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Review

Innovations in extractable compounds from date seeds: Farms to future

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Abstract: Since ancient times, date fruit has been used as a staple food because of its high nutritional value and caloric content. With the development of food science and the application of modern instrumentation, we now know that date seeds contain large amounts of dietary fiber, phenols, polyphenols, amino acids, fatty acids, and many vitamins and minerals. Due to the presence of these functional food ingredients, date seeds are used in various applications, including foods such as bread, hot beverages, cosmetics such as hair and skin products, and as feed for culturing aquatic animals. Date seeds have been used in clinical applications, making use of their antioxidant, anti-inflammatory, anti-cancer, anti-diabetic, and antimicrobial properties. There is now growing awareness of the value of date seeds, which were considered a waste product. In this review, we focused on explaining the major biochemical constituents of date seeds and developing these constituents for various applications. We also highlight the expected developments in date seed use for the future.

Keywords: date seeds; date seed extraction; aquaculture; clinical setting; cosmeceuticals; nutraceuticals

1. Introduction

The date palm fruit is known by the scientific name *Phoenix Dactylifera L*. and belongs to the *Arecaceae* family. Date fruit is rich in vitamins, minerals (such as calcium, phosphorus, magnesium,

and potassium), and sugar [1–3]. Date fruit has important cultural significance in countries of the Middle East where it is used to break the fast of Muslims during Ramadan because it is easily digested and its nutrients easily absorbed by the body [1]. Date fruit is one of the most important commercially grown fruits of the Arabian Peninsula, North Africa, and the Middle East. As an agricultural crop, date fruit is mentioned in the Holy Qur'an and modern literature emphasizes its continued economic importance to the region [3–5]. The largest date-producing country is Egypt, followed by Iran in second place, and Saudi Arabia, Algeria, and Iraq jointly in third place [6].

Dates have been consumed as a staple food for more than 6,000 years [7], while production and consumer demand for date fruit continue to increase today. In the 2022/2023 period, the global production of date fruits exceeded one million metric tons, with Iraq, Algeria, and Iran emerging as the leading harvesters on a worldwide scale [8]. In addition, the date market is expected to increase from $12.14 billion in 2020 to $16.4 billion in 2026 [9]. There are different types of date fruit grown around the world, including Khudri, Khalas, Rothana, Sukkari, Sefri, Ajwa, Hilali, and Munifi. These species have been found to have medicinal value for the prevention of diseases through their antioxidant, anti-inflammatory, and anti-bacterial activities [4,10].

The date fruit is not only considered a complete diet but also a medicinal plant [11]. Chemical studies of the components of the date fruit have shown that it contains anthocyanins, phenols, sterols, carotenoids, and flavonoids. Date fruit has also been used in traditional medicine in the Middle East and Africa, where date fruit has been variously described to have effects on anti-aging, constipation, cancer, T2DM, anti-atherosclerosis, stomach ulcers, neuropathy, male fertility, and wound healing [12–15].

In this review, we discuss the significance of dates, particularly date seeds or stones, by presenting the chemical composition of date seeds, including fatty acids, amino acids, fiber, phenolics, minerals, and vitamins. Additionally, we explore some of the techniques used to analyze these components. The application of these ingredients in various industries and sectors, such as aquaculture, clinical settings, nutraceuticals, and cosmeceuticals, is also covered.

2. Date seed composition

The composition of date seeds, encompassing vital chemical constituents such as fatty acids, amino acids, fiber, phenolics, vitamins, and minerals, is rigorously determined through a variety of analytical methods as shown in Figure 1 [16]. Techniques such as Gas Chromatography-Mass Spectrometry (GC-MS) unveil the intricate profiles of fatty acids [17], while High-Performance Liquid Chromatography (HPLC) provides insights into amino acid content [18]. Sodium Dodecyl Sulphate-Polyacrylamide Gel Electrophoresis (SDS-PAGE) aids in separating proteins for further analysis [19]. Additionally, Atomic Absorption Spectrometry delves into mineral concentrations, offering a comprehensive understanding of essential elements [20]. This diverse array of analytical methods facilitates a thorough exploration of the multifaceted chemical composition inherent in date seeds.

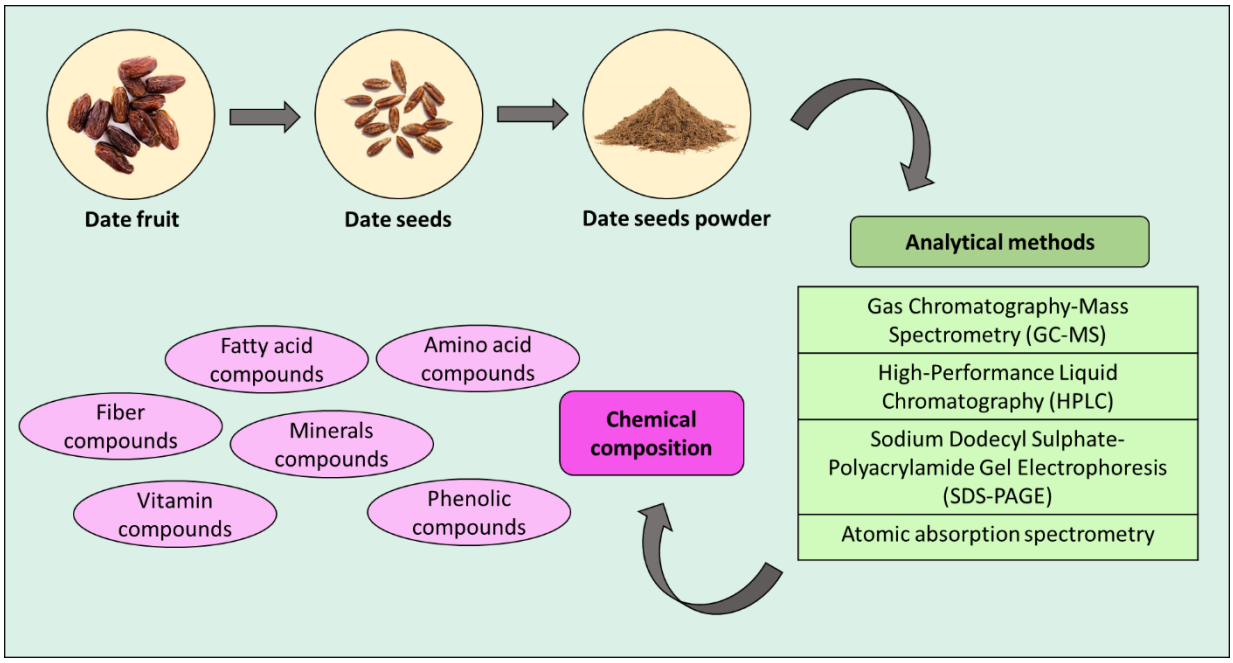

Figure 1. Comprehensive analysis of date seed composition using advanced analytical methods.

2.1. Fatty acid compounds

Fatty acids are primary nutritional components found in edible seed oils. The fatty acid composition of date seed oils has been the subject of extensive research, providing valuable insights into their nutritional and therapeutic potential. Date seeds were shown to contain 20–24% of the total fat [21]. The fatty acid content, analyzed through GC-MS, showcases the predominance of saturated and unsaturated fatty acids, contributing to the overall nutritional and therapeutic value of date seeds [22]. GC-MS stands as a potent analytical method employed for the identification and quantification of individual components within intricate mixtures. This specialized chromatographic technique utilizes a gaseous mobile phase, involving the separation of a sample into its constituents through gas chromatography, followed by the analysis of each component using mass spectrometry. A significant advantage of GC-MS lies in its ability to effectively identify volatile impurities but it is expensive [23]. Moreover, the major fatty acids found in these oils are oleic acid, linoleic acid, palmitic acid, myristic acid, and lauric acid, which constitute more than 90% of the total fatty acid content, making date seed oil a rich source of diverse fatty acids with potential health benefits [16,24]. Additionally, as per the findings of Murthy et al. [25], stearic acid constitutes a significant portion (11.67%) and is identified as one of the primary fatty acids present in date seeds.

Studies have shown that the specific composition of fatty acids in date seed oils can vary based on factors such as date variety, ripening stage, and extraction method. This variation results in date seed oil containing approximately 50% saturated fatty acids, 43% monounsaturated fatty acids, and 8% polyunsaturated fatty acids, offering a balanced profile of different fatty acid types [26,27]. Similar to the study conducted by Qadir et al. [22], these components were analyzed using GC-MS. The GC-MS is an analytical process involving the conversion of a 40 mg oil sample into methyl esters through a series of steps. Initially, 1 mL of n-hexane was added to the oil, followed by the addition of 200 µL of sodium methoxide (2 M). Maintaining the mixture at 50 °C for 1 hour was followed by the addition of

200 μL of HCl (2 M), and 0.5 mL of distilled water was subsequently added. The resulting fatty acid methyl esters were dissolved in pure hexane, and a 1 μL aliquot was injected into GC-MS for detailed analysis [26].

Moreover, studies conducted on Iranian and Tunisian dates highlight a prevalence of unsaturated over saturated fatty acids, with oleic acid emerging as the primary unsaturated fatty acid, ranging from 41% to 48% [24]. The Deglet Nour cultivar is characterized by a dominance of lauric acid (17.8%) among saturated fatty acids, while the Allig cultivar exhibits a higher proportion of linoleic acid (15%). Despite a lower degree of unsaturation compared to common olive oils, date seed oil stands out as a valuable source of oleic acid, comparable to rice bran oil [28]. Additionally, trace amounts of other fatty acids, including capric (C10:0), palmitoleic (C16:1), linolenic (C18:3), and gadoleic (C20:1) acids, are detected [24].

The fatty acid content in date seeds ranges from 53.2–58.8%, highlighting their significance as a source of unsaturated fatty acids, particularly oleic acid (42.3%) and linoleic acid (13.7%) [29]. Oils with elevated oleic acid content are of great interest due to their high stability and nutritional importance. Oleic acid, known for its preventive effects on cardiovascular diseases and cholesterol reduction, is considered crucial for human health [24,30]. Furthermore, date seed extracts, particularly in the form of whole fruit syrup (date honey), exhibit antimicrobial activity, emphasizing their potential in functional food and pharmaceutical applications [31].

2.2. Amino acid composition

The amino acid composition of date seeds, as highlighted in various studies, demonstrates notable variations depending on the date cultivar being examined as shown in Table 1. In one instance, the date seed was found to be rich in specific amino acids, with notable concentrations of glutamic acid (16.44 g/100 g), phenylalanine (5.93 g/100 g), and leucine (6.10 g/100 g) [16]. In another study, major non-essential amino acids were reported to include aspartic acid (1.72 g/100 g), alanine (1.2 g/100 g), and tyrosine (1.2 g/100 g) [32]. Conversely, essential amino acids, determined through an automatic amino acid analyzer, were identified as leucine (1.7 g/100 g), lysine (1.1 g/100 g), and phenylalanine (1.08 g/100 g) [32].

