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Valorization of the potential use of date press cake (date syrup by-product) in food and non-food applications: a review

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Date palm is the most important fruit crop in the Middle East, North Africa, and Southwest Asia. However, a large amount of waste is generated through various industries related to date processing. Date press cake (DPC) is the main by-product of the date honey or syrup industry, where it gives 17–28 g of DPC /100 g of fruit and is usually discarded as waste. Due to its higher content of nutrients and bioactive compounds, it can be valorized through inclusion in various food and nonfood applications. The potential applications of DPC as a promising ingredient and innovative substrate in different applications were discussed in this review, including chemical composition, nutritional value, functionality, current applications of DPC, limitations, and future trends.

KEYWORDS

date press cake, valorization, nutritional and biochemical composition, functional properties, value-added products

1 Introduction

Date palm (*Phoenix dactylifera*), the most important fruit crop in several countries, is mainly grown in arid and semiarid regions including the Middle East, North Africa, and South-West Asia (Al-Khalili et al., 2023). Recently, the cultivated area of date palm increased rapidly due to several reasons including its ability to grow under tough conditions (e.g., long summers, low rainfall, low relative humidity, and high temperatures). Moreover, dates have various unique properties including a high content of nutrients, various health benefits due to the higher content of bioactive compounds, economic advantages, cultural values, and their role in agroecosystems (Muñoz-Tebar et al., 2023). According to FAO statistics in 2021, the total cultivated area of date palm was 1.3 million ha with annual global production of 9.66 million tons (Abdel Rahman et al., 2023).

Date fruits can be consumed as fresh fruit or in a processed form, such as dried fruits, jam, juice, syrup (Dibs), jelly, powder, bar, butter, paste, pickle, and others (Oladzad et al., 2021). Generally, several types of by-products can be generated during date fruit processing, e.g., low-quality fruits, peels, seeds, and date press cake (date pomace), which if not well managed can cause serious environmental problems. Date press cake (DPC), the main by-product of date syrup (also known as Dibs in the Arabian Peninsula) industry (Figure 1), is a good source of dietary fiber, sugars, protein, minerals, and bioactive compounds, e.g., phenolics and flavonoids (Alqahtani et al., 2022). The date syrup industry results in approximately 17–28 g DPC/100 g fruit (Al-Farsi et al., 2007). Although the chemical composition of DPC is valuable, it is still underutilized and considered a waste product.

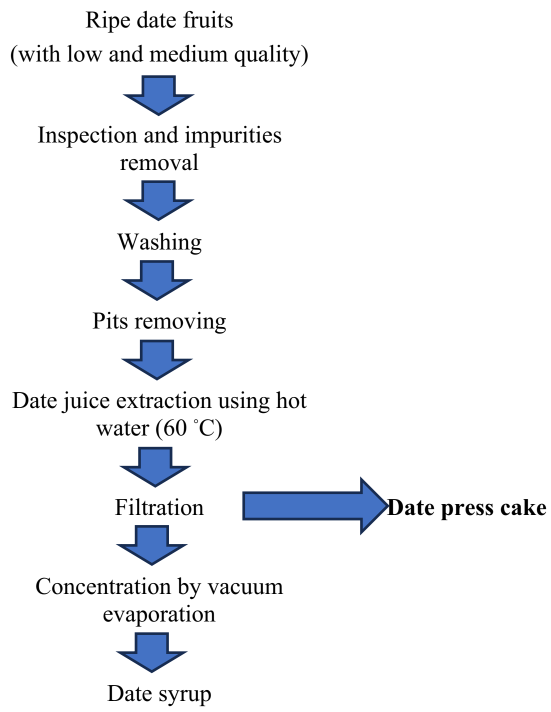

FIGURE 1
Flowchart of date syrup production [adapted from Najjar et al. (2020)].

DPC is a rich source of organic compounds, particularly sugars, in addition to its higher moisture content; therefore, inappropriate disposal of DPC can cause undesirable fermentation, the generation of unpleasant odors, and gas emissions, and therefore can increase environmental pollution (Plazzotta et al., 2017). Moreover, such conditions can facilitate the growth and spread of bacteria, pests, and mice, and therefore increase the risk of diseases. On the other hand, recent studies have discussed the use of DPC as a potential source of bioactive and functional ingredients in food and non-food applications (Oladzad et al., 2021). It has been reported to be used as a gelling agent in jam processing (Alqahtani et al., 2022), an ingredient in the production of biscuits and protein bars (Sheir, 2022), an ingredient in cake production (Majzoobi et al., 2020), a natural component for the development of drinkable yogurt (Alqahtani et al., 2023), an abundant precursor for the production of activated carbon (Heidarinejad et al., 2018; Majzoobi et al., 2019), a green precursor for the production of volatile fatty acids and organic acids (Oladzad et al., 2021; Haris et al., 2023a), and a natural additive for soap production (Rambabu et al., 2020). DPC can be utilized as a source of nutrients for the microbial bioconversion process, which produces high-value products like biofuels, carboxylic acids, enzymes, amino acids, and SCP (single-cell protein) since it is a good supply of fermentable sugars and dietary fiber (Oladzad et al., 2021).

