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Nutritional, nutraceutical attributes, microbiological and chemical safety of different varieties of dates—A review

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ABSTRACT

Dates are valued as a highly nutritious food with multiple nutraceutical properties. Date fruits are widely consumed, especially in the Middle Eastern regions. Dates are a vital source of readily metabolisable natural sugars, minerals, vitamins, dietary fibre, protein, and other high-value natural antioxidant compounds such as carotenoids and phenolics. Nutritional and nutraceutical composition and properties of dates vary according to variety, origin, fruit maturity level, and post-harvest processing conditions. Dates, like many other fruits, are susceptible to microbial contamination, particularly during improper pre- and post-harvest handling and storage. The prevalence of mycotoxin and bacterial contamination not only spoils the functional food quality of dates nevertheless it poses potential adverse effects on human health. With increased interest in the health benefits of dates, there is a greater need to examine and understand potential microbiological safety issues linked with commercial dates. The main goal of this review is to present comprehensive and most up-to-date scientific findings about the high-value components profile, nutritional and nutraceutical qualities, and microbiological safety of various types of dates consumed around the world. Furthermore, the study urges innovative mitigation strategies to combat microbial contamination while maintaining the safety and quality of dates supplied and consumed as part of the food chain.

1. Introduction

The date palm, or *Phoenix dactylifera* L., is regarded as one of the most ancient and most valuable fruit crops due to its nutritional, medicinal, religious and socio-economic importance. Date palm is mainly grown and/or cultivated in hot regions like North Africa, South West Asia and some countries of South Asia such as Pakistan and India (Al-Farsi and Lee 2008a; Ali et al., 2012). Dates are valued as a highly nutritious food and widely consumed, especially in the Middle Eastern countries (Ali et al., 2012; Umar et al., 2014). Due to their energising role and dietary benefits, however, dates are marketed and consumed world over (Food and Agriculture Organization, 2022). Dates are consumed in different forms and ways like fresh fruit (30–40 %), or dried form (60–70 %), and also as an ingredient of various processed foods.

Dates are well recognised as a nutrient-dense food with a healthy combination of essential dietary components. They are a primary source of carbohydrates (around 60–70 %) and contain appreciable amounts of vitamins B complex, vitamin C, electrolytic minerals (especially potassium) and dietary fibre. Despite having a lower protein and fat content, dates contain an important group of necessary amino acids and healthy fatty acids, including linoleic (C18:2) and oleic (C18:1) acids (Al-Farsi and Lee, 2008a; Younas et al., 2020). Furthermore, dates contain a variety of medicinally important bioactive components such as phenolic acids, carotenoids and polyphenols. The content of these bioactives varies depending on date cultivars, agro-climatic conditions, geographical region, fruit ripeness, and post-harvest processing processes (Vayalil, 2014; Odeh et al., 2014; Al-Farsi et al., 2005). The occurrence of a diverse range of high-value bio compounds in dates has been linked to an array of biological effects, such as antimutagenic, antimicrobial, antioxidant, anticancer, immunostimulant and anti-inflammatory properties (Younas et al., 2020; Vayalil, 2014;

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Al-Farsi, 2005; Odeh et al., 2014). In the modern era of optimal nutrition, consumers and industries are more interested in the functional food benefits of dates. According to pharmacological studies, dates and date products may have health-promoting effects. Date phytochemicals (DFPs) in particular, have shown significant promise in lowering cholesterol levels and reducing the likelihood of frequent civilisation diseases such as cancer, diabetes, and cardiovascular disorders (Younas et al., 2020; Vayalil, 2014; Rahmani et al., 2014; Ali et al., 2012; Al-Mssallem, 2020).

The consumption of dates mainly depends upon general quality criteria such as appearance in terms of size, shape, colour, physical state and texture, taste and nutritional value (Ali et al., 2012). Dates' nutritional quality and shelf-life are determined not only by morphological and physicochemical tests as such, but also by microbial contamination monitoring. Dates are amongst fruits that are vulnerable to microbial invasion due to excessive humidity, weather, temperature, and hygienic conditions during harvesting and post-harvest handling and storage (Zamir et al., 2018). Fresh dates (rutab), in particular, which are consumed in large quantities by communities without additional processing, are extremely susceptible to microbial load due to their high moisture contents (35 to 40 %) (Siddiq et al., 2013; Zamir et al., 2018). Microbial contamination of dates is mostly caused by moulds, which attack fruit during the ripening phase as well as during processing and storage (Al Hazzani et al., 2014). As a result, dates could be attacked by a fungus that creates mycotoxins. Mycotoxins are secondary metabolites mostly produced by fungi such as *Aspergillus, Penicillium*, and *Alternaria*. Aflatoxin is one of the types of mycotoxins that are harmful to human health since it is the most poisonous and can cause toxicity in the human body (Iqbal et al., 2014). Dates can often be contaminated with aflatoxin (B_1, B_2, G_1, and G_2) as a result of poor agricultural, post-harvest processing, and storage practices (Carla et al., 2011).

Dates nutritional qualities are extensively studied in the literature as a significant component of traditional diets; nevertheless, the functional food prospects are often underestimated and have recently received attention. Furthermore, the nutritional quality and functional food value of dates are highly linked and/or influenced by microbial contamination of the fruit. Therefore, a review of the most recent scientific research on the nutritional and nutraceutical qualities, as well as the microbiological safety, of dates consumed in various parts of the world is necessary. The primary objective of the current review paper is to provide comprehensive and up-to-date information regarding the nutritional, functional food, and nutraceutical properties of dates along with detailed profiles of their high-value components. In addition, the paper evaluates the likelihood of microbial contamination of dates with regard to the safety and quality of this highly valued food. Moreover, this study explores innovative methods for mitigating microbial contamination while ensuring the safety and quality of dates consumed in the food chain.

2. Methodology

A search of the literature was conducted to find recent articles and studies that demonstrated the relationship between nutritional properties, nutraceutical quality, and food safety of dates. ScienceDirect, Google Scholar, ResearchGate, Wiley Online Library, PubMed, Scopus, and Web of Science were amongst the online databases queried and used. Aflatoxin, date fruits, dates, nutrition, quality, and food safety were the keywords used individually and in combination as inclusion criteria for the articles considered for this review. The papers were selected based on the following criteria: (i) research focusing on the nutritional quality, functional food and nutraceutical profile, and microbial contamination and safety of dates; (ii) English-language papers; and (iii) papers with full-text access. This investigation spans around 20 years and includes mainly publications from 2002 to 2023.

3. Cultivation and dates production

Date palm belongs to the Arecaceae family, often known as Arecaceae. The cultivation of date palm, one of the earliest trees in human history, is noticed to have started dating back to 5500–3000 BCE (Tengberg, 2003). Due to the prehistoric perspective, it is rather difficult to determine the exact date and place of the origin of the date palm plantation. However, generally, it is believed that this species is native to the surrounding areas of the Persian Gulf, with its cultivation starting as early as 4000 BCE, from Mesopotamia to prehistoric Egypt (Chao and Krueger, 2007). It is also predicted that dates in Mesopotamia (likely Southern Iraq) or western India are the native areas of date palms (Chao and Krueger, 2007; Rahmani et al., 2014). Similarly, in the light of pre-Islamic archaeological perspectives, south-eastern Arabia can be predicated as the first domestication area of the date palm as old as 2500 BCE (Rahmani et al., 2014). According to another report, it is guessed that its cultivation started in Mehrgarh as early as ca.7000 BCE and in the Indus Valley around 2600 to 1900 BCE (Kenoyer and Heuston, 2005).