In the study conducted by Shina et al. [32], major non-essential amino acids were identified through the use of an automatic amino acid analyzer. The concentrations of specific non-essential amino acids were reported as follows: aspartic acid at 1.72 g/100 g, alanine at 1.2 g/100 g, and tyrosine at 1.2 g/100 g. The analysis also involved determining the concentrations of essential amino acids using the same automatic amino acid analyzer. The reported concentrations for essential amino acids were leucine at 1.7 g/100 g, lysine at 1.1 g/100 g, and phenylalanine at 1.08 g/100 g.

The automatic amino acid analyzer mentioned is a specialized instrument designed for precisely determining the concentration of individual amino acids in each sample. This type of analytical tool plays a crucial role in providing accurate and detailed information about the amino acid composition of the samples under investigation [33]. To prepare the sample for analysis, a 100g portion underwent hydrolysis in a sealed tube with 10 mL of 6M HCl, then subjected to a temperature of 110 °C in an oven for 24 hours. Subsequently, excess acid was removed through evaporation in a vacuum evaporator under reduced pressure at 78 °C. The resulting residue, now free of HCl, was dissolved in 4 mL of loading buffer with a pH of 2.4 and a concentration of 0.2 M. This prepared solution was then employed for injection into the designated apparatus [32].

Table 1. Amino acid composition of different date seed cultivars.

Date seed cultivars	Extraction methods	Analytical methods	Amino acid	Concentration (g/100g protein)	References
Barheewas	Not identifed	High-Performance Liquid Chromatography (HPLC)	Glutamic acid Leucine phenyl alanine Isoleucine Lysine Alanine	16.44 6.10 5.93 2.88 2.37 4.24	[34]
Dabino	250 mL distilled water	Amino acid analyzers (ion exchange liquid chromatography)	Leucine Lysine Phenylalanine Alanine Aspartic acid Glutamic acid	1.70 1.10 1.08 1.20 1.72 0.80	[32]
Deglet Nour Allig	Lyophilised water extraction	Sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE)	Glutamic acid Glutamic acid	0.0096 0.0107	[35]

Moreover, the amino acid profiles of date seeds from the Deglet Nour and Allig varieties were investigated by Bouaziz et al. [35], they described how Sodium Dodecyl Sulphate-Polyacrylamide Gel Electrophoresis (SDS-PAGE) protein profiles were obtained for Allig and Deglet Nour from extracts of date seeds that were lipid-extracted. The protein profiles of both extracts were similar, revealing three principal bands with a molecular weight of around 70 kDa, 60 kDa, and 32 kDa as shown in Figure 2. These protein bands could be albumins, globulins, glutelins, and/or prolamin, which are all soluble in alkaline solutions.

SDS-PAGE is a widely used technique in biochemistry and molecular biology for the separation and analysis of proteins based on their molecular weight [36]. An advantage of this technique is the enhanced visibility of protein bands, allowing for more accurate molecular mass calculations. However, it presents a disadvantage as it hinders the precise estimation of the molecular mass ofproteins. Additionally, the method poses challenges in effectively separating both small molecular mass proteins and proteins with similar molecular mass [37].

Furthermore, the potential health benefits of non-proteogenic amino acids are present in date seeds. These amino acids, such as γ-amino-n-butyric acid and 1-aminocyclopropane-1-carboxylic acid, have been associated with the ability to bind with antibodies, produce T lymphocytes, eliminate toxic compounds in the liver, and reduce creatinine levels in the body. These findings underscore the multifaceted nutritional and potential therapeutic aspects of date seeds [38,39].

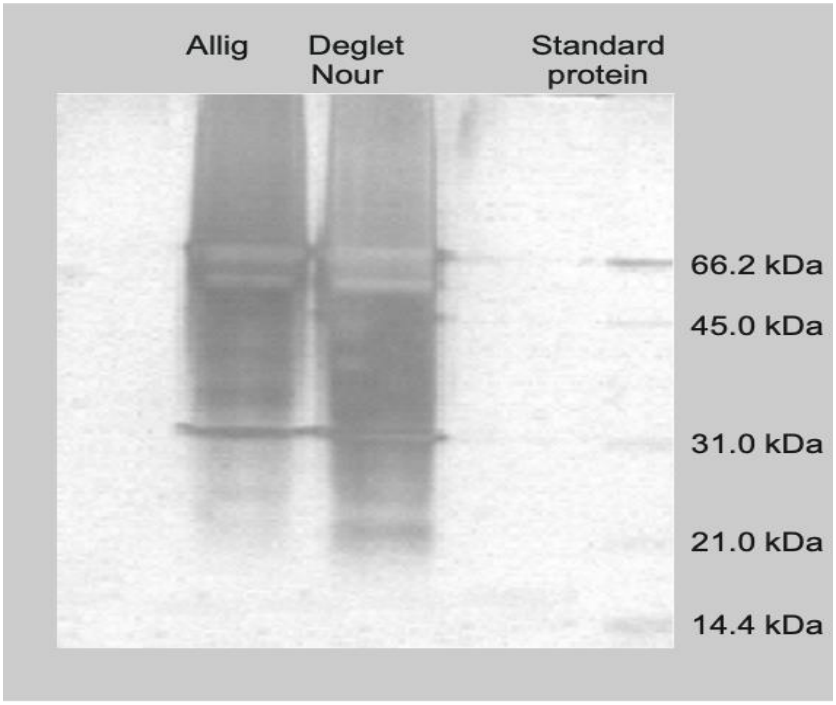

Figure 2. Electrophoretic profile of soluble protein from Allig and Deglet Nour date seed. This result was generated by (Bouaziz et al. [35]).

2.3. Fiber compounds

Date seeds are indeed a rich resource of dietary fiber, constituting around 15% of their composition. Notably, these seeds boast a significant presence of water-insoluble mannan fibers, making them stand out as a valuable source of functional dietary fibers. Surpassing the fiber levels found in cereals, date seeds offer a robust nutritional profile [40].

In comparison with other grains such as yellow corn and barley, date seeds exhibit a superior fiber content. The values range impressively, showcasing their richness in various fiber components: 39.6% to 57.5% for acid detergent fiber, 51.6% to 75.0% for neutral detergent fiber, 12.0% to 17.5% for hemicellulose, 26.1% to 42.5% for cellulose, and 7.21% to 11.0% for lignin. This signifies a substantial advantage in dietary fiber content over traditional grains [41]. Furthermore, the overall dietary fiber in date seeds reported an impressive 58%, of which 53% exists as insoluble dietary fiber in the form of lignin, cellulose, and hemicelluloses [42]. The carbohydrate profile of date seeds leans heavily towards insoluble fiber, with the renowned Deglet Nour seeds containing approximately 50% cellulose and 20% hemicellulose [40]. Moreover, investigations into different date varieties reveal a range of dietary fiber levels, reaching as high as 65% to 69% in certain cases. The milling process also influences the fiber content, with coarsely milled date seeds showcasing an impressive 80% dietary fiber, while finely milled seeds retain about 71%. These findings suggest that date seeds, with their high fiber content, can be beneficial for addressing intestinal complaints [43]. Notably, when date seeds are properly milled, they can function as a rich source of fiber without adversely affecting the sensory quality of end-products [44].

Beyond their culinary potential, the remarkable fiber content in date seeds makes them an enticing candidate for various food applications. This, coupled with their potential health benefits due to

antioxidants, underscores their versatility and possible therapeutic implications for conditions such as diabetes, obesity, and hyperlipidemia. In essence, date seeds emerge as a nutritious and functional addition to dietary choices, offering both gastronomic and potential health advantages [41–44].

2.4. Phenolic compounds

Phenolic compounds are produced as secondary metabolites via the shikimic acid and phenylpropanoid pathways. These compounds exhibit various bioactive properties. Despite not being considered nutrients, their presence in the diet contributes to health-protective effects and acts as antioxidants [45,46].

Date seeds have a substantial number of phenolic compounds. The data revealed that the methanolic extract of date pits contained 24.84 mg of phenolic compounds per gram. High-performance liquid chromatography (HPLC) analysis of the date seeds extract identified six phenolic compounds. Among them, gallic acid emerged as the most abundant, with a concentration of 11.85 mg per gram, while caffeic acid exhibited the lowest content at 0.05 mg per gram of dry weight [47]. This differed from the study of Barakat et al. [48], who found caffeic acid to be one of the major phenolic compounds after protocatechuic acid and rutin. These compounds represented 37%, 21%, and 17% of the total phenolic content (TPC), respectively. Using the same analytical method, HPLC, other studies have examined the phenolic profiles of water extracts from three different date seeds: Aseel, Karbalaen, and Khupro. These investigations identified eight phenolic compounds, including gallic acid, caffeic acid, p-coumaric acid, vanillic acid, catechin, epicatechin, chlorogenic acid, and sinapic acid in date seeds as shown in Table 2. Aseel exhibited the highest phenolic content, followed by Karbalaen and Khupro date seeds, respectively [49].

Table 2. Individual Phenolic Compounds: Identification and quantification.

Phenolic compounds	Concentration (mg/kg)		
	Aseel	Karbalaen	Khupro
Gallic acid	210.4	246.08	572.46
Catechin hydrate	109.1	178.4	108.48
Chlorogenic acid	16.86	45.09	16.49
Epicatechin	6.98	38.68	39.07
Caffeic	1.62	4.69	4.11
Vanillic acid	4.64	11.61	8.98
Sinapic acid	36.65	39.31	Not detected
p-Coumaric acid	14.25	5.33	5.68

This table presents the identification and quantification of each phenolic compound found in Aseel, Karbalaen, and Khupro date seeds, and this information is obtained from Majid et al. [49].

Previous studies have concurred on employing the HPLC technique for analyzing phenolic and other compounds in date seeds. This preference is attributed to the fact that HPLC, formerly known as high-pressure liquid chromatography, is a fundamental analytical method utilized for the separation, identification, and quantification of specific components within mixtures, especially in pharmaceutical and biological samples [50]. It is acknowledged as the most versatile, secure, reliable, and expeditious chromatographic technique [51].

