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Review

Prospective applications of phenolic compounds in processing by-products of date fruits (*Phoenix dactylifera* L.)

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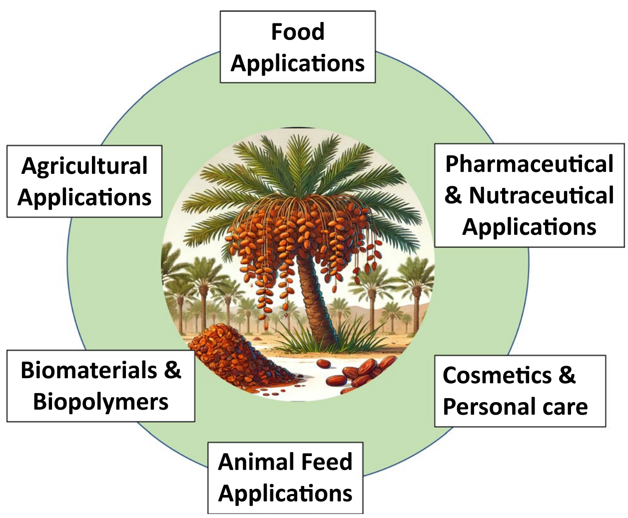
Abstract
This review highlights the potential of generating value-added products rich in phenolic compounds from date fruit (*Phoenix dactylifera L.*) and its processing by-products. The review presents the phenolic contents in date fruits and seeds and their potential applications as feedstocks in food, pharmaceutical, and cosmetic industries. It discusses the extraction and characterization protocols for phenolic compounds and the research that is needed to fill the gaps in knowledge and standardization methods. The safety and suitability of date seeds as a functional food ingredient were discussed. The review aimed to serve as a guide towards innovative, scalable, and sustainable strategies for maximizing the environmental and economic benefits of date fruits.

Graphical Abstract



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Keywords Dates · Seed · Pomace · Processing waste · Value-addition

1 Introduction

Date palm (*Phoenix dactylifera* L.) is a dioecious tree belonging to the Arecaceae (syn. Palmae) family [36]. Date palms can adapt to a variety of climate conditions, and are common trees in the Middle East and North Africa, where the warm and dry climate conditions suit cultivation of the trees. The global date fruit production reached approximately 9.75 million tonnes in 2022 [56]. Middle Eastern and North African countries cultivate nearly 85 million trees representing about ~ 70% of the world's date palm trees [108], contributing significantly to the economy, food security, cultural heritage, and environmental sustainability.

The date palm is highly appreciated for its edible sweet fruit, which is mostly consumed at the mature stage or fresh at different ripening stages for some varieties. Table 1 presents the proximate composition, dietary fiber, and minerals of date fruits, pomace, and seeds [95]. The soluble sugars in the pomace mainly include fructose and glucose in the soft cultivars and sucrose in the dry and semi-dry cultivars [16]. Date fruit pomace is also rich in dietary fiber and mineral content and is a good source of phenolic antioxidants [7, 51, 95].

2 Date fruit processing by-products

Over two million tons of date fruits are lost annually due to preharvest loss and improper postharvest handling and processing [72]. Date fruit syrup processing yields 52–64% syrup, 17–24% date fruit pomace, and 8–15% date palm seeds on dry fruit basis [18]. Date palm seeds constitute 10–15% of the fruit's fresh weight and can easily be removed as a single seed [61]. The date industry generates around one million tons of seeds annually as a by-product [43]. Date seeds contain 4–13% oil, and approximately 127,000 metric tons of date seed oil is produced annually worldwide [76].

3 Valorization of date processing by-products

The escalating quantities of unutilized date processing by-products are considered serious economic and environmental challenges facing the countries with high palm date production. The traditional methods of waste elimination, including landfill, burning, and land dispersal, may cause adverse environmental effects such as the production of greenhouse gases, unpleasant odors, pollution of underground water, and proliferation of harmful insects and microbes. Zero-waste and circular economy concepts are currently targeted to provide environmental mitigation

Table 1 Proximate composition (%), dietary fiber (%), and mineral content (mg/100 g) of date fruit, pomace and seed

Parameters	Fruit	Pomace	Seed
Proximate composition (%)			
Moisture	9.4–21.5	6–13	8.6–12.3
Protein	1.2–3.3	4–10	4.8–5.8
Fat	0.1–7.3	5–5.1	5.7–8.8
Total carbohydrates	66–88	66– 79	2–5
Total dietary fiber	2–17	11.7–12	68–74
Ash	1.4–6.2	2.8	0.8–1.1
Minerals (mg/100 g)			
Mg	56–150	82.6–109.3	52–59
Ca	123–187	42–50	29–39
P	12–27	54–116	84–69
K	290–512	54–116	229–293
Fe	0.3–2.2	7.1–9.0	2.3–2.2

References: [18, 66, 95]

and economically profitable strategies [94]. Thus, the transformation of industrial date fruit by-products and waste as additional revenue streams contributes to the adoption of these concepts and the valorization of date processing industry [92, 94, 95, 106]. On the commercial scale, the large abundance and the good nutritional properties of low-grade date fruits, pomace, and seeds make these residues of high potential to be valorized via several food, pharmaceutical and nutraceutical, cosmetics and personal care, agricultural and animal feed, and biofuels and biopolymers industrial products. The low-grade date fruits and pomace can be used in several applications [90, 94], e.g.

- as functional food ingredients and nutritional-enhancing agents in bakery, meat, and snacks products due to their high dietary fiber contents and antioxidant activity,
- as bioactive compounds in pharmaceutical and nutraceutical products due to their health-promoting and anti-aging effects,
- as cosmetic and personal care products that rely on the anti-aging, moisturizing, and healing properties of the phenolic compounds in date fruits and pomace,
- as additives in animal feed, e.g. cattle and poultry, to improve their nutritional value and stability,
- in the utilization of the lignin and associated polysaccharides in biomedical and other biological applications such as tissue engineering and structuring, and
- the use of the low-value processing by-products in agricultural applications such as soil enhancement and anti-microbial and insecticidal applications.

4 Prospective applications based on the bioactivities of date's phenolic compounds

4.1 Low-grade date fruits and pomace

Low-grade date fruits refer to the small and not-properly grown fruits and pomace is the fibrous by-product of the industrial extraction of date syrup. The presence of high concentrations of phenolic compounds in date fruits enriches them with antioxidants that protect against numerous diseases **(**Table 2**).** The polyphenols in date fruit contribute positively to human health through its diverse biological activities which include antimicrobial, antioxidant, anti-inflammatory, and anti-carcinogenic [29–31, 55, 70, 71, 116]. The antioxidant properties of date fruits help neutralize harmful free radicals in the body, reduce oxidative stress, and protect cells from damage [30]. These activities may contribute to the inhibition of a variety of chronic diseases, including cardiovascular disease, diabetes, and several cancer types [20, 29, 78, 100]. High levels of phenolic and flavonoid content in the extracts from four Saudi varieties of date palm fruits were associated with strong antioxidant activities and a significant protective effect against induced in vivo myocardial infarction [20]. The phenolic compounds in dates may also act as prebiotics, promoting the growth of beneficial gut bacteria and supporting a healthy gut microbiome [7]. Antihyperlipidemic and hepatoprotective properties [4] of the antioxidants suggest date fruits as a potent ingredient in functional foods.

Consumption of 60 g of date fruits did not increase postprandial glucose levels and was safe for individuals with type-2 diabetes [46]. A systematic literature review found that consumption of date fruits have lowered plasma glucose levels despite their high sugar content [85]. Another systematic review of 26 randomized and non-randomized clinical trials was not able to detect an impact of consumption of date fruit on clinical outputs due to risk of bias [32]. Thus, extensive long-term clinical trials are recommended to understand the impact of dates on blood sugar and insulin levels in patients with type 2 diabetes mellitus.

Knowledge regarding the characteristics of date fruit pomace and its potential for conversion to valuable products is limited and information on products with direct relevance to the phenolic content of date pomace is scarce [95]. Date fruit pomace can be used as a low-cost value-added material in the food industry due to its high levels of sugars, minerals, dietary fiber, pectin, phenolic compounds, and antioxidants [95]. Muñoz-Tebar et al. [92] reviewed the incorporation of date fruit and by-products in several food products. Desugared date fruit pomace has been added to bread [28] and meat analogues [99] to increase their fiber and antioxidant contents. Al-Hamdani [21] reported that pomace fiber increased blood hemoglobin and decreased blood glucose serum and urine levels in women, highlighting the beneficial effects of pomace fiber. Natural constituents are increasingly used in cosmetics, paving the way for introducing new phytoconstituents to the beauty market. The significant levels of synthesized chemical substances in cosmetics can be replaced with natural substances. Phenolic compounds are used in the cosmetic industry as skin peels, sunscreens,

Table 2 Potential bioactivities of the phenolic compounds in date fruits and seeds

Compounds	Biological activities	References	Compounds
Phenolic acids			
• Hydroxylated benzoic acid derivatives: (protocatechuic acid, p-hydroxybenzoic acid, and vanillic acid, syringic acid)	• Antioxidant • Preservative • Antimicrobial • Anti-sickling • Antimutagenic • Estrogenic • Skin lightening	• Anti-inflammatory • Antiviral • Antipathogenic • Teratogenic • Antidiabetic • Fragrance ingredient • Surfactant-emulsifying	Manuja et al. [84]; Wianowska et al. [114]
• Cinnamic acid derivatives (caffeic acid, coumaric acid, and ferulic acid, p-hydroxycinnamic acid and chlorogenic acids)	• UV stabilizer • Stimulates wound healing, • Delays photoaging • Promotes skin tone • Decreases melanogenesis • Improves angiogenesis	• Antioxidant • Anticancer • Antibacterial • Antidiabetic • Anti-neurological disorders • Anti-inflammatory • Antimicrobial • Antiparasitic • Antidiabetic	Alharbi et al. [22]; Ruwizhi et al. [101]
Polyphenols			
• Flavonoids: (quercetin-3-O-glucoside, catechin, procyanidin, anthocyanins)	• Anti-inflammatory • Antimicrobial • Antibacterial • Antifungal • Antioxidants,	• Antiviral • Anticancer • Cardio-protective • Preservatives • Pigments	Dias et al. [48]
• Proanthocyanidins	• Antioxidant • Anti-inflammatory	• Anticancer • Inhibition of LDL oxidation	Gary [57]

skin-lightening creams, and hair care products. The addition of date fruit syrup waste in soap confers beneficial anti-bactericidal and antioxidant activities [98].