Dates are viewed as a symbol of desert life as they can grow in hot and dry regions with average temperatures of 12.7 to 27.5 °C. Plus, they can survive in temperatures up to 50 °C and withstand frost temperatures of −5 °C for a short period. This important plant has been grown in harsh environments around the world for more than 6000 years as a source of food, fuel, fibre, and shelter. Although primarily grown for nutritional needs, this major fruit crop continues to be essential in the socio-cultural and religious evolution of civilizations amongst nations in the Middle East and North Africa (Beech and Shepherd, 2001; Tengberg, 2003). Interestingly, the date palm remains the fruit crop of greatest significance in the Middle East; however, cultivation is currently being widened in some subtropical and tropical areas worldwide, as well as semi-arid to dry regions in Australia, Southern Spain, the United States, and Mediterranean coastal areas in West Asia and Africa (Amadou, 2016). So far, more than 2000 date palm varieties have been reported, with approximately 600 of these being farmed globally. Date varieties that are well-known and widely consumed include Ajwa, Halawi, Barhe, Khlas, Khodry, Sukkary, Sefri, Segae, Hilali and Munifi, Medjool, Sukkari, and Lulu, which differ in nutritional value and organoleptic flavours (Barakat and Alfheeaid, 2023; Rahmani et al., 2014).

Dates are cultivated globally as a high-value cash crop (Echegaray et al., 2020; Siddiq and Greiby, 2013). Over the past few decades, a remarkable increase in the growth (accounting for 181 %) of the dates produced worldwide has been noticed with increasing yield from 3.4 million tonnes in 1990 to 9.60 million tonnes in 2021 (FAO, 2023). Hence, both the date cultivation area and the date production showed positive growth trends.

Fig. 1 depicts the global market share of major countries that produce dates. Dates are mostly produced in the Africa and Middle East. In 2021, Egypt produced the highest quantity of dates (1.70 million tons), followed by Saudi Arabia (1.54 million tons), contributing to 18 and 16 % of global production, correspondingly. Thus, from 1990 to 2021, both of the major date-producing countries increased their production yield by as much as 222 and 197 %, respectively (FAO, 2023). Following Egypt and Saudi Arabia, which contribute 34 % of global output, Iran is third on the list of top ten date-producing countries with 1.28 million tons, followed by Algeria with 1.15 million tons, and Iraq with 735 thousand tons (FAO, 2022). Egypt had a significantly lower cultivation area (50,834 hectares) than Saudi Arabia and Iran amongst the top three date producers. However, it has the highest date production yield due to ample access to water in the plantation area, which allows the palm trees to grow well (Bekheet and El-Sharabasy, 2015). Furthermore, the increased date yields in Egypt can be attributed to better agronomic practices and higher tree density (number of trees planted per hectare) (Barakat and Alfheeaid, 2023; Siddiq and Greiby, 2013). As a result, date yield could not be decided merely by cultivation area, but rather by the country's well-developed pre- and post-harvest systems.

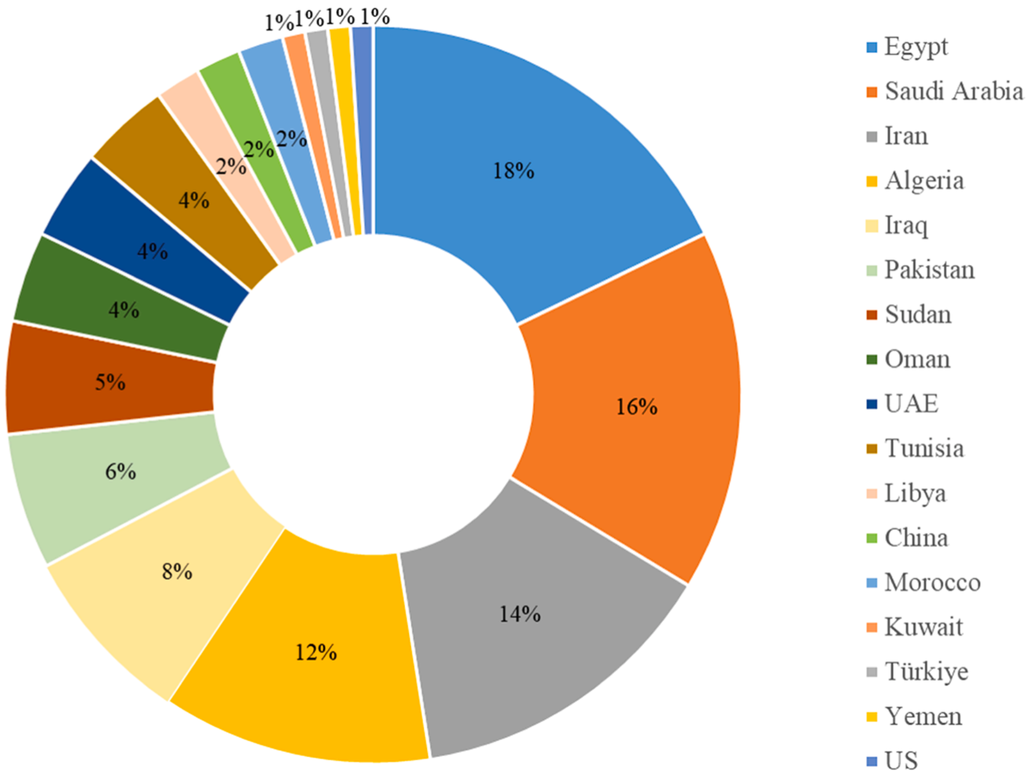

Fig. 1. World's top date-producing countries and their shares in the global market, based on statistics from the Food and Agriculture Organization, 2022 (FAO, 2022).

According to the data in Fig. 1, the top five countries contributed to approximately 68 % of total production worldwide. Iran, Algeria, Iraq, Pakistan, Sudan, Oman, the United Arab Emirates, and Tunisia account for 57 % of total output. Other countries, such as Libya, China, Morocco, Kuwait, Turkey, Yemen, and the United States, contributed roughly 10 % of total date production (FAO, 2023, 2022). Mexico, Albania, and Peru also contribute a minor fraction of the world's date production (less than 0.5 %) (FAO, 2023). On a regional basis, Asia, Africa, the Americas, and Europe account for the majority of date production by region in 2020 and 2021 (FAO, 2022). Asia is the largest date producer, with a 56–57 % share, because the majority of date-producing countries are in Asia, including Saudi Arabia, Iran, Iraq, Israel, Pakistan, Palestine, and Oman. The second region is Africa, which comprises Egypt, Algeria, Sudan, Tunisia, and Libya and is anticipated to produce 42–43 % of all dates (FAO, 2023, 2022). Although the African region produced the most dates, total production was lower than in Asia. Finally, the American region produces just around 0.82 %, followed by Europe, which produces 0.15 % (FAO, 2022).