In another study, the investigators compared the concentrations of various compounds in three different date seed varieties: Ajwa, Hallawi, and Aseel. Among these varieties, Ajwa exhibited the highest levels of Chromatotrophic acid (54.77 ± 2.11 mg/kg), Gallic acid (175.13 ± 7.45 mg/kg), Chlorogenic acid (82.88 ± 3.87 mg/kg), and Ferulic acid (61.46 ± 2.81 mg/kg). The Aseel variety exhibited the lowest concentrations among the three varieties for these phenolic compounds with abundances of Chromatotrophic acid (19.6 ± 0.88 mg/kg), Gallic acid (105.58 ± 4.26 mg/kg), Chlorogenic acid (35.56 ± 1.45 mg/kg), and Ferulic acid (24.44 ± 1.22 mg/kg) respectively. Furthermore, this date seed extract contained moderate amounts of the phenolic compounds Syringic acid, p-Coumaric acid (10.22 ± 0.46 mg/kg) and m-Coumaric acid (15.45 ± 0.74 mg/kg), and also vitamin C (29.31 ± 1.33 mg/kg) [52].

According to (Ahmed et al. [52]), Ajwa date seed powder had the highest phenolic content compared to other varieties. The variation in polyphenolic content in other varieties examined might be due to the stage of fruit development. As the date fruit matures, the polyphenolic content decreases with maximum polyphenol content at the unripe stage and minimum at the ripe stage. This decrease is due to the oxidation and enzymatic browning of polyphenols that results in the production of secondary products [53]. The high polyphenol content in Ajwa may also be due to the favorable conditions for date cultivation in the region. Iranian date palm seed has a relatively high antioxidant activity due to the contribution of phenolic compounds [54]

Previous research has established a correlation between TPC and antioxidant capacity [55]. Synthetic antioxidants are not only expensive but also pose potential harm and exhibit higher immunogenicity compared to naturally occurring phenolics. Omani date seeds, in particular, have shown elevated TPC and antioxidant capacity in contrast to other varieties of date seeds [56]. It is worth noting that in 2022, a study was conducted to enhance the extraction of date seed phenols by applying hydrothermal treatment at 160 and 180 degrees for 60 minutes. The elevated temperatures facilitate the solubilization of a significant quantity of phenolic compounds, allowing the extraction of a phenol-rich solution with high antioxidant activity [57].

2.5. Minerals and vitamins compounds

For metals, atomic absorption spectrometry stands out as an exceptionally sensitive technique for elemental analysis. This method involves measuring the reduction in the intensity of optical radiation after it passes through a cell containing gaseous atoms, enabling precise metal determination in various samples at the picogram level [58–60]. Researchers utilized this technique to identify minerals in date seeds, revealing that date seeds serve as a rich source of sodium, magnesium, potassium, calcium, phosphorus, and iron [61,62]. The mineral concentrations (mg/L) in four date seed samples, namely Ami, Taboni, Raht, and Omvitity, for copper, chromium, and cadmium, were found to be low, ranging between 0 and 0.434 mg/L. The copper concentrations for each sample were as follows: Ami (0.228 mg/L), Taboni (0.293 mg/L), Raht (0.180 mg/L), and Omvitity (0.434 mg/L). These results indicate a minimal presence of these minerals in the analyzed date seed samples. These elements are known to be toxic to human health when their concentrations are high in food matter [63]. For instance, figs and dates share similar nutritional values [64]; however, when comparing the copper concentration in their seeds, it becomes evident that fig seeds (Bourqui 2210 sample) contain 27.43 ± 0.48 mg/kg, a significantly higher amount than that found in date seeds [65].

However, the potassium, sodium, and calcium contents in date seeds are lower compared to date

fruit [61]. Date seeds have a relatively high potassium content compared to sodium [61,62]. The presence of sodium and potassium in the body is beneficial for various intercellular activities, maintaining osmotic balance in body fluids, preventing excessive fluid loss, and playing a role in muscle cell contraction and nerve impulse conduction. The sodium-to-potassium ratio in the body also has a significant effect in patients with cardiovascular disease [61]. Additionally, the sample was found to be relatively rich in iron, which is crucial for red blood cell formation. The phosphorus and calcium content in date seeds (19.32 mg/100 g and 18.20 mg/100 g, respectively) is relatively high and these minerals are important for bone formation and development, and both phosphorus and calcium play crucial roles in metabolism [62]. Other minerals include boron, cobalt, copper, phosphorus, fluorine, selenium, and zinc [16,66]. Furthermore, date seed and fruit extracts are good sources of vitamins A, B, C, E, and folate [29,67].

Additionally, in research conducted by Bijami et al. [68], to evaluate the mineral content and phenolic profile of the Mozafati seeds, with a particular focus on different developmental stages, alterations in mineral levels were examined at four-week intervals spanning from 4 to 16 weeks after pollination. calcium, potassium, magnesium, and manganese exhibited a decline from 4 to 16 weeks after pollination. In contrast, the concentrations of phosphorus, zinc, and iron showed an increase from 4 to 12 weeks after pollination, followed by a decrease at 16 weeks after pollination. At 16 weeks after pollination, the macronutrient concentration exhibited the following relative order: Calcium < Phosphorus < Potassium < Magnesium, while for micronutrients, the sequence was Iron < Zinc < Manganese < Copper.

3. DS Compound development into various industries and sectors

Date seeds are a rich source of valuable ingredients, as shown by chemical studies [69–71,12]. Date seeds are rich in carbohydrates, fiber, proteins, oils, natural antioxidants, and biologically active polyphenols, which are secondary metabolites in plants that are related to the prevention of inflammation processes, cancer, cardiovascular, and neurodegenerative diseases [72,73]. Despite all these beneficial constituents, date seeds are widely referred to as a waste product. In recent years, research has focused on the possibility of using date seeds commercially in various fields and sectors such as clinical settings [74], nutraceuticals [29] and cosmeceuticals, aquaculture [75], and others. The following is a discussion of the results of the various research studies on the use of date seeds in different sectors of application.

3.1. Nutraceuticals

There are various studies on the use of date seeds in foods, where date seeds were used in hot drinks, bakery products, and meat products as shown in Figure 3.

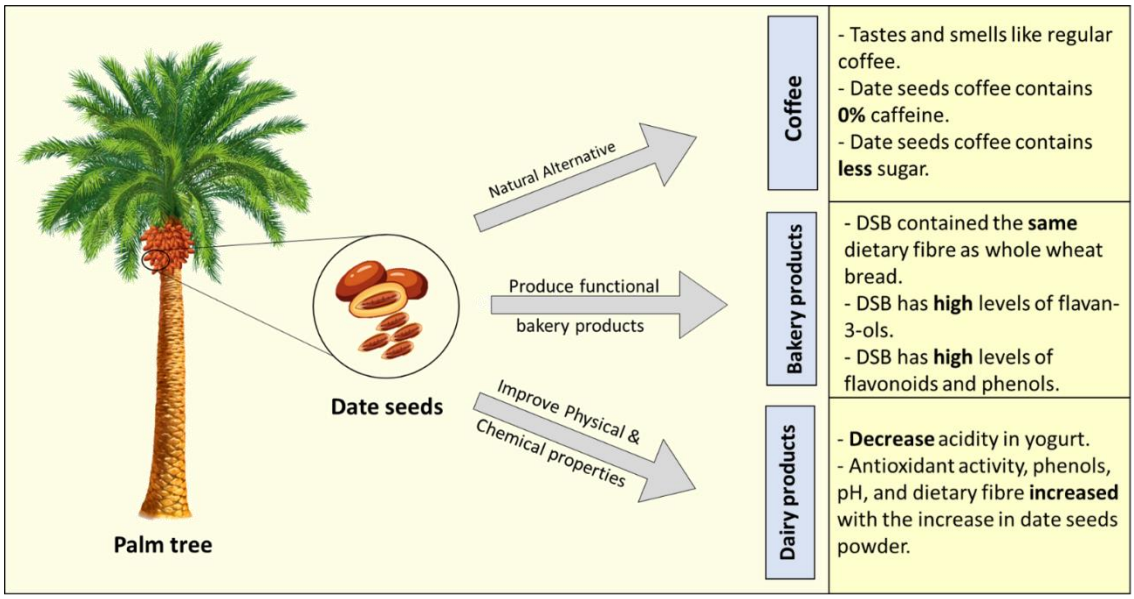

Figure 3. Innovative uses of date seeds in nutraceutical. This figure shows the different innovative uses of date seeds in nutraceuticals that will turn the date seeds from waste into a functional food ingredient. DSC: Date seed coffee; DSB: Date seed bread.

3.1.1. Hot beverages (Coffee)

The nature of date seed is similar to the nature of Arabica coffee [76]. Arabica coffee has been an essential part of Arab culture for centuries, symbolizing generosity and kindness [77]. From a scientific point of view, regular coffee consumption affects the blood flow to the heart muscle and can lead to cirrhosis of the liver, depression, hearing disorders, and cognitive disorders because it contains a high amount of caffeine [78]. Therefore, there is a desire for a natural alternative that tastes and smells like coffee but poses no health risks. Roasted date seeds are now used in the preparation of hot beverages, the most important of which is coffee, and can partially or completely replace regular coffee [76]. In a study conducted by Venkatachalam and Sengottian date seed powder roasted at a temperature of 125 degrees Celsius for 30 minutes was tested. Using Fourier-transform infrared spectroscopy, date seeds were found to contain 0% caffeine, while regular coffee contains 20–40% caffeine. The study also showed that the appropriate proportion for the use of roasted date seed powder is 9% and is suitable as a substitute for regular coffee [79]. In another study by Fikry and his associates, it was found that the optimal conditions for roasting date seed powder are 199.9 degrees Celsius and a duration of 21.5 minutes, based on their physical, chemical, and organic properties [80].

Spices, herbs, or milk can also be added to date-seed coffee to enhance flavor. In 2012, Abdillah and Andriani made a hot and healthy drink by mixing date seed preparation and ginger. This drink was a viable alternative to regular coffee because it was caffeine-free and cheaper [81].

3.1.2. Bakery products

Scientists are now focusing on fortifying bakery products with functional and sustainable food ingredients [82]. Dietary fiber has been quantified in date seeds, making them an attractive food

ingredient for use in baked goods [76]. The introduction of date seeds in bakery products will help to produce functional bakery products that meet consumer needs and industry standards, leading to a reduction in the environmental impact caused by the production of date seed waste [82].

Carine Platat and colleagues compared pita bread made with date seed powder to pita bread made with whole wheat flour. The flour was replaced with date seed powder in varying concentrations. The result was that the pita bread made with date seed powder contained the same dietary fiber as the whole wheat bread. Interestingly, the pita bread made with date seed powder contains particularly high levels of flavan-3-ols, flavonoids and phenols [83]. In another study, the effect of adding date seed water-soluble polysaccharides and hemicellulose to wheat bread was tested. The result of this study was that the addition of 0.75% date seed hemicellulose to low-quality wheat flour increased the quality of wheat bread by improving the paleography of the bread dough [84].

