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Applications of date pits in foods to enhance their functionality and quality: A review

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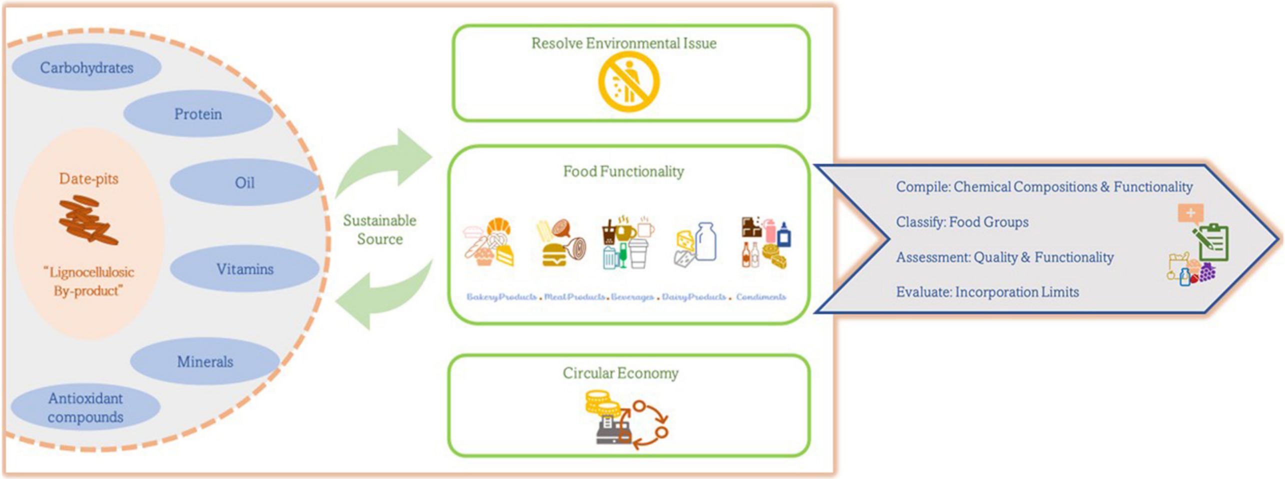
Agro-byproducts are substances generated by the bioprocessing industry that may provide functionality and bioactivity when used in foods, health supplements, and bio-composites. Date pits accumulate in very large quantities as a by-product of date processing factories, and they contain valuable bioactive compounds. Date pits and their treated fractions can serve as a cheap additive in food products, providing functionality such as improved composition in terms of fibers, proteins, fat, vitamins, minerals, polyphenols, and antioxidant compounds. Additionally, date pits have been used as a natural preservative, fat replacer, tenderizing agent, hydrocolloid, and emulsifying agent. Their health functionalities include their antioxidant capacity, dietary fiber content, probiotic enhancement through dietary fibers, and the fact that they are caffeine free. This paper begins by presenting the chemical composition of date pits and their functionalities in various food products. The multifunctional roles of date pits when incorporated into food products are subsequently reviewed. In addition, this review focuses on the applications of date pits in many food products, such as coffee and other beverages, baked goods, meat products, dairy products, desserts, spreads, condiments, and other food-related products. However, it is a challenge to achieve the aforementioned functionality by incorporating date pits into food products at high levels.

KEYWORDS

date pits, by-product, functional, added value, fortification, bioactive, incorporation ratio, Whole Quality Index

1. Introduction

The date palm tree (*Phoenix dactylifera L.*) is an important crop in most Middle East countries. Date pits, also known as seeds, kernels, stones, or pips, are by-products of date processing factories. Despite the valuable nutritional composition of date pits as a source of carbohydrates, dietary fiber, protein, oil, natural antioxidants, and bioactive polyphenols, they remain underutilized and are widely treated as a waste product. Recent research, however, has focused on how date pits could function as a potential source of bioactive materials in various products, such as medicinal supplements, cosmetics, and food products (Guizani et al., 2014; Shi et al., 2014; Tafti et al., 2017; Mrabet et al., 2020; Al-Harbi et al., 2021). The consumption of functional foods fortified with date pit powder could help individuals to satisfy the recommendations of the FDA and other health guidelines on daily intake of fiber (Mahmood et al., 2015). Fibers are considered to be valuable ingredients due to their broad functionality in food systems, fulfilling roles such as fat replacers, fat absorbers (i.e., during cooking processes), stabilizers, volume enhancers, binders, and bulking agents (Verma and Banerjee, 2010). The high antioxidant capacity of date pits is due to their high levels of phenol and tocopherols. Thus, this by-product could be used as a natural preservative (Metoui et al., 2019; Hussain et al., 2020; Khalid et al., 2021). It has particularly strong potential given that market demand leans toward natural preservatives with no adverse effects on the health value or sensory qualities of foods.



GRAPHICAL ABSTRACT
Summary of the abstract

Food functionality is an ever-increasing demand in food manufacturing, and this demand needs to be met in a sustainable manner. Consequently, a great deal of attention should be paid to naturally occurring compounds and their associated bioactive derivatives. However, in some cases, natural resources may be scarce, and alternative by-products can provide for the ever-growing need for food bio-additives (Herrero et al., 2015; Patel et al., 2021). Annual global production of dates was estimated at 7.5 million tons in 2008 (FAOSTAT[1]). Considering that 10% of this total production consists of the weight of date pits (according to the average percentage estimated; Ghnimi et al., 2017; Essa and Elsebaie, 2022), the annual total amount of date pits accumulated globally is about 750 thousand tons. Moreover, there has been a tremendous expansion in the land area cultivated with date palm trees; thus, total production is expected to grow over time. Unfortunately, date pits are mostly discarded, used as animal feed (Al-Juhaimi et al., 2018), or (in the best cases) used for Arabic coffee (Ranasinghe et al., 2022).

Date pits have been applied in many food products with diverse functionalities. Food products such as baked goods, dairy, beverages, meat, desserts, and condiments have been fortified with date pits in raw or treated form. Studies have suggested various ratios for the addition of date pits to foods, taking into account nutritional and health functionality and sensory acceptability. Despite these existing uses, date pits are undervalued, and they could be put to innovative applications through the use of primary treatments (e.g., grinding or treating with acid or alkali) and secondary treatments (e.g., use of selected chemicals, enzymatic and microbial).

This review offers guidance for the development of food products incorporating date pits. It may provide an indication of the optimum ratio in which they can be added to various food products. In addition, it presents the functionality gains attained in food products as a result of including date pits. The incorporation of date pits into food products has the potential to address food security concerns to some degree, in addition to complying with the principles of circular economy. The objectives of this review were: (i) to compile information on the chemical composition and functionality of date pits so that appropriate applications could be determined; (ii) to explore the applications of date pits in various food categories; (iii) to assess the quality and functionality of newly formulated food products; and (iv) to evaluate the limits on incorporation of date pits to enable attainment of the desired functionality without loss of sensory quality.

2. Chemical components of date pits and their functionality

Date pits are a rich source of valuable and potentially valuable ingredients (Joardder et al., 2012; Habib et al., 2013; Ali et al., 2015; Fadhil and Kareem, 2021; Oladipupo Kareem et al., 2021). Table 1 presents the chemical composition of date pits; this can be used to determine their proper utilization (Shi et al., 2014). Al-Khalili et al. (2022) have analyzed the mineral composition of date pit powder, observing that the majority of heavy metals (i.e., arsenic, cadmium, chromium, lead, and mercury) are absent from powdered date pits. However, other minerals have been found to be present; these include nickel, copper, and zinc, which have been found to occur at 1.4, 9.6, and 20.5 mg/kg, respectively. According to Lenntech (2013), the daily recommended allowances for these minerals are <1, 2, and 15 mg/day, respectively. In order to reach the toxicity thresholds for these minerals, consumption would need to approach or exceed 1 kg/day of date pits, which would not be realistic. In particular, the applications of date pits depend on the requirement for fibers, oil, protein, polyphenols, and antioxidant compounds in the targeted food products.

