at different concentrations (125–1000 μg/mL) showed a highly significant (**P < 0.01) positive correlation with K (r² = 0.800) and Ca (r² = 0.664) but a highly significant (**P < 0.01) negative correlation with Zn (r² = -0.745) and significant (*P < 0.05) negative correlation with Cu (r² = -0.589), and Mn (r² = -0.488). Moreover, chelation of Fe²⁺ of date fruit extracts at various concentrations correlated positively (**P < 0.01) with Mg (r² = 0.666) and Zn (r² = 0.753), but showed a major significantly negative (**P < 0.01) correlation with Na (r² = -0.856) and Fe (r² = -0.728), and a significantly negative (*P < 0.05) correlation with P (r² = -0.728). The results also showed no correlation between iron chelating activity and potassium and copper extractability. Additionally, scavenging of H₂O₂ of Sudanese dates extracts was positively correlated with K (**P < 0.01, r² = 0.726) and with Mn (*P < 0.05, r² = 0.575) and negatively (**P < 0.01) correlated with Ca (**P < 0.01, r² = -0.789), Na (r² = -0.717), P (r² = -0.647), and Cu (r² = -0.786). It is worth noting that there was a highly significant (**P < 0.01) and significant (*P < 0.05) correlation between antioxidant capacity and mineral extractability of date palm fruit extracts. Despite the wealth of literature available on minerals and antioxidant content of date fruits, there are unfortunately hardly any available studies on the correlation between mineral extractability, polyphenol and flavonoid content, and antioxidant activity of dates. Thus, this is the first report on the correlation between antioxidant capacity and mineral extractability not only on date fruits but also on other fruits and vegetables. All previously published reports described the correlation of polyphenols and antioxidants with mineral content but not with mineral extractability (Sulaiman et al. 2011; Perna et al. 2012). It would be interesting to analyze the correlation between mineral extractability and isolated antioxidant phenolic and flavonoids compounds

### Table 6. Correlation coefficient of antioxidant activity and mineral extractability of Sudanese dates varieties.

| Pearson correlation | Ca    | Mg    | Na    | K     | P     | Fe    | Cu    | Zn    | Mn    |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Total flavonoid content (TFC) | -0.588* | 0.776** | -0.191 | 0.889** | -0.399 | 0.073 | 0.173 | -0.061 | 0.485* |
| Total polyphenol content (TPC) | 0.103 | -0.105 | 0.826** | -0.078 | 0.598** | 0.302 | -0.467 | -0.851** | -0.370 |
| Ferric reducing power (FRAP125) | 0.496* | -0.402 | 0.068 | 0.800** | -0.507* | -0.281 | -0.121 | -0.616** | -0.443 |
| Chelation of Fe²⁺ (Ch125) | 0.309 | 0.610** | -0.830** | -0.020 | -0.161 | -0.037 | 0.015 | 0.753** | -0.018 |
| Scavenging of H₂O₂ (SC250) | -0.789** | 0.045 | -0.110 | 0.726** | -0.534* | -0.094 | -0.332 | -0.263 | 0.575* |
| FRAP250 | 0.176 | -0.025 | 0.213 | 0.337 | -0.262 | -0.254 | -0.425 | -0.745** | -0.078 |
| Ch250 | 0.209 | 0.666** | -0.808** | -0.100 | -0.230 | -0.077 | 0.109 | 0.729** | -0.096 |
| SC250 | -0.055 | 0.258 | -0.127 | 0.233 | -0.171 | -0.404 | -0.786** | -0.574* | 0.367 |
| FRAP500 | 0.088 | -0.135 | 0.283 | 0.065 | -0.073 | -0.287 | -0.505* | -0.745** | -0.092 |
| Ch500 | 0.245 | 0.385 | -0.856** | -0.061 | -0.565* | -0.581* | 0.158 | 0.588* | -0.284 |
| SC500 | -0.191 | 0.014 | -0.717** | 0.178 | -0.647** | -0.257 | -0.104 | -0.467 | 0.260 |
| FRAP1000 | 0.664** | -0.226 | 0.026 | 0.559* | -0.244 | -0.189 | -0.589* | -0.202 | -0.488* |
| Ch1000 | 0.160 | 0.093 | -0.436 | -0.123 | -0.583* | -0.728** | 0.125 | 0.075 | -0.253 |
| SC1000 | -0.065 | 0.210 | -0.697** | 0.086 | -0.377 | -0.034 | -0.421 | -0.247 | 0.110 |

*Correlation is significant at P < 0.05.
**Correlation is significant at P < 0.01.
with the aim of establishing a more precise correlation between antioxidants and mineral extractability of date fruits.