The use of date seeds in baking is not limited to bread, powdered seeds are also used to enrich other products such as biscuits, cookies, cakes, and chaboura. For example, date seed powder has been used to enrich cookies by adding it alone or as a mixture with other ingredients to achieve the desired functional value [85]. Abushal and colleagues found that adding date seed powder to cookies at a percentage of 5–15% helped to increase the dietary fiber content to 15% of the required daily nutritional value [86].

3.1.3. Dairy products

Date seed powder can be added to foods to improve their physical and chemical properties. In Hanan's study, yogurt samples were prepared with different proportions of date seed powder to improve nutritional value and acceptability. During 21 days at a temperature of 4 °C, physiochemical properties such as pH, titratable acidity, synerase, minerals, dietary fiber, total phenolic content, antioxidant activity, and sensory evaluation were studied. The results showed a decrease in acidity with increasing amount of date seed powder. In contrast, antioxidant activity, phenols, pH, and dietary fiber increased with the increase in date seed powder. Surprisingly, the yogurt prepared with 3% date seed powder had the same appearance, texture, taste, consistency, and overall acceptability as the control yogurt; however, acceptability was reduced for yogurt prepared with more than 3% date seed powder [87].

In a separate study that showed similar results, the sensory and textural properties of processed cheese spread with the addition of roasted date seed powder were investigated. The results showed that the date seed powder increased the solids and dietary fiber content of the cheese, while there were only minor differences in fat, dry matter, and protein content. The pH also increased with the addition of date seed powder, while it decreased with increasing storage time. Thus, the study showed that roasted date seed powder has the potential to confer cheese with high-quality characteristics while maintaining sensory acceptability [88].

3.2. Clinical setting

Studies have shown that eating a diet rich in plant material such as fruits and vegetables helps reduce the risk of chronic diseases such as coronary heart disease, cardiovascular disease, diabetes mellitus, cancer, and infections, and also slow the effects of aging [89,90]. This is due to the presence of an ideal blend of beneficial phytochemicals such as fiber, phenolic compounds, and natural

antioxidants such as vitamins E, C, and beta-carotene. Seeds including date seeds contain those ingredients making them a good ingredient for inclusion in functional [91,92]. Date seeds may have value in augmenting the nutrient composition of the diet to support good health, and directly slowing the progression of pathological conditions.

3.2.1. Anti-hyperglycemic activity

T2DM is a metabolic disorder resulting from a lack of or poor control of glucose levels in the blood [93]. Date seeds can lower blood glucose levels in patients with hyperglycaemia and yet do not affect the blood glucose levels in healthy people. The possible reason for this is the presence of active compounds such as polyphenols and phenols. These compounds reduce free radical oxidation and lipid peroxidation in cell membranes, repair pancreatic cells, and inhibit pancreatic lipase, α-amylase, and β-glucosidase [94,95].

In vitro, the effect of polyphenols contained in date seeds on glucose uptake was tested in 3T3-L1 and C2C12 myelin cells. The cells used were treated with specific proliferation media for differentiation. Glucose was used to check the glucose level in the cells. The results showed an increase in the upregulation of phospho-AMPK in 3T3-L1 cells and an increase in the upregulation of glucose transporters, which contributed to an increased uptake of glucose by the cells, raising the possibility that date seeds act as anti-hyperglycaemic agents [96]. In addition, Mahdi and his co-workers observed 24 patients with T2DM over an 8-week period who were given 8 g of date seed powder per day. The consumption of date seed powder as a functional food helped T2DM patients improve their metabolism, oxidative stress, inflammation, metabolic endotoxin, and mental health [97].

3.2.2. Anti-Tumor activity

Numerous studies have been conducted to verify the efficacy of using date seed extracts to treat malignant tumors. Hilary and his colleagues demonstrated the anti-tumor potential of date seeds through the induction of apoptosis. A panel of cancer cell lines including MCF-7, MDA-MB-123, Hep-G2, Caco-2, and PC-3 were treated with date seed extract at a concentration of 50–3000 μg/mL for 24, 48, and 72 hours. The antitumor activity was tested by cell viability assay and PARP cleavage assay. Experimental results showed that the viability of MCF-7 and Hep-G2 cells treated with date seed extracts decreased viability after 48 hours. While date seed extracts did not show significant cytotoxicity in MDA-MB-123, Caco-2, and PC-3 cell lines at clinically relevant doses (<1000 μg/mL) [96].

However, the results of another study showed that date seed extracts have an antitumor effect on MDA-MB-123 cells. In the study conducted by Khattak et al. on MDA-MB-123 cells derived from breast cancer tissue, seed extracts from three date fruit varieties (Khalas, Abu-Maan, and Mabroom) were tested. Date seed extracts were found to have toxic effects on MDA-MB-123, cancer cells and significantly alter their shape. The maximum effect was observed at a concentration of 2.5 mg/mL after 72 hours [98].

One study investigated the activity of a methanolic extract of date seeds for its apoptotic potency on human colon cancer cells. HT29 cells were cultured and treated with date seed extracts at concentrations of 100, 200, and 400 μg/mL. Surprisingly, the results showed that date seed methanolic extract did not induce apoptosis in HT29 cells. Moreover, the apoptosis rate in the control group, which received no treatment, was higher than that of the cells treated with the methanolic extract suggesting

a growth-supporting activity [99].

Exposure to high-energy radiation, such as γ-rays, can lead to DNA damage that promotes the development of cancer [100]. Therefore, the radioprotective effect of date seed extracts on whole-body γ-radiation was investigated. Davood et al. first studied the toxicity of date seed extracts in 60 mice and divided them into 5 injection groups, with each group receiving a dose of 100, 200, 300, 400, and 500 mg/kg of date seed extract. Mortality and weight loss were determined in all mice over 30 days. Then, the radioprotective effect of the extracts of date seeds was investigated in a laboratory experiment on 36 mice, which were divided into 3 groups: The control group, test group (received 500mg/kg date seed extract half an hour before irradiation), and placebo group. Then, each group was irradiated through cobalt-60 exposure. The results showed that there were no deaths among the mice fed the extract; thus, the date seeds had no toxicity. Surprisingly, the number of surviving irradiated mice with and without injection of date seed extracts was 81% and 41%, respectively, indicating a significant difference ($P = 0.035$) and protective effect [101].

3.2.3. Anti-microbial activity

Date seeds have constituents that are antimicrobial and can penetrate the cytoplasmic membrane of bacteria, and this property can be exploited for clinical application [102]. Significant antibacterial activity of date seed ethanol extracts was found against *Escherichia coli*, *Klebsiella pneumoniae, Salmonella typhimurium, Bacillus subtilis*, and *Shigella flexneri* [103]. In addition, the potential antibacterial activity of ethyl acetate extract was observed against several Gram-positive and Gram-negative pathogens. In terms of potency, methicillin-resistant *Staphylococcus aureus* strains were more sensitive to date seed ethyl acetate extract, followed by *Escherichia faecalis*, while Gram-negative bacteria (*E.coli* and *P. aeruginosa*) were less sensitive to this extract [104].

The active properties and phenolic content of Agua date seeds were studied to investigate the antibacterial activities of these compounds. The inhibitory activity of gallic acid from purified date seeds on both Gram-positive and Gram-negative bacteria was found. The growth of *S. aurues* cells was completely inhibited at a concentration of 200 μg/mL for 6 hours. It is noteworthy that gallic acid can also be used as an antimutagenic agent against *S. typhimurium* with the greatest antimutagenic effect observed on *S. typhimurium* TA98 [105].

In a study conducted by Saddiq et al, the effect of date seed extracts on the inhibition of *K. pneumonia* was found to be similar to that of the antiviral cefotaxime, where the zone of inhibition was 16.351 ± 0.00 and 10.00 ± 0.32 mm, respectively. In contrast, the effect of the antibiotic colistin was less than that of date seed extracts, reaching 0.833 ± 0.211 and 0.533 ± 0.021 mm for *K. pneumonia* and *E. coli*, respectively [106].

3.3. Cosmeceuticals

Within the cosmetics realm, organic ingredients take precedence over synthetic counterparts due to their widespread popularity, overall safety, superior quality, cruelty-free nature, and often heightened efficacy. Extensive research has substantiated the efficacy of date seed components in cosmetics, demonstrating their ability to enhance skin moisture and elasticity, while also mitigating issues such as dark spots, acne, melanin, and eczema, as depicted in Figure 4 [107].

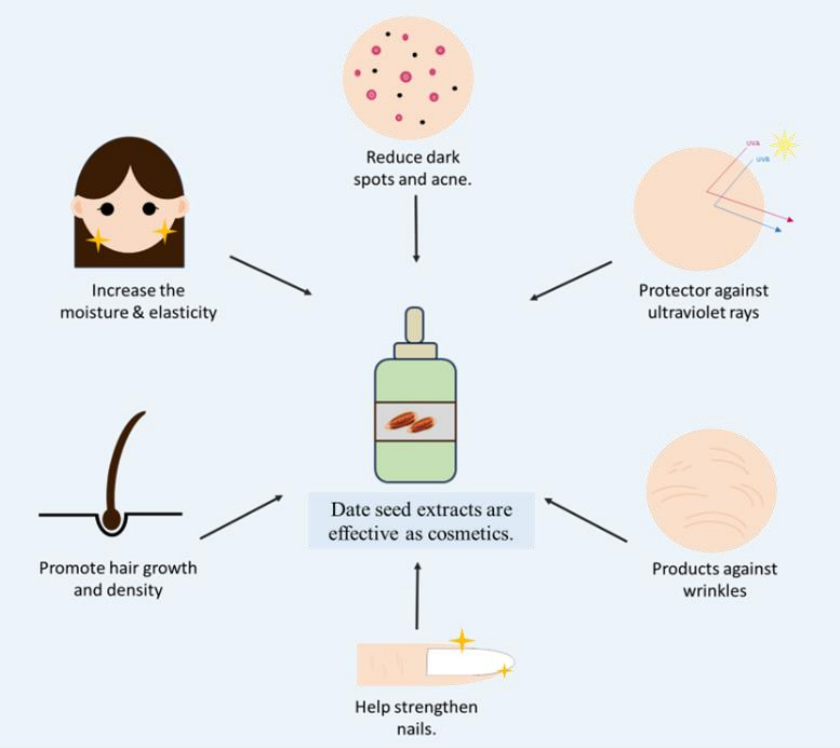

Figure 4. Effect of adding date seed powder on cosmetics products. Modified from [107].

Date seeds harbor biologically active compounds that effectively thwart the formation of free radicals responsible for skin damage. Furthermore, preparations derived from date seeds serve as insulators and shields against ultraviolet rays, addressing prevalent skin issues such as sunburn, wrinkles, premature aging, and the risk of skin cancer. [108].