The fortification of food products with DPC could help to cover the daily human fiber requirements recommended by the FDA. It is vital to involve fibers in diets due to their broad functionality in food systems (e.g., it can be used as stabilizers, fat replacers, fat absorbers, binders, and bulking agents) and their various health benefits particularly for the digestive system (Al-Khalili et al., 2023). Furthermore, DPC represents a good source of phenolics and antioxidants and can be used as an inexpensive natural antioxidant (Al-Farsi et al., 2007). Accordingly, it can be used in the food industry to improve quality and functionality (Al-Farsi et al., 2007). Sustainable development through the conversion of agricultural by-products to value-added products will efficiently support the economics of the food industry and minimize the pollution caused by the discarding of such waste. The aims of the current review are: (1) to present sufficient information about the chemical composition of DPC; (2) to explore the utilization of DPC in various food and non-food applications.

2 Chemical composition of date press cake (DPC) and their functionality

DPC is a rich source of valuable ingredients, e.g., dietary fiber, sugars, minerals, phenolics, and flavonoids. Table 1 shows the chemical composition of DPC, which can be used to determine its potential utilization. Generally, the applications of DPC mainly depend on the requirement for each component in the targeted product.

2.1 Fiber content

The variations in the fiber content of DPC samples in the literature could be related to the date palm variety, agricultural practices, environmental conditions, extraction methods, and date syrup industry conditions. According to a recent study conducted by Haris et al. (2023a), the scanning electron microscope images showed that DPC fibers consisted of two types of fibrous bundles: (1) insoluble fibers (cellulose, hemicellulose, and lignin) which represent the major part, and (2) soluble fibers (fructans and pectin) which represent the minor part. Generally, insoluble fibers from different plant sources are usually involved in the food industry, e.g., bakery products and breakfast cereals (Al-Khalili et al., 2023). Similarly, it could be suggested that fibers from DPC can be employed as a fat substitute in some food products such as chicken sausages and ice cream. According to the recommendations of the World Health Organization in 2023, the intake of fiber should be at least 25 g/day (Veda and Srinivasan, 2011); accordingly, it is of vital importance to include fiber in our daily meals. Moreover, pectin, a soluble fiber, represents one of the most important ingredients in the food industry and the most popular gelling agent with unique physical-functional properties. The pectin content of DPC was 3.2 g/100 g, which may make DPC a proposed functional ingredient in various food products such as jelly and jam. It is worth noting that the DPC fibers showed strong thermal stability with Tmax (temperature of maximum weight loss) of about 200 and 350°C according to thermogravimetric analysis (Haris et al., 2023a). This property may qualify the DPC fibers to be used as a packaging material or as a filler in biocomposites.

2.2 Fat content

The fat content of DPC varies due to several factors, including variety, agricultural practices, growing conditions, fat extraction method, and date syrup industry conditions. Although the lower fat content of DPC, it has an excellent lipid profile due to the higher

TABLE 1 Chemical composition of date press cake.