2.1. Dietary fibers

Date pits are a rich source of fibers, with fiber content varying between 60 and 80 g/100 g total weight (Habib and Ibrahim, 2009; Ataye et al., 2011; Habib et al., 2017; Metoui et al., 2019; Alyileili et al., 2020a; Al-Khalili et al., 2021). As lignocellulosic biomaterial, the insoluble fiber content consists of cellulose, hemicellulose, and lignin,

1 http://faostat.fao.org/site/339/default.aspx

TABLE 1 Chemical composition of date pits.

Chemical component		Range (g/100 g sample)*	References
Fiber	**Insoluble**		
	Crude	60–80	Habib and Ibrahim, 2009; Ataye et al., 2011; Habib et al., 2017; Metoui et al., 2019; Alyileili et al., 2020a; Al-Khalili et al., 2021
	Cellulose	20.0–46.8	Briones et al., 2011; Nabili et al., 2016; Bouaziz et al., 2017; Abu-Thabit et al., 2020.
	Hemicellulose	17.5–55.0	
	Lignin	11.0–30.6	
	Soluble	5.0	Goksen et al., 2018
Protein		4.8–12.5	Chaira et al., 2007; Habib and Ibrahim, 2009; Ashraf and Hamidi-Esfahani, 2011; Ataye et al., 2011; Azodi et al., 2014; Habib et al., 2017; Suresh et al., 2017; Metoui et al., 2019; Ahmed M. M. et al., 2020; Alyileili et al., 2020a.
Oil	Crude	3.9–13.8	Chaira et al., 2007; Habib and Ibrahim, 2009; Ashraf and Hamidi-Esfahani, 2011; Ataye et al., 2011; Azodi et al., 2014; Habib et al., 2017; Suresh et al., 2017; Metoui et al., 2019; Ahmed M. M. et al., 2020; Alyileili et al., 2020a.
	Unsaturated fatty acids (UFAs) (g/100 g oil)		
	Oleic	39.5–55.4	Ashraf and Hamidi-Esfahani, 2011
	Linoleic	6.2–19.8	Rahman et al., 2007; Basuny and Al-Marzooq, 2010; Ataye et al., 2011; Jamil et al., 2016; Al-Juhaimi et al., 2018; Metoui et al., 2019; Lieb et al., 2020.
	Linolenic	0.3–8.1	
	Saturated fatty acids (SFAs) (g/100 g oil)		
	Lauric	6.793–45.4	Rahman, 2007; Ataye et al., 2011; Basuny and Al-Marzooq, 2011; Azodi et al., 2014; El Sheikh et al., 2014; Al-Juhaimi et al., 2018; Nehdi et al., 2018; Metoui et al., 2019; Jamil et al., 2020; Lieb et al., 2020.
	Palmitic	2.64–12.6	
	Stearic	1.3–47.9	
	Capric	0.25–11	
	Myristic	0.04–12.8	
	Arachidic	0.02–0.39	
	α-tocotrienol	30.2–37.4	Al-Juhaimi et al., 2018; Nehdi et al., 2018
Polyphenols	g GAE/100 g*	5.1–9.5	Metoui et al., 2019

*Composition on wet basis, **GAE: gallic acid equivalent per g dry weight.

and content of these varies between 20.0 and 46.8 g/100 g, between 17.5 and 55.0 g/100 g, and between 11.0 and 30.6 g/100 g, respectively (Briones et al., 2011; Nabili et al., 2016; Bouaziz et al., 2017; Abu-Thabit et al., 2020). Soluble fiber content in date pits is very low at 5 g/100 g date pits, while insoluble fiber content is 53/100 g date pits (Goksen et al., 2018).

Insoluble fibers from various plant sources are commonly used in food products, such as bakery products and breakfast cereals (Hu et al., 2009; Ragaee et al., 2011; Cerniauskiene et al., 2014). Fibers from date pits can be utilized in a similar way to other fruit by-products as a replacement for fats in certain food products, such as chicken sausages and various types of ice cream (De Moraes Crizel et al., 2013; Crizel et al., 2014; Choe and Kim, 2019). According to the American Dietetic Association, the recommended range of fiber intake is between 25 and 30 g/day, at a 3:1 ratio of insoluble to soluble fiber for adults (Sofi et al., 2017). Meat products are usually rich in fat and protein but deficient in complex carbohydrates (i.e., dietary fiber). Additionally, agricultural by-products and waste products are a cheap source of dietary fiber, and their incorporation into meat products at varying levels reduces cost and adds functionality. Fat replacers simulate the eating qualities of foods that are high in fat, preserving a smooth texture and mouthfeel. Since date pits are primarily a polysaccharide biomaterial, they could be used as carbohydrate-based fat replacers in a similar way to the food industry's typical use of starch, gum, and cellulose of plant origin. The relevant products could include imitation cream, margarine, salad dressings, sauces, frozen desserts, baked goods, and processed meats (Wang et al., 2022). Fibers from date pits have also been used in the development of edible coatings for foods. Hydrocolloids and phenolic compounds extracted from date pits have been claimed to reduce oil uptake in potato strips during deep-fat frying at a relatively low content ratio (i.e., <5%); at this ratio, they are still able to reduce oil uptake by over 70%, which is higher than the reduction achieved in earlier attempts (Mousa, 2016). The principle of using date pits as a hydrocolloid-based coating is reliant on their fiber content, as this is similar to resistant starch. Likewise, starchy gum coatings are used in food processing to improve the functional properties of products, such as their viscosity, water-binding capacity, and emulsion stability (WIlliams and Phillips, 2021).

2.2. Oil content

The oil content of date pits depends on factors such as date palm variety, growing conditions, and method of extraction; it has been found to vary between 3.9 and 13.8 g/100 g (Habib and Ibrahim, 2009; Ashraf and Hamidi-Esfahani, 2011; Ataye et al., 2011; Azodi et al., 2014; Habib et al., 2017; Suresh et al., 2017; Metoui et al., 2019; Ahmed M. M. et al., 2020; Alyileili et al., 2020a). The oil extracted from date pits is considered to be a rich source of unsaturated fatty acids, primarily oleic acid (which occurs at 39.5–55.4 g/100 g of oil; Ashraf and Hamidi-Esfahani, 2011). Other unsaturated fatty acids occurring in date pits are linoleic acid (6.2–19.8 g/100 g of oil) and linolenic acid (0.3–8.1 g/100 g of oil; Basuny and Al-Marzooq, 2010; Ataye et al., 2011; Jamil et al., 2016; Al-Juhaimi et al., 2018; Metoui et al., 2019; Lieb et al., 2020). In contrast, the saturated fatty acid content of date pits consists primarily of lauric (6.793–45.4 g/100 g of oil), palmitic (2.64–12.6 g/100 g of oil), stearic (1.3–47.9 g/100 g of oil), capric (0.25–11 g/100 g of oil), myristic (0.04–12.8 g/100 g of oil), and arachidic (0.02–0.39 g/100 g of oil) acids (Rahman, 2007; Ataye et al., 2011; Basuny and Al-Marzooq, 2011; Azodi et al., 2014; El Sheikh et al., 2014; Al-Juhaimi et al., 2018; Nehdi et al., 2018; Metoui et al., 2019; Jamil et al., 2020; Lieb et al., 2020). This means that date pits can be considered to be a valuable source of edible and pharmaceutical oils (Saafi et al., 2008).