Herbal extracts contribute to hair care by promoting growth and density while serving as anti-stick and anti-dandruff agents [109]. The study by Hong et al. highlights the presence of phenolics and procyanidin flavonoid compounds in date seed extracts, offering skin protection and improving hair health through the stimulation of hair follicles [110]. Date seed extracts, as identified in cosmetic products, contain vitamins B and E [16]. These vitamins play a crucial role in fortifying hair and nails. Vitamin E specifically fosters scalp skin cell growth, safeguards nails from aging and enhances moisture levels, resulting in a healthy and robust appearance [111].

3.4. Aquaculture

Aquaculture makes an important contribution to meeting the needs of fish and aquatic life, so supporting the conservation of marine and fluvial species [76]. In addition, foods derived from aquatic animals are rich in health benefits for humans and aquaculture can reduce reliance on harvesting from wild populations. Dietary benefits obtained from fish and aquatic animals from aquaculture include high-quality omega-3 polyunsaturated fatty acids, which are found in the low-calorie dietary fats of fish, as well as high-quality protein, vitamins, and minerals [112,113]. More recently, aquaculture has diversified, with more than 40% of the world's fish, shellfish, algae, and aquatic plants consumed in the human diet being grown in a variety of managed freshwater, brackish water, and marine

environments, including in low-income countries, to achieve sustainable global food security [113–115]. In 2017, Asia was the largest producer of aquaculture, accounting for 92% of the live weight of livestock and seaweed globally [116].

The overuse of medications in aquatic animal husbandry, whether for prevention or treatment of diseases caused by bacteria and microorganisms, has resulted in these bacterial species developing resistance to antibiotics [117]. Feeding and maintaining aquatic animals is dependent on the availability of an economic protein source. The current sources of protein available to aquaculture are animal and plant in origin, and due to the increasing demand for these types of proteins, likely, these sources will likely not be able to meet the increasing demand for the production of fish feed [30]. It is expected that the demand for aqua feed will increase to 37.4 million tons by 2050 [118]. Therefore, due to the high cost of production and limited availability of resources, experts aim to develop aquatic feeds to promote the growth of capital at a low cost. Date seeds can be an alternative to conventional animal and vegetable proteins. Using date seeds in aquatic feeds reduces production costs, increases the growth rate of fish and aquatic organisms, maintains sustainable aquaculture, reduces bacterial infection rates in fish, and achieves food security [30,119].

Various studies have been reported on the use of date seeds as a dietary supplement in aquatic feeds, investigating the effects of date seed extract use on body composition, lipid peroxidation, tissue quality, and other aspects in various fish species such as common carp, African catfish, gilt-head seabream, and Nile tilapia. Table 3 shows the details of the various studies on the use of date seeds in aqua feed.

In the study by Mohammadi et al. [120] the total volatile nitrogen test was used to evaluate the use of date seed extracts as a dietary supplement for common carp (*Cyprinus carpio*). The common carp belongs to the Cyprinidea family. It lives in freshwater and is widely distributed in the weedy waters of large lakes and rivers in Asia and Europe [121]. They began by rearing juvenile carp weighing about 32 g in freshwater, and the carp were observed and studied over a period of 60 days. Date seed extracts were added to the fish feed at different dosages of 0.5%, 1%, 2%, and 4% and compared with the control group. The results showed that supplementation of carp with just 0.5% date seed extract improved the quality of body composition. On the other hand, increasing the concentration of date seed extract to more than 0.5% helped to further maintain the body composition and improve the nutrient balance in the fish feed [112]. Similarly, the effect of date seed extracts on the growth and immune physiology of the same fish species at the same doses was studied. As for immunophysiology, the hematological values of the number of leukocytes, neutrophils, lymphocytes, and monocytes increased with increasing concentration of date seed extract in fish feeds. In addition, it was found that chemiluminescence reaction, lysozyme activity, total protein, and albumin were high in all groups fed with date seed extracts [120].

A study looking at the possibility of introducing date seeds as an addition to aquatic feeds was conducted on a group of African catfish (*Clarias gariepinus*). The results after 70 days showed that the indicators of weight gain, specific growth rate, protein efficiency ratio, and protein yield were much higher in date seed-fed fish than in the control fish [117].

A recent study conducted in Tunisia, where date seed powder was used in the diet of gilt-head seabream (*Sparus aurata* L.) to investigate growth performance, immunity, and antioxidant status found no significant change in growth performance, antioxidant enzyme activity, or total skin mucus antioxidant activity when gilthead seabream was fed 1.5% and 3% date seed powder as compared to gilthead seabream in the control group. However, an improvement in cellular and humoral immunity was observed in gilt-head seabream fed with date seed powder. Finally, fish fed with 1.5% date seed

powder showed an increase in serum protease enzyme activity within 30 days compared to other gilthead seabream groups [119].

Table 3. Results of inclusion of date seeds as additives in aquatic feed for various fish species.

Fish species (Scientific name)	Fish wight in the beginning	Observation period (days)	DSCs Inclusion level	Main results	References
Common carp (*Cyprinus carpio*)	32 g	60 days	0% (control), 0.5%,1%, 2%, and 4%	Fishes fed with 0.5% DSC have higher crude protein and crude lipid than the control group, while the ash and moisture increase with the ratio of the DSC diet (i.e., 1%, 2, & and 4% respectively).	[120]
		60 days		Fishes fed with 0.5% DSC show the highest levels of iron and HDL. Also, using 0.5% DSC in commercial carp feed improves fish growth and condition.	[120]
African catfish (*Clarias gariepinus*)	81.1–91.3 g	70 days	0% (control), 0.5%,1%, 1.5%, and 2%	The effect of DSCs in feed on the growth performance of African catfish and improving their health.	[117]
Gilt-head seabream (*Sparus aurata* L.)	8.2g ± 1.1 g	30 days	0% (control), 1.5%, and 3%	The addition of DSCs to fish feed strengthens the immune system of fish, preventing diseases and infections.	[119]
Nile tilapia (*Aspergillus oryzae*)	26.6.93g ± 0.01 g	60 days	0% (control), 0.5%,1%, 1.5%, and 2%	The addition of DSCs significantly affected the length of intestinal villi and the number of goblet cells, which increased digestive activity. It also improves growth and immune response.	[122]

Note: DSC: Date seed components; HDL: High-density protein.

3.5. Other applications

Because of the rich and varied constituents of date seeds, they have become the focus of interest for researchers around the world. Dr. Elnajjar investigated the use of date seeds in the fields of energy generation and chemical engineering, where the energy potential and chemical composition of date seeds were studied. Date seeds proved to be a good candidate for use as a renewable energy source and in addition, their composition suggested the possibility of using it as a raw material for the production of fuel and biodiesel [123].

Energy resources are very limited in the Mediterranean region; thus, agricultural and industrial waste is used to search for alternative resources. In the study of de la Cruz-Lovera et al., the characteristics of date palm fruits were investigated to evaluate their suitability as a new biofuel. The results showed that date seed biomass has a higher caloric value than the fruit, which is very similar to that of other biomass sources at 19.121 MJ/kg. Therefore, it is possible to use date fruit or stones as biomass in combustion [124].

In one application that helps people prepare fried potatoes at home with little fat, date seeds can be used. The effect of date seeds in reducing oil absorption in fried potatoes was studied by covering the potatoes with an aqueous solution containing hydrocolloids and phenolics extracted from date seeds at different concentrations (0.5–6%). The results showed that potato slices covered with a 4% hydrocolloid and phenolic extract from date seeds reduced oil absorption by 77.7%. Based on texture and color analysis, date seed extract-covered fries showed equal brittleness, crispiness, and lightness compared to fries coated with conventional methylcellulose [125].

4. Future outlook

Date seeds possess a unique composition that lends itself to a wide range of applications, including cooking, pharmaceutical, and cosmetic uses, as well as the production of biodiesel or bioplastics. This diverse utilization of date seeds can contribute to the economic and social development of regions involved in date fruit production and manufacturing [24]. GC-MS analysis of date seeds has revealed the presence of 40 and 27 distinct phyto-compounds in the n-hexane and methanol fractions respectively. The identification of these bioactive compounds provides compelling evidence supporting the potential use of Ajwa date seeds in future drug discovery systems, particularly in the areas of anti-inflammatory, antioxidant, cardiovascular, anticancer, and immunosuppressant activities. Further exploration of these properties can unlock their full therapeutic potential. Overall, date seeds present a valuable resource with significant industrial and medicinal prospects, showcasing their multifaceted benefits in various sectors [22].

According to (Qadir et al. [22]), date seeds contain terpenoids and steroidal compounds with significant potential for future drug discovery investigation. Notably, lanostane triterpenoids and steroidal compounds exhibit adaptogenic and anabolic properties, enhancing overall organism performance by restoring physiological processes and bodily functions under stressful conditions. Moreover, organic acids, such as octadecenoic acid, pelargonic acid, and butyl butanoic acid, along with flavonoids and esters of aromatic phenolic compounds, demonstrate various biological activities, including antioxidant, antimicrobial, and mast cell-stabilizing effects. The fractionated oil derived from date seeds holds promise for applications in cosmetics and pharmaceutical care products, owing to the presence of fatty acids like palmitic acid, stearic acid, and oleic acid. In addition, date seed oil rich in stearic and oleic acid content, can serve as an effective percutaneous absorption enhancer, facilitating the diffusion of lipophilic non-steroidal anti-inflammatory drugs commonly used in the treatment of chronic rheumatic disorders. The diverse components found in the oil, including steroids, terpenoids, organic acids, flavonoids, and esters of aromatic phenolic compounds, have the potential to augment the anti-inflammatory and analgesic potency of pharmaceutical preparations. Furthermore, dietary intake of oleic acid has shown the ability to increase high-density lipoprotein levels while reducing low-density lipoprotein cholesterol and lipid content, thereby exhibiting anti-atherosclerotic effects. Consequently, the fractionated date seed oil could be utilized by the pharmaceutical industry in the development of drug formulations for treating various cardiovascular and chronic rheumatic disorders [22].

5. Conclusions

There are numerous types of dates cultivated worldwide, each possessing unique sensory and phytochemical properties. Despite being biochemically rich, date seeds are often considered waste in the date industry. The analysis of date seeds using various analytical techniques has yielded valuable insights into their composition and potential applications. Date seed oil composition varies based on factors such as variety, ripening stage, and extraction method, with oleic, linoleic, palmitic, myristic, and lauric acids constituting over 90% of total fatty acids. Date seeds exhibit amino acid variations, including essential ones and higher sulfur content, featuring health-beneficial non-proteogenic amino acids. With a dietary fiber content of 15%, date seeds surpass traditional grains, and HPLC analysis shows a phenolic content of 24.84 mg per gram, primarily composed of gallic acid. Atomic Absorption Spectroscopy analysis reveals rich sodium, magnesium, potassium, calcium, phosphorus, and iron levels in date seeds, contributing to cardiovascular health. Date seed extracts offer vitamins A, B, C, E, folate, and essential minerals, with date seed oil being particularly rich in α-tocopherol, α-tocopheryl acetate, γ-tocopherol, and vitamin K1.