Chemical component*		Range	References
Moisture (g/100 g)		8.30–10.59	Al-Farsi et al. (2007)
Ash (g/100 g)		1.68–4.80	Al-Farsi et al. (2007), Ashraf and Hamidi-Esfahani (2011), Oladzad et al. (2021), Alqahtani et al. (2022), and Haris et al. (2023a)
Protein (g/100 g)		3.62–13.00	Al-Farsi et al. (2007), Ashraf and Hamidi-Esfahani (2011), Majzoobi et al. (2019), Oladzad et al. (2021), Alqahtani et al. (2022), and Haris et al. (2023a)
Fat (g/100 g)		1.30–5.37	Al-Farsi et al. (2007), Ashraf and Hamidi-Esfahani (2011), Majzoobi et al. (2019), Oladzad et al. (2021), Alqahtani et al. (2022), and Haris et al. (2023a)
Total sugar (g/100 g)		16.25–35.30	Majzoobi et al. (2019) and Haris et al. (2023a)
Fructose (g/100 g)		11.05–20.60	Majzoobi et al. (2019) and Haris et al. (2023a)
Glucose (g/100 g)		4.84–14.60	Majzoobi et al. (2019) and Haris et al. (2023a)
Sucrose (g/100 g)		0.10–0.41	Majzoobi et al. (2019) and Haris et al. (2023a)
Total dietary fiber (g/100 g)		25.39–49.00	Al-Farsi et al. (2007), Alqahtani et al. (2022), and Haris et al. (2023a)
Pectin (g/100 g)		3.2	Haris et al. (2023a)
Total phenolic content (mg GAE/100 g)		165–435	Al-Farsi et al. (2007), Majzoobi et al. (2019), and Haris et al. (2023a)
Total flavonoid content (mg of quercetin /100 g)		184–195	Majzoobi et al. (2019)
Antioxidant activity (micromoles of Trolox equivalents (TE)/g)		134–357	Al-Farsi et al. (2007)
Elements (ppm)**	Ca	46.0	Haris et al. (2023a)
	K	145.7	
	Mg	26.7	
	Na	8.2	
	P	28.7	
	Cu	0.2	
	Fe	2.0	
	Mn	0.2	
	Zn	0.5	

*Values are reported on a fresh weight basis.
**Values are reported on a dry matter basis.

content of monounsaturated fatty acids (FA) (Muñoz-Tebar et al., 2023). According to a study conducted by Majzoobi et al. (2019) on the chemical composition of DPC, the lipid profile showed that unsaturated FA represents about 50% of the total fat content. Moreover, the percentage of mono and polyunsaturated FA was 41.07 and 9.24% of total fat content, respectively. Oleic acid was the major monounsaturated FA, whereas linoleic acid was the major polyunsaturated FA. Myristic acid was the major saturated FA, while capric acid was the minor saturated FA (Majzoobi et al., 2019; Muñoz-Tebar et al., 2023). The FA content of DPC consists of oleic acid (41.07 g/100 g of oil), myristic acid (23.77 g/100 g of oil), stearic acid (12.42 g/100 g of oil), palmitic acid (12.58 g/100 g of oil), linoleic acid (9.24 g/100 g of oil), lauric acid (0.61 g/100 g of oil), behenic acid (0.53 g/100 g of oil), and capric acid (0.52 g/100 g of oil) (Majzoobi et al., 2019). However, there is not sufficient data available in the literature on the lipid profile of DPC for a complete comparison. Generally, it can be considered that DPC is a good source of edible and pharmaceutical oils.

2.3 Protein content

As mentioned in the previous section, the variations in the protein content in DPC in the previous studies can be ascribed to the plant origin, agricultural practices, environmental conditions, protein determination method, and date syrup industry conditions. Al-Farsi et al. (2007) investigated the compositional and functional properties of date syrup by-products and reported that the protein content of DPC was higher than that of date seeds. Moreover, DPC revealed a higher protein content than the press cake of apple, orange, and pineapple (Muñoz-Tebar et al., 2023). Vegan people can use DPC for partial replacement of animal proteins as it lower in cost and more sustainable sources (Al-Khalili et al., 2023). Due to the high protein content of DPC, it can be used as an excellent and natural substrate to produce glutamic acid through a submerged fermentation process using *Corynebacterium glutamicum* (Davati et al., 2010). In addition, the inclusion of DPC in ruminant diets improved nutrient digestibility, milk yield, and milk composition; the study revealed that there were no negative impacts on treated animals' health (Morsy et al., 2021). The extraction of proteins from DPC may open new horizons for the utilization of such proteins in food and non-food applications. Currently, there are no available studies about the detailed composition of the protein extracted from DPC to give a clear visualization of the suitable applications of this protein. Accordingly, it is of vital importance to direct the researchers' attention toward the chemical, physical, and functional properties of DPC protein.

2.4 Total sugar content

The sugar content of DPC was higher than that determined for the press cake of apple (10.2 g/100 g), pear (7.6 g/100 g), and orange (9 g/100 g) (Haris et al., 2023a). The predominant sugars in DPC were fructose and glucose with contents ranging from 11.05 to 20.60 and 4.84 to 14.60 g/100 g, respectively, while sucrose was found in lower concentrations (0.10–0.41 g/100 g) (Majzoobi et al., 2019; Haris et al., 2023a). As DPC has a higher content of sugars, this may cause undesirable fermentation when it is dumped into landfills, leading to serious environmental concerns; the problem worsens if there are high humidity conditions. On the other hand, the high sugar content of DPC may be advantageous in various food and non-food applications. DPC with high sugar content can be used as a promising, natural, low-cost, and eco-friendly substrate for the production of valuable products, e.g., ethanol, biofuel, organic acids (lactic acid, citric acid, itaconic acid), amino acids, enzymes, and volatile fatty acids through controlled fermentation and other microbial bioconversion processes (Oladzad et al., 2021; Haris et al., 2023a). In addition, Ashraf and Hamidi-Esfahani (2011) stated that sugars are considered the main substrate for the production of antibiotics, baker's yeast, and single-cell proteins through fermentation processes. Also, vinegar is an important product of the date industry, whereas DPC could be used for the production of vinegar through fermentation processes. It could be suggested that sugars can be extracted from DPC and used as a natural sweetener and a healthy alternative to sugar in the bakery and confectionery industries.