Conclusions

This study reported on the total flavonoid and polyphenol content, mineral content and extractability, and antioxidant capacities of Sudanese date fruits for the first time. Moreover, the correlation between antioxidant capacity and mineral extractability of date fruits was also attempted for the first time. Sudanese date varieties demonstrated high amounts of macro- and micromineral content with a significant varietal dependence. Generally, lower extractability was observed in most of the macrominerals and some microminerals. Regarding antioxidant constituents, Sudanese date varieties have high amounts of total polyphenols and total flavonoids, suggesting potential protection capabilities of these dates against the action of reactive oxygen species. Moreover, the FRAP, chelation of Fe²⁺ ion and H₂O₂ scavenging of Sudanese date fruits demonstrated moderate to high values and varied significantly between varieties. Strikingly, the correlations of antioxidants, total polyphenols, and flavonoids with mineral extractability suggested the influence of antioxidant compounds on mineral bioavailability.

Acknowledgments

We thank Professor Kip A. Kates (Faculty of Regional Sciences, Tottori University, Editor, Global issues in Language Education Newsletter, MA instructor, Teachers College, Columbia University) and Professor Sudhindra Nath Panda (Department of Agricultural & Food Engineering, Indian Institute of Technology Kharagpur) for their assistance in English editing. This study benefited substantially from the comments by the two anonymous reviewers and Editor’s Desk Review.

Conflict of Interest

None declared.

References

Ahmed, A. I., A. W. K. Ahmed, and R. K. Robinson. 1995. Chemical composition of date varieties as influenced by the stage of ripening. Food Chem. 54:305–309.
Al-Farsi, M., and C. Y. Lee. 2008. Optimization of phenolics and dietary fibre extraction from date seeds. Food Chem. 108:977–985.
Al-Farsi, M., C. Alasalvar, A. Morris, M. Baron, and F. Shahidi. 2005a. Compositional and sensory characteristics of three native sun-dried date (Phoenix dactylifera L.) varieties grown in Oman. J. Agric. Food Chem. 53:7586–7591.
Al-Farsi, M., C. Alasalvar, A. Morris, M. Baron, and F. Shahidi. 2005b. Comparison of antioxidant activity, anthocyanins, carotenoids, and phenolics of three native fresh and sun-dried date (Phoenix dactylifera L.) varieties grown in Oman. J. Agric. Food Chem. 53:7592–7599.
Al-Farsi, M., C. Alasalvar, M. Al-Abid, K. Al-Shoaily, M. Al-Amry, and F. Al-Rawahy. 2007. Compositional and functional characteristics of dates, syrups, and their by-products. Food Chem. 104:943–947.
Al-Mamary, M., M. Al-Habori, and A. S. Al-Zubairi. 2010. The in vitro antioxidant activity of different types of palm dates (Phoenix dactylifera) syrups. Arabian J. Chem. doi: 10.1016/j.arabjc.2010.11.014.
Al-Shahib, W., and R. J. Marshal. 2003. The fruit of the date palm: it’s possible use as the best food for the future. Food Sci. Nutr. 54:247–259.
Al-Showiman, S. S. 1990. Chemical Composition of date palm seeds (Phoenix dactylifera L.) in Saudi Arabia. Arab Gulf J. Sci. Res. 8:15–24.
Amira, E. A., F. Guido, S. E. Behija, I. Manel, Z. Nesrine, F. Ali, et al. 2011. Chemical and aroma volatile compositions of date palm (Phoenix dactylifera L.) fruits at three maturation stages. Food Chem. 127:1744–1754.
AOAC. 2003. Official methods of analysis of AOAC international. 17th ed. Association of the Official Analytical Chemists (AOAC), Gaithersburg, MD.
Baliga, M. S., B. R. V. B. Baliga, S. M. Kandathil, H. P. Bhat, and P. K. Vayalil. 2011. A review of the chemistry and pharmacology of the date fruits (Phoenix dactylifera L.). Food Res. Int. 44:1812–1822.
Barbosa-Pereira, L., I. Angulo, P. Paseiro-Losada, and J. M. Cruz. 2013. Phenolic profile and antioxidant properties of a crude extract obtained from a brewery waste stream. Food Res. Int. 51:663–669.
Benmeddour, Z., E. Mehinagic, D. Le Meurlay, and H. Louailleche. 2013. Phenolic composition and antioxidant capacities of ten Algerian date (Phoenix dactylifera L.) cultivars: a comparative study, J. Funct. Foods 5:346–354.
Biglari, F., A. F. M. Alkarkhi, and A. M. Easa. 2008. Antioxidant activity and phenolic content of various date palm (Phoenix dactylifera L.) fruits from Iran. Food Chem. 107:1636–1641.
Chapman, H., and F. Pratt. 1982. pp, 169–170 in Methods of analysis of soil, plants and water. 2nd ed. University of California Agriculture Division, Riverside, CA, USA.
Chauhan, B., and H. Mahjan. 1988. Effect of natural fermentation on the extractability of minerals from pearl millet flour. J. Food Sci. 53:1576–1577.
FAOSTAT. 2010. Food and agriculture organization of the United Nation, statistical data. FAOSTAT, Rome, Italy.
Fu, L., B.-T. Xu, X.-R. Xu, R.-Y. Gan, Y. Zhang, E.-Q. Xia, et al. 2011. Antioxidant capacities and total phenolic contents of 62 fruits. Food Chem. 129:345–350.