Due to the nutritional content of date seeds, considerable attention has been devoted to exploring their various uses. In aquaculture, date seed preparations have been incorporated into aquatic feeds for their protein composition and antioxidants. Date stones have found application in cosmetics, including hair, skin, and nail care products. More recently, date seeds have been utilized in the production of foods such as bread, cakes, cookies, and rusk, as well as in hot beverages, particularly coffee. From a clinical perspective, date seeds hold the potential for preventing and treating chronic diseases such as cancer, type 2 diabetes, infections, and cardiovascular diseases. The presence of phyto compounds in date seeds, encompassing terpenoids, steroidal compounds, organic acids, flavonoids, and esters of aromatic phenolic compounds, underscores their medicinal and industrial prospects. Overall, date seeds represent a valuable resource with significant potential for economic and social development in regions engaged in date fruit production and manufacturing.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

All authors declare that there are no competing interests.

References

1. Al-Okbi SY (2022) Date palm as source of nutraceuticals for health promotion: A review. *Curr Nutr Rep* 11: 574–591. https://doi.org/10.1007/s13668-022-00437-w
2. Al-Dashti YA, Holt RR, Keen CL, et al. (2021) Date palm fruit (Phoenix dactylifera): Effects on vascular health and future research directions. *Int J Mol Sci* 22: 4665. https://doi.org/10.3390/ijms22094665
3. Karimi A, Elmi A, Zargaran A, et al. (2020) Clinical effects of date palm (Phoenix dactylifera L.): A systematic review on clinical trials. *Complementary Ther Med* 51: 102429. https://doi.org/10.1016/j.ctim.2020.102429
4. Rahmani AH, Aly SM, Ali H, et al. (2014) Therapeutic effects of date fruits (Phoenix dactylifera) in the prevention of diseases via modulation of anti-inflammatory, anti-oxidant and anti-tumour activity. *Int J Clin Exp Med* 7: 483.
5. Marwat SK, Khan MA, Rehman, et al. (2009) Aromatic plant species mentioned in the holy Qura'n and Ahadith and their ethnomedicinal importance. *Pak J Nutr* 8: 1472–1479. https://doi.org/10.3923/pjn.2009.1472.1479
6. Taleb H, Maddocks SE, Morris RK, et al. (2016) Chemical characterisation and the anti-inflammatory, anti-angiogenic and antibacterial properties of date fruit (Phoenix dactylifera L.). *J Ethnopharmacol* 194: 457–468. https://doi.org/10.1016/j.jep.2016.10.032
7. Abdel S, Itimad E, Awad A (2012) Comparative study on five Sudanese date (Phoenix dactylifera L.) fruit cultivars. *Food Nutr Sci* 3: 22292.
8. Shahbandeh M (2023) Statista. Fruit date market. Available from: https://www.statista.com/topics/6326/fruit-date-market/.
9. Solo D (2023) Date Fruit Market 2023: Producers, Market Offerings, And End Use Outlook I Khoshbin Group. Available from: https://ratinkhosh.com/date-fruit-market/.
10. Elsharawy N, Al-Mutarrafi M, Alayafi A (2019) Different types of dates in Saudi Arabia and its most fungal spoilage and its most preservation methods. *Int J Sci Res* 10: 35787–35799.
11. Al-Farsi M, Lee C (2008) Nutritional and functional properties of dates: A review. *Crit Rev Food Sci Nutr* 48: 877–887. https://doi.org/10.1080/10408390701724264
12. Al-Shahib W, Marshall RJ (2003) The fruit of the date palm: Its possible use as the best food for the future? *Int J Food Sci Nutr* 54: 247–259. https://doi.org/10.1080/09637480120091982
13. Gul F, Shinwari ZK, Afzal I (2012) Screening of indigenous knowledge of herbal remedies for skin diseases among local communities of North West Punjab, Pakistan. *Pak J Bot* 5: 1609–1616.
14. Kabbaj FZ, Meddah B, Cherrah Y (2019) Ethnopharmacological profile of traditional plants used in Morocco by cancer patients as herbal therapeutics. *Am J Ethnomed* 2: 243–256.
15. El-Far AH, Oyinloye BE, Sepehrimanesh M, et al. (2019) Date palm (Phoenix dactylifera): Novel findings and future directions for food and drug discovery. *Curr Drug Discov Technol* 16: 2–10. https://doi.org/10.2174/1570163815666180320111937
16. Alkhoori MA, Kong AS-Y, Aljaafari MN, et al. (2022) Biochemical composition and biological activities of date palm (Phoenix dactylifera L.) seeds: A review. *Biomolecules* 12: 1626. https://doi.org/10.3390/biom12111626
17. Ren J, Mozurkewich EL, Sen A, et al. (2013) Total serum fatty acid analysis by GC-MS: Assay validation and serum sample stability. *Curr Pharm Anal* 9: 331–339. https://doi.org/10.2174/1573412911309040002

18. Gao L, Xu P, Ren J (2023) A sensitive and economical method for simultaneous determination of D/L- amino acids profile in foods by HPLC-UV: Application in fermented and unfermented foods discrimination. *Food Chem* 410: 135382. https://doi.org/10.1016/j.foodchem.2022.135382
19. Saraswathy N, Ramalingam P (2011) Phosphoproteomics. In: Saraswathy N, Ramalingam P (Eds.), *Concepts and Techniques in Genomics and Proteomics,* Woodhead Publishing, 203–211. https://doi.org/10.1533/9781908818058.203
20. Slavin W (1994) Atomic absorption spectrometry Flame AAS. In: Herber RFM, Stoeppler M (Eds.), *Techniques and Instrumentation in Analytical Chemistry,* Elsevier, 87–90. https://doi.org/10.1016/S0167-9244(08)70146-X
21. Yu L, Choe U, Yanfang L, et al. (2020) *Oils from Fruit, Spice, and Herb Seeds,* 1–35.
22. Qadir A, Singh SP, Akhtar J, et al. (2018) Chemical composition of Saudi Arabian Sukkari variety of date seed oil and extracts obtained by slow pyrolysis. *Indian J Pharm Sci* 80: 940–946.
23. Bolla AS, Patel AR, Priefer R (2020) The silent development of counterfeit medications in developing countries—A systematic review of detection technologies. *Int J Pharm* 587: 119702.
24. Mrabet A, Jiménez-Araujo A, Guillén-Bejarano R, et al. (2020) Date seeds: A promising source of oil with functional properties. *Foods* 9: 787.
25. Murthy HN, Yadav GG, Dewir YH, et al. (2021) Phytochemicals and biological activity of desert date (Balanites aegyptiaca (L.) Delile). *Plants* 10: 32.
26. Bouallegue K, Allaf T, Besombes C, et al. (2019) Phenomenological modeling and intensification of texturing/grinding-assisted solvent oil extraction: case of date seeds (Phoenix dactylifera L.). *Arabian J Chem* 12: 2398–2410.
27. Habib HM, Kamal H, Ibrahim WH, et al. (2013) Carotenoids, fat soluble vitamins and fatty acid profiles of 18 varieties of date seed oil. *Ind Crops Prod* 42: 567–572.
28. AL-Kahtani HA, Abdul Rahman R, Mansor TST, et al. (2013) Date seed and date seed oil. *Int Food Res J* 20: 2035.
29. Alharbi KL, Raman J, Shin H-J (2021) Date fruit and seed in nutricosmetics. *Cosmetics* 8: 59.
30. Kari ZA, Goh KW, Edinur HA, et al. (2022) Palm date meal as a non-traditional ingredient for feeding aquatic animals: A review. *Aquacult Rep* 25: 101233. https://doi.org/10.1016/j.aqrep.2022.101233
31. Bentrad N, Gaceb-Terrak R, Benmalek Y, et al. (2017) Studies on chemical composition and antimicrobial activities of bioactive molecules from date palm (Phoenix dactylifera L.) pollens and seeds. *Afr J Tradit, Complementary Altern Med* 14: 242–256. https://doi.org/10.21010/ajtcam.v14i3.26
32. Shina S, Izuagie T, Shuaibu M, et al. (2013) The nutritional evaluation and medicinal value of date palm (Phoenix dactylifera). *Int J Modern Chem* 4: 147–154.
33. Sheikh DME, El-Kholany EA, Kamel SM (2014) Nutritional value, cytotoxicity, anti-carcinogenic and beverage evaluation of roasted date pits. *World J Dairy Food Sci* 9: 308–316.
34. Bouaziz MA, Besbes S, Blecker C, et al. (2008) Protein and amino acid profiles of Tunisian Deglet Nour and Allig date palm fruit seeds. *Fruits* 63: 37–43. https://doi.org/10.1051/fruits:2007043
35. Xu W, Zhong C, Zou C, et al. (2020) Analytical methods for amino acid determination in organisms. *Amino Acids* 52: 1071–1088. https://doi.org/10.1007/s00726-020-02884-7
36. Yamanaka M (2018) Supramolecular gel electrophoresis. *Polym J* 50: 627–635. https://doi.org/10.1038/s41428-018-0033-y
37. Sharma N, Sharma R, Rajput YS, et al. (2021) Separation methods for milk proteins on polyacrylamide gel electrophoresis: Critical analysis and options for better resolution. *Int Dairy J* 114: 104920. https://doi.org/10.1016/j.idairyj.2020.104920