4.2 Date seeds

Date seeds have abundant phenolic compounds that are useful for multiple therapeutic applications including nutraceuticals, pharmaceuticals and cosmetics formulations [27]. The phenolic compounds in date seeds were reported beneficial to human and recognized with significant potentials for numerous utilizations in nutraceuticals and pharmaceuticals [25, 27, 44], folk medicine [41], and cosmetics formulations [22]. Recent studies have emphasized the use of date seed powder in food products to boost their antioxidant and dietary fiber content. For example, several studies described the addition of date seed powder to bread items [17] and cookies [87]. Date seeds contain edible oil rich in phenolic compounds that are useful food components such as in mayonnaise [89]. The principal phenolic acids in date seeds that may function as pharmacological agents include gallic acid, syringic acid, and caffeic acid [5]. The phenolic components in date seed oils exhibit antimutagenic, anticarcinogenic, and anti-inflammatory properties [27]. Date seed oil has a slower oxidation rate than vegetable oils and can be preserved longer,thus, date seed oil can be used as a preservative in cosmetics [49]. In addition, date seed oil is used in various cosmetic and beauty products [22].

5 Phenolic compounds in date by-processing products

5.1 Phenolic compounds in date fruit and pomace

Soluble, hydrolyzable, and insoluble phenolic compounds are found in date fruits [10]. The soluble phenolic compounds can be directly extracted with aqueous organic solvents, and the hydrolyzable phenolic compounds can be extracted using organic solvents after alkaline hydrolysis to break the ester bonds. The soluble and hydrolyzable phenolic compounds include phenolic aglycones and glycosylated derivatives. The insoluble phenolic compounds include oligomeric and polymeric forms of condensed tannins, melanin, and lignin.

The phytochemical constituents of date fruits and pomace include phenolic compounds such as phenolic acids, flavonoids, proanthocyanidin aglycones, and their derivatives. Table 3 summarises studies identifying and quantifying phenolic compounds in date fruits. Benzoic acid, p-hydroxybenzoic acid, protocatechuic acid, vanillic acid, gallic acid, cinnamic acids (including o-coumaric acid, p-coumaric acid, caffeic acid, and ferulic acid, and syringic acid, sinapic acid, 5-o-caffeoyl shikimic acid), were identified in date varieties (Fard, Khasab, and Khalas) [19]., were also detected in these dates. Soluble and hydrolyzable phenolic compounds were identified and quantified in 18 date Emirati fruit cultivars by Alam et al. [10]; at concentrations of 27.5–54.0, and 24–78.5 mg/100 g fresh weight, respectively. Gallic acid and ferulic acid were predominant in both the soluble and hydrolyzable fractions; quercetin and taxifolin were predominant in the soluble fraction, and caffeic acid and chlorogenic acid were abundant in the hydrolyzable fraction. Analysis of Amari and Hallawi date varieties at the Tamr stage revealed ferulic acid as the predominant phenolic component in both cultivars; the Amari variety also contains caffeic acid derivatives and the most abundant phenolic acid in Hallawi is salicylic acid [42].

Phenolic compounds from date fruits contain flavonoids [74]. Flavonoids are a diverse group of polyphenolic compounds widely distributed in fruits and vegetables. The flavonoid glycoside and procyanidin compositions of Deglet-Noor date fruit, harvested at the Khalal stage, were examined using liquid chromatography-electrospray ionization/tandem mass spectrometry [69],13 flavonoid glycosides of apigenin, luteolin, and quercetin, consisting of 19 isomeric forms, and flavonoid sulfates were identified. Singh et al. [110] investigated the total flavonoid content in three major date varieties (Fardh, Khasab, and Khalas) in Oman at two ripening stages (Rutab and Tamr). Hamad et al. [63] identified apigenin, luteolin, quercetin, isoquercetrin, and rutin in 11 distinct Saudi date fruit varieties. Amari and Hallawi date fruits contain kaempferol, a natural flavonol, and its derivatives. In addition, Amari contains five flavonols, and Hallawi contains one major flavonol [42].

The sensory and chemical properties of date fruits undergo various changes during the ripening stages [8]. Phenolic compounds determine sensory properties, such as the color, flavor, bitterness, and astringency of foods [102]. Date browning is associated with enzymatic and nonenzymatic metabolic activities during fruit development and storage [13]. Polyphenol oxidase and peroxidase enzymes are involved in postharvest browning in dates; these enzymes catalyze the *ortho*-hydroxylation of monophenol to diphenol and the oxidation of diphenol to quinones. Quinones polymerize into melanin and form brown pigments [13]. Condensed tannins (catechin monomers, proanthocyanidin oligomers, and

Table 3 Overview of studies on the identification and quantification of phenolic compounds in date fruits

Extraction method	Analytical method	Major phenolic compounds (Concentration, ppm)	References
Date fruits (3 g) were extracted with methanol (10 mL, 80% v/v) by heating in a water bath for 5 h	HPLC–DAD	Benzene-1,2-diol (6–29), syringic acid (0.8–14), caffeic acid (1.3–3.3), (+)-catechin (3–29), gallic acid (16–112), isorhamnetin (2.6–6.6), kaempferol (1.5–4.7), and rutin trihydrate (0.1–5)	Al Juhaimi et al. [6]
Date fruits (10 g) were extracted with ethanol (100 mL) by boiling for 10 min	HPLC–DAD	Caffeic acid, ferulic acid, gallic acid, o-coumaric acid, *p*-coumaric acid, syringic acid, and vanillic acid. Total phenolic acids 104–164 ppm	Siddiqi et al. [109]
Date fruits (20 g) were extracted with ethanol (60 mL, 80% v/v) at room temperature with constant agitation for 24 h	LC-ESI-MS	Quinic acid (0–62), kaempferol (3.0–10.6), and rutin (0.2–5.8). The total phenolic content was 13–88 ppm	Bettaieb et al. [37]
Date fruits (3 g) were extracted with acidified methanol (30 mL, 80% v/v) followed by acetone (30 mL, 70% v/v) at room temperature	LC-ESI-MS	Caffeic acid (3.3), (+)-catechin (0–1150), (−)-epicatechin (0–1242), hesperidin (7.5–16.8), iso-quercitrin (10.4–19.0), rutin (11–13), and luteolin-7-O-glucoside (8.2–26.6)	Muñoz-Bas et al. [91]
Date fruits (3 g) were extracted with methanol (15 mL, 80% v/v) using ultrasound-assisted water bath sonication. The pellet was re-extracted with ethyl acetate (15 mL) after NaOH treatment (3 M, 10 mL) in a shaking water bath (40 °C for 24 h) followed by acidification (pH 2 with 37% HCl)	LC-ESI-MS	Gallic acid (1.2–5.3), ferulic acid (5.1–11), quercetin (1.2–6.3), taxifolin (1.2–8.3), caffeic acid (3.2–6.8), and chlorogenic acid (2–7.8)	Alam et al. [10]

LC liquid chromatography, *HPLC* high-performance liquid chromatography, *DAD* diode array detector, *ESI* electron spray ionization, *MS* mass spectrometry polymers) are present at the mature stage of the Deglet-Noor cultivar; the degree of proanthocyanidin polymerization ranges from 7 to 33 [69]. High oligomerization levels are associated with lower astringency; tetramic and lower proanthocyanidin oligomers are associated with more bitterness [82]. Anthocyanin levels were compared in fresh versus dried date fruits by Al-Farsi et al. [19], anthocyanin was found only in fresh dates. The different anthocyanin levels between fresh and dried fruit may be due to the destruction of anthocyanins in response to sunlight exposure.

5.1.1 Lignin and melanin

Date fruit pomace contains insoluble phenolic compounds, including lignin and melanin, which contribute to the antioxidant activity of date fruits. Lignin is a high molecular weight phenolic polymer that is considered as a part of the insoluble dietary fiber. Lignin exists in several forms in date fruits especially in the sclereid (or stone) sclerenchyma cells under the fruit skin as well as in the xylem vessels (Fig. 1). The later forms are phytoliths of different shapes, i.e. spheroidal or echinate phytoliths and spiral or tracheary phytoliths that are supported by silica co-deposition [59]. Lignin, which is the main determinant of the total dietary fiber in date fruits [58], contributes hardness to the fruits and pomace and increases the recalcitrance nature of the biomass [75]. Thus, understanding the contribution of lignin to the nutritional and industrial value of date fruits and pomace and developing methods and strategies to utilize date fruits and by-products having low and high lignin contents merits more detailed future studies.