3.1. Consumption of dates

The dates have historically played a vital role in the lives of communities, elsewhere due to their nutritional and traditional significance (Ali et al., 2012; Iqbal et al., 2014). Given its sanctified significance in three major Biblical religions (Abrahamic religions), including Christianity, Islam, and Judaism, the date palm is known as a blessed tree. Because of their high admiration for Prophet Abraham, these religions put a distinguished position on date palms and dates. The Bible, for example, acknowledges the numerous benefits of dates and date palm fruit. Dates is also regarded as one of the fortunate foods by Jews. In Islam, dates are particularly esteemed. The Holy Qur'an has 20 verses from 17 Surahs (Chapters) that mention date palm and dates. The dates are mentioned in the Qur'an (55:68, Surah Ar Rahman) amongst the blessing of heaven. Allah (SWT) advises Maryam (the mother of the Prophet Jesus) to eat dates in the Qur'an (Al-Qur'an, 19:23–26, Surah Maryam). Dates are given special dietary priority and are regularly consumed by Muslims during Ramadan a holy month in Islam (Al-Shahib and Marshall, 2003; Ali et al., 2012; Kenoyer and Heuston, 2005). The last Prophet Muhammad (Peace Be Upon Him) recommended Muslims to eat dates because of their nutritional and health benefits against an array of ailments (Al-Shahib and Marshall, 2003; Rahmani et al., 2014).

Dates are becoming more popular worldwide due to their high nutritional status and medicinal value. Dates consumption patterns, however, may differ from region to region and country to country, depending on the socioeconomic and cultural elements of the people. Dates are consumed at different phases of maturity, including (i) Khalal (fresh), and (ii). Rutab (semi-ripened) and (iii) Tamar (completely ripened or dried form), depending on the degree of ripening and variety. Dates' morphological features, such as length, weight, and width, as well as organoleptic flavour, have a significant effect on consumption (Al-Kharusi et al., 2009; Younas et al., 2020). Dates are mostly consumed in underdeveloped countries. Higher dates consumption has been linked to the local people's prominent social role and the availability of numerous date varieties on the market. Fig. 2 shows some of the important date varieties available such as Ajwa, Medjool, Mabroum, Mariami, Red Dates, Omani, Lulu, Safina, Zahidi, Sukkari, Sukkari Mufatal and Deglet Nour.

Date consumption is likewise seasonal, peaking during the Muslim holy month of Ramadhan (Karizaki, 2017). During Christmas, Christians consume more dates (Al-Farsi and Lee, 2008a), although Chinese people regard dates as a tonic and healthful food. Chinese red dates also known as jujubes are the edible fruits of *Ziziphus jujuba* (Ping Ming Health, 2010). Although Chinese dates are not regarded as the same Aceraceae family (Angiosperms, monocotyledon), these dates are used as herbal remedies due to their health benefits (Al-Alawi et al., 2017). On important occasions, many people buy quality dates and give them as gifts to friends and family (Ping Ming Health, 2010). The advancement

Fig. 2. Some important varieties of dates available in the local market.

of optimal nutrition has led to a shift in food consumption patterns toward healthier diets (Haris, et al., 2018). As a result, there is currently a greater demand for dates and their consumption is no longer seasonal as it is supplied and consumed throughout the year following the market demand (Chang et al., 2016). As a result, there is currently a higher demand for dates, and its consumption is no longer seasonal, as it is available and consumed year-round in response to market demand (Chang et al., 2016).

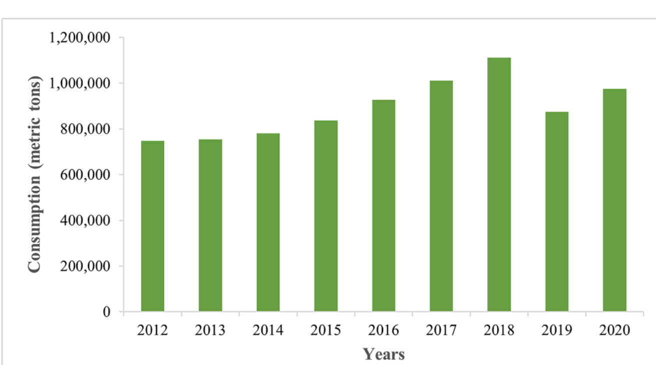

Fig. 3. Magnitude of annual consumption of dates worldwide (2012–2020) (Source: FAO, 2022).

Furthermore, due to increased demand, global yearly consumption of dates grew from 2012 to 2018 (Fig. 3). Date consumption has risen dramatically from 747,000 metric tons in 2012 to 1,111,000 metric tons in 2018. However, during 2018 and 2019, global annual consumption of dates fell to as low as 878,840 metric tons (FAO, 2022). The Arab world's date palm plants were being attacked by the red palm weevil (*Rhynchophorus ferrugineus* (Olivier), which may have contributed to the drop in consumption. Furthermore, the annual consumption in 2020 has been slightly increased to 974,360 metric tons (FAO, 2022). Following that, per capita data consumption varies greatly between countries. Typically, Oman has the highest per capita date consumption of the 134 nations examined for the year 2020, with 49.6 kg, followed by Saudi Arabia (38.0 kg) and Kuwait (27 kg).

3.2. Morphological features and nutritional composition of dates

3.2.1. Morphological features

The morphological features of dates, in terms of their size, calculated in length (L) × width (W) × height (H) in millimetres (mm) and weight in grams, may differ significantly based on the origin and varieties. The key factor influencing consumer acceptability is colour. It is a crucial quality indicator for commercial dates. Research done by (Ghnimi et al., 2018) shows that the Medjool varieties have L*a*b* of 33.17 ±2.46, 9.39 ± 2.28, and 10.28 ± 2.24, respectively, whereby, the coordinates for brightness are denoted by L*, red/green by a*, and yellow/blue by b*. Higher values indicate "lighter" colour parameters of lightness 'L', redness/greenness ‘a, and blueness/yellowness ‘b’ (Biglari, 2009; Konica, 2022). Thus, it can be explained that the Medjool varieties from Saudi Arabia, Morocco, Jordan and Palestine have higher lightness but lower redness/greenness, and blueness/yellowness. Determination and comparison of the colour of various date cultivars may be used as an indicator to ensure the quality and benefit of the processed date goods sold internationally. In addition to the effect of post-harvest treatment, the colour variation of the dates is primarily due to the genetic variability of the date palm (Al-Jasass et al., 2015).

3.2.2. Nutritional attributes

Dates are viewed as a "complete diet" due to their high nutritional profile and are thus considered an important food component. It is well-known for being high in carbohydrates, amino acids, vitamins, dietary fibre, and important minerals (Ghnimi et al., 2017). Dates contain a high level of natural antioxidants, making them a superfood with health benefits (Abdallah et al., 2018). Table 1 compares the nutritional content of some important varieties of dates based on calories (kcal), total carbohydrate (g), protein (g), total fat (g), dietary fibre (g), vitamins (%), and minerals (mg).