2.5 Ash

Compared to the press cakes obtained from some common fruits, DPC revealed a higher ash content than apple, orange, and pineapple press cake, while it was lower than that of strawberry and blackberry press cake (O'shea et al., 2015; Muñoz-Tebar et al., 2023). A recent study conducted by Haris et al. (2023a) showed that DPC is a good source of minerals, including potassium calcium, phosphorus, and magnesium with concentrations of 145.7, 46, 28.7, and 26.7 ppm, respectively. Additionally, they verified that DPC contains iron, copper, and manganese in lesser quantities. Additionally, they found that DPC is free of heavy metal pollution with trace amounts of chromium, cobalt, lead, and cadmium (< 0.002 ppm). The inclusion of DPC in some food products, such as biscuits and protein bars, improved the nutritional value, particularly, minerals and fibers (Sheir, 2022). Moreover, Al-Hamdani (2019) revealed adding DPC to diets raised blood hemoglobin levels, which are correlated with iron levels, and decreased blood glucose, serum, and uric acid levels. Based on its greater mineral content, it may be deduced that fortifying food products with DPC can improve their nutritious value.

2.6 Total phenolics, flavonoids, and antioxidant activity

The phenolic content of date fruit can be divided into two main categories: (1) soluble phenolic compounds which can be extracted directly by solvents, e.g., methanol or water and (2) insoluble phenolic compounds which require alkali hydrolysis before extraction as they are strongly tied with the cell wall fibers by ester bonds (Alam et al., 2021). The variations in the total phenolic and flavonoid contents of DPC presented by various researchers could be related to the methods applied for extraction and determination of bioactive compounds, processing conditions of date syrup and juice, date palm variety, agricultural practices, cultivation environment, and the inclusion of seeds in the press cake. The total phenolic content and antioxidant activity of DPC was lower than the press cake of apple and grape which can be imputed to the inclusion of seeds in the press cake of apple and grapes (Haris et al., 2023a). Al-Farsi et al. (2007) reported that the total phenolic content and antioxidant activity of DPC were higher than those determined for date flesh and date syrup but lower than those of date pits. On the contrary, Majzoobi et al. (2019) observed a decrease in the antioxidants, particularly flavonoids, in the DPC compared to date juice and date syrup. They ascribed this decrease to the juice and syrup processing conditions, particularly, thermal treatments. As DPC is a good source of bioactive compounds with antioxidant activity, it can be used in the food industry to improve nutritional quality and enhance product stability, either by delaying or eliminating oxidation processes or by reducing microbial growth. It is well known that antioxidants can keep products' quality through scavenging free radicals, and therefore retarding or delaying the formation of undesirable flavors, delaying lipid oxidation, and preventing color changes of food products (Al-Khalili et al., 2023). Furthermore, because to the presence of bioactive components, the addition of DPC to food products may lower triglyceride and total cholesterol levels and offer protection against diabetes, liver illnesses, inflammation, and gastrointestinal ailments, among other health benefits. Meanwhile, further studies are still required to provide a complete visualization of the bioactive compounds and their percentage in DPC to optimize their use in food and non-food applications.

3 Applications of DPC

Based on the literature, it could be confirmed that DPC is not just a by-product but a promising source of functional ingredients that can be utilized to develop value-added products. According to each component in DPC and the requirements of the targeted product, various valorization plans and engineering possibilities can be suggested and implemented in compatibility with the aim of sustainable development. The food and non-food applications of DPC are mentioned in Table 2.

3.1 Food applications

3.1.1 Bakery products

Bakery products represent the most consumed foods around the world and are considered the major source of energy in daily meals for all populations. Nowadays, the inclusion of new ingredients with a higher content of bioactive compounds and fibers to meet the consumer's demands for foods with additional health benefits has become a common trend (Muñoz-Tebar et al., 2023). It is well known that wheat flour represents the main component of bakery products and is principally responsible for the physical-functional and sensory properties of the product, followed by the secondary ingredients including water, yeast, salt, and other components. Additionally, because bakery products are high in carbs, especially starch, they are a major contributor to a number of chronic illnesses, including diabetes, obesity, high blood pressure, and cardiovascular disorders. Accordingly, the enrichment of bakery products with functional ingredients is of vital importance to improve functionality and nutritional value and protect or decrease the risk of such diseases (Ranasinghe et al., 2022).