Melanin is another type of phenolic polymers that exist at high levels in date fruits, *ca* 1–5% [11, 12]. This type of allomelanin was found to be concentrated in the tanniferous cells between the inner and outer mesocarp tissues of date fruit. Like other melanin, the date fruit melanin is insoluble in water and most organic solvents but is soluble in high concentrations of sodium hydroxide or sodium carbonate (pH 12) and dimethyl sulfoxide. The solubilization of melanin by sodium hydroxide is attributed to its conversion to anionic forms while its solubilization by dimethyl sulfoxide (DMSO) explained this solvent acts as a hydrogen bond acceptor that breaks the hydrogen bonds within the melanin polymer. The color of melanin from different date cultivars was light to dark brown and it is characterized by a featureless broadband UV spectrum due to π-π^* transitions with significant Mie and Rayleigh scattering [11, 12]. Date fruit lignin has strong radical-scavenging and antioxidant properties [11]. Using high-performance size-exclusion chromatography and nuclear magnetic resonance spectroscopy, Alam et al. [11] demonstrated that date fruit melanin is composed by the primarily of (−)-epicatechin oligomers. It is formed by the polymerization of proanthocyanidins during fruit ripening. Further exploration into the building blocks of melanin oligomers and the extraction and characterization of melanin and lignin from date pomace and seed may open up a new area of research, leading to the development of value-added products.

5.2 Phenolic compounds in date seeds

During harvesting and industrial processing of date palms, a significant amount of waste consisting of discarded seeds and date pomace is produced. Simple phenolic compounds such as phenolic acids, polyphenols such as flavonoids, and high-molecular-weight compact polymers have been identified in dates seeds [34]. Date seeds contain hydroxylated benzoic acid derivatives such as protocatechuic acid, p-hydroxybenzoic acid, and vanillic acid, and cinnamic acid derivatives such as caffeic acid, coumaric acid, and ferulic acid. In addition, flavonoids such as quercetin-3-O-glucoside, catechin and procyanidin [79]. Table 4 summarizes studies showing very large variations in the quantification of phenolic compounds in date seeds and powders. This can be attributed to the differences in efficiency of the extraction methods.

5.3 Extraction and characterization of phenolic compounds from date fruit waste

Extracting phenolic compounds from fruit waste is essential for their utilization in various industrial products, including food, pharmaceuticals, and cosmetics. The extraction of phenolic compounds is affected by several factors such as the sample preparation methods, and the extraction parameters, such as solvent type, time and temperature, agitation, material particle size, and solvent-to-solid ratio [14, 47, 65, 80, 97]. Among the common extraction techniques is the solvent extraction method which involve the use of aqueous mixtures of organic solvents, such as methanol, ethanol, and acetone, to extract soluble phenolic compounds [3, 19, 77, 93]. The solvent extraction is a simple, cost-effective, and widely used technique for phenolic compound extraction [96]. However, it may lead to the extraction of unwanted compounds and may require additional purification process. Other methods for the extraction of soluble phenolic compounds from fruit waste include ultrasound-assisted extraction, microwave-assisted extraction, supercritical fluid extraction, and pressurized liquid extraction [60, 96, 105]. These methods offer faster extraction times, higher extraction

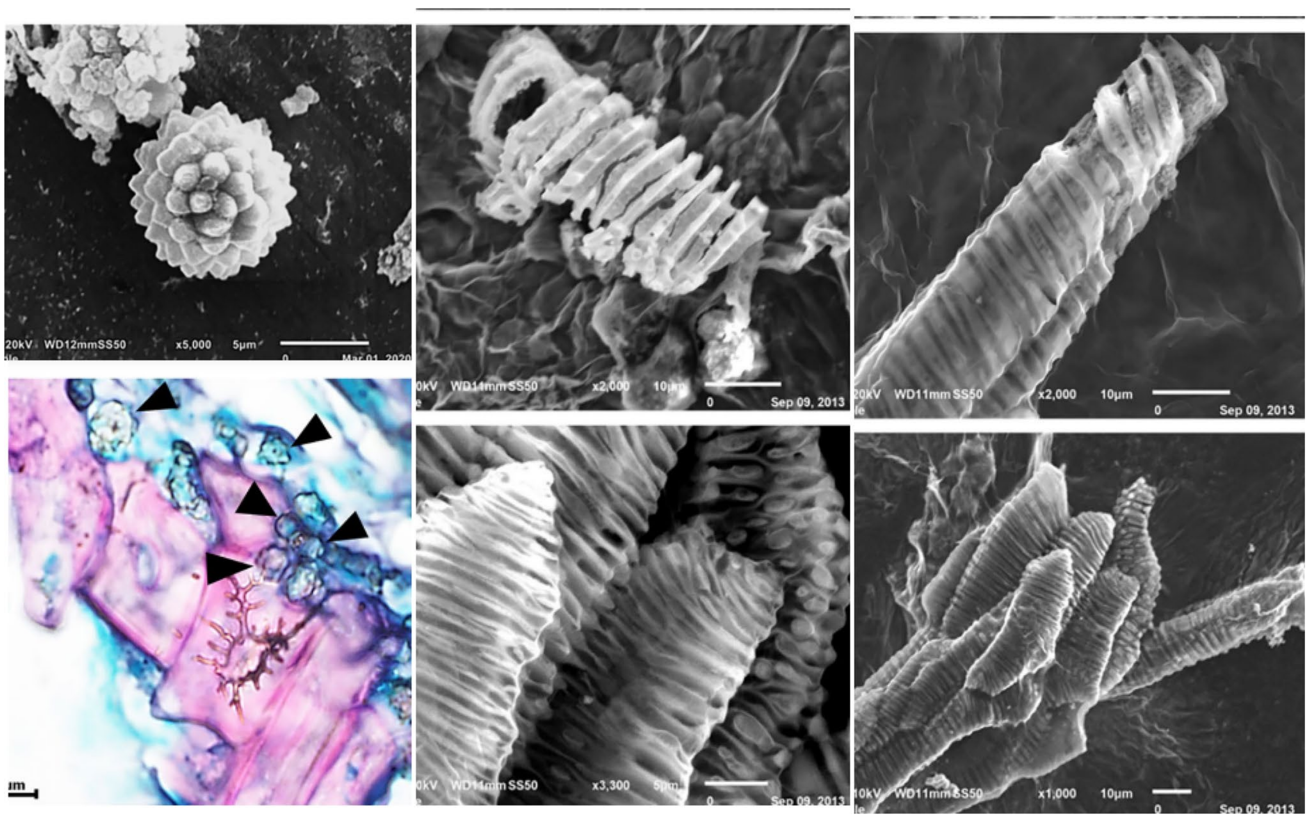

Fig. 1 Different forms of existence of lignin in date fruit tissues including spiral forms in combination with silica (Source: [59])

yields, and reduced solvent consumption [105]. Elsayed et al. [54] emphasizes the need for eco-friendly extraction methods, such as bioreactors and enzyme-assisted extraction, to reduce the ecological impact of fruit waste management. Overall, the choice of extraction technique depends on factors such as the targeted phenolic compounds, the scale of extraction, and the desired efficiency.

Phenolic compounds in fruit wastes are not generally analyzed by high performance liquid chromatography but rather using total antioxidant activity methods (Tables 5 and 6). These assays are not always correlated and may detect different types of antioxidant activities. For instance, the DPPH assay measures radical scavenging ability, while the FRAP assay assesses reducing power. Also, the lack of standardization in terms of assay conditions (e.g., pH, temperature, reaction time) can explain the variability in findings across different studies. In the lack of standardization, it is rather uneasy to draw a comprehensive conclusion about the antioxidant capacity. The limitations of the antioxidant assays also include the lack of methodological equivalency that allows conversion of one assay value to another [9, 81]. The absence of a single in vitro 'antioxidant activity' assay that can reflect the total antioxidant capacity is considered a crucial limitation factor [62]. Allaith [26] reported inconsistency in total phenolic content within the same cultivar and between 243 cultivars of date fruits from 18 countries. In a detailed review, high inconsistency regarding the used analytical methods, citation references for procedures, measurement units, extraction solvents, and data presentation methods, were reported for date fruits total antioxidant assays [1]. Thus, the industrial utilization of dates phenolic extracts requires standardization of the extraction and determination methods.

6 Safety concerns about date seed utilization in food products

Current research is promoting the inclusion of date seed powder in a number of food products in order to enhance their quality and some functionalities [24]. Due to their very high phenolic antioxidant contents, date seeds possess anti-inflammatory and oxidative stress modulating activities [86]. Date seed powders or their extracts have been used for the supplementation of several food products including bakery, dairy, beverages, meat, desserts, and condiments to promote their dietary fiber and antioxidant contents [24]. Since date seeds were not consumed as a common commodity in the

Table 4 Overview of some studies conducted on the identification and quantification of phenolic compounds of date seeds