Galleano, M., S. V. Verstraeten, P. I. Oteiza, and C. G. Fraga. 2010. Antioxidant actions of flavonoids: thermodynamic and kinetic analysis. Arch. Biochem. Biophys. 501:23–30.

Haminiuk, C. W. I., G. M. Maciel, M. S. V. Plata-Oviedo, and R. M. Peralta. 2012. Phenolic compounds in fruits—an overview. Int. J. Food Sci. Technol. 47:2023–2044.

Harris, G. M., and S. E. Livingstone. 1964. Bidentate chelates. P. 95 in F. P. Dwyer and D. P. Mellor, eds. In: chelating agents and metal chelates Vol. I. Academic Press, New York, NY.

Hung, H. C., K. J. Joshipura, R. Jiang, F. B. Hu, D. Hunter, S. A. Smith-Warner, et al. 2004. Fruit and vegetable intake and risk of major chronic disease. J. Natl. Cancer Inst. 96:1577–1584.

Ismail, B., I. Haffar, R. Baalbaki, Y. Mecheref, and J. Henry. 2006. Physicochemical characteristics and total quality of five date varieties grown in the United Arab Emirates. Int. J. Food Sci. Technol. 41:919–926.

Jayaprakasha, G. K., R. L. Jagann Mohan, and K. K. Sakariah. 2004. Antioxidant activities of flavdin in different in vitro model systems. Bioorg. Med. Chem. 12:5141–5146.

Kim, D.-O., S. W. Jeong, and C. Y. Lee. 2003. Antioxidant capacity of phenolic phytochemicals from various cultivars of plums. Food Chem. 81:321–326.

Mansouri, A., G. Embarek, E. Kokkalou, and P. Kefalas. 2005. Phenolic profile and antioxidant activity of the Algerian ripe date palm fruit (Phoenix dactylifera). Food Chem. 89:411–420.

Molyneux, D. H. 2004. “Neglected” diseases but unrecognized successes – challenges and opportunities for infectious disease control. Lancet 364:380–383.

Osman, A. M. A. 2001. Development of Date Palm Culture in Republic of Sudan. Paper presented at a Workshop on Date Palm Culture and Dates Production in Republic of Sudan. Date Palm Research and Development Network, 17–22 August, Khartoum, Sudan.

Oyaizu, M. 1986. Studies on products of the browning reaction: antioxidative activities of browning reaction products prepared from glucosamine. Japan. J. Nutr. [Eiyogaku Zasshi] 44:307–315.

Perna, A., A. Simonetti, I. Intaglietta, A. Sofo, and E. Gambacorta. 2012. Metal content of southern Italy honey of different botanical origins and its correlation with polyphenol content and antioxidant activity. Int. J. Food Sci. Technol. 47:1909–1917.

Rastegar, S., M. Rahemi, A. Baghizadeh, and M. Gholami. 2012. Enzyme activity and biochemical changes of three date palm cultivars with different softening pattern during ripening. Food Chem. 134:1279–1286.

Rehecho, S., O. Hidalgo, M. G.-I. de Cirano, I. Navarro, I. Astiasarán, D. Ansoarena, et al. 2011. Chemical composition, mineral content and antioxidant activity of Verbena officinalis L. WLT - Food Sci. Technol. 44:875–882.

Sulaiman, S. F., N. A. M. Yusoff, I. M. Edean, E. M. Seow, A. A. B. Sajak, Supriatno, and K. L. Ooi. 2011. Correlation between total phenolic and mineral contents with antioxidant activity of eight Malaysian bananas (Musa sp.). J. Food Compos. Anal. 24:1–10.

Suliman, A. M. E., I. A. Abd Elhafise, and A. M. Abdelrahim. 2012. Comparative Study on Five Sudanese Date (Phoenix dactylifera L.) Fruit Cultivars. Food Nutr. Sci. 3:1245–1251.

Tang, Z.-X., L.-E. Shi, and S. M. Aleid. 2013. Date fruit: chemical composition, nutritional and medicinal values, products. J. Sci. Food Agric. 93:2351–2361.

Tapas, A. R., A. M. Sakarkar, and R. B. Kakde. 2008. Flavonoids as nutraceuticals: a review. Trop. J. Pharm. Res. 7:1089–1099.

Whittaker, A., C. Vazzana, V. Vecchio, and S. Benedettelli. 2009. Evaluation of direct and indirect effects of flavonoids, mineral elements and dry weight on antiradical scavenging activity in leaf material of field-grown Trifolium pretense cultivars using path analysis. Field Crops Res. 113:1–11.