Date pit oil has an oxidative stability higher than that of most vegetable oils, which means that it can be conserved for a longer period (Mrabet et al., 2020). Thus, using date pit oil in food products could increase their nutritional value and their shelf life. The oil extracted from date pits has been investigated for its potential use for culinary purposes due to its stability at higher temperatures. Evaluation of the physicochemical properties and oxidative induction of date pit oil under a variety of thermal conditions could provide an indication of the stability of these characteristics. Food industry applications may expose date pit oil to high temperatures, such as those involved in frying and other forms of cooking, which may affect the maintenance of its original properties. In particular, the oxidation stability and the considerable total phenol content of date pit oil could be reflected in its resistance to thermal treatment over a longer period.

The use of date pit oil in wax coatings is another innovative application. Date pit oil is liquid at ambient temperatures, is yellowish in color, and has a pleasant odor (Mrabet et al., 2020). Wax coatings typically consist of hydrophilic polymers, a thickening agent, a hydrophobic agent, and an emulsifying agent (Ahmed A. et al., 2020). Date pit oil can function simultaneously as both a hydrophobic and an antimicrobial agent; thus, it has been incorporated by replacing water on a percentage basis, as discussed in a following section, in the formulation of wax coatings (Ahmed A. et al., 2020). An edible wax coating is typically used to reduce water evaporation from plant products and also helps to protect them against pathogens (Al-Saggaf et al., 2017). The benefits of wax coating are an improved appearance, reduced bruising during handling and shipping, reduced weight loss, and the fact that the coating can function as a carrier for active compounds (Iñiguez-Moreno et al., 2021). Another promising application of date pit oil is in meat tenderizing; however, the bioactive compound responsible for this process has not yet been identified, so further studies are required (Nor et al., 2018).

2.3. Protein content

According to the literature, the protein content of date pits can vary between 4.8 and 12.5 g/100 g (Chaira et al., 2007; Habib and Ibrahim, 2009; Ashraf and Hamidi-Esfahani, 2011; Ataye et al., 2011; Azodi et al., 2014; Habib et al., 2017; Suresh et al., 2017; Metoui et al., 2019; Ahmed M. M. et al., 2020; Alyileili et al., 2020a). This consists primarily of soluble proteins, such as globulin, albumin, prolamin, and glutelin. Proteins of plant origin can be used as substitutes for those of animal origin, which are normally higher in cost and are less sustainable. Because of their high abundance, proteins of plant origin are generally more appealing. However, the extraction of plant proteins is usually difficult and might disrupt their functional properties (Schutyser and Van Der Goot, 2011). In the case of date pits, the protein extracted has been investigated for potential use as an emulsifying agent (Akasha et al., 2016). However, it is crucial to determine whether this protein can be extracted cost-effectively.

2.4. Antioxidant and antimicrobial activity in date pits

Date pits offer antioxidant potency due to their rich content of flavonoids and other active components (Besbes et al., 2009; Habib et al., 2017; Al-Juhaimi et al., 2018; Nehdi et al., 2018; Metoui et al., 2019). Date pits are a rich source of polyphenol compounds with marked antioxidant capacity (Al-Farsi et al., 2007; Al-Oqla et al., 2014; Al-Juhaimi et al., 2018; Radfar et al., 2019). The antioxidant effects of date pits could be exploited either through use of date pit oil or through their use in powdered form. In both cases, the use of date pits would have a positive impact on food stability, either by promoting oxidation processes or by reducing microbial degradation. Antioxidants attack free radicals, which in turn delays the development of unpleasant flavors, retards lipid oxidation, and enhances color stability (Aminzare et al., 2019). In addition, the use of date pits could provide many health benefits, such as antigenotoxic activity; anti-inflammatory activity; protection against diabetes, liver diseases, and gastrointestinal disorders; and reduction of plasma triglycerides and total cholesterol levels (Diab and Aboul-Ela, 2012; Rahmani et al., 2014; Al-Rasheed et al., 2015; Kchaou et al., 2016; Al-Alawi et al., 2017).

The high antioxidant capacity of date pit oil is additionally related to its rich tocopherol and phenolic content. The primary form of tocopherol occurring in date pits is α-tocotrienol, at a concentration of 30.2–37.4 g/100 g of oil (Al-Juhaimi et al., 2018; Nehdi et al., 2018). Similarly, the phenolic content of date pits is dominated by polyphenols [specifically, 5.1–9.5 g of gallic acid equivalent (GAE)/100 g dry weight; Metoui et al., 2019]. The phenol compounds occurring in date pits have been found to consist of hydroxytyrosol (10.21%), protocatechuic acid (9.62%), tyrosol (8.10%), caffeic acid (4.95%), gallic acid (4.11%), p-coumaric acid (0.26%), and oleuropein 0.18%; Habib et al., 2014; Mrabet et al., 2020]. The chemical composition and stability of date pit oil support its application as a replacement for conventional oils in certain food products, for culinary purposes, and as a shelf life extender. Date pits also show evidence of antimicrobial activity against gram-positive (Metoui et al., 2019) and gram-negative bacteria (Gadang et al., 2008; Sivarooban et al., 2008).

The potential of date pits for possible applications as a natural antimicrobial agent has also been explored. Based on this potential, they could have benefits over chemical additives when used in food products. In many instances, chemical additives may induce undesirable effects (Silva et al., 2022). Recently, studies have shown that the addition of antioxidant agents to food delays oxidation, maintains product quality, and extends shelf life. This is mainly due to a reduction in the auto-oxidation process, thereby preserving the food product (Sui et al., 2016). Manufacturers can label their products as "natural" if antioxidants from date pits are used; thus, their use could prove appealing to consumers in comparison to the use of synthetically derived antioxidants (Messina et al., 2015). For example, polyphenol compounds have antioxidant and antimicrobial effects, and recently these have been used as a natural preservative in the meat industry. Similarly, the antioxidant properties and sensory quality of bread can be improved by adding buckwheat flour, since this has been found to have the highest phenolic and flavonoid content (Chlopicka et al., 2012). Therefore, the antioxidant activity of date pits could potentially be used in food products to extend their shelf life.

3. Applications of date pits in foods

3.1. Food products

Research results on the applications of date pits in foods of various categories have been reported in the literature over the course of more than four decades. Drawing on this body of research, 14% of the studies included in this review relate to the use of date pits in hot drinks (i.e., products similar to caffeine-free coffee), 36% relate to bakery products, and 14% to meat products. Date pits have long been used to prepare drinks, mainly similar in nature to Arabic coffee, due to their abundance and low cost in the Arab region. More recently, researchers have explored whether date pits, as a rich source of fiber, could be suitable for use as an additive in bakery products. This application in fortification has subsequently progressed to their use in the enhancement of other functionalities beyond traditional nutritional enrichment. Examples of the functionalities of date pits include their use to enhance consumers' perceptions of a product's physical and textural properties (Bouaziz F. et al., 2020; Darwish et al., 2020; Alqattan et al., 2021), to increase shelf life (Najafi et al., 2016; Ghasrehamidi and Daneshi, 2019; Sayas-Barberá et al., 2020; Abushal et al., 2021), as a fat replacer (Ammar et al., 2014; Essa and Elsebaie, 2018; Alqattan et al., 2021), and as a natural meat tenderizer (i.e., to enhance sensory juiciness, texture, and taste; Nor et al., 2018). Recently, date pits have been used in more innovative ways, such as in the formulation of biodegradable edible coatings that can enhance shelf life, and in the production of low-fat products *via* reduction of oil uptake during the frying process. Table 2 illustrates the set of food products that have been fortified with date pits. They are grouped into various food categories, and by the form of date pits used and the level at which they are added.