Extraction method	Analytical method	Major phenolic compounds (Concentration, ppm)	References
Date seed powder (200 mg) was extracted with aqueous methanol (2 mL, 80%) by shaking at room temperature for 2 h	HPLC-LC-UV	Catechin (140), *p*-coumaric acid (110), sinapic acid (270), and vanillin (30)	Bijami et al. [39]
Date seed powder (150 mg) was extracted with aqueous methanol (10 mL, 70%, acidified with HCl 0.1%). by sonication in a water bath for 5 min	HPLC-ESI-UV/MS/MS	27 phenolic compounds were found in date seed powder including flavan-3-ols (48,000 ppm after depolymerization)	Hilary et al. [68]
Date seeds powder (30 g) was extracted with aqueous methanol (80%, 150 mL) by shaking at 35 °C for 12 h	HPLC—DAD	*p*-Coumaric acid (1161–14,360, Caffeic acid (594–886), ferulic acid (55–122), gallic acid (103–176), vanillic acid (53–108), chlorogenic acid (45–103), syringic acid (0–14), rutin (395–802), quercetin (22–364), and luteolin (76–127)	Bouhlali et al. [45]
Date seed powder was extracted with 50% acetone and 2% acetic acid in a solvent/sample ratio (10:1, w/v) by stirring at 120 rpm and 45 °C for one hour	HPLC–DAD-MS	Caffeic acid (597), chlorogenic acid (584), 3,4 dihydroxybenzoic acid (193), p hydroxybenzoic acid (173), and 3-hydroxybenzoic acid (116) in phenolic fraction concentrate	Bikri et al. [40]
Date seed powder (1 g) was extracted with aqueous ethanol (50%, 20 mL) for 24 h	HPLC-ESI-UV/MS/MS	Hydroxybenzoic acid, hydroxycinnamic acid, flavan-3-ols (monomers, dimers, and trimers). Total polyphenols varied 4746–8488 ppm	Bettaieb et al. [38]
Date seed powder (2 g) was extracted with aqueous methanol (80%, 30 mL) by shaking for 4 h	HPLC	Gallic acid (210–572), catechin hydrate (108–178), chlorogenic acid (16–45), epicatechin (7–39), sinapic acid (0–39), *p*-coumaric acid (5–14), vanillic acid (4.6–11.6), caffeic acid (1.6–4.7)	Majid et al. [83]

DAD diode array detector, *ESI* electron spray ionization, *LC* liquid chromatography, *MS* mass spectrometry, *HPLC* high-performance liquid chromatography

Table 5 Overview of studies conducted on total antioxidant activities of date fruit extracts

Extraction method	Analytical method	Quantities	References
Date fruits (10 g) were extracted by boiling in ethanol (100 mL) for 10 min	TPC	104–164 (mg GAE/100 g FW)	Siddiqi et al. [109]
Date fruits (5 g) were extracted with methanol: water (65:35 v/v, 20 mL) followed by acetone: water (65:35 v/v, 20 mL) and water (20 mL) by boiling for 1 h	ABTS DPPH FRAP TPC	79–142 (mMoL TE/kg DW) 6–15 (IC_{50} mg/mL) 70–130 (mMoL TE/kg DW) 95–193 (mg GAE/100 g DW)	Tassoult et al. [112]
Date fruits (5 g) were extracted with aqueous methanol (50 mL, 80% v/v) at room temperature for 24 h	DPPH FRAP TFC TPC	0.07–0.18 (IC_{50} mg/mL) 5–9 (mMoL AEAC) 3–12 (mg QE/100 g DW) 154–279 (mg GAE/100 g DW)	Bensaci et al. [35]
Date fruits (1 g) were extracted with aqueous ethanol (20 mL, 50% v/v) using irradiation at 1000 Watt for 3 min	ABTS DPPH TFC TPC	2–4 (mg TE/g FW) 1.2–2.4 (mg TE/g FW) 0.2–0.5 (mg QE/g FW) 3–5 (mg GAE/g FW)	Djaoudene et al. [50]
Date fruits (20 g) were extracted with aqueous ethanol (60 mL, 80% v/v) with constant agitation at room temperature for 24 h	ABTS DPPH TCT TFC TPC	28–107 (mg TE/100 g FW) 21–132 (mg TE/100 g FW) 40–147 (mg CE/100 g FW) 45–117 (mg RE/100 g FW) 10–297 (mg GAE/100 g FW)	Bettaieb et al. [37]
Date fruits (100 g) were extracted with aqueous methanol (300 mL, 80% v/v) in an orbital shaking	ABTS DPPH FRAP TPC	69–208 (µg TE/mL) 2,717–3,060 (µg TE/mL) 220–239 (µg TE/mL) 217–570 (mg GAE/100 g FW)	Hamdi et al. [64]
Date fruit powder (0.6 g) was extracted with aqueous acetone (6 mL, 50%v/v) by vertexing for 2 min	DPPH FRAP TFC TPC	3.4–5.1 (IC_{50} g/L) 855–1,662 (µmol TE/100 g DW) 87–190 (mg QE/100 g DW) 209–496 (mg GAE/100 g DW)	Jdaini et al. [73]
Date fruits (3 g) were extracted with acidified aqueous methanol (30 mL, 80% v/v), followed by acetone (30 mL, 70% v/v) at room temperature	ABTS DPPH FIC FRAP	0.9–1.1 (mg TE/g DW) 26–32 (µg TE/g DW) 3.7–4.6 (µg TE/g DW) 0.6–0.7 (µg TE/g DW)	Muñoz-Bas et al. [91]
Date fruits (2 g) were extracted using a methanol, acetone, and water (40 mL, 7:7:6 v/v) at room temperature	ABTS DPPH FRAP TCT TFC TPC	865–1,815 (µmol TE/100 g DW) 0.02–0.176 (IC_{50} mg/L) 863–1,980 (µmol TE/100 g DW) 21–76 (mg CE/100 g DW) 14–59 (mg CE/100 g DW) 97–372 (mg GAE/100 g DW)	Bahiani et al. [33]

ABTS 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt radical cation, *CE* (+)-catechin equivalent, *DW* dry weight, *DPPH* 2-diphenyl-1-picrylhydrazyl, *FIC* ferrous ion chelating activity, *FW* fresh weight, *FRAP* ferric reducing antioxidant power, *GAE* gallic acid equivalent, IC_{50} inhibitory concentration, *QE* quercetin equivalent, *RE* rutin equivalent, *TCT* total condensed tannins, *TFC* total flavonoid content, *TPC* total phenolic content, *TE* trolox equivalent

Table 6 Overview of some studies conducted on total antioxidant properties of date seeds

Extraction method	Analytical method	Quantities	References
Date seed powder (2 g) was extracted twice with aqueous acetone (25 mL, 50%) at room temperature for 1 h	TFC	84–95 (mg QE/ 100 g DW)	Abuelgassim et al. [2]
	TPC	2014–2060 (mg GAE/100 g DW)	
Date seed powder was extracted with 50% acetone and 2% acetic acid in a solvent/sample ratio (10:1, w/v) by stirring at 120 rpm and 45 °C for one hour	DPPH	0.21 (IC_{50} mg/mL)	Bikri et al. [40]
	FRAP	4.15 (mg TE/g PFC)	
	TCT	14 (mg CE/g PFC)	
	TEAC	16 (AAE/g PFC)	
	TFC	25 (mg QE/g PFC)	
	TPC	152 (mg GAE/g PFC)	
Date seed powder (150 g) was extracted by subcritical CO_2 with 75 mL pure ethanol as co-solvent	TPC	228–275 (mg GAE/100 g)	Ghafoor et al. [60]
	TFC	98–142 (mg QE/100 g)	
	TAC	0.6–1 (mg/100 g)	
	Phosphomolybdenum	13–24 (ug AAE/mL)	
	DPPH	110–162 (IC_{50} ug/mL)	
	FRAP	1.6–2.1 (mmol TE/100 g)	
	ABTS	546–717 (umol TE/100 g)	
Dates seeds (2 kg dry) were extracted with steam in 100 hydrothermal reactor at 160 °C (5.5 Bar) followed by 180 °C (9.1 Bar) for 1 h each	DPPH	0.34–0.37 (EC_{50} mg/L)	Mrabet et al. [88]
	ABTS	3–7 (mg TE /g dried extract)	
	ORAC	10–13 (mmol TE/g dried extract)	
	TPC	1284–2950 (mg GAE/L)	
Date seed powder (1 g) was extracted with aqueous ethanol (50%, 20 mL) for 24 h	TPC	136–285 (mg GAE/g DW)	Bettaieb et al. [38]
	TFC	34–94 (mg RE/g DW)	
	TCT	24–202 (mg CE/g DW)	
	DPPH	83–127 (mg TE/g extract)	
	ABTS	46–124 (mg TE/g extract)	
Date seeds (4 g) were extracted with aqueous ethanol (40 mL, 70%) by ultrasonic-assisted extraction	TPC	18 (mg GAE/g FW)	Shi et al. [107]
	TCT	40 (mg CE/g FW)	
	TFC	0.52 (mg QE/ g FW)	
	DPPH	25 (mg TE/g FW)	
	FRAP	42 (mg TE/g FW)	
	ABTS	65 (mg TE/g FW)	
	FICA	0.10 (mg EE/ g FW)	
	TAC	17 (mg AAE/g FW)	
Date seed powder (2 g) was extracted with aqueous methanol (80%, 30 mL) by shaking for 4 h	TPC	34–44 (mg GAE/g DW)	Majid et al. [83]
	ABTS	42–72 (µM TE/g DW)	
	ORAC	12–23 (µM TE/g DW)	
	FRAP	12–14 (µM Fe^{2+}/g DW)	

ABTS 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt radical cation, *DW* dry weight, *DPPH* 2-diphenyl-1-picrylhydrazyl, *FICA* Ferrous Ion chelating ability, *FW* fresh weight, *FRAP* ferric reducing antioxidant power, *ORAC* oxygen radical absorbance capacity, *TAC* total antioxidant capacity, *TCT* total condensed tannins, *TFC* total flavonoids contents; *TPC* total phenolic contents, *AAE* ascorbic acid equivalent, *CE* catechin equivalents, EC_{50} effective concentration, *EE* ethylenediaminetetraacetic acid (EDTA) equivalents, *GAE* Gallic acid equivalent, IC_{50} fifty percent inhibitory concentration, *TE* Trolox equivalent, *QE* quercetin equivalents, *RE* rutin equivalent, *PFC* phenolic fraction concentrate human diet, the seeds and their extracts may fall under the classification of novel foods. Novel foods, i.e. whole foods, food ingredients, and food products derived from non-commonly consumed foods should be subject to through toxicological investigations before they can be allowed for human consumption [113]. According to EU regulation 2015/2283, approval of novel foods requires *inter alias* complete chemical characterization, metabolic studies, history of use, dietary exposure, and nutritional, toxicological, and allergy considerations [52]. The FDA (USA) evaluate food additive in terms of GRAS (generally recognized as safe) status, which in principle require the same type of information demanded by the European Food Safety Authority (EFSA).