3.1.1.1 Biscuits

It is worth noting that the inclusion of cereal brands could negatively affect the quality of bakery products particularly dough structure and volume (Onipe et al., 2015). Likewise, the replacement of wheat flour with cassava flour adversely affected the dough stability and development time (Rodriguez-Sandoval et al., 2017). On the other hand, the incorporation of date palm by-products into bakery products improved the water absorption capacity, resistance, and extensibility of the dough (Ranasinghe et al., 2022). Sheir (2022) investigated the possibilities of using DPC powder in replacement ratios of 5, 10, and 15% to formulate innovative biscuits. In comparison to other treatments, the biscuits enriched with 10% DPC obtained the best overall acceptance scores, according to the results of the sensory evaluation. Moreover, the developed biscuits revealed improved nutritional quality with higher protein, fiber, Fe, Zn, Ca, K, Mg, and Mn content. The developed biscuits showed better storage stability with lower microbial growth based on microbiological analysis during a storage period of 8 months.

3.1.1.2 Cakes

Cakes, a well-known bakery product, is a common food product with a high energy content, but deficient in some nutrients such as fibers, minerals, vitamins, and antioxidants. To improve its nutritional value, the press cakes of some common fruits, such as apples and berries have been added to the cake formula. Unfortunately, this procedure reduced the cake quality particularly volume, texture, and sensory properties (Rohm et al., 2015). To minimize some of these undesirable effects, adjusting the level of incorporation and particle size of fiber sources could be an effective strategy (Gómez and Martinez, 2018). Majzoobi et al. (2020) investigated the rheological, physical, and nutritional properties of cake enriched with DPC at incorporation levels of 10, 20, 30, and 40% and particle sizes of 210 μm and 500 μm. They reported that the inclusion of 10% DPC with a particle size of 210 μm resulted in a new cake with acceptable sensory properties. Furthermore, the fibre, ash, and antioxidants contents of the new cake were higher than those of the control sample. The developed cake showed enhanced consistency of the batter, stickiness, firmness, cohesiveness, viscosity, and microstructure properties. In contrary, the higher incorporation levels of DPC resulted in hard and less cohesive cakes. However, the cake developed from the DPC of 210 μm was softer and less cohesive than that produced from the DPC of 500 μm.

3.1.2 Protein bar

Protein bar is a fast, easy, and convenient snack food with higher nutrients and calories content; accordingly, it has a high worldwide popularity. Due to the higher protein content, protein bar can be oriented to specific groups of people, e.g., athletes, sick, elderly, children, and those who are at risk of malnutrition or sarcopenia (Małecki et al., 2020). However, several types of protein bars contain added sugars, saturated fats, and other low-nutrient ingredients; therefore, it is not recommended as healthy foods. Various strategies have been suggested to improve nutritional quality and decrease the drawbacks of protein bars (Małecki et al., 2020). One of these strategies is to find suitable alternatives to traditional ingredients used currently in the production of protein bars. The utilization of DPC powder in the development of an innovative protein bar was also investigated by Sheir (2022). According to sensory results, the developed protein bar exhibited higher flavor, taste, texture, and overall acceptability scores than the commercial protein bar, but lower color scores. Moreover, the developed bar with DPC revealed higher protein, fiber, ash, and minerals contents with lower fat, available carbohydrates, energy, and moisture contents than the commercial bar. Storage studies showed that the DPC-based protein bar was safe to consume in 8 months. In general, the developed protein bar could be a suitable choice for adolescents and athletes, particularly, vegetarians (Sheir, 2022).

3.1.3 Jam

Jam is one of the most desirable semi-solid food products, particularly for children, with specific moisture levels and total soluble solids (TSS) content. It can be obtained by cooking the pulp of one or more types of fruits with water, sugar, acid, and a gelling agent to form a homogenous and gelatinous mixture. The precise balancing of pH, TSS, and pectin determines the jam's quality. The most often used gelling agent in the jam industry is high methoxyl pectin (HMP), which has special functional qualities. However, due to its higher cost, the attention of researchers and manufacturers was focused on finding suitable replacers of HMP. DPC can be utilized as an inventive and affordable gelling agent in the jam industry because it is high in dietary fiber and pectin and has a good supply of sugars, minerals, phenolic compounds, and antioxidants (Al-Farsi et al., 2007; Alqahtani et al., 2022; Haris et al., 2023a). The utilization of DPC in the production of date jam was investigated in a recent study conducted by Alqahtani et al. (2022). They found that the texture, phenolic content, and antioxidant activity of date jam were improved by adding 9% DPC during processing. When DPC was added up to 9% of the produced jam, its sensory metrics and microstructure features increased significantly. The morphological features and sensory attributes of the produced jam were adversely affected by an additional rise in DPC concentration of up to 12%. The authors suggested that DPC can be used as a natural, functional, and low-cost component in jam processing.