3.2. Date pits in beverage preparation

In the Arab world, one of the ancient applications of date pits is in the formulation and preparation of beverages (Rahman et al., 2007; Habib et al., 2013). Roasted date pits are used to brew hot drinks similar to coffee; they may function as either a full or a partial replacement for coffee itself. In some instances, milk, spices, or herbs are also added to drinks formulated with date pits. Abdillah and Andriani (2012) produced a healthy drink consisting of date pits combined with ginger (a functional ingredient); this represents a healthy and cheap alternative to regular coffee. The best ratio for the inclusion of date pits in regular coffee has been found to be 9% (Venkatachalam and Sengottian, 2016). A range of roasting times and temperatures for date pit powder have been explored, with the optimum roasting conditions, considering its physicochemical and organoleptic characteristics, found to be 199.9°C for 21.5 min (Fikry et al., 2019).

Rahman et al. (2007) studied the composition and thermal transition characteristics of roasted date pit powder; their results elucidated the nature and characteristics of this biomaterial. In another study, date pit powder was mixed with barley, cardamom, button roses, nutmeg, and cloves at three different concentrations (specifically, 100, 92.5, and 61.67% concentration of date pits). The nutritional value of each of the three blends was higher than that of regular coffee, with low caffeine content. The blend with 61.67% date pit concentration was found to provide the best overall sensory acceptability compared to a control (with scores of 8.7 and 8.5, respectively), and it was also higher in antioxidant activity than control coffee (with activity occurring at 91.7 and 84.2%, respectively; Ragab and Yossef, 2020). Similarly, six cappuccino and latte formulations were prepared, with Nescafe product substituted with date pit powder at concentration levels of 10, 20, 30, 40, 50, and 60%. The caffeine-free cappuccino formulation with 50% substitution was rich in minerals, dietary fibers, and antioxidants, and this was found to be the most acceptable ratio in a sensory analysis (Al-Garni, 2020). El Sheikh et al. (2014) substituted cocoa with 9% date pit powder to produce a cocoa drink; sensory evaluation of taste showed that this was considered to be superior to the original cocoa drink.

Other studies have focused to a greater extent on the pharmaceutical impact of date pits. Mirghani (2012) investigated the chemical composition of a date pit drink prepared at a ratio of 1:15 (w:v). Their results showed that the prepared drink contained protein (2%), copper (0.9 mg/g), calcium (2% mg/g), iron (0.9 mg/g), manganese (0.4 mg/g), magnesium (5 mg/g), potassium (6.7 mg/g), glucose (0.74 g/L), and fructose (0.6 g/L). Additionally, researchers explored the effects of the anti-atherogenic properties of a date pit beverage in 32 menopausal women. The participants consumed a dosage of 2.5 g of date pits per day for 14 days in the form of a drink, and lipid profiles were conducted before and after this treatment. The results revealed that routine consumption of date pit beverages could enable maintenance of a healthy lipid profile (Saryono and Proverawati, 2018).

TABLE 2 Ratios at which date pits can be incorporated into various types of food products.

Food group	Form of date pits (untreated/treated)	Level of addition (%)	References
Beverages	Untreated powder	6.6–100	Rahman et al., 2007; Abdillah and Andriani, 2012; Mirghani, 2012; El Sheikh et al., 2014; Venkatachalam and Sengottian, 2016; Saryono and Proverawati, 2018; Fikry et al., 2019; Al-Garni, 2020; Ragab and Yossef, 2020.
Desserts/spreads/condiments	Untreated powder Soluble and insoluble fiber Oil	0.25–60	Al-Farsi et al., 2007; Basuny and Al-Marzooq, 2010; Al-Amri et al., 2014b; Bouaziz et al., 2017; Zamzam et al., 2018; Alqahtani, 2019; Abushal et al., 2021.
Meat products	Untreated powder Soluble and insoluble fiber Aqueous hexane extracts Crude extracts Alkaline-treated Phenolic compound extracts	0.04–50	Amany et al., 2012; Ammar et al., 2014; Maqsood et al., 2016; Essa and Elsebaie, 2018, 2022; Nor et al., 2018; Zinina et al., 2019; Bouaziz M. A. et al., 2020; Sayas-Barberá et al., 2020; Ursachi et al., 2020.
Bakery products	Untreated powder Defatted date pits Date pit powder hydrolysate Polysaccharides Hemicellulose Fermented	0.03–20	Al-Amri et al., 2014a; Halaby et al., 2014; Hejri-Zarifi et al., 2014.
Dairy products	Untreated powder	1.0–10	Jambi, 2018; Ghasrehamidi and Daneshi, 2019; Darwish et al., 2020; Alqattan et al., 2021.
Other functionalities (food-related products)	Untreated powder Defatted date pits Silver nitrate treated Low-density polyethylene Antimicrobial agents (EDTA) Oil extract Biologically degraded Hydrocolloid extract Phenolic extracts Protein extract	0.5–more than 60	Rojas-Graü et al., 2009; Al-Farsi and Lee, 2011; Akasha et al., 2016; Mousa, 2016; Ahmed A. et al., 2020; Alyileili et al., 2020b; Radfar et al., 2020; Ramadan et al., 2020; Alqahtani et al., 2021; Mostafa et al., 2022.

3.3. Date pits in bakery products

Enrichment of foods with dietary fiber is an efficient strategy to elevate consumers' daily fiber intake. Most commonly, wheat products are consumed daily, and these are a common vehicle by which the consumption of fibers can be increased. However, the quality of bakery products could be adversely affected by the addition of cereal brans, which can alter the structure and volume of dough (Onipe et al., 2015). Similarly, substitution of wheat flour with cassava flour has been found to produce adverse effects on dough stability and development time (Rodriguez-Sandoval et al., 2017). In contrast, the incorporation (at a 1–15% level) of date pit fibers into various bakery products has been found to enhance the water absorption capacity of the dough, which could affect dough performance positively by increasing its resistance and extensibility, and may help to maintain the dough's properties (Ranasinghe et al., 2022).

Bakery products fortified with date pits have attracted considerable attention due to their rich fiber content. Additionally, fortification of bakery products (specifically, bread, biscuits, cakes, muffins, and shaboura) with date pit fibers extends their shelf life (i.e., spoilage is delayed; Table 3). Moreover, date pits act as fat replacer, produce an expanded loaf volume, and maintain sensory acceptance (Bouaziz et al., 2010; Salem et al., 2011; Platat et al., 2013; Salem and Habiba, 2013; Al-Amri et al., 2014a; Ambigaipalan and Shahidi, 2015; Najafi et al., 2016; Hira et al., 2017; Nabi et al., 2018; Samea and Zidan, 2019; Bouaziz F. et al., 2020; Ghasemi et al., 2020; Abushal et al., 2021; Hamzacebi and Tacer-Caba, 2021; Saeed et al., 2021).