Date seeds were reported to have hormonal effects in animals, raising concerns about their use in food products, especially bakery products. In mature male rats, sperm counts, spermatogenesis, testosterone, follicle-stimulating hormone, and luteinizing hormone increased in response to seed consumption [23]. Ingestion of date seeds increased uterine weights and date seed extracts induced uterine contractions, indicating estrogenic activity [53]. Estrogen-like compounds in date seeds [67] may be responsible for the lower estradiol levels in female rats after ingesting date seeds [15]. Date seeds elicited negative feedback effects on endogenous gonadotropin-induced secretion of estradiol and pituitary secretion of follicle-stimulating and luteinizing hormones in women [103]. Shehzad et al. [104] reviewed the literature and concluded that date seeds have positive effects on male and female fertility.

Zakeri et al. [117] reported the first case of portal vein thrombosis and other complications after long-term oral consumption of date seed powder. Support for the adverse side effects of date seeds is insufficient, and further human studies are required. Due to the limited food applications and lack of safety studies, date seeds should be regarded as novel ingredients with possible endocrine-disrupting effects, and their use in food products should require adequate toxicological studies. Thus, there is a need to investigate whether the consumption of date sees as a food ingredient will cause any negative health effects [111]. When the endocrine activity is associated with negative effects on health, the activity is recognized as endocrine disrupting and the safety of the food or the chemical within is questioned. Extracts of date seeds require testing of any negative interference, including binding to the hormonal receptors and/or to the hormone transport proteins in the body [111, 115].

7 Conclusion

As the demand and supply of date fruits expands, innovative products generated from the huge accumulation of date wastes, which can cause serious air, water, and soil pollution, should be developed. This dilemma can be resolved by adding value to the date fruit processing industry through the adoption of good harvest and postharvest techniques, efficient utilization of bioactive constituents, and their incorporation in safe products with environmental and economic feasibility. The phenolic compounds in the date fruit processing waste offers several add-value possibilities especially in food and nutraceutical products. Insufficient research on phenolic compound extraction and analytical methods highlights the need for in-depth investigations to detect phenolic compounds in date fruits and wastes and standardize their extraction methods. Applications of other agro-industrial wastes may be applied to the date industry to expand the range of applications. Valorization of date by-products would contribute to global sustainable development goals, especially those focus on responsible production, economic growth and climate actions.

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Declarations

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References

1. Abdullah AlFaris N, Zaidan AlTamimi J, Abdulaziz AlMousa L, Ali AlGhamidi F, Alzaheb RA, Abdullah Albaridi N. Antioxidant content determination in ripe date fruits (*Phoenix dactylifera* L.): a scoping review. Food Anal Methods. 2021;14:897–921. https://doi.org/10.1007/s12161-020-01923-z.
2. Abuelgassim AO, Eltayeb M, Ataya FS. Palm date (*Phoenix dactylifera* L.) seeds: a rich source of antioxidant and antibacterial activities. Czech J Food Sci. 2020;38(3):171–8. https://doi.org/10.17221/269/2019-CJFS.
3. Abu-Reidah IM, Gil-Izquierdo A, Medina S, Ferreres F. Phenolic composition profiling of different edible parts and by-products of date palm (*Phoenix dactylifera* L.) by using HPLC-DAD-ESI/MS. Int Food Res J. 2017;100:494–500. https://doi.org/10.1016/j.foodres.2016.10.018.
4. Ahmed S, Khan RA, Jamil S. Anti-hyperlipidemic and hepatoprotective effects of native date fruit variety "Aseel" (*Phoenix dactylifera*). Pak J Pharm Sci. 2016;29(6):1945–50.
5. Al Juhaimi F, Özcan MM, Adiamo OQ, Alsawmahi ON, Ghafoor K, Babiker EE. Effect of date varieties on physico-chemical properties, fatty acid composition, tocopherol contents, and phenolic compounds of some date seed and oils. J Food Process Preserv. 2018;42: e13584. https://doi.org/10.1111/JFPP.13584.
6. Al Juhaimi F, Özcan MM, Uslu N, Ghafoor K, Babiker EE, Mohamed Ahmed IA. Bioactive properties, fatty acid compositions, and phenolic compounds of some date palm (*Phoenix dactylifera* L.) cultivars. J Food Process Preserv. 2020;44(5):1–8. https://doi.org/10.1111/jfpp.14432.
7. Al-Alawi R, Al-Mashiqri JH, Al-Nadabi JSM, Al-Shihi BI, Baqi Y. Date palm tree (*Phoenix dactylifera* L.): natural products and therapeutic options. Front Plant Sci. 2017;8: 845. https://doi.org/10.3389/fpls.2017.00845/full.
8. Alam MZ, Al-Hamimi S, Ayyash M, Rosa CT, Yahia EM, Haris S, Al-Marzouqi AH, Kamal-Eldin A. Contributing factors to quality of date (*Phoenix dactylifera* L.) fruit. Sci Hortic. 2023;321:112256. https://doi.org/10.1016/j.scienta.2023.112256.
9. Alam MZ, Alhebsi MSR, Ghnimi S, Afaf Kamal-Eldin A. Inability of total antioxidant activity assays to accurately assess the phenolic compounds of date palm fruit (*Phoenix dactylifera* L.). NFS J. 2021;22:32–40. https://doi.org/10.1016/j.nfs.2021.01.001.
10. Alam MZ, Fristedt R, Landberg R, Kamal-Eldin A. Soluble and hydrolyzable phenolic compounds in date fruits (*Phoenix dactylifera* L.) by UPLC-QTOF-MS/MS and UPLC-DAD. J Food Compos Anal. 2024;132:106354. https://doi.org/10.1016/j.jfca.2024.106354.
11. Alam MZ, Okonkwo CE, Cachaneski-Lopes JP, et al. Date fruit melanin is primarily based on (−)-epicatechin proanthocyanidin oligomers. Sci Rep. 2024;14: 4863. https://doi.org/10.1038/s41598-024-55467-x.
12. Alam MZ, Ramachandran T, Antony A, Hamed F, Ayyash M, Kamal EA. Melanin is a plenteous bioactive phenolic compound in date fruits (*Phoenix dactylifera* L.). Sci Rep. 2022;12: 6614. https://doi.org/10.1038/s41598-022-10546-9.
13. Al-Amrani M, Al-Alawi A, Al-Marhobi I. Assessment of enzymatic browning and evaluation of antibrowning methods on dates. Int J Food Sci. 2020. https://doi.org/10.1155/2020/8380461.
14. Alara OR, Abdurahman NH, Ukaegbu CI. Extraction of phenolic compounds: a review. Curr Res Food Sci. 2021;4:200–14. https://doi.org/10.1016/j.crfs.2021.03.011.
15. Aldhaheri A, Alhadrami G, Aboalnaga N, Wasfi I, Elridi M. Chemical composition of date pits and reproductive hormonal status of rats fed date pits. Food Chem. 2004;86:93–7. https://doi.org/10.1016/j.foodchem.2003.08.022.
16. Al-Farsi MA, Lee CY. Nutritional and functional properties of dates: a review. Crit Rev Food Sci Nutr. 2008;48(10):877–87. https://doi.org/10.1080/10408390701724264.
17. Al-Farsi M, Alasalvar C, Al-Abid M, Al-Shoaily K, Al-Amry M, Al-Almanaa H, Mahmoud R. Palm date seeds as an alternative source of dietary fiber in Saudi bread. Ecol Food Nutr. 2010;32:261–70. https://doi.org/10.1080/03670244.1994.9991406.
18. Al-Farsi M, Alasalvar C, Al-Abid M, Al-Shoaily K, Al-Amry M, Al-Rawahy F. Compositional and functional characteristics of dates, syrups, and their by-products. Food Chem. 2007;104(3):943–7. https://doi.org/10.1016/j.foodchem.2006.12.051.
19. Al-Farsi M, Alasalvar C, Morris A, Baron M, Shahidi F. 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. 2005;53(19):7592–9. https://doi.org/10.1021/jf050579q.
20. Alhaider IA, Mohamed ME, Ahmed KKM, Kumar AH. Date palm (*Phoenix dactylifera*) fruits as a potential cardioprotective agent: the role of circulating progenitor cells. Front Pharmacol. 2017;8: 592. https://doi.org/10.3389/fphar.2017.00592.
21. Al-Hamdani H. The effect of eating date pomace on increasing hemoglobin levels in a sample of women. Plant Arch. 2019;19(1):1427.
22. Alharbi KL, Raman J, Shin HJ. Date fruit and seed in nutricosmetics. Cosmetics. 2021. https://doi.org/10.3390/cosmetics8030059.
23. Ali BH, Bashir AK, Alhadrami GA. Reproductive hormonal status of rats treated with date pits. Food Chem. 1999;66:437–41. https://doi.org/10.1016/S0308-8146(98)00060-0.