3.1.4 Drinkable yogurt

Yogurt is a widely consumed dairy product that is becoming more and more popular due to its numerous nutritional benefits, ease of digestion, and overall health advantages (Desobry-Banon et al., 1999). Yogurt is a semisolid milk product with a creamy texture and a moderate acid taste, and is manufactured by fermenting of milk with certain bacterial strains, e.g., *Streptococcus thermophilus* and *Lactobacillus bulgaricus* (Andrade et al., 2010). Yogurt is becoming an indispensable item in the human daily meals as it is a good source of probiotics with higher digestibility, gel-like structure, desirable taste, and favorable mouthfeel (Mittal et al., 2020). To meet consumers' demands and enhance sensory properties, particularly, texture and firmness, the addition of other ingredients such as pectin, gelatin, inulin, and dietary fiber can be appropriate strategies (Sigdel et al., 2018).

In the last few years, multiple studies have been conducted on the conversion of agro-industrial by-products into value-added products with high functionality through their inclusion in various food products (Alqahtani et al., 2022). This kind of strategy might aid in reducing pollution to the environment, promoting low-cost goods, and creating novel functional foods. Moreover, the utilization of natural ingredients can help to avoid the extensive use of artificial additives and therefore minimize their negative impacts on human

TABLE 2 Applications of date press cake.

DPC concentration	Applications	Effect	References
10%	Biscuit	• Improved sensory and nutritional quality particularly protein, fiber, and minerals. • Enhanced storage stability.	Sheir (2022)
10%	Cake	• Improved sensory properties and nutritional quality, mainly, fiber, ash, and antioxidants contents. • Enhanced batter consistency, stickiness, firmness, cohesiveness, viscosity, and microstructure properties of the developed cake.	Majzoobi et al. (2020)
10%	Protein bar	• Showed higher flavor, taste, texture, and overall acceptability scores, but lower in color. • Revealed higher protein, fiber, ash, and minerals contents with lower fat and carbohydrates content. • Enhanced storage stability (8 months).	Sheir (2022)
9%	Jam	• Enhanced phenolics content and antioxidant activity. • Enhanced the texture profile and microstructure characteristics. • Morphological traits and sensory qualities were adversely affected by an additional increase in DPC concentration to 12%.	Alqahtani et al. (2022)
2–6%	Drinkable yogurt	• Texture profile improved. • Physical, functional, and sensory properties enhanced. • Adding 2% of DPC showed the best overall sensory acceptability.	Alqahtani et al. (2023)
The main raw material.	Activated carbon	• DPC could be used as an innovative, low-cost, and renewable raw material to produce activated carbon. • The activated carbon produced from DPC showed excellent surface properties with more oxygen functional groups. • It efficiently adsorbed Pb (II), Cr (VI), and methylene blue even from saline aqueous solutions.	Heidarinejad et al. (2018), Norouzi et al. (2018), and Heidarinejad et al. (2019)
3%	Soap	• Improved the physicochemical properties, antibacterial effects, and antioxidant activity of the developed soap.	Rambabu et al. (2020)
The main substrate.	Organic acids	• The citric acid yield increased to 98.42 g/L. • It was found that 1 kg of DPC can produce 209 g of lactic acid after enzymatic hydrolysis.	Acourene and Ammouche, (2012), Haris et al. (2023b)
The main substrate.	Enzymes	• Endopectinase was successfully produced from DPC through a fermentation process.	Bari et al. (2010)

health (Difonzo et al., 2022; Muntean et al., 2022). A recent study discussed the effects of adding DPC on the physicochemical properties, texture profile, and sensorial quality of drinkable yogurt after processing and during 15 days of cold storage (Alqahtani et al., 2023). The results revealed the potential fortification of drinkable yogurt with 2–4% DPC as a natural and innovative functional additive with general acceptance. Generally, the sample containing 2% DPC showed the best physical, functional, and sensory properties after processing and during the storage period. Further studies are still needed for processing conditions, digestibility, and health benefits of the inclusion of DPC in dairy products.