The date’s moisture content changes from 50 % to 60 % in the early phases to 20 % when they reach the ripening stage (Ghnimi et al., 2017; Rashwan et al., 2020). Furthermore, the moisture level of the dates reduces when they get dry. Fresh dates have an average moisture percentage of 42.4, while dried dates contain a moisture level of 15.2 %. The sun’s drying power has traditionally been employed to preserve and dry dates. Because sun drying is subject to unpredictability, including daily variations in humidity and temperature, the production of persistent high-quality dates is not possible (Al-Farsi and Lee, 2008a).

Dates contain a variety of carbohydrates, including glucose, fructose, sucrose, maltose, mannose, and a trace of cellulose and starch. According to Al-Farsi and Lee (2008a), fresh and dried dates have an average carbohydrate value of 54.9 and 80.6 g/100 g, respectively. The Naghal fresh dates variety has 52.6 g/100 g carbohydrates while the dried dates have 86.2 g/100 g carbohydrates (Ahmed et al., 1995). Additionally, the Bushibal fresh and dried dates variety has 57.00 g/100 g and 79.90 g/100 g carbohydrates, respectively (Al-Hooti et al., 1997). Based on Table 1, the carbohydrate content is the highest in Omani varieties at 75.10 g/100 g (Mariyam and Mary, 2015).

Sugars and fibre make up the majority of the carbs; hence high carbohydrate content is expected. Owing to their high sugar content, dates are considered an excellent energy source. Fresh and dried dates offer caloric values of 213 and 314 kcal/100 g, respectively. Adult women require between 1900 and 2200 kcal per day, while adult men require between 2300 and 2900 kcal per day. A 100 g serving of dates contains 12 to 15 % of an adult’s daily energy requirements (Al-Farsi and Lee 2008a). As shown in Table 1, the Medjool variety has a sugar content of 66.20 g/ 100 g and provides 290 kcal/100 g. In contrast, the Mariami variety has a sugar content of 48.61 g/100 g sugar content and provides 9 kcal/100 g. Dates are mostly made up of sugar, which comes in the form of monosaccharides (fructose and glucose) and polysaccharides (sucrose) (Al-Farsi and Lee, 2008a; Hamad et al., 2015). Furthermore, when the dates ripen, the sugar content rises from 30 to 40 % in the early stages to 75–80 % in the ripening stages (Zhang et al., 2015). Sugar differences may be connected to the maturity stage as well as moisture reduction (Al-Farsi and Lee, 2008a). The Mabroum variety has the highest sugar content at 76.40 g/100 g, while the Khalas variety has the lowest at 46.20 g/100 g. Dates’ natural sugars are the most important components and substantial energy sources for humans. Carbohydrates, such as glucose, which is quickly absorbed after digestion and cause an increase in the level of blood sugar. Fructose has double the sweetness of glucose and produces satiety, which may help consumers consume fewer calories overall (Liu et al., 2000).

Dried and fresh dates have typical protein contents of 2.14 and 1.50 g/100 g, respectively. Mariami has the highest protein content at 2.93 g/ 100 g, followed by Ajwa at 2.91 g/100 g and Lulu at 2.40 g/100 g (Table 1). The fat value of fresh dates is 0.14 g/100 g, whereas the fat content of dried dates is 0.38 g/100 g. On the other hand, Omani date variety contained the highest fat content at 4.60 g/100 g while the Khalas variety had the lowest fat content at 0.10 g/100 g. The protein content of dates also decreases during ripening as the maturity progresses (Punia 2016). The increase in protein and fat content of dates upon drying can be attributed primarily to moisture loss. However, variations in these values should be expected due to varietal and agro-climatic differences (Al-Farsi and Lee 2008a).

According to Sayas-Barberá et al. (2020), the date’s seed contains polysaccharide-associated proteins that confer functional characteristics and improve emulsifying capacity. Dates protein, despite its small amount, contains vital amino acids required for the body’s metabolism to function. Date proteins include 23 amino acids; a number of these are absent from common fruits including bananas, apples, and oranges. Amino acids such as serine, lysine, valine, proline, histidine, methionine, glycine, arginine, isoleucine, aspartic acid, leucine, threonine, phenylalanine, glutamic acid and tyrosine are present in most date cultivars (Ayad et al., 2020). The amino acid content of dates also decreases as the fruit matures. However, an increase in amino acid content has been seen as a result of drying dates, which could be attributed to water loss (Ishurd et al., 2004). Date flesh has a fat content of 0.1 % to 0.5 %, but the pit or seed has a fat level ranging from 7.7 to 9.7 % (Baliga et al., 2011). Date seed oil contains more than 90 % oleic, linoleic, palmitic, myristic, and lauric acids. Date seed oil, which has a high level of oleic acid, ranging from 41.1 % to 58.8 %, and thus could be used as a dietary component with potential health benefits, especially in preventing heart disorders (Al-Farsi and Lee 2008b; Ayad et al., 2020; Nehdi et al., 2010). Moreover, high-oleic date seed oil can be explored as a valuable ingredient in preparing cosmeceuticals and personnel health care products (Vermaak et al., 2011).

Furthermore, dates are high in dietary fibre, and the amount of total

Table 1
Comparison of the nutritional value of some different varieties of dates (*Pheonix dactylifera* L.).

Varieties	Ajwa	Medjool	Mabroum	Mariami	Khalas	Omani	Lulu
Energy (kcal/100 g)	–	290	–	91	218	–	204
Total Carbohydrate (g/ 100 g)	–	75.00	–	72.24	56.8	75.10	75.10
Protein (g/100 g)	2.91	1.80	1.72	2.93	1.10	2.29	2.40
Total Fat (g/100 g)	0.47	0.20	0.27	0.17	0.10	4.60	0.20
Dietary Fibre (g/100 g)	–	6.70	–	–	7.10	2.50	6.62
Total Sugars (g/100 g)	74.30	66.20	76.40	48.61	46.20	–	57.60
Minerals							
Sodium (mg/100 g)	7.5	1.0	–	–	124.0	–	50.0
Calcium (mg/100 g)	187.00	64.00	52.00	71.34	11.00	–	8.00
Iron (mg/100 g)	–	0.90	–	0.95	0.80	5.50	0.50
Potassium (mg/100 g)	476.3	696.0	–	868.7	345.0	590.0	0.1
References	Assirey (2015)	Al-Farsi and Lee (2008a)	Assirey (2015)	Khairuddin et al. (2017)	Al-Farsi and Lee (2008a)	Mariyam and Mary (2015)	Al-Farsi and Lee (2008a)

dietary fibre in dates can range from 2.50 to 10.9 % (Al-Farsi and Lee 2008b). Khalas had the highest dietary fibre content followed by Madjool, Lulu and Omani at 7.10, 6.70, 6.62 and 2.50 g/100 g, respectively. The majority of the dietary fibre in dates is insoluble. Dates contain the majority of their dietary fibre as insoluble fibre. The high insoluble fibre content induces satiety has a cleansing effect and may lower the incidence of diverticular illness and colon cancer (Marlett et al., 2002). Based on the 25 g daily recommended intake of total dietary fibre, Marlett et al. (2002) assessed that an intake date of 100 g could provide 32 % of the day-to-day dietary fibre requirement.