24. Al-Khalili M, Al-Habsi N, Rahman MS. Applications of date pits in foods to enhance their functionality and quality: a review. Front Sustain Food Syst. 2023. https://doi.org/10.3389/fsufs.2022.1101043.
25. Alkhoori MA, Kong AS, Aljaafari MN, Abushelaibi A, Erin Lim SH, Cheng WH, Chong CM, Lai KS. Biochemical composition and biological activities of date palm (*Phoenix dactylifera* L.) seeds: a review. Biomolecules. 2022;12(11):1626. https://doi.org/10.3390/biom12111626.
26. Allaith A. Antioxidants in date fruits and the extent of the variability of the total phenolic content: review and analysis. Antioxidants. 2019. https://doi.org/10.5772/intechopen.83851.
27. Al-Meqbaali F, Habib H, Othman A, Al-Marzooqi S, Al-Bawardi A, Pathan JY, Hilary S, Souka U, Al-Hammadi S, Ibrahim W, Platat C. The antioxidant activity of date seed: Preliminary results of a preclinical in vivo study. Emir J Food Agric. 2017;29(11):822–32. https://doi.org/10.9755/ejfa.2017.v29.i11.1477.
28. Almoumen A, Mohamed H, Ayyash M, Yuliarti O, Kamleh R, Al-Marzouqi AH, Kamal-Eldin A. Harnessing date fruit pomace: extraction of high fibre dietary ingredient and its impact on high fibre wheat flour dough. NFS J. 2024;35:100178. https://doi.org/10.1016/J.NFS.2024.100178.
29. Al-Okbi SY. Date palm as source of nutraceuticals for health promotion: a review. Curr Nutr Rep. 2022;11(4):574–91. https://doi.org/10.1007/s13668-022-00437-w.
30. Al-Shwyeh HA. Date palm (*Phoenix dactylifera* L.) fruit as potential antioxidant and antimicrobial agents. J Pharmacogn Phytochem. 2019. https://doi.org/10.4103/jpbs.JPBS_168_18.
31. Ashraf Z, Hamidi-Esfahani Z. Date and date processing: a review. Food Rev Int. 2011;27(2):101.
32. Bagherzadeh Karimi A, Elmi A, Zargaran A, Mirghafourvand M, Fazljou SMB, Araj-Khodaei M, Baghervand Navid R. Clinical effects of date palm (*Phoenix dactylifera* L.): a systematic review on clinical trials. Complement Ther Med. 2020;51:102429. https://doi.org/10.1016/j.ctim.2020.102429.
33. Bahiani M, Babahani S, Nani A, Boukhetache I. Dates (*Phoenix dactylifera* L.) from the Adrar region of Algeria are rich in polyphenols, and ternary solvent extracts' antioxidant activity correlates with condensed tannins content. Vegetos. 2024;37:918–29. https://doi.org/10.1007/s42535-023-00622-4.
34. Baliga MS, Baliga BRV, Kandathil SM, Bhat HB, Vayalil PK. A review of the chemistry and pharmacology of the date fruits (*Phoenix dactylifera* L.). Food Res Int. 2011;44(7):1812–22. https://doi.org/10.1016/j.foodres.2010.07.004.
35. Bensaci C, Ghiaba Z, Dakmouche M, Belfar A, Belguidoum M, Bentebba FM, Saidi M, Hadjadj M. In vitro evaluation of antioxidant potential of date palm collected in algeria using electrochemical and spectrophotometrical techniques. Korean Chem Eng Res. 2021;59(2):153–8. https://doi.org/10.9713/kcer.2021.59.2.153.
36. Ben Sassi C, Talbi W, Ghazouani T, Ben Amara S, Fattouch S. Date palm. In: Jaiswal AK, editor. Nutritional composition and antioxidant properties of fruits and vegetables. Cambridge: Academic Press; 2020. p. 681–94.
37. Bettaieb I, Kilani A, Ben Othman K, Benabderrahim MA, Elfalleh W. Phenolic profile, sugar composition, and antioxidant capacities of some common date palm (*Phoenix dactylifera* L.) cultivars as a potential nutraceutical and functional food ingredients. J Food Qual. 2023. https://doi.org/10.1155/2023/2474900.
38. Bettaieb I, Benabderrahim MA, Arcos RR, Araujo AJ, Elfalleh W. Date seeds (*Phoenix dactylifera*): antioxidant potential and profile of free and bound polyphenols from different cultivars. Chem Biodivers. 2023;20: e202300179. https://doi.org/10.1002/cbdv.202300179.
39. Bijami A, Rezanejad F, Oloumi H, Mozafari H. Minerals, antioxidant compounds and phenolic profile regarding date palm (*Phoenix dactylifera* L.) seed development. Sci Hortic. 2020;262:109017. https://doi.org/10.1016/j.scienta.2019.109017.
40. Bikri S, Aboussaleh Y, Abuelezz N, Benmhammed H, Berrani A, Louragli I, Ahami AOT. Phenolic fraction concentrates of *Phoenix dactylifera* L. seeds: a promising antioxidant and glucose regulator. J Pharm Pharmacogn Res. 2021;9(6):921–36.
41. Bnouham M, Mekhfi H, Legssyer A, Ziyyat A. Ethnopharmacology forum medicinal plants used in the treatment of diabetes in Morocco. Int J Diabetes Metab. 2002;10(1):33–50.
42. Borochov-Neori H, Judeinstein S, Greenberg A, Volkova N, Rosenblat M, Aviram M. Antioxidant and antiatherogenic properties of phenolic acid and flavonol fractions of fruits of "Amari" and "Hallawi" date (*Phoenix dactylifera* L.) varieties. J Agric Food Chem. 2015;63:3189–95. https://doi.org/10.1021/jf506094r.
43. Bouallegue K, Allaf T, Besombes C, Ben Younes R, Allaf K. Phenomenological modelling and intensification of texturing/grinding-assisted solvent oil extraction: case of date seeds (*Phoenix dactylifera* L.). Arab J Chem. 2019;12(8):2398–410. https://doi.org/10.1016/J.ARABJC.2015.03.014.
44. Bouhlali EDT, Alem C, Ennassir J, Benlyas M, Mbark AN, Zegzouti YF. Phytochemical compositions and antioxidant capacity of three date (*Phoenix dactylifera* L.) seed varieties grown in the South East Morocco. J Saudi Soc Agric Sci. 2017;16(4):350–7. https://doi.org/10.1016/J.JSSAS.2015.11.002.
45. Bouhlali ET, Hmidanib A, Bourkhis B, Khouya T, Ramchoun M, Filali-Zegzouti Y, Alem C. Phenolic profile and anti-inflammatory activity of four Moroccan date (*Phoenix dactylifera* L.) seed varieties. Heliyon. 2020;6: e03436. https://doi.org/10.1016/j.heliyon.2020.e03436.
46. Butler AE, Obaid J, Wasif P, Varghese JV, Abdulrahman R, Alromaihi D, Atkin SL, Alamuddin N. Effect of date fruit consumption on the glycemic control of patients with Type 2 Diabetes: a randomized clinical trial. Nutrients. 2022;14(17):3491. https://doi.org/10.3390/nu14173491.
47. Dai J, Mumper RJ. Plant phenolics: extraction, analysis and their antioxidant and anticancer properties. Molecules. 2010;15:7313–52. https://doi.org/10.3390/molecules15107313.
48. Dias MC, Pinto DCGA, Silva AMS. Plant flavonoids: chemical characteristics and biological activity. Molecules. 2021;26(17):5377. https://doi.org/10.3390/molecules26175377.PMID:34500810;PMCID:PMC8434187.
49. DiBaise M, Tarleton SM. Hair, nails, and skin: differentiating cutaneous manifestations of micronutrient deficiency. Nutr Clin Pract. 2019;34(4):490–503. https://doi.org/10.1002/ncp.10321.
50. Djaoudene O, Mansinhos I, Gonçalves S, Jara-Palacios MJ, Bachir Bey M, Romano A. Phenolic profile, antioxidant activity and enzyme inhibitory capacities of fruit and seed extracts from different Algerian cultivars of date (*Phoenix dactylifera* L.) were affected by in vitro simulated gastrointestinal digestion. South Afr J Bot. 2021;137:133–48. https://doi.org/10.1016/j.sajb.2020.10.015.