3.3.1. Bread

Good loaf volume and rich fiber content were observed by Al-Amri et al. (2014a) with the addition of milled date pits to bread dough at a concentration of 4 to 12%. Taking a different approach, Hejri-Zarifi et al. (2014) germinated date pits at 30°C for 2 weeks, before detaching the germs from the seeds, with the date pits themselves being considered a residue of this process. The addition of date pit germs and powdered residue to dough at a ratio of 0.5–3% was associated with a reduction in bread spoilage when the bread was stored for 5 days.

The inclusion of raw milled date pits in bread at a 15% ratio has been claimed to reduce the risk of diabetes *via* a beneficial hypoglycemic effect (Halaby et al., 2014), while enrichment of Arabic bread with 5–20% date pit powder has been shown to provide a boost in flavonoids and antioxidant capacity (Platat et al., 2013). Similar effects have been observed for pita bread fortified with date pit powder at a ratio of 5–20%. Regular bread and whole wheat bread were analyzed as controls in this study; these were found to have fiber content of 1 and 6.2%, respectively. In comparison to the bread enriched with date pits, regular bread was lower in fiber in all cases; however, whole wheat bread was found to have a lower fiber content than only date pit bread enriched at concentrations above 10% (i.e., 15 and 20%, with 8.1 and 8.9% fiber content, respectively). Total flavones and total phenolic compounds were found to be higher in whole wheat pita bread compared to regular bread, and higher levels were observed in bread enriched with date pits than in both controls, in a dosage-dependent manner (specifically, there was an increase from 10 to 26.9 and from 16 to 6732.6 μg/g, respectively; Platat et al.,

TABLE 3 Effects on shelf life of adding date pits to foods in various food groups.

Food product	Form of date pits	Level of addition (%)	Effects/attributes modified	Acceptable storage period	References
Bakery					
Bread	Date pit germs and date pit residue powder	0.5–3	Bread hardness	5 days	Hejri-Zarifi et al., 2014
	Untreated powder	10–20	Delayed staling in bread	4 days	Nabi et al., 2018
	Fermented pulverized date pits with *Lactobacillus plantarum*, *Lactobacillus brevis*, and/or *Saccharomyces cerevisiae*	20	Reduced bread staling according to sensory analysis	7 days	Najafi et al., 2016
Biscuits and cookies	Untreated date pits	5, 10, 15	Extended shelf life due to moisture content reduction	NM*	Abushal et al., 2021
Coconut biscuits	Untreated date pits mixed with fenugreek seed	0.03	Maintenance of sensory attributes	60 days	Hira et al., 2017
Meat products					
Beef burgers	Untreated powder	1.5–3	Positive color change indicating better quality over the period	3, 6, and 10 days	Sayas-Barberá et al., 2020
Ground beef	Phenolic extract of date pits	0.5–1	Reduction in hydroperoxides (an oxidative marker)	10 days	Amany et al., 2012
Camel meat sausages	Untreated date pits and green tea powder	0.04	Less effective compared to pure phenolic compound	12 days (refrigerated storage)	Maqsood et al., 2016
Dairy products					
Yogurt	Untreated date pits	1	Improved survival of probiotic bacteria and physicochemical and sensory characteristics	14 days	Ghasrehamidi and Daneshi, 2019
Sweets					
Chocolate	Untreated date pits	5–15	Extended shelf life due to moisture content reduction	NM*	Abushal et al., 2021

*NM, Not mentioned.

2015). Nabi et al. (2018) prepared flatbread and thick bread with date pit powder added at a 10–20% ratio; they observed improvements in nutritional value (specifically, a higher fiber content) and delayed staling of the bread over the course of four days. However, according to a sensory analysis conducted after 4 days, there was an insignificant difference in hardness between the bread prepared with date pits and the control (i.e., standard bread) on the first and second days after preparation. Although the quality of the texture declined over time for all samples, including the control bread, this reduction was more strongly evident in the case of the control bread compared to the bread with added date pits on the fourth day. The bread with added date pits was found to have higher acceptability in terms of texture and taste, but its color was less acceptable than that of the control bread.

Date pits need to be treated in particular ways to achieve better functionality in bread. A defatting process is commonly used, in which oil is extracted to produce defatted date pit powder. A 1–3% enrichment level has been found to be the optimum dosage for the use of defatted date pits in bread (Bouaziz et al., 2010). Bouaziz F. et al. (2020) also extracted water-soluble polysaccharides and hemicellulose for use as an additive in bread. They observed better sensory properties (i.e., superior appearance, color, odor, taste, tenderness, and overall appreciation) with the addition of 0.75% hemicellulose in comparison to 0.5% soluble polysaccharides. Pulverized date pits fermented with *Lactobacillus plantarum*, *Lactobacillus brevis*, and/or *Saccharomyces cerevisiae* were added at a concentration of 20% to Barbari flatbread; this product exhibited comparable quality to a control (wheat flour bread), and the use of this additive could improve the product's sourdough acidity, quality, shelf life, and sensory characteristics. Furthermore, the authors' results indicated that fermented date pits could potentially enhance the sensory attributes of bread supplemented in this way. A texture analysis of bread samples over the course of seven days of storage indicated reduced staling in the sourdough bread (Najafi et al., 2016).

3.3.2. Biscuits and cookies

Date pit powder has been used as a fortification agent in biscuits, either alone or as a blend with other ingredients, to achieve a desired functionality. Najjar et al. (2022) produced cookies using date pit powder as a flour replacement at levels of 2.5, 5.0, and

7.5%. Two types of flour were used (white and whole wheat), and two baking temperatures were tested (10 min at 180°C and 8 min at 200°C). Thus, their study included cookies produced with a total of 12 different combinations of the aforementioned factors, with each combination tested for date pits from several date varieties. The moisture content of the formulas was primarily affected by baking temperature and flour type. The cookies' color was primarily affected by the ratio at which date pit powder was added (specifically, addition at a higher ratio produced a darker color), which had a negative effect on consumer acceptance in most cases. Overall acceptability of the cookies was found to be higher for the whole wheat flour versions in the case of all date pit varieties. Overall, for all combinations and date pit varieties, consumer acceptance was affected by the ratio at which date pits were added and the type of flour used. The formulas containing date pits of the Khalas and Zahidi date varieties at a level of 7.5% were considered the best, according to sensory analysis.

In another study, conducted by Abushal et al. (2021), the addition of date pit powder to cookies (at a 5–15% ratio) was found to enhance their nutritional value, primarily by increasing their fiber content to a level covering 15% of the daily required value. Additionally, it was found to extend their shelf life (due to the significant reduction in moisture content) and to improve consumer acceptance in terms of color, taste, odor, flavor, texture, and overall acceptability based on a seven-point hedonic scale. Similarly, the use of date pits as a natural fat replacer in cookies at various concentrations (10, 20, 30, and 40%) was associated with increased total phenolic content (from 18.56 to 451.60 mg GAE/100 g of sample) and total flavonoids (from 27.43 to 361.20 mg CE/100 g of sample) in a dose-dependent manner. In addition, the crude fiber and protein content of the cookies fortified with date pits increased from 0.44 to 8.70% and 11.79 to 12.69%, respectively, in a dose-dependent manner. The sensory and textural acceptability of the cookies, including their taste, color, appearance, texture, and overall acceptability, were observed to be significantly higher when fat was replaced by date pit powder at 20% or below, compared to the use of commercial wheat flour (used in a control product). In contrast, the addition of date pit powder at more than 20% was found to produce an unpleasant mouthfeel and hard texture compared to the control (Saeed et al., 2021).