Dates are a valuable source of important dietary nutrients, with 100 g providing over fifteen percent of the RDA/AI for selenium, magnesium, copper, and potassium (Baliga et al., 2011). Dates are low in sodium and high in potassium, making them a good option for individuals with high blood pressure (Al-Farsi and Lee 2008a). A few studies have reported the minerals content of dates. Mariami variety has 868.7 mg/100 g of potassium, 71.34 mg/100 g of calcium and 0.95 mg/100 g of iron (Khairuddin et al., 2017), the Medjool variety has 1.00 mg/100 g sodium, 64.00 mg/100 g calcium, 0.90 mg/100 g iron and 696.0 mg/100 g potassium. Khalas variety which has 11.00 mg/100 g calcium, 124.00 mg.100 g sodium, 345.00 mg/100 g potassium and 0.80 mg/ 100 g of iron (Al-Farsi and Lee, 2008a). Though every mineral has its own set of health benefits, they are all required for various metabolic processes in the body (Al-Farsi and Lee 2008a; Soetan et al., 2010).

Additionally, dates are a great source of vitamins, including vitamin C and B complex (Table 2). A 100 g serving of dried dates may contain more than 9 % of the adult RDA/AI for vitamins B9, B6, and B3, B2. Based on the study done by Al-Farsi and Lee (2008a); Whitney and Rolfes (2002), the Sayer variety has the highest vitamin C (ascorbic) and B_1 vitamin (thiamin) in dates at 16,000 μg/100 g and 120 μg/100 g, respectively. Moreover, vitamins A, B3 and B6 were detected in Medjool and Deglet Noor varieties. Vitamin B9 has been detected in Hallawi, Khadrawi, Zahdi and Sayer varieties at 53, 39, 58 and 65 μg/100 g, respectively. While daily requirements are low, vitamins are vital to health maintenance. Each cell in our body needs coenzymes, such as vitamins B and C, to function properly. Vitamin C functions as an antioxidant and a tissue protector, reducing oxidative stress and potentially aiding in disease prevention (Whitney and Rolfes, 2002).

Understanding the morphological qualities of dates, such as their size, colour, and overall appearance, as well as their nutrient makeup, can help to assess their potential nutritional and commercial value. This data serves as the foundation for further investigation into the bioactive compounds and therapeutic agents that contribute to the physiological benefits of dates. Dates are high in carbs and dietary fibre, but they also contain appreciable levels of high-value bioactive compounds including carotenoids and polyphenols. Such natural antioxidant components can boost health while also providing dates with their distinct flavour and colour. Therefore, a thorough knowledge of the functional components and high-value bioactive in dates is vital to understanding their physiological benefits and nutraceutical potential.

3.3. Functional components/high-value bioactives

Dates contain a wide array of high-value components, such as tocopherols, phenolics, flavonoids, and carotenoids, all of which have antioxidant effects. These antioxidants can be found in dates in variable levels and forms depending on the date palm genotype and post-harvest processing processes (Younas et al., 2020). Due to the presence of free radical scavengers and singlet oxygen ($^1O_2$) quenchers, dates have a high antioxidant potential. The primary antioxidants found in dates' flesh and seeds are phenolic acids, polyphenols, and tannins. These antioxidants protect the brain by acting as markers for the antioxidant enzyme in the defence process (Pujari et al., 2014). The presence of these natural antioxidants in dates offers numerous health benefits, including the ability to prevent cancer, protect against pathogens and chronic inflammation, and reduce the risk of cardiovascular disease (Neeser and Bruce, 2004; Younas et al., 2020). It is worth mentioning that date seeds contain more phenolic, tocopherols, and flavonoids than the fleshy part, resulting in increased antioxidant content of the seeds thus supporting their usage as functional ingredients for the development of innovative functional foods (Al-Farsi and Lee, 2008b).

3.3.1. Tocopherols

The vitamin E family is made up of eight lipophilic vitamins called tocopherols and tocotrienols. Tocopherols and tocotrienols share a similar fundamental chromanol ring and act as lipid peroxyl radical scavengers by electron transfer (Ciarcià et al., 2022). Tocopherols and tocotrienols, which are typically found in vegetable oils, can lower LDL cholesterol and the risk of some malignancies (Nehdi et al., 2010; Yuen et al., 2011). Based on the quantity and position of methyl groups attached to the phenolic ring of the polar head system determines the tocopherol isomers' antioxidant activity: $\alpha > \beta > \gamma > \delta$. Alpha-tocopherol, with three methyl groups in its chemical structure, has the highest antioxidant activity, whereas δ-tocopherol, with only one methyl group in the ring, has the lowest (Niki and Abe, 2019). Date seed oil has a considerable amount of tocopherols and tocotrienols, which are referred to as tocochromanols, with a higher proportion of α-tocotrienol. The main tocols found in Tunisian date seeds include α-tocotrienol, ϒ-tocopherol and ϒ-tocotrienol (Nehdi et al., 2010). Date seed oil is also high in α-tocopherol acetate, a form of vitamin E, which has better photoxodative stability than tocopherol (Habib et al., 2013; Nehdi et al., 2010). Another study also revealed α-tocotrienol to be the pre-dominant tocopherol tested in 12 date seed varieties (Al-Juhaimi et al., 2018). Therefore, date seeds may be addressed as a potential natural vitamin E antioxidant source, especially due to the presence of a high amount of tocols.

Table 2
Vitamins content of some different varieties of dates (*Pheonix dactylifera* L.) (μg/100 g)[a].

Varieties	Vitamin C (Ascorbic)	Vitamin B Complex					Vitamin A (Retinol)
		B_1 (Thiamin)	B_2 (Riboflavin)	B_3 (Niacin)	B_6 (Pyridoxal)	B_9 (Folate)	
Medjool	—	50	60	1610	249	—	44.7
Deglet noor	400	52	66	1274	165	—	3.0
Hallawi	3300	92	160	—	—	53	—
Sayer	16000	120	125	—	—	65	—
Khadrawi	2900	85	135	—	—	39	—
Zahdi	2200	73	153	—	—	58	—
Khudari	1000	—	—	—	—	—	—
Sullaj	1500	—	—	—	—	—	—
Average	3900	78.67	116.5	1442	207	53.75	23.85
RDA/AI μg/day	90000	1200	1300	16000	1300	400	900

[a] All data point is presented using a wet-weight basis. The Recommended Dietary Allowance/Adequate Intakes for an adult male each day is known as RDA/AI (Source: Al-Farsi and Lee, 2008a; Whitney and Rolfes, 2002).

3.3.2. Phenolics and other antioxidants in dates

Natural antioxidants are regarded to be beneficial in the prevention of cardiovascular diseases, neurological illness, cancer, and inflammation due to their therapeutic potential (Prior and Cao, 2000; Wargovich, 2000). Natural antioxidants, mostly comprised of carotenoids, tocopherols (vitamin E), vitamin C, and plant phenolics are valued as safer and healthier alternatives to synthetic additives (Shahidi, 2000). Phenolics are one of the most notable families of natural antioxidants found in plants. They have a variety of health benefits, including antioxidant, anticancer, antimicrobial, and anti-inflammatory properties (Zhang et al., 2020). A great deal of research reveals that dietary phenolics' functions and health advantages extend beyond their antioxidant activity (Edwards et al., 2017). Phenolics act as potent anti-inflammatory agents that inhibit the gene expression of pro-inflammatory cytokines that alter immune responses, improve gut microbiome with potential benefits for probiotics, and influence cell signalling pathways (Zhang et al., 2020). These compounds may also interact with insoluble fibres or their byproducts, playing a synergistic role in the gut microbiota-low-grade inflammation-metabolic syndrome axis (Burcelin, 2016; Edwards et al., 2017). Diets high in phenolics have been connected to several health benefits. Fruits, vegetables, and whole grains are the primary dietary sources of phenolics. Plant phenolics are present in various forms based on their structure and interaction with the food matrix, such as forms that are insoluble-bound, soluble esters or conjugated, and soluble-free (Zhang et al., 2020).