51. Echegaray N, Pateiro M, Gullón B, Amarowicz R, Misihairabgwi JM, Lorenzo JM. *Phoenix dactylifera* products in human health—a review. Trends Food Sci Technol. 2020;105:238–50. https://doi.org/10.1016/j.tifs.2020.09.017.
52. EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS), Younes M, Aggett P, Aguilar F, Crebelli R, Dusemund B, Filipic M, Frutos MJ, Galtier P, Gundert-Remy U, Kuhnle GG, Lambré C, Leblanc JC, Lillegaard IT, Moldeus P, Mortensen A, Oskarsson A, Stankovic I, Waalkens-Berendsen I, Gott D. Guidance on safety evaluation of sources of nutrients and bioavailability of nutrients from the sources. EFSA J. 2018;16(6): e05294. https://doi.org/10.2903/j.efsa.2018.5294.
53. Elgasim EA, Alyousif YA, Homeida AM. Possible hormonal activity of date pits and flesh fed to meat animals. Food Chem. 1995;52:149–50. https://doi.org/10.1016/0308-8146(94)P4195-L.
54. Elsayed N, Marrez DA, Ali MA, El-Maksoud AAA, Cheng W, Abedelmaksoud TG. Phenolic profiling and in-vitro bioactivities of corn (*Zea mays* L.) tassel extracts by combining enzyme-assisted extraction. Foods. 2022;11(14):2145.
55. El Sohaimy S, Abdelwahab A, Brennan C, Aboul-Enein A. Phenolic content, antioxidant and antimicrobial activities of Egyptian date palm (*Phoenix dactylifera* L.) fruits. Aust J Basic Appl Sci. 2015;9:141–7.
56. FAOSTAT. FAOSTAT: Statistical database. 2023. https://www.fao.org/faostat/en/#data/QV. Accessed 22 May 2025.
57. Gary RB. Proanthocyanidins: biological activities associated with human health. Pharm Biol. 2004;42:2–20. https://doi.org/10.3109/13880200490893474.
58. George N, Andersson AAM, Andersson R, Kamal-Eldin A. Lignin is the main determinant of total dietary fiber differences between date fruit (*Phoenix dactylifera* L.) varieties. NFS J. 2020;21:16–21. https://doi.org/10.1016/j.nfs.2020.03.002.
59. George N, Antony A, Ramachandran T, Hamed F, Kamal-Eldin A. Microscopic investigations of silicification and lignification suggest their coexistence in tracheary phytoliths in date fruits (*Phoenix dactylifera* L.). Front Plant Sci. 2020;11:997. https://doi.org/10.3389/fpls.2020.00977.
60. Ghafoor K, Sarker MZI, Al-Juhaimi FY, Babiker EE, Alkaltham MS, Almubarak AK. Extraction and evaluation of bioactive compounds from date (*Phoenix dactylifera*) seed using supercritical and subcritical CO_2 techniques. Foods. 2022;11:1806. https://doi.org/10.3390/foods11121806.
61. Ghnimi S, Umer S, Karim A, Kamal-Eldin A. Date fruit (*Phoenix dactylifera* L.): an underutilized food seeking industrial valorization. NFS J. 2017;6:1–10. https://doi.org/10.1016/j.nfs.2016.12.001.
62. Granato D, Shahidi F, Wrolstad R, Kilmartin P, Melton LD, Hidalgo FJ, Miyashita K, van Camp J, Alasalvar C, Ismail AB, Elmore S, Birch GG, Charalampopoulos D, Astley SB, Pegg R, Zhou P, Finglas P. Antioxidant activity, total phenolics and flavonoids contents: Should we ban in vitro screening methods? Food Chem. 2018;264:471–5. https://doi.org/10.1016/j.foodchem.2018.04.012.
63. Hamad I, AbdElgawad H, Al Jaouni S, Zinta G, Asard H, Hassan S. Metabolic analysis of various date palm fruit (*Phoenix dactylifera* L.) cultivars from Saudi Arabia to assess their nutritional quality. Molecules. 2015;20:13620–41. https://doi.org/10.3390/molecules200813620.
64. Hamdi M, Mostafa H, Aldhaheri M, Mudgil P, Kamal H, Alamri AS, Galanakis CM, Maqsood S. Valorization of different low-grade date (*Phoenix dactylifera* L.) fruit varieties: a study on the bioactive properties of polyphenolic extracts and their stability upon in vitro simulated gastrointestinal digestion. Plant Phys Biochem. 2023;200:107764.
65. Haminiuk CWI, Maciel GM, Plata-Oviedo MSV, Peralta RM. Phenolic compounds in fruits—an overview. Int J Food Sci Technol. 2012;47(10):2023–44. https://doi.org/10.1111/j.1365-2621.2012.03067.x.
66. Haris S, Alam M, Galiwango E, Mohamed MM, Kamal-Eldin A, Al-Marzouqi AH. Characterization analysis of date fruit pomace: an underutilized waste bioresource rich in dietary fiber and phenolic antioxidants. Waste Manage. 2023;163:34–42. https://doi.org/10.1016/j.wasman.2023.03.027.
67. Heftmann E, Bennett RD. Identification of estrone in date seeds by thin layer chromatography. Naturwissenschaften. 1965;52:431–2. https://doi.org/10.1007/BF00589690.
68. Hilary S, Tomás-Barberán FA, Martinez-Blazquez JA, Kizhakkayil J, Souka U, Al-Hammadi S, Habib H, Ibrahim W, Platat C. Polyphenol characterisation of *Phoenix dactylifera* L. (date) seeds using HPLC-mass spectrometry and its bioaccessibility using simulated in-vitro digestion/Caco-2 culture model. Food Chem. 2020;311:125969. https://doi.org/10.1016/j.foodchem.2019.125969.
69. Hong YJ, Tomas-Barberan FA, Kader AA, Mitchell AE. The flavonoid glycosides and procyanidin composition of Deglet Noor dates (*Phoenix dactylifera)*. J Agric Food Chem. 2006;54:2405–11. https://doi.org/10.1021/jf0581776.
70. Ibrahim S, Ayad A, Williams LL, Ayivi R, Gyawali R, Krastanov AI, Aljaloud SO. Date fruit: a review of the chemical and nutritional compounds, functional effects and food application in nutrition bars for athletes. Int J Food Sci Technol. 2021. https://doi.org/10.1111/ijfs.14783.
71. Idowu AT, Igiehon OO, Adekoya AE, Idowu S. Dates palm fruits: a review of their nutritional components, bioactivities and functional food applications. AIMS Agri Food. 2020;5(4):734–55. https://doi.org/10.3934/agrfood.2020.4.734.
72. Inayat A, Jamil F, Raza M, Khurram S, Ghenai C, Al-Muhatseb AH. Upgradation of waste cooking oil to biodiesel in the presence of green catalyst derived from date seeds. Biofuels. 2021;12(10):1245–50. https://doi.org/10.1080/17597269.2019.1608036.
73. Jdaini K, Alla F, Mansouri F, Barmar A, Elhoumaizi MA. Optimizing the extraction of phenolic antioxidants from date palm fruit by simplex-centroid solvent mixture design. Heliyon. 2023;9: e12738. https://doi.org/10.1016/j.heliyon.2022.e12738.
74. Jaouhari Y, Disca V, Ferreira-Santos P, Alvaredo-López-Vizcaíno A, Travaglia F, Bordiga M, Locatelli M. Valorization of date fruit (*Phoenix dactylifera* L.) as a potential functional food and ingredient: characterization of fiber, oligosaccharides, and antioxidant polyphenols. Molecules. 2024. https://doi.org/10.3390/molecules29194606.
75. Kamal-Eldin A, George N, Sobti B, AlRashidi N, Ghnimi S, Ali AA, Andersson AAM, Andersson R, Antony A, Hamed F. Dietary fiber components, microstructure, and texture of date fruits (*Phoenix dactylifera*, L.). Sci Rep. 2020;10(1):1–12. https://doi.org/10.1038/s41598-020-78713-4.
76. Kamil M, Ramadan K, Olabi AG, Ghenai C, Inayat A, Rajab MH. Desert palm date seeds as a biodiesel feedstock: extraction, characterization, and engine testing. Energies. 2019;12:3147. https://doi.org/10.3390/en12163147.
77. Khallouki F, Ricarte I, Breuer A, Owen RW. Characterization of phenolic compounds in mature Moroccan Medjool date palm fruits (*Phoenix dactylifera* L.) by HPLC-DAD-ESI-MS. J Food Compos Anal. 2018;70:63–71. https://doi.org/10.1016/j.jfca.2018.03.005.