38. Ali HSM, Alhaj OA, Al-Khalifa AS, et al. (2014) Determination and stereochemistry of proteinogenic and non-proteinogenic amino acids in Saudi Arabian date fruits. *Amino Acids* 46: 2241–2257. https://doi.org/10.1007/s00726-014-1770-7
39. Khalid S, Khalid N, Khan RS, et al. (2017) A review on chemistry and pharmacology of Ajwa date fruit and pit. *Trends Food Sci Technol* 63: 60–69. https://doi.org/10.1016/j.tifs.2017.02.009
40. Ghnimi S, Umer S, Karim A, et al. (2017) Date fruit (Phoenix dactylifera L.): An underutilized food seeking industrial valorization. *NFS J* 6: 1–10. https://doi.org/10.1016/j.nfs.2016.12.001
41. Attia AI, Reda FM, Patra AK, et al. (2021) Date (Phoenix dactylifera L.) by-products: Chemical composition, nutritive value and applications in poultry nutrition, an updating review. *Animals* 11: 1133. https://doi.org/10.3390/ani11041133
42. Tafti A, Dahdivan N, Ardakani SA (2017) Physicochemical properties and applications of date seed and its oil. *Int Food Res J* 24: 1399–1406.
43. Niazi S, Khan I, Pasha I, et al. (2017) Date palm: Composition, health claim and food applications. 2: 9–17.
44. Idowu AT, Igiehon OO, Adekoya AE, et al. (2020) Dates palm fruits: A review of their nutritional components, bioactivities and functional food applications. *AIMS Agric Food* 5: 734–755. https://doi.org/10.3934/agrfood.2020.4.734
45. Rosa LA, Moreno-Escamilla JO, Rodrigo-García J, et al. (2019) Phenolic compounds. In: Yahia EM (Ed.), *Postharvest Physiology and Biochemistry of Fruits and Vegetables,* Woodhead Publishing, 253–271. https://doi.org/10.1016/B978-0-12-813278-4.00012-9
46. Saranraj P, Behera SS, Ray RC (2019) Traditional foods from tropical root and tuber crops: Innovations and challenges. In: Galanakis CM (Ed.), *Innovations in Traditional Foods,* Woodhead Publishing, 159–191. https://doi.org/10.1016/B978-0-12-814887-7.00007-1
47. Selim S, Abdel-Mawgoud M, Al-sharary T, et al. (2022) Pits of date palm: Bioactive composition, antibacterial activity and antimutagenicity potentials. *Agronomy* 12: 54. https://doi.org/10.3390/agronomy12010054
48. Barakat AZ, Hamed AR, Bassuiny RI, et al. (2020) Date palm and saw palmetto seeds functional properties: antioxidant, anti-inflammatory and antimicrobial activities. *J Food Meas Charact* 14: 1064–1072. https://doi.org/10.1007/s11694-019-00356-5
49. Majid A, Naz F, Bhatti S, et al. (2023) Phenolic profile and antioxidant activities of three date seeds varieties (Phoenix Dactylifera L.) of Pakistan. *Explor Res Hypothesis Med* 8: 195–201. https://doi.org/10.14218/ERHM.2022.00118
50. Malviya R, Bansal V, Pal O, et al. (2010) High performance liquid chromatography: A short review. *J Global Pharma Technol* 2: 22–26.
51. Sadaphal P, Dhamak K (2022) Review article on high-performance liquid chromatography (HPLC) method development and validation. *Int J Pharm Sci Rev Res* 74: 23–29. https://doi.org/10.47583/ijpsrr.2022.v74i02.003
52. Ahmed A, Arshad M, Saeed F, et al. (2016) Nutritional probing and HPLC profiling of roasted date pit powder. *Pak J Nutr* 15: 229–237. https://doi.org/10.3923/pjn.2016.229.237
53. Al-Shwyeh HA (2019) Date palm (Phoenix dactylifera L.) fruit as potential antioxidant and antimicrobial agents. *J Pharm Bioallied Sci* 11: 1–11. https://doi.org/10.4103/JPBS.JPBS_168_18
54. Shams Ardekani MR, Khanavi M, Hajimahmoodi M, et al. (2010) Comparison of antioxidant activity and total phenol contents of some date seed varieties from Iran. *Iran J Pharm Res* 9: 141–146.

55. Phull AR, Hassan M, Abbas Q, et al. (2018) In vitro, In silico elucidation of antiurease activity, kinetic mechanism and COX-2 inhibitory efficacy of coagulansin A of Withania coagulans. *Chem Biodiversity* 15: e1700427. https://doi.org/10.1002/cbdv.201700427
56. Saleh EA, Tawfik MS, Abu-Tarboush HM (2011) Phenolic contents and antioxidant activity of various date palm (Phoenix dactylifera L.) fruits from Saudi Arabia. *Food Nutr Sci* 2: 1134–1141. https://doi.org/10.4236/fns.2011.210152
57. Mrabet A, Jiménez-Araujo A, Fernández-Prior Á, et al. (2022) Date seed: Rich source of antioxidant phenolics obtained by hydrothermal treatments. *Antioxidants* 11: 1914. https://doi.org/10.3390/antiox11101914
58. Michalke B, Nischwitz V (2013) Speciation and element-specific detection. In: Fanali S, Haddad PR, Poole CF, et al. (Eds.), *Liquid Chromatography*, Amsterdam, Elsevier, 633–649. https://doi.org/10.1016/B978-0-12-415806-1.00022-X
59. Dai S, Finkelman RB, Hower JC, et al. (2023) Analytical methods for elements in coal. In: Dai S, Finkelman RB, Hower JC, et al. (Eds.), *Inorganic Geochemistry of Coal,* Elsevier, 3–35. https://doi.org/10.1016/B978-0-323-95634-5.00009-1
60. Butcher DJ (2005) ATOMIC ABSORPTION SPECTROMETRY | Interferences and Background Correction. In: Worsfold P, Townshend A, Poole C (Eds.), *Encyclopedia of Analytical Science (Second Edition),* Oxford, Elsevier, 157–163. https://doi.org/10.1016/B0-12-369397-7/00025-X
61. Ogungbenle HN (2011) Chemical and fatty acid compositions of date palm fruit (*Phoenix dactylifera* L) flour. *Bangladesh J Sci Ind Res* 46: 255–258. https://doi.org/10.3329/bjsir.v46i2.8194
62. Adeosun AM, Oni SO, Ighodaro OM, et al. (2016) Phytochemical, minerals and free radical scavenging profiles of Phoenix dactilyfera L. seed extract. *J Taibah Univ Med Sci* 11: 1–6. https://doi.org/10.1016/j.jtumed.2015.11.006
63. Hribesh SO (2020) Determination of some chemical composition of four date seeds from AL-Khums Libya. *IJERT* 8: 2278–0181. https://doi.org/10.17577/IJERTV8IS120326
64. Essa MM, Subash S, Akbar M, et al. (2015) Long-term dietary supplementation of pomegranates, figs and dates alleviate neuroinflammation in a transgenic mouse model of Alzheimer's disease. *PLOS ONE* 10: e0120964. https://doi.org/10.1371/journal.pone.0120964
65. Irchad A, Ouaabou R, Aboutayeb R, et al. (2023) Lipidomic profiling reveals phenotypic diversity and nutritional benefits in Ficus carica L. (Fig.) seed cultivars. *Front Plant Sci* 14: 1229994. https://doi.org/10.3389/fpls.2023.1229994
66. Hinkaew J, Aursalung A, Sahasakul Y, et al. (2021) A comparison of the nutritional and biochemical quality of date palm fruits obtained using different planting techniques. *Molecules* 26: 2245. https://doi.org/10.3390/molecules26082245
67. Al-Alawi RA, Al-Mashiqri JH, Al-Nadabi JSM, et al. (2017) Date palm tree (Phoenix dactylifera L.): Natural products and therapeutic options. *Front Plant Sci* 8: 00845. https://doi.org/10.3389/fpls.2017.00845
68. Bijami A, Rezanejad F, Oloumi H, et al. (2020) Minerals, antioxidant compounds and phenolic profile regarding date palm (Phoenix dactylifera L.) seed development. *Sci Hortic* 262: 109017. https://doi.org/10.1016/j.scienta.2019.109017
69. Guizani N, Suresh S, Rahman MS (2014) Polyphenol contents and thermal characteristics of freeze-dried date-pits powder. *Proceedings International Conference of Agricultural Engineering, Zurich,* C0296.

70. Shi LE, Zheng W, Aleid SM, et al. (2014) Date pits: Chemical composition, nutritional and medicinal values, utilization. *Crop Sci* 54: 1322–1330. https://doi.org/10.2135/cropsci2013.05.0296
71. Mrabet A, Jiménez-Araujo A, Guillén-Bejarano R, et al. (2020) Date seeds: A promising source of oil with functional properties. *Foods* 9: 787. https://doi.org/10.3390/foods9060787
72. Pandey KB, Rizvi SI (2009) Plant polyphenols as dietary antioxidants in human health and disease. *Oxid Med Cell Longev* 2: 270–278. https://doi.org/10.4161/oxim.2.5.9498
73. Pinto T, Aires A, Cosme F, et al. (2021) Bioactive (poly)phenols, volatile compounds from vegetables, medicinal and aromatic plants. *Foods* 10: 106. https://doi.org/10.3390/foods10010106
74. Saryono, Warsinah, Isworo A, et al. (2020) Anti-inflammatory activity of date palm seed by downregulating interleukin-1β, TGF-β, cyclooxygenase-1 and -2: A study among middle age women. *Saudi Pharm J* 28: 1014–1018. https://doi.org/10.1016/j.jsps.2020.06.024
75. Al-Alawi RA, Al-Mashiqri JH, Al-Nadabi JSM, et al. (2017) Date palm tree (Phoenix dactylifera L.): Natural products and therapeutic options. *Front Plant Sci* 8: 845. https://doi.org/10.3389/fpls.2017.00845
76. Al-Khalili M, Al-Habsi N, Rahman MS (2023) Applications of date pits in foods to enhance their functionality and quality: A review. *Front Sustainable Food Syst* 6: 1101043. https://doi.org/10.3389/fsufs.2022.1101043
77. Maspul K (2021) Emirati Gahwa Arabiya; a review of signature Arabic coffee in the United Arab Emirates. *Academia Letters* No.2. https://doi.org/10.20935/AL3655
78. Cornelis MC (2019) The impact of caffeine and coffee on human health. *Nutrients* 11: 416. https://doi.org/10.3390/nu11020416
79. Venkatachalam CD, Sengottian M (2016) Study on roasted date seed non caffeinated coffee powder as a promising alternative. *Asian J Res Soc Sci Humanit* 6: 1387. https://doi.org/10.5958/2249-7315.2016.00292.6
80. Fikry M, Yusof YA, Al-Awaadh AM, et al. (2019) Effect of the roasting conditions on the physicochemical, quality and sensory attributes of coffee-like powder and brew from defatted palm date seeds. *Foods* 8: 61. https://doi.org/10.3390/foods8020061
81. Abdillah L, Andriani M (2012) Friendly alternative healthy drinks through the use of date seeds as coffee powder. *Proceeding of ICEBM* 2012: 80–87.
82. Ranasinghe M, Manikas I, Maqsood S, et al. (2022) Date components as promising plant-based materials to be incorporated into baked goods—A review. *Sustainability* 14: 605. https://doi.org/10.3390/su14020605
83. Platat C, Habib HM, Hashim IB, et al. (2015) Production of functional pita bread using date seed powder. *J Food Sci Technol* 52: 6375–6384. https://doi.org/10.1007/s13197-015-1728-0
84. Bouaziz F, Abdeddayem A, Koubaa M, et al. (2020) Date seeds as a natural source of dietary fibers to improve texture and sensory properties of wheat bread. *Foods* 9: 737. https://doi.org/10.3390/foods9060737
85. Najjar Z, Alkaabi M, Alketbi K, et al. (2022) Physical chemical and textural characteristics and sensory evaluation of cookies formulated with date seed powder. *Foods* 11: 305. https://doi.org/10.3390/foods11030305
86. Abushal SA, Elhendy HA, Maged EM, et al. (2021) Impact of ground Ajwa (Phoenix dactylifera L.) seeds fortification on physical and nutritional properties of functional cookies and chocolate sauce. *Cereal Chem* 98: 958–967. https://doi.org/10.1002/cche.10437