The most noticeable antioxidant compounds in dates are phenolics, which include both phenolic acids and flavonoids. The concentration of these antioxidants in various dates varies based on cultivar, harvest circumstances, ripening stage, and post-harvest treatment (Al-Farsi and Lee, 2008b; Oni et al., 2015; Younas et al., 2020). Table 3 lists the total phenolic contents along with other antioxidant functions of some varieties of marketed dates. The magnitude of these antioxidants varies based on the variety and agroclimatic conditions, maturity stage, and harvesting conditions (Al-Farsi and Lee, 2008b; Hussain et al., 2020; Oni et al., 2015; Younas et al., 2020). It can be noted that different varieties of fresh and dried dates contain significant amounts of total phenolics, ranging from 88 to 280 and 3.91 to 661.0 mg/100 g, respectively (Table 3).

Different varieties of dates contain total phenolic compounds (gallic acid equivalents, GAE) varying over a wide range between 26.47 to 27,000 mg/100 g. For example, Lulu and Khenaizi types, which are extensively consumed in Malaysia, contain high levels of 26,000–27,000 mg GAE/100 g (Razali, 2019). Dates are a very good source of phenolics and polyphenols and the contents of these compounds generally increases due to drying (Al-Farsi et al., 2005; Barakat and Alfheeaid, 2023; Maqsood et al., 2020; Mohamed and Al-Okbi, 2005; Vayalil, 2012; Younas et al., 2020). The phenolic contents of Omani dates (Al-Farsi et al., 2005) and Iranian dates (Biglari et al., 2008) were noted to be significantly increased after drying while it did not increase in California dates (Vinson et al., 2005). Similarly, the fresh Khalas variety contained 134 mg/100 g of total phenolics, yet, the concentration rose to 339 mg/100 g after drying (Al-Farsi et al., 2005).

Besides, the fruit maturation or development stage also significantly affects the phenolic contents of dates. According to Lemine et al. (2014), khalal-stage dates contain more phenolics than fully ripe Tamr-stage fruits. Haider et al. (2018) reported similar TPC decreasing trends in Pakistani dates from Khalal to Tamar stages, indicating that dates at Khalal stage have superior antioxidant nutritional status. A further investigation of seven Mauritanian date types found that the Khalal stage was more antioxidant-rich than the Tamar stage (Lemine et al.,

Table 3
Phenolics, anthocyanins content and antioxidant activities of different varieties of fresh and dried dates (*Pheonix dactylifera* L.).

Varieties	Phenolics (mg/100 g)	Anthocyanins (mg/100 g)	ORAC (μmol trolox/100 g)	DPPH (%)	FRAP (μmol/100 g)	ABTS (%)	Reference
Fresh dates							
Arechti	156.1	–	–	25.0	–	50.6	Harkat et al. (2022)
Ashaal	88.0	–			0.80	–	Allaith (2008)
Berhi	100.0				0.70	–	Allaith (2008)
Degla-Baida	193.4	–	–	54.2	–	86.0	Harkat et al. (2022)
Deglet-Nour	154.6	–	–	14.1	–	40.7	Harkat et al. (2022)
Fard	280.0	0.9	1738.0	–	–	–	Al-Farsi et al. (2005)
Ghars	173.2	–	–	47.1	–	74.1	Harkat et al. (2022)
Haloua	166.4	–	–	41.0	–	70.6	Harkat et al. (2022)
Itima	170.1	–	–	44.8	–	70.2	Harkat et al. (2022)
Khalas	134.0	0.2	2060.0	–	0.70	–	Al-Farsi et al. (2005), Allaith (2008)
Khasab	167.0	1.5	1169.0	–	–	–	Al-Farsi et al. (2005)
Khnaizi	135.0	–			0.60	–	Allaith (2008)
Mech-Degla	157.0	–	–	27.2	–	60.1	Harkat et al. (2022)
Tentbouchet	177.7	–	–	50.6	–	75.6	Harkat et al. (2022)
Average	160.9	0.9	1655.7	38.0	0.70	66.0	
Dried dates							
Deglet noor	6.73	–	–	0.17	–	–	Mansouri et al. (2005)
Deglet Noor	661.0	–	3895.0	–	1.97	–	Allaith (2008), Wu et al. (2004)
Fard	343.0	ND	999.0	–	–	–	Al-Farsi et al. (2005)
Hallaw	342.0	–	–	–	0.70	–	Allaith (2008)
Kentichi	272.0	–	–	–		–	Besbes et al. (2009)
Khalas	339.0	ND	1254.0	–	0.99	–	Al-Farsi et al. (2005), Allaith (2008)
Kharak	130.0	–	–	–	–	–	Biglari et al. (2008)
Khasab	217.0	ND	821.0	–	–	–	Al-Farsi et al. (2005)
Medjool	572.0	–	2387.0	–	–	–	Wu et al. (2004)
Ruzaiz	301.0	–	–	–	1.00	–	Allaith (2008)
Tafizioune	4.59	–	–	0.12	–	–	Mansouri et al. (2005)
Tantbouchte	8.36	–	–	0.22	–	–	Mansouri et al. (2005)
Tazerzait	3.91	–	–	0.1	–	–	Mansouri et al. (2005)
Average	246.2	–	1871.2	0.15	1.20	–	

All data are expressed on a wet-weight basis.
ORAC: Oxygen Radical absorbance Capacity; DPPH: 2,2-diphenyl-1-picrylhydrazyl; FRAP: Ferric Reducing Antioxidant Power;.
ABTS: 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid).

2014). The overall phenolic content varies considerably with fruit development (10–290 mg/100 g). Kimri has the highest polyphenol content (290 mg/100 g), followed by Khalal (150 mg/100 g), Rutab (20 mg/100 g), and Tamar (10 mg/100 g) (Eid et al. 2013). The reduction in phenolic contents with maturity can be linked to the loss of some polyphenols on fruit maturation. Flavonoids like anthocyanins contribute to date colouring by providing a dark red hue, although they break down during the ripening process (Ashraf and Hamidi-Esfahani, 2011).

Dates also contain condensed tannins or proanthocyanidins, with up to 3 % dry weight (DW) (Hong et al., 2006). Proanthocyanidins make up about 1.5 % or nearly 95 % of total polyphenols of all polyphenols when only the edible portion of ripe dates is taken into consideration. Unripe dates have an astringent flavour as the fruit contains soluble tannins (Hammouda et al., 2013). As anticipated, the amount of soluble tannin in dates reduces with maturity. Unlike proanthocyanidins, soluble tannins have no interaction with other phenolic compounds, which suggests that their effects on human health are restricted (Pompella et al., 2014).