Mohammadi et al. (2022) formulated gluten-free cookies using various proportions of chestnut flour (added at 0–50%), date pit powder (0–20%), and modified starch (0.3–0.9%). Sensory analysis revealed that the blend containing 20% date pit powder, 30% chestnut flour, and 0.9% modified starch produced the highest consumer acceptance. A combination consisting of 5% date pits mixed with olive seed powders has been found to be optimal in maintaining the quality of biscuits (Samea and Zidan, 2019). Similarly, date pit powder has been found to work synergistically with fenugreek seed in coconut biscuits; this combination has been found to extend the shelf life and maintain the biscuits' sensory attributes for 60 days at an ambient temperature. Additionally, it was observed that the addition of date pit powder at 0.03% produced the best score in a sensory analysis (Hira et al., 2017).

3.3.3. Cakes and muffins

In a study of sponge cake formulations, date pit powder was added at concentrations of 5 and 10%, and these products were compared to a control cake with 0% date pits. The results of the comparison between the control cake and the cake enriched with date pits at 10% showed that the latter contained elevated amounts of total phenol (from 0 to 38.53 GAE g/100 g dry weight), and thus an elevated proportion of free radical scavenging activity; an increased mineral content (potassium increased from 41 to 3,894 mg/ kg and sodium from 2 to 178 mg/kg); increased protein (raised from 8.5 to 19.9%); and a higher fiber content (raised from 1.7 to 13.7%). Sensory acceptability was higher for the formulation with date pits included at a 10% ratio. The attributes of flexibility, elasticity, and chewiness were insignificantly affected by the addition of date pit powder. However, significant differences were observed between the cakes formulated with date pits and the control in gumminess, cohesiveness, and hardness (Ghasemi et al., 2020). In a separate study, a concentration of 2.5% date pit powder was found to be optimal, compared to higher levels of inclusion (i.e., 5, 7.5, or 10%) in terms of the organoleptic properties of butter cake formulations (Salem and Habiba, 2013).

Muffins with date pit powder included (at a level of 5%) have been explored in a blend also including quinoa and oat bran; the inclusion of date pits was found to deliver the desired hardness (Hamzacebi and Tacer-Caba, 2021). In a separate study, muffins prepared with the incorporation of date pit powder hydrolysate (at 2.5%) were compared to muffins prepared with raw date pit powder (at 2% or 5%). The muffins prepared with date pit flour hydrolysate were found to be highly acceptable in terms of flavor and texture as compared to those prepared with raw date pit powder (Ambigaipalan and Shahidi, 2015). Salem et al. (2011) examined 2, 5, and 10% inclusion ratios for date pits in the preparation of muffins and shaboura. For both products, the fiber content, phenols, and antioxidant activity increased with the addition of date pits in a dose-dependent manner. In the case of muffins, the fiber content increased from 1.7 to 3.4 g/100 g dry weight, phenol content increased from 52.11 to 88.23 GAE g/100 g dry basis, and antioxidant activity increased from 46.22 to 86.30 BHT/100 g dry basis. For shaboura, the increase in fiber was from 1.88 to 4.79 g/100 g dry weight, the increase in phenols was from 42.96 to 83.50 GAE g/100 g dry basis, and antioxidant activity increased from 32.66 to 91.50 BHT /100 g dry basis. However, inclusion ratios of 5% and below were associated with higher sensory satisfaction compared to higher levels. Overall, type of pretreatments and the particle size of added date pits have been found to affect the properties and sensory acceptability of baked products. In addition, blending date pits with other ingredients could produce favorable effects on the quality of these products.

3.4. Date pits in meat products

The nutritional content of meat products can be improved by increasing their antioxidant properties, vitamins, minerals, or dietary fiber content (Ursachi et al., 2020). Dietary fiber enrichment could also enhance the structural characteristics of meat products (Zinina et al., 2019). The reduction of fat content in meat products is one of the most important priorities of the meat industry. Dietary fibers from fruit by-products have been found to improve functionality, since the addition of such fibers reduces cooking loss in meat products and improves their water-holding capacity. Date pit powder can be used as a fiber source in meat products, and it acts as fat replacer, natural preservative (Table 3), and tenderizing agent.

In the case of beef burgers, the addition of date pit powder has been found to exert positive effects on their shelf life and improve their cooking properties. Color change has been observed over the course of a storage period (on days 3, 6, and 10) for control burgers compared to burgers fortified with date pits, in the case of both refrigerated and cooked burgers. Burgers containing date pits had higher yellowness values than the control when they were uncooked, but lower values when they were cooked. The redness of the meat was positively affected by the addition of date pits, which was favored by panelists. Finally, a consumer panel identified the beef burgers with date pits substituted at 1.5–3% as providing sensory acceptability (Sayas-Barberá et al., 2020).

Amany et al. (2012) observed a reduction in the formation of hydroperoxides (an oxidative marker) in ground beef during storage (over a total duration of 10 days) with the addition of phenolic extract of date pits (at 0.5–1%). Maqsood et al. (2016) examined the effect of adding 0.04% crude extract (from both date pits and green tea powder) and pure phenolic compounds to camel meat sausages, over the course of 12 days of refrigerated storage. They observed that the addition of pure phenolic compounds (i.e., the control) was more effective than the addition of date pit extract. Bouaziz M. A. et al. (2020) extracted the insoluble fibers from date pits and used these in turkey burgers. The quality enhancement of the turkey burgers was greater when insoluble fibers (at a 3–10% enrichment level) were used as compared to a control (using raw date pits). In comparison with the burgers enriched with date pit powder, insoluble fiber enrichment was associated with an increased level of carbohydrates (82.55 vs. 88.85%, respectively). The oil-holding capacity of the burgers was also improved by 57.14% in the case of insoluble fiber enrichment compared to enrichment with date pits; the results of a sensory panel additionally indicated that addition of the extract at 5% produced the best outcome.

In separate research, the functional components of date pits have been extracted using various polar solvents. These extracts were tested as a meat tenderizer (for knuckle meat) at a ratio of 1 ml/100 g meat; they were found to improve the textural properties of the knuckle meat (Nor et al., 2018). Essa and Elsebaie (2022) treated date pit powder with alkaline hydrogen peroxide and isolated the suspension residue; this isolated extract was further treated using the enzymatic–gravimetric method and used along with gelatin in the formulation of a composite gel. This formulated mixture was added to beef burgers as a fat replacer. Two control forms of beef burger included in the study contained 10 and 20% fat. In comparison to the controls, beef burger mixtures formulated with added date pits (at a 20% replacement level) exhibited higher water holding capacity, a higher swelling ratio, and enhanced freeze–thaw stability. Additionally, beef burgers containing these fat replacers were found to have a softer texture and improved nutritional value (with higher levels of moisture, ash, protein, Na, and Ca).

In another study, a mixture of date pit powder, wheat germ, and pumpkin flour was used as a fat replacer in meatballs (resulting in a 25 to 75% reduction of animal fat). It was observed that meatballs prepared with this mixture were superior to a control (full-fat meatballs) in terms of cooking yield in the case of both frying (84.51–93.75) and roasting (80.62–86.85%). Additionally, there were insignificant differences in sensory properties between this formulation and the control meatballs in terms of taste, odor, and texture (Ammar et al., 2014). Similarly, Essa and Elsebaie (2018) observed higher levels of polyphenols before cooking (354.19 mg GAE/100 g vs. 2.8 mg/100 g) and after cooking (i.e., 309.22 GAE mg/100 g vs. 2 mg/100 g on dry weight basis) in beef burgers enriched with date pits (at 75% fat replacement) compared to a control. In addition, enhancements were observed to other properties, such as fat retention, cooking yield, and moisture retention, while shrinkage was decreased as a result of the addition of date pits. Overall, the use of treatments, the extraction of components, and calibration of the level of addition all play a significant role in the use of date pits in enhancing the quality of meat products.