87. Hanan AJ (2018) Evaluation of physio-chemical and sensory properties of yogurt prepared with date pits powder. *Curr Sci Int* 7: 01–09.
88. Darwish AA, Tawfek MA, Baker EA (2020) Texture, sensory attributes and antioxidant activity of spreadable processed cheese with adding date seed powder. *J Food Dairy Sci* 11: 377–383. https://doi.org/10.21608/jfds.2021.60281.1014
89. Boeing H, Bechthold A, Bub A, et al. (2012) Critical review: Vegetables and fruit in the prevention of chronic diseases. *Eur J Nutr* 51: 637–663. https://doi.org/10.1007/s00394-012-0380-y
90. Pem D, Jeewon R (2015) Fruit and vegetable intake: Benefits and progress of nutrition education interventions—Narrative review article. *Iran J Public Health* 44: 1309–1321.
91. Brouk M, Fishman A (2016) Antioxidant properties and health benefits of date seeds. In: Kristbergsson K, Ötles S (Eds.), *Functional Properties of Traditional Foods,* Boston, MA, Springer US, 233–240. https://doi.org/10.1007/978-1-4899-7662-8_16
92. Al-Farsi MA, Lee CY (2011) Chapter 53—Usage of date (Phoenix dactylifera L.) seeds in human health and animal feed. In: Preedy VR, Watson RR, Patel VB (Eds.), *Nuts and Seeds in Health and Disease Prevention,* San Diego, Academic Press, 447–452. https://doi.org/10.1016/B978-0-12-375688-6.10053-2
93. Kharroubi AT, Darwish HM (2015) Diabetes mellitus: The epidemic of the century. *World J Diabetes* 6: 850–867. https://doi.org/10.4239/wjd.v6.i6.850
94. Arshad FK, Jelani DS (2015) A relative in vitro evaluation of antioxidant potential profile of extracts from pits of Phoenix dactylifera L. (Ajwa and Zahedi Dates). *Int J Adv Inf Sci Technol* 4: 11.
95. Saryono S (2019) Date seeds drinking as antidiabetic: A systematic review. *IOP Conf Ser: Earth Environ Sci* 255: 012018. https://doi.org/10.1088/1755-1315/255/1/012018
96. Hilary S, Kizhakkayil J, Souka U, et al. (2021) In-vitro investigation of polyphenol-rich date (Phoenix dactylifera L.) seed extract bioactivity. *Front Nutr* 8: 667514. https://doi.org/10.3389/fnut.2021.667514
97. Zadeh MM, Dehghan P, Eslami Z (2023) Effect of date seed (Phoenix dactylifera) supplementation as functional food on cardiometabolic risk factors, metabolic endotoxaemia and mental health in patients with type 2 diabetes mellitus: a blinded randomised controlled trial protocol. *BMJ Open* 13: e066013. https://doi.org/10.1136/bmjopen-2022-066013
98. Khattak MNK, Shanableh A, Hussain MI, et al. (2020) Anticancer activities of selected Emirati Date (Phoenix dactylifera L.) varieties pits in human triple negative breast cancer MDA-MB-231 cells. *Saudi J Biol Sci* 27: 3390–3396. https://doi.org/10.1016/j.sjbs.2020.09.001
99. Rezaei M, Khodaei F, Hooshmand N (2015) Date seed extract diminished apoptosis event in human colorectal carcinoma cell line. *MOJ Toxicol* 1: 00017. https://doi.org/10.15406/mojt.2015.01.00017
100. Sia J, Szmyd R, Hau E, et al. (2020) Molecular mechanisms of radiation-induced cancer cell death: A primer. *Front Cell Dev Biol* 8: 41. https://doi.org/10.3389/fcell.2020.00041
101. Khezerloo D, Mortezazadeh T, Farhood B, et al. (2019) The effect of date palm seed extract as a new potential radioprotector in gamma-irradiated mice. *J Cancer Res Ther* 15: 517. https://doi.org/10.4103/jcrt.JCRT_1341_16
102. Juhaimi FA, Ghafoor K, Özcan MM (2012) Physical and chemical properties, antioxidant activity, total phenol and mineral profile of seeds of seven different date fruit (Phoenix dactylifera L.) varieties. *Int J Food Sci Nutr* 63: 84–89. https://doi.org/10.3109/09637486.2011.598851

103. Olaniyi OO, Samuel IA, Igbe FO (2022) Phytochemical content, antioxidant properties and antibacterial activities of date (Phoenix dactylifera L.) seed extracts. *J Food Saf Hyg* 8: 78–93. https://doi.org/10.18502/jfsh.v8i2.10670
104. Alrajhi M, AL-Rasheedi M, Eltom SEM, et al. (2019) Antibacterial activity of date palm cake extracts (Phoenix dactylifera). *Cogent Food Agric* 5: 1625479. https://doi.org/10.1080/23311932.2019.1625479
105. Selim S, Abdel-Mawgoud M, Al-sharary T, et al. (2022) Pits of date palm: Bioactive composition, antibacterial activity and antimutagenicity potentials. *Agronomy* 12: 54. https://doi.org/10.3390/agronomy12010054
106. Saddiq AA, Bawazir AE (2010) Antimicrobial activity of date palm (Phoenix dactylifera) pits extracts and its role in reducing side effect of methyl prednisolone on some neurotransmitter content in the brain, hormone testosterone in adulthood. *ISHS Acta Hortic* 882: 665–690. https://doi.org/10.17660/ActaHortic.2010.882.74
107. Alharbi KL, Raman J, Shin HJ (2021) Date fruit and seed in nutricosmetics. *Cosmetics* 8: 59. https://doi.org/10.3390/cosmetics8030059
108. Cherubim DJ, Martins CV, Fariña L, et al. (2020) Polyphenols as natural antioxidants in cosmetics applications. *J Cosmet Dermatol* 19: 33–37. https://doi.org/10.1111/jocd.13093
109. Patel S, Sharma V, Chauhan NS, et al. (2015) Hair growth: Focus on herbal therapeutic agent. *Curr Drug Discovery Technol* 12: 21–42. https://doi.org/10.2174/1570163812666150610115055
110. Hong YJ, Tomas-Barberan FA, Kader AA, et al. (2006) The flavonoid glycosides and procyanidin composition of Deglet Noor Dates (Phoenix dactylifera). *J Agric Food Chem* 54: 2405–2411. https://doi.org/10.1021/jf0581776
111. Dattola A, Silvestri M, Bennardo L, et al. (2020) Role of vitamins in skin health: A systematic review. *Curr Nutr Rep* 9: 226–235. https://doi.org/10.1007/s13668-020-00322-4
112. Mohammadi M, Soltani M, Siahpoosh A, et al. (2018) Effects of dietary supplementation of date palm (Phoenix dactylifera) seed extract on body composition, lipid peroxidation and tissue quality of common carp (Cyprinus carpio) juveniles based on the total volatile nitrogen test. *Iran J Fish Sci* 17: 394–402.
113. Arshad N, Samat N, Lee LK (2022) Insight into the relation between nutritional benefits of aquaculture products and its consumption hazards: A global viewpoint. *Front Mar Sci* 9: 925463. https://doi.org/10.3389/fmars.2022.925463
114. Metian M, Troell M, Christensen V, et al. (2020) Mapping diversity of species in global aquaculture. *Rev Aquacult* 12: 1090–1100. https://doi.org/10.1111/raq.12374
115. Naylor RL, Hardy RW, Buschmann AH, et al. (2021) A 20-year retrospective review of global aquaculture. *Nature* 591: 551–563. https://doi.org/10.1038/s41586-021-03308-6
116. Software for Fishery and Aquaculture Statistical Time Series Food and Agriculture Organization of the United Nations FAO. Available from: https://www.fao.org/fishery/en/topic/166235/en.
117. Sotolu A, Kigbu A, Oshinowo A (2014) Supplementation of date palm (Phoenix dactylifera) seed as feed additive in the diets of juvenile African catfish (Burchell, 1822). *J Fish Aquat Sci* 9: 359–365. https://doi.org/10.3923/jfas.2014.359.365
118. Hua K, Cobcroft JM, Cole A, et al. (2019) The future of aquatic protein: Implications for protein sources in aquaculture diets. *One Earth* 1: 316–329. https://doi.org/10.1016/j.oneear.2019.10.018
119. García-Beltrán JM, Mahdhi A, Abdelkader N, et al. (2020) Effect of the administration of date palm seeds (Phoenix dactylifera L.) in Gilthead Seabream (Sparus aurata L.) Diets. 1: 21.

120. Mohammadi M, Soltani M, Siahpoosh A, et al. (2018) Effect of date palm (Phoenix dactylifera) seed extract as a dietary supplementation on growth performance immunological haematological biochemical parameters of common carp. *Aquacult Res* 49: 2903–2912. https://doi.org/10.1111/are.13760
121. Dawood MAO, Eweedah NM, Khalafalla MM, et al. (2020) Evaluation of fermented date palm seed meal with Aspergillus oryzae on the growth, digestion capacity and immune response of Nile tilapia (Oreochromis niloticus). *Aquacult Nutr* 26: 828–841. https://doi.org/10.1111/anu.13042
122. FAO: Common carp home Food and Agriculture Organization of the United Nations FAO. Available from: https://www.fao.org/fishery/affris/species-profiles/common-carp/common-carp-home/en/.
123. Prospecting the biofuel potential of the UAE's 'Allig' date seed issuu. Available from: https://issuu.com/moeuae/docs/explorer_6456_research_magazine_edition_2_en_final/s/11762721.
124. Cruz-Lovera C, Manzano-Agugliaro F, Salmerón-Manzano E, et al. (2019) Date seeds (*Phoenix dactylifera L.*) valorization for boilers in the Mediterranean climate. *Sustainability* 11: 711. https://doi.org/10.3390/su11030711
125. Mousa R (2016) Hydrocolloids of date pits used as edible coating to reduce oil uptake in potato strips during deep-fat frying. *Alexandria J Food Sci Technol* 13: 39–50. https://doi.org/10.12816/0038469

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