Phenolics have a redox potential that allows them to scavenge free radicals, specifically DPPH (1,1-diphenyl-2-picrylhydrazyl) radicals, which in turn suppresses lipid peroxidation. Several kinds of dates tested exhibited considerable DPPH scavenging antioxidant capacity ranging from 55 to 75 % (Razali et al., 2019). During the assessment of the different varieties of dates' antioxidant activity, it was discovered that phenolics have high DPPH scavenging antioxidant activity ranging from 55 to 75 % (Razali et al., 2019). In another study, nine distinct date varieties had DPPH inhibition activities between 22 and 40 % (Abdul-Hamid et al., 2020). Furthermore, three solvent (methanolic, ethyl acetate, and aqueous) extracts from Ajwa dates decreased lipid peroxidation by 70, 88, and 91 %, respectively (Zhang et al., 2013). Based on DPPH and lipid peroxidation experiments, Ajwa fruit and pit extracts were found to demonstrate substantial antioxidant activity (74.19 mg/mL of gallic acid equivalents) in both methanolic and acetone extracts (Arshad et al., 2015). These studies support the idea that the antioxidant mechanism in Ajwa dates is based on free radical scavenging (Khalid et al., 2017; Zhang et al., 2017). According to Mrabet et al. (2016), fresh dates of Eguwa, Garen Gazel, and Smeti varieties revealed good oxygen radical antioxidant capacity (ORAC) with contributions of 43.1, 46.5 and 62.5 mmol Trolox/kg, respectively. Interestingly, dates had higher ORAC than elderberry and bilberry when compared to other antioxidant-high fruits (Ou et al., 2001). Dates were placed second in antioxidant activity in prior research on 28 Chinese fruits (Guo et al., 2003).

Overall, it can be revealed that dates have an effective antioxidant capacity, making this high-value fruit an attractive ingredient for the development of innovative functional foods and nutraceuticals. Dates are particularly valued for their high levels of phenolic compounds, which mainly contribute to their antioxidant status. To fully comprehend the multiple health benefits of eating dates, however, it is necessary to identify and understand the chemical composition of specific phenolic compounds.

3.3.3. *Composition of individual phenolic compounds in dates*

Phenolics, which include flavonoids and non-flavonoids, are one of the most important secondary metabolites of plants, and they have antioxidant capabilities that make them appealing as nutraceuticals. Anthocyanidins, isoflavones, flavonols, and flavones are more classified forms of flavonoids. Non-flavonoids mainly include phenolic acids consisting of both hydroxybenzoic and hydroxycinnamic-acid derivatives. Phenolic acids have been identified as multifunctional bioactive chemicals, and the majority of these are present in a wide range of plant foods, such as fruits and vegetables, cereals, and others; they are employed in both therapeutic preparations and as part of the human diet (Ambigaipalan and Shahidi, 2015). The biological effects such as antioxidant, antimicrobial, antimutagenic, anticarcinogenic, and anti-inflammatory phenolic compounds have been linked to health benefits (Ambigaipalan and Shahidi, 2015). Dates fruit and date seeds both contain a diverse range of phenolics. The most prevalent phenolics identified in dates include apigenin, luteolin, quercetin, kaempferol, chrysoeriol and malonyl derivatives (Al-Farsi et al., 2005; Mansouri et al., 2005). the composition, structure, and availability of phenolic compounds are all influenced by date variety, stage of maturation, and environmental conditions (Allaith, 2008). Dates contain varying amounts of gallic acid, vanillic acid, protocatechuic acid, *p*-coumaric acid, o-coumaric acid, syringic acid, ferulic acid, 3-caffeoylquinic acid, and 3-*o*-caffeoyl shikim acid and *p*-hydroxybenzoic acid (Allaith, 2008).

Furthermore, soluble phenolics such as hydroxycinnamates, hydroxybenzoates, and flavonols have been discovered to date (Hammouda et al., 2013). Deglet Noor and other Algerian types contain dactyliferic acid and flavonoid glycosides (quercetin, luteolin, and apigenin) (Hong et al., 2006; Mansouri et al., 2005). The contents of important flavonoids in some common varieties of dates are given in Table 4. Isoquerecitin, rutin and querecitin are the major flavonoid compounds detected in different date varieties with contributions in the range of 0.16–3.03, 0.17–2.78 and 0.34–1.86 mg/100 g DW, respectively.

Dates may be regarded as a fruit high in phenolic acid compared to other fruits and berries (Mattila et al., 2006). Dates mainly contained gallic acid, p-hydroxybenzoic acid, protocatechuic acid, caffeic acid, *p*-coumaric acid, syringic acid, vanillic acid, and ferulic acid (Al-Farsi et al., 2005; Mansouri et al., 2005). Additionally, Mansouri et al. (2005) discovered that seven distinct varieties of mature Algerian dates contained sinapic acid, 5 o-caffeoyl shikimic acid, and its three isomers (xantoxylin, hydrocaffeic acid, and coumaroylquinic acid). Dates have chlorogenic and isochlorogenic acids, based on ethnopharmacological studies (Duke 2001; Duke and Beckstrom-Sternberg, 2007). These date bioactives, being free radical quenchers, can prevent oxidation of food components including proteins and lipids (Atmani et al., 2009). Dates seed, which is frequently considered as waste, contains a variety of phenolic components. The Khalas variety of UAE date seed contains caffeic acid, coumaric acid and procatechuic acid (Habib et al., 2014). The Mabseeli date seed contained nine phenolic acids, including five cinnamic acid derivatives (caffeic acid, ferulic acid, *p*-, *m*-, and *o*-coumaric acid) and four vanillic and benzoic acid hydroxylated derivatives, the most abundant of which were *o*-coumaric acid, *p*-hydroxybenzoic acid, and protocatechuic acid (Al Farsi and Lee, 2008b). The contents (mg/100 g) of some important phenolic acids in various fresh and dried varieties of dates (*Pheonix dactylifera* L.) are presented in Fig. 4 (a and b).

The composition of phenolic compounds in dates varies based on genetic and agroclimatic variables in the fruit. Ferulic, gallic, caffeic, hydroxybenzoic, vanillic, chlorogenic, isovanillic, protocatechuic, hydroxycinnamic acid, and isoferulic acid, for example, are prominent in ajwa dates (Eid et al., 2013). Ripe Ajwa dates have high levels of catechin (0.73 mg/100 g), rutin (0.65–0.85 mg/100 g), and caffeic acid (0.57 to 1.84 mg/100 g) (Hamad et al., 2015). Other widely consumed date varieties, including Mabroom, Sukkari, Khalas, and Nabtat-Saif,

Table 4
Flavonoids composition of some varieties of dates (*Pheonix dactylifera* L.) (mg/100 g DW).