3.5. Date pits in dairy products

Date pits can also be used in dairy products to improve their functionality. Ghasrehamidi and Daneshi (2019) examined the survival of probiotic bacteria in yogurt on days 1, 7, 14, and 21 with the addition of date pit powder at concentrations of 0.5, 1, and 2%. The physicochemical and sensory characteristics of the yogurt and the survival rate of probiotic bacteria were maintained for up to 2 weeks in the case of 1% date pit powder. Similarly, yogurt enriched with up to 3% date pit powder was found to be of similar quality to a control in terms of flavor, texture, appearance, consistency, and overall acceptance. However, adverse effects on texture, palatability, and overall acceptability were observed when date pits were added at more than 3% (Jambi, 2018). Alqattan et al. (2021) investigated the addition of date pit powder to block cheese at 5–20%. Replacement with date pit powder at 5% elicited the highest ratings on sensory acceptability and overall acceptability. Similarly, in the case of spreadable cheese, the addition of date pit powder at levels of up to 10% was found to be acceptable in relation to antioxidant activity and sensory properties (Darwish et al., 2020). Overall, the acceptable concentration range for the addition of date pits is lower in the case of dairy products as compared to other food products.

3.6. Date pits in desserts, spreads, and condiments

Typically, date pits have been used as an additive in various types of sweets, pastes, and sauces. The addition of insoluble dietary fibers can reduce calories, extend their shelf life (Table 3), and improve the texture.

In the case of chocolate products, Zamzam et al. (2018) studied the addition of raw date pit powder (at 150 and 300 µm particle size) to chocolate at ratios of 1:9, 3:7, 5:5, and 7:3. They found that the highest homogeneity (according to microscopic evaluation) was achieved when date pit powder with 150 µm particle size was added at a 1:9 ratio. The addition of date pits at 150 µm particle size was associated with improved taste (rated as "very good") when they were added in ratios of 1:9 and 3:7. Moreover, calories and fat content decreased as the level of added date pits increased (Zamzam et al., 2018). Abushal et al. (2021) investigated the addition of date pit powder to a cocoa substitute for use in chocolate sauce formulation at 5, 10, and 15% levels. Viscosity fell significantly with the addition of date pits, and the authors concluded that date pit powder could enhance the nutritional value of the product (specifically, by increasing its fiber content to cover 15% of the daily requirement) and extend its shelf life, due to the reduction in moisture content, without significant effects on sensory acceptability. Finally, Bouaziz et al. (2010) added extracts of soluble and insoluble dietary fibers from date pits to chocolate spread at levels from 1 to 5%. At all these levels, there was an insignificant effect on the firmness, chewiness, and adhesiveness of the chocolate spreads. Sensory analysis also revealed that chocolate spread with added soluble fibers was comparable to a control. However, enrichment with insoluble fiber produced a significant difference from the control in terms of texture and taste.

Other dessert products, such as pudding, have been enriched with date pits through addition at a level of almost 30% of the whole mixture. Pudding enriched with date pits in this way has been found to be comparable to a commercial product in terms of viscosity, gel hardness, and cohesiveness; panelists liked the color and flavor of the pudding with date pits and found it acceptable overall (Al-Amri et al., 2014b). Al-Farsi et al. (2007) were able to prepare an enriched date fruit paste with the addition of 3% date pits; as a result, antioxidant activity reached 580–929 μmol of Trolox equivalent/g fresh weight.

Condiments are another class of products with the potential for inclusion of date pit powder. Alqahtani (2019) added date pits to ketchup at 0.25, 0.50, 1.00, and 1.50% ratios. Ketchup with date pits added at concentration levels of 0.50% and below were associated with the highest sensory ratings in terms of texture; however, overall acceptability scores were significantly higher at the 0.5 and 1% levels. In another study, oil extracted from date pits was used as a replacement for vegetable oil in mayonnaise, and the taste of mayonnaise made in this way was found to be superior as compared to a control (Basuny and Al-Marzooq, 2010).

3.7. Other applications

The functionality of date pit powder as a food ingredient has been examined in its raw form, and in the form of microbially digested date pits, defatted date pits, or extracted protein (Al-Farsi and Lee, 2011; Akasha et al., 2016; Alyileili et al., 2020b). Date pits have been used in synthesis of a nanoparticle powder *via* hydrolysis with acid followed by ultrasound-assisted extraction, combined with the use of water-based and methanol-based solvents. This treatment enhances their antioxidant activity level and their solubility in water, and has been found to have potential uses in food processing and other applications (Mostafa et al., 2022). The aforementioned studies do not specify the ratio at which date pits were included, nor the food product to which they were added. However, all agree on the positive effect of date pits and their extracts as an antioxidant agent, for their emulsifying effect, and for the overall improvement in nutritional value.

Other studies have demonstrated more innovative functionalities for date pits in the domain of food preparation and processing. For example, biodegradable films (Figure 1) are among the new technologies that help to extend the shelf life of foods by maintaining food quality and nutritional value *via* solute migration and reducing moisture, respiration, gas exchange, oxidative reaction rates, and physiological disorders (Rojas-Graü et al., 2009). Date pits have been explored in this application in the form of a blended composite with other ingredients; this composite has been used either in raw or in treated form. In a study of the raw powder form, date pit powder was mixed with corn starch at various ratios (range: 10–40%); the incorporation of date pits at 30% was associated with improved morphological properties (Alqahtani et al., 2021). Ramadan et al. (2020) introduced another functional degradable food packaging material: they treated date pits with silver nitrate and combined the result with raw fabrics and chitosan. This composite was found to have positive effects, such as reduced microbial degradation, increased permeability, and water absorbance. The authors of this study propose that this composite could be used as packaging for seeds and powdered food materials. Other advanced biodegradable films have been formulated with date pits as a component to produce selective antibacterial activity against *E. coli* and *S. aureus*. In a study of this application, date pit powder was mixed with corn starch, low-density polyethylene, antimicrobial agents, and Cloisite in blends at 20 different proportions. The optimal incorporation rate for date pits in terms of the material's antibacterial and mechanical properties was found to be 4.1% (Radfar et al., 2020). Similarly, date pit oil has been used as an edible wax coating to extend the storage stability of guava fruit, substituted for water at 0.5–2.0% compared to the standard wax formulation. After a storage period of 16 days, results showed that the highest substitution ratio (i.e., 2.0%) led to the best qualities in terms of storage stability (i.e., pH, firmness, titratable acidity, total soluble solids, and ascorbic acid content; Ahmed A. et al., 2020).

One of the more remarkable contexts in which date pit extracts provide added value is the implementation of hydrocolloids and phenolic extracts (HSDP) as a coating for potato strips with the purpose of decreasing oil absorption during deep-fat frying. In a study exploring this use, the experimental inclusion range was 0.5–6%, and the results indicated that the use of 4% HSDP coating reduces oil uptake by 77.7%, which is higher than similar effects reported in other previously published work (Mousa, 2016).