78. Khan F, Khan TJ, Kalamegam G, Pushparaj PN, Chaudhary A, Abuzenadah A, Kumosani T, Barbour E, Al-Qahtani M. Anti-cancer effects of Ajwa dates (*Phoenix dactylifera* L.) in diethylnitrosamine-induced hepatocellular carcinoma in Wistar rats. BMC Complement Altern Med. 2017;17(1):418. https://doi.org/10.1186/s12906-017-1926-6.
79. Khan SA, Al Kiyumi AR, Al Sheidi MS, Al Khusaibi TS, Al Shehhi NM, Alam T. In vitro inhibitory effects on α-glucosidase and α-amylase level and antioxidant potential of seeds of *Phoenix dactylifera* L. Asian Pac J Trop Biomed. 2016;6(4):322–9. https://doi.org/10.1016/j.apjtb.2015.11.008.
80. Khoddami A, Wilkes MA, Roberts TH. Techniques for analysis of plant phenolic compounds. Molecules. 2013;18(2):2328–75. https://doi.org/10.3390/molecules18022328.
81. Kotha RR, Tareq FS, Yildiz E, Luthria DL. Oxidative stress and antioxidants—a critical review on in vitro antioxidant assays. Antioxidants. 2022. https://doi.org/10.3390/antiox11122388.
82. Ma W, Guo A, Zhang Y, Wang H, Liu Y, Li H. A review on astringency and bitterness perception of tannins in wine. Trends Food Sci Technol. 2014;2014(40):6–19. https://doi.org/10.1016/j.tifs.2014.08.001.
83. Majid A, Naz F, Bhatti S, Phull AR. Phenolic profile and antioxidant activities of three date seeds varieties (*Phoenix dactylifera* L.) of Pakistan. Explor Res Hypothesis Med. 2023;8(3):195–201. https://doi.org/10.14218/ERHM.2022.00118.
84. Manuja R, Sachdeva S, Jain A, Chaudhary J. A comprehensive review on biological activities of p-hydroxy benzoic acid and its derivatives. Int J Pharm Sci Rev Res. 2013;22(2):109–15.
85. Mirghani HO. Dates fruits effects on blood glucose among patients with diabetes mellitus: a review and meta-analysis. Pak J Med Sci. 2021;37(4):1230–6. https://doi.org/10.12669/pjms.37.4.4112.
86. Moslemi E, Dehghan P, Khani M. The effect of date seed (*Phoenix dactylifera*) supplementation on inflammation, oxidative stress biomarkers, and performance in active people: a blinded randomized controlled trial protocol. Contemp Clin Trials Commun. 2022;28:100951. https://doi.org/10.1016/j.conctc.2022.100951.
87. Mrabet A, Hamdi A, Rodríguez-Arcos R, Bejarano RG, Jiménez-Araujo A. Date seed by-products as a source of bioactive ingredient for healthy cookies. Food Biosci. 2024;61:104543. https://doi.org/10.1016/j.fbio.2024.104543.
88. Mrabet A, Jiménez-Araujo A, Fernández-Prior Á, Bermúdez-Oria A, Fernández-Bolaños J, Sindic M, Rodríguez-Gutiérrez G. Date seed: rich source of antioxidant phenolics obtained by hydrothermal treatments. Antioxidants. 2022;11(10):1914. https://doi.org/10.3390/antiox11101914.
89. Mrabet A, Jiménez-Araujo A, Guillén-Bejarano R, Rodríguez-Arcos R, Sindic M. Date seeds: a promising source of oil with functional properties. Foods. 2020;9:787. https://doi.org/10.3390/foods9060787.
90. Mrabet A, Rodríguez-Gutiérrez G, Rodríguez-Arcos R, Guillén-Bejarano R, Ferchichi A, Sindic M, Jiménez-Araujo A. Quality characteristics and antioxidant properties of muffins enriched with date fruit (*Phoenix dactylifera* L.) fiber concentrates. J Food Qual. 2016;39(4):237–44. https://doi.org/10.1111/jfq.12194.
91. Muñoz-Bas C, Muñoz-Tebar N, Candela-Salvador L, Pérez-Álvarez JA, Lorenzo JM, Viuda-Martos M, Fernández-López J. Quality characteristics of fresh date palm fruits of "Medjoul" and "Confitera" cv. from the Southeast of Spain (Elche Palm Grove). Foods. 2023;12(14):2659.
92. Muñoz-Tebar N, Viuda-Martos M, Lorenzo JM, Fernández-López J, Pérez-Álvarez JA. Strategies for the valorization of date fruit and its co-products: a new ingredient in the development of value-added foods. Foods. 2023;12:1456. https://doi.org/10.3390/foods12071456.
93. Najm OA, Addnan FH, Mohd-Manzor NF, Elkadi MA, Abdullah WO, Ismail A, Mansur F-AF. Identification of phytochemicals of *Phoenix dactylifera* L. Cv Ajwa with UHPLC-ESI-QTOF-MS/MS. Int J Fruit Sci. 2021;21(1):848–67. https://doi.org/10.1080/15538362.2021.1939227.
94. Nirmal NP, Khanashyam AC, Mundanat AS, Shah K, Babu KS, Thorakkattu P, Al-Asmari F, Pandiselvam R. Valorization of fruit waste for bioactive compounds and their applications in the food industry. Foods. 2023;12(3):556. https://doi.org/10.3390/foods12030556.
95. Oladzad S, Fallah N, Mahboubi A, Afsham N, Taherzadeh MJ. Date fruit processing waste and approaches to its valorization: a review. Biores Technol. 2021;340:125625. https://doi.org/10.1016/j.biortech.2021.125625.
96. Patra A, Abdullah S, Pradhan RC. Review on the extraction of bioactive compounds and characterization of fruit industry by-products. Bioresour Bioprocess. 2022;9(1):1–25.
97. Pinelo M, Del Fabbro P, Manzocco L, Nuñez MJ, Nicoli MC. Optimization of continuous phenol extraction from Vitis vinifera byproducts. Food Chem. 2005;92(1):109–17. https://doi.org/10.1016/j.foodchem.2004.07.015.
98. Rambabu K, Achazhiyath Edathil A, Nirmala GS, Hasan SW, Yousef AF, Show PL, Banat F. Date-fruit syrup waste extract as a natural additive for soap production with enhanced antioxidant and antibacterial activity. Environ Technol Innov. 2020;20:101153. https://doi.org/10.1016/j.eti.2020.101153.
99. Rasul S, Tarique M, Obaid Hamdan Alkaabi A, Kamal-Eldin A, Chiang JH, Yuliarti O. Evaluating the effects of insoluble date fruit (*Phoenix dactylifera* L.) fibers on meat analogue patties composed of pea and wheat protein isolates. Food Res Int. 2024;197:115158. https://doi.org/10.1016/j.foodres.2024.115158.
100. Roshankhah S, Abdolmaleki A, Salahshoor MR. Anti-inflammatory, anti-apoptotic, and antioxidant actions of Middle Eastern Phoenix dactylifera extract on mercury-induced hepatotoxicity in vivo. Mol Biol Rep. 2020;47(8):6053–65. https://doi.org/10.1007/s11033-020-05680-4.
101. Ruwizhi N, Aderibigbe BA. Cinnamic acid derivatives and their biological efficacy. Int J Mol Sci. 2020;21(16):5712. https://doi.org/10.3390/ijms21165712.
102. Shahidi F, Hossain A. Importance of insoluble-bound phenolics to the antioxidant potential is dictated by source material. Antioxidants. 2023;12:203. https://doi.org/10.3390/antiox12010203.
103. Shaw ND, Histed SN, Srouji SS, Yang J, Lee H, Hall JE. Estrogen negative feedback on gonadotropin secretion: evidence for a direct pituitary effect in women. J Clin Endocrinol Metab. 2010;95(4):1955–61. https://doi.org/10.1210/jc.2009-2108.
104. Shehzad M, Rasheed H, Naqvi SA, Al-Khayri JM, Lorenzo JM, Alaghbari MA, Manzoor MF, Aadil RM. Therapeutic potential of date palm against human infertility: a review. Metabolites. 2021;11:408. https://doi.org/10.3390/metabo11060408.
105. Shi L, Zhao W, Yang Z, Subbiah V, Suleria HAR. Extraction and characterization of phenolic compounds and their potential antioxidant activities. Environ Sci Pol Res. 2022;29(54):81112–29.

106. Shi L, de Souza TSP, Ahmadi F, Imran A, Dunshea FR, Barrow C, Suleria HAR. Valorization of date fruit (*Phoenix dactylifera* L.) processing waste and by-products: a review. Appl Sci. 2023;13:12315. https://doi.org/10.3390/app132212315.
107. Shi L, Lib W, Rahman MS, Al-Habsi N, Ashokkumar M, Dunshea FR, Suleria HAR. Comparison of phenolic composition in date (*Phoenix dactylifera* L.) flesh and seeds extracted by an ultrasonic-assisted and conventional method. Int J Food Prop. 2023;26(2):2939–62. https://doi.org/10.1080/10942912.2023.2261787.
108. Shokrollahi S, Denayer JFM, Karimi K. Efficient bioenergy recovery from different date palm industrial wastes. Energy. 2023;272:127057. https://doi.org/10.1016/j.energy.2023.127057.
109. Siddiqi SA, Rahman S, Khan MM, Rafiq S, Inayat A, Khurram MS, Seerangurayar T, Jamil F. Potential of dates (*Phoenix dactylifera* L.) as natural antioxidant source and functional food for a healthy diet. Sci Total Environ. 2020;748:141234. https://doi.org/10.1016/j.scitotenv.2020.141234.
110. Singh V, Guizani N, Essa MM, Hakkim FL, Rahman MS. Comparative analysis of total phenolics, flavonoid content and antioxidant profile of Phoenix dactylifera L. seeds. Food Bioprocess Technol. 2012;5(5):1964–73. https://doi.org/10.1007/s11947-011-0615-5.
111. Stiefel C, Stintzing F. Endocrine-active and endocrine-disrupting compounds in food – Occurrence, formation and relevance. NFS Journal. 2023;31:57–92. https://doi.org/10.1016/J.NFS.2023.03.004.
112. Tassoult M, Kati DE, Fernández-Prior MÁ, Bermúdez-Oria A, Fernández-Bolanos J, Rodríguez-Gutiérrez G. Antioxidant capacity and phenolic and sugar profiles of date fruits extracts from six different Algerian cultivars as influenced by ripening stages and extraction systems. Foods. 2021;10(3):503. https://doi.org/10.3390/foods10030503.
113. Ververis E, Ackerl R, Azzollini D, Colombo PA, de Sesmaisons A, Dumas C, Fernandez-Dumont A, Ferreira da Costa L, Germini A, Goumperis T, Kouloura E, Matijevic L, Precup G, Roldan-Torres R, Rossi A, Svejstil R, Turla E, Gelbmann W. Novel foods in the European Union: Scientific requirements and challenges of the risk assessment process by the European Food Safety Authority. Food Res Int. 2020;137:109515. https://doi.org/10.1016/j.foodres.2020.109515.
114. Wianowska D, Olszowy-Tomczyk M. A concise profile of gallic acid-from its natural sources through biological properties and chemical methods of determination. Molecules. 2023;28(3):1186. https://doi.org/10.3390/molecules28031186.
115. Wuttke W, Jarry H, Seidlova-Wuttke D. Definition, classification, and mechanism of action of endocrine-disrupting chemicals. Hormones. 2010;9(1):9–15. https://doi.org/10.1007/BF03401276.
116. Younas A, Naqvi SA, Khan MR, Shabbir MA, Jatoi MA, Anwar F, Inam-Ur-Raheem M, Saari N, Aadil RM. Functional food and nutraceutical perspectives of date (*Phoenix dactylifera* L.) fruit. J Food Biochem. 2020;44(9): e13332. https://doi.org/10.1111/jfbc.13332.
117. Zakeri MA, Bagheripour MH, Iriti M, Dehghan M. Portal vein thrombosis after the consumption of date seed powder: a case study. Case Rep Med. 2021. https://doi.org/10.1155/2021/6668722.