3.2 Non-food applications

3.2.1 Activated carbon

Heavy metal pollution, particularly in aquatic ecosystems, represents one of the most serious problems that threaten the environment and human health. The problem worsens with the continuous advancement of some industrial activities, including those related to plastic, alloys, pigments, glassware, ceramics, electronics, lead-acid batteries, and cables (Bradl, 2005). The presence of heavy metals in water can alter the kidney, liver, nervous system, reproductive system, and cause infertility and fetal abnormalities (Heidarinejad et al., 2019). It is of vital importance to find efficient technologies to purify the water before its utilization in food, juice, drinking water, and other related applications to protect human health and the environment. Various methods have been applied to purify aqueous systems from heavy metals such as adsorption, photocatalysis, electrodialysis, precipitation, reduction, ion exchange, and membrane processes (Norouzi et al., 2018; Heidarinejad et al., 2019). The utilization of activated carbon, as an adsorbent, is one of the most common and efficient industrial techniques for the removal of heavy metals from water and various aqueous solutions due to its excellent properties, e.g., large surface area, unique internal pore structure with high porosity, and high content of functional groups (Heidarinejad et al., 2018, 2019). In the last few years, the attention of many researchers has been focused on the development of activated carbon from low-cost and renewable resources, particularly, agroindustrial by-products, e.g., lemon peel, *Cucumis melo* peel, tamarind wood, palm oil mill effluent, cherry kernels, and DPC (Heidarinejad et al., 2019).

According to the literature, DPC has been used as an innovative, low-cost, and renewable raw material to produce activated carbon (Heidarinejad et al., 2018; Norouzi et al., 2018; Heidarinejad et al., 2019). Heidarinejad et al. (2019) studied the efficiency of activated carbon, produced from DPC through the carbonization and activation process at 750°C, in the removal of Pb (II) from aqueous solutions. The authors concluded that activated carbon produced from DPC and activated in dry KOH: CM (carbonized material) at weight ratios of 4:1 showed excellent surface properties with more oxygen functional groups and adsorbed Pb (II) even from saline aqueous solutions. Likewise, the KOH-activated carbon produced from DPC showed high efficiency in removing methylene blue, as a representative of cationic dyes, from aqueous solution through the adsorption process (Heidarinejad et al., 2018). The study showed that the adsorption efficiency could be enhanced by low-frequency ultrasound. Similar findings have been reported by Norouzi et al. (2018) who reported that NaOH-activated carbon produced from DPC had a large surface area with a higher adsorption capacity of Cr (VI) from aqueous solution. Further studies are required to explore more applications of activated carbon derived from DPC to remove other heavy metals from water and various aqueous solutions.

3.2.2 Soap

Soap, the most common detergent in our daily life, is a salt of fatty acids produced by alkaline hydrolysis of triglycerides in fats and oils through the saponification reaction. However, soap prepared from vegetable oils is susceptible to degradation by oxidation reactions (rancidity), leading to color deterioration, odor change, texture damage, and shelf-life reduction (Zauro et al., 2016). In addition to preventing soap oxidation, adding antioxidants and antimicrobials to soap can help reduce inflammation, heal scars, and give skin a more radiant, young appearance (Anbarasu et al., 2012; Atolani et al., 2016). However, the majority of soap producers rely on artificial substances like butylated hydroxytoluene and butylated hydroxyanisole to increase antioxidant activity. Meanwhile, prolonged exposure to these chemicals for a long time can cause multiple health concerns including allergies, inflammation, and may lead to carcinogenic symptoms (Atolani et al., 2016). Accordingly, the replacement of such chemicals with natural sources in the soap and cosmetics industry is of vital importance. As DPC is rich in antioxidants, it can be used in cosmetics and the soap industry. The extraction of antioxidants from DPC and incorporation in the soap industry is an environmentally friendly, economical, and innovative method; and encourages the conversion of DPC from a waste into a valuable ingredient (Rambabu et al., 2020). Rambabu et al. (2020) used DPC as a substitute for artificial chemicals in soap production. They investigated the effect of the antioxidant-rich DPC extract on the physicochemical and antimicrobial properties of soaps prepared from different vegetable oils, e.g., coconut oil, palm oil, and pomace olive oil. The results of the study demonstrated that the developed soap enriched with DPC extract had significantly improved physicochemical properties (pH, moisture content, foam height, surface hardness, and total fatty matter) and antibacterial effects against gram-positive (*Streptococcus pyogenes*) and gram-negative (*Pseudomonas aeruginosa*) bacteria, which was comparable to that of commercial turmeric soap. It can be concluded that the DPC extract can be used as a natural, inexpensive, and effective antioxidant and antibacterial agent in the soap and cosmetics industry (Rambabu et al., 2020).