4. Challenges and future work

The attractiveness of date pits in food fortification is highly related to their composition in terms of bioactive compounds, such as vitamins, minerals, essential amino acids, organic acids, phenolic compounds, sugars, dietary fiber, and antioxidants. Increasing the health value of food without sacrificing its sensory attributes is a common challenge. The thresholds for incorporation ratio must be considered when using any value-added product. Specifically, this threshold represents how much of the product can be added, proportionately to the food, without producing adverse effects compared to the original product. The challenges of increasing the incorporation of date pits into baking formulations could be related to the fact that they compete for water as compared to the original ingredients (i.e., flour and sugar), and thus their inclusion could negatively affect the product's sensory acceptability. In this regard, studies need to target methods of modifying the structural characteristics of date pits so that they can be incorporated at higher proportions without compromising the sensory and rheological characteristics of baked products.

The transformation of date pits from their raw condition to treated fractions and extracts *via* treatment with various solvents could enhance their organoleptic properties when used in food products. At present, results have mostly been reported for a basic grinding process; however, other physical treatments (e.g., ultrasound, cooking, and steam pretreatment), chemical treatments (e.g., with alcohol, acids, and alkali), and microbial treatments (i.e., microbial degradation or enzymatic hydrolysis) need to be applied to explore the possibility of improving their desirable characteristics. It

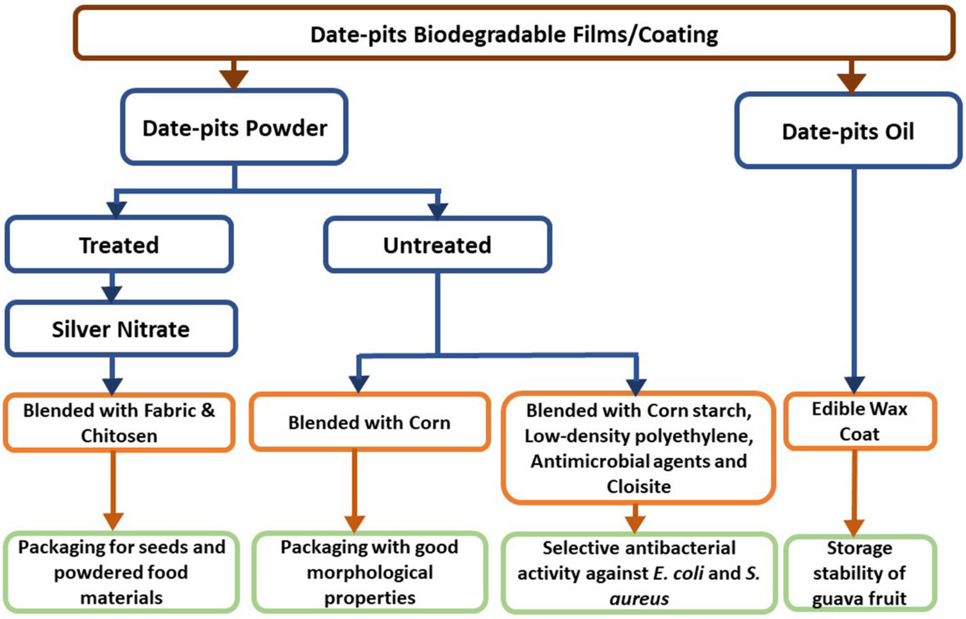


FIGURE 1
Date pits in biodegradable films and coatings.

would be interesting to explore whether hemicellulose and cellulose could be separated and used to improve the structural and functional characteristics of food products developed to make use of these. Ideally, lignin is isolated from date pit biomass before it is added to food products, since this is very difficult to digest (Li et al., 2018).

In addition, the separation of crystalline and amorphous fractions of date pits could have wider applications. For example, crystalline fibers could be used to enhance the formation of the desired level of crust in bread, while amorphous fractions could increase the softness of the crumb (Al-Khalili et al., 2021, 2022). Date pits could function as a plant-source protein for use in food and other bioproducts. A negligible amount of work has been reported on the extraction of protein from date pits; detailed structural and functionality analyses need to be performed.

Assays have been used to analyze the effects of incorporating date pits or their bioactive extracts into food products at various ranges of levels. Physiochemical characteristics, chemical composition (i.e., fiber, fat, protein, saccharides, polyphenols, and flavonoid content), the morphology of samples, and rheological characteristics have been commonly investigated for foods fortified with date pits (Salem and Habiba, 2013; Al-Amri et al., 2014a; Najafi et al., 2016; Bouaziz et al., 2017; Alqahtani et al., 2021; Alqattan et al., 2021). Most studies have evaluated organoleptic attributes, such as color, texture, taste, odor, appearance, and overall acceptability, in order to assess palatability. Under this approach, panelists evaluate foods using a hedonic scale, with scores provided on a numerical basis to represent particular attributes on a scale from most liked to less liked. The rate of decay of food products has also been explored, in order to determine their shelf life, by monitoring a food's attributes over a certain time period and in some cases by tracking microbial activity (Hejri-Zarifi et al., 2014; Najafi et al., 2016; Nabi et al., 2018; Ghasrehamidi and Daneshi, 2019; Samea and Zidan, 2019; Sayas-Barberá et al., 2020; Abushal et al., 2021).

Overall, the analytic procedures and protocols used to evaluate the addition of date pits to food products in different ratios have accounted for both nutritional and sensory value. Most studies have aimed to identify the maximum ratio at which date pits can be added for optimal functionality, without affecting the sensory acceptability of the product. However, no assessment tools have been used to quantify the overall quality achieved by the addition of date pits in a particular ratio. The Whole Quality Index is one of the approaches used to optimize the formulation of fortified foods with a particular food by-product (Spinelli et al., 2019; Cedola et al., 2020; Marinelli et al., 2021). The two aspects of the food considered in this index are its chemical composition (i.e., nutritional value) and its sensory acceptability. In making use of it, food samples are prepared at several degrees of fortification, and the sensory and nutritional properties of each version are assessed. In the future, it would be beneficial if a Whole Quality Index could be devised for the use of date pits in the development of food products.

5. Conclusion

Over more than four decades, significant progress has been made in the addition of date pits to various foods and bioproducts. The literature on applications of date pits in food has been comprehensively reviewed here, considering their uses across various food groups. In addition, threshold limits for the addition of date pits have been compiled, considering the nutritional value and sensory characteristics of the fortified products. The utilization of date pits in foods could help the date fruit industry to optimize the use of its waste products, and could also contribute to local food security and reduce negative environmental impact. This survey of the literature has indicated that the optimal ratios at which date pits can be added are dependent on factors including the type of food, the particle size in date pit powder, treatments applied, and whether other ingredients are also added. In most cases, applying treatments to the date pits and including other ingredients enabled the incorporation of date pits at higher levels. Initially, researchers studied date pit drinks as a cheap alternative to Arabic coffee. The applications of this ingredient were then expanded to the fortification of baked goods in order to increase their nutritional value. The value of this fortification surpassed basic nutrition to encompass other functionalities (e.g., texture and shelf life); thus, other food products, including meat, dairy, condiments, and desserts, were subsequently fortified with date pits. In most cases, the result of this fortification was an improved texture, greater health functionality (in terms of antioxidants, dietary fibers, and phenolic compounds), reduced oxidation, improved colloidal properties and water holding capacity, and extension of the product's shelf life. Recently, date pits have begun to be used in more innovative applications in food processing. Specifically, they have been included in the formation of bio-composites to improve their functionality in terms of biodegradability, improved morphological properties, resistance to microbial degradation, selective antibacterial activity, increased permeability and water absorbance, and a reduction in the amount of oil absorbed by potato strips during deep-fat frying.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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