3.2.3 Organic acids and enzymes

Citric acid, a member of the carboxylic acid family and one of the most significant organic acids, finds extensive application in a variety of industries, including food, beverage, confectionery, pharmaceutical, medicine, cosmetics, and chemicals. It can be made chemically, and organically from citrus fruits, or by fermenting citrus fruit with the help of microbial strains (Chandrasekaran and Bahkali, 2013; Oladzad et al., 2021). The most widely used microbe for fermentation-based citric acid synthesis is the Aspergillus niger fungal strain (Sawant et al., 2018). Nonetheless, a variety of agroindustrial byproducts, including citrus peel, grape pomace, apple, and other agricultural leftovers, can be utilized as substrates in the citric acid fermentation process (MAZAHERI and Nikkhah, 2002). *Aspergillus niger* PTCC 5010 has been used to produce citric acid from date pulp through a solid-state fermentation process with a yield of 168 g citric acid per kg of date pulp under controlled conditions of pH (3.5–4.5), temperature (30°C), and moisture content (70–80%) (MAZAHERI and Nikkhah, 2002). Acourene and Ammouche (2012) used the fungal strain of *Aspergillus niger* ANSS-B5 to produce citric acid through a solid-state fermentation process using DPC as a low-cost feedstock.

Lactic acid is an organic carboxylic acid that is of great importance due to its wide spectrum of applications in the food, medicinal, cosmetic, and chemical industries. Not only does it occur naturally in a variety of food products like yogurt and sourdough bread, but it is also generated commercially by microbial fermentation and chemical synthesis (Haris et al., 2023b). For sustainability, research is currently focused on the use of agro-industrial by-products as low-cost precursors in the fermentation process to produce lactic acid such as sugarcane press mud, wheat bran, date palm waste, soybean curd residues, dairy industry waste starchy food waste, and mixed restaurant food waste (Haris et al., 2023b). Haris et al. (2023b) examined the process by which *Lactobacillus casei* ferments DPC to make lactic acid, and using response surface methods, identified the ideal production conditions. The authors found that 1 kg of DPC can produce 209 g of lactic acid after enzymatic hydrolysis. Moreover, the yield of produced lactic acid can be increased up to 457 g if the fermentation process is carried out under the optimum conditions.

Endopectinase is one of the most important enzymes in the fruit juice industry, particularly, for extraction and clarification purposes as it breaks down the pectin present in fruit juice into short molecules, and therefore decreases the time of filtration and improves the efficiency of the extraction and purification processes (Jayani et al., 2005). Bari et al. (2010) investigated the possibility of using *Aspergillus niger* PC5 to produce endopectinase from DPC through the fermentation process using the response surface methodology. They reported that a fermentation time of 76.05 h, a pH of 5, an aeration rate of 250 rpm, an ammonium sulphate concentration of 0.3%, a potassium dihydrogen phosphate of 8 mg ml^{-1}, a date pomace concentration of 60 mg ml^{-1} and a total spore count of 105 spores ml^{-1} were the optimal fermentation condition for endopectinase production.

4 Research needs and future vision

Although DPC has many advantages and valuable applications of DPC, there are some further investigations still required. The inclusion of DPC in an industrial scale requires a full and detailed understanding of date palm industry, i.e., the amount of waste produced from each region, the geographical distribution of date palm processing factories, and the companies that may benefit or involve DPC in their products. A deep understanding of the chemical, physical, and functional properties of DPC will facilitate the approach to its valorization. The development and improvement of fermentation processes regarding microbial strains, fermenter design, and fermentation conditions (pH, temperature, nitrogen source, additives, and pre-treatments of the substrate) can maximize the benefit of DPC and produce higher yields with higher quality value-added products. The potential use of DPC in food packaging such as biodegradable films. The possibility of using DPC in agricultural applications such as peat moss and fertilizers. Accordingly, further studies are needed to cover all the above-mentioned points.

5 Conclusion

Date press cake (DPC), as one of the most important date syrup processing by-products, has a high content of dietary fiber, sugars, protein, minerals, and bioactive compounds, e.g., phenolics and flavonoids. This review confirmed that DPC can be employed as a valuable component or suitable substrate for food and non-food applications. The conversion of agro-industrial by-products into new value-added products can minimize environmental pollution, save natural resources, support the local and global economy, and finally contribute to sustainable development. However, further studies are needed to achieve the optimum utilization of DPC in various applications.

Author contributions

NA: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, Investigation.

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Conflict of interest

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

Publisher's note

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