Date Variety	Rutin	Quercetrin	Luteolin	Isoquercetrin
Mech Degla	1.21	1.43	-	0.60
Deglet Ziane	0.73	0.39	0.07	1.24
Deglet Nour	1.08	1.21	0.05	1.62
Thouri	0.26	0.64	0.05	0.24
Sebt Mira	2.78	1.86	nd	2.64
Ghazi	1.59	1.50	0.04	3.03
Degla Beida	0.43	0.54	0.03	0.16
Arechti	0.43	0.74	-	0.64
Halwa	2.39	1.70	-	1.90
Itima	0.17	0.34	0.04	0.34

(Source: Benmeddour et al., 2013).

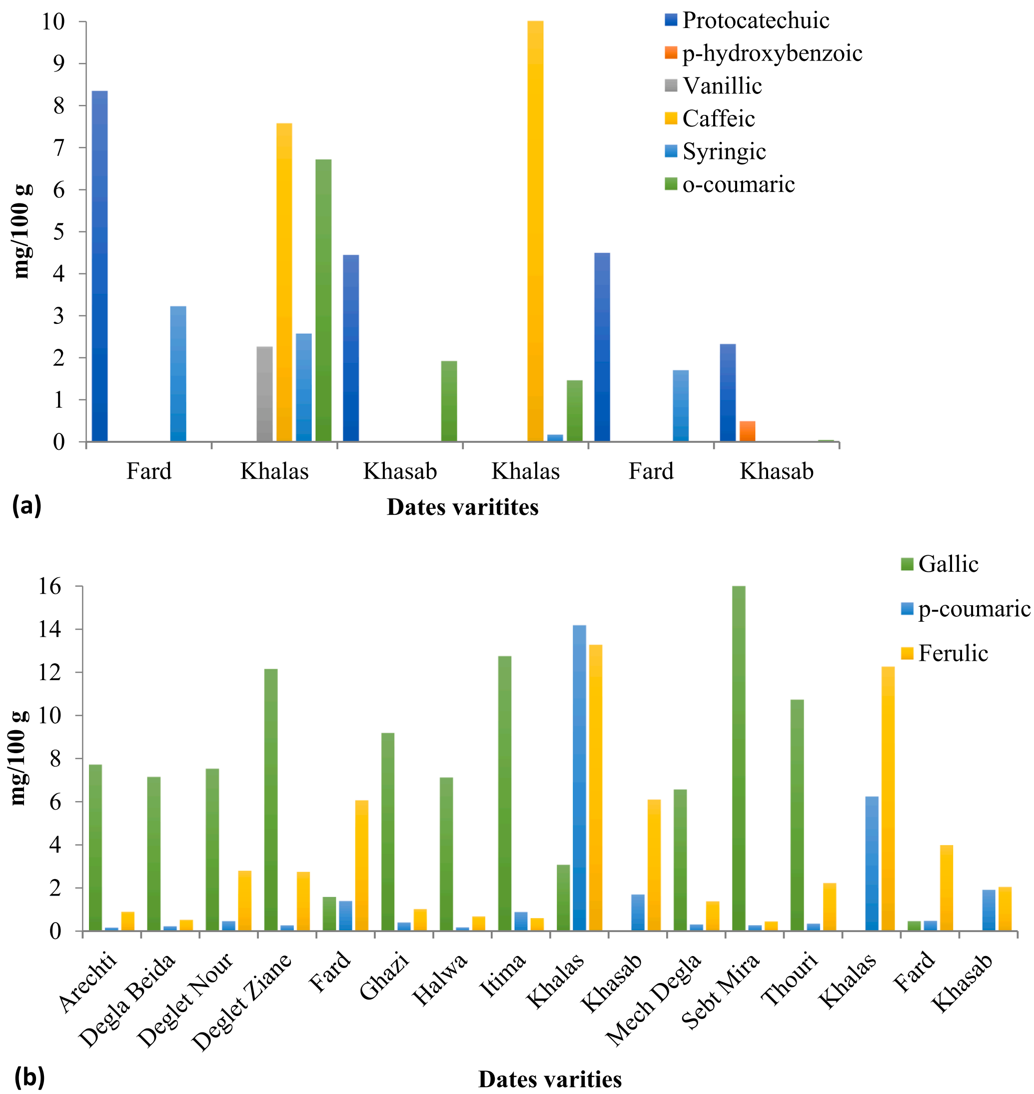

Fig 4. Contents (mg/100 g) of important phenolic acids in different varieties of dates (*Pheonix dactylifera* L.); (a). protocatechuic acid, *p*-hydroxy benzoic acid, vanilic acid, caffeic acid syringeic acid, *o*-coumeric acid, (b) gallic acid, *p*-coumeric acid, ferulic acid (Benmeddour et al., 2013; Al-Farsi et al., 2005).

have total flavonoids ranging from 1.2 to 2.8 mg/ 100 g (Hamad et al., 2015). The amount of phenolic substances in dates changes according to its ripening stage. Depending on the stage of growth, the principal phenolic components are gallic acid, isoferulic acid, ferulic acid, caffeic acid, hydroxycinnamic acid, hydroxybenzoic acid, protocatechuic acid, chlorogenic acid, isoferulic acid and vanillic acid (Eid et al., 2013). Furthermore, significant differences in phenolic contents, either free-form or conjugated, are being reported amongst various date types (Mrabet et al., 2012). When comparing different kinds, this variable may be the cause of the observed variations in the overall antioxidant activity of dates. Based on the high phenolic content of dates, it is now agreed that 250 to 450 mg of phenolic compounds can probably be obtained from 100 g of dates.

Kuwaiti, Algerian, Bahraini, Omani and American dates were studied individually but not compared (Al-Farsi et al., 2005a; Allaith, 2008; Mansouri et al., 2005). Such studies regularly show dates have varying levels of antioxidant potential according to the cultivar, ripening stage, and location. Significant research on Ajwa dates has been conducted, specifically using various extraction methods, and it was discovered that both alcoholic and aqueous extracts contained hydrophilic antioxidants, with aqueous extracts having higher activity than alcoholic extracts (Saleh et al., 2011). Another study discovered that the Ajwa date aqueous extract had appreciable antioxidant content (Arshad et al., 2015).

3.3.4. Carotenoids

Carotenoids are another important class of high-value components present in dates, with antioxidant properties. Carotenoids are tetraterpenoid pigments with yellow, orange, red, and purple shades distributed in many plants and some species of photosynthetic bacteria, fungi and algae. The majority of carotenoids are made up of eight isoprene units with a skeleton of 40 carbons. There are two types of carotenoids: carotenes and xanthophylls (Maoka, 2020). Carotenes, such as α-carotene, β-carotene, γ-carotene, and lycopene, are of hydrocarbon nature. Xanthophylls, which include -cryptoxanthin, zeaxanthin, lutein, astaxanthin, fucoxanthin, and peridinin, are carotenoids with oxygen atoms in the form of carbonyl, aldehyde, carboxylic, hydroxyl, epoxide, and furanoxide groups. Carotenoids, especially consumed as a dietary part of various fruits and vegetables, are recognized to promote human health by avoiding the development of some chronic diseases (Maoka, 2020; Sa'nchez-Moreno et al., 2003).

The carotenoid content of several significant fresh and dried date cultivars is displayed in Fig. 5. The primary carotenoids present in dates are lutein, neoxanthin and β-carotene. The qualitative and quantitative variations in carotenoid content are most likely caused due to differences in variety, maturity stage, post-harvest drying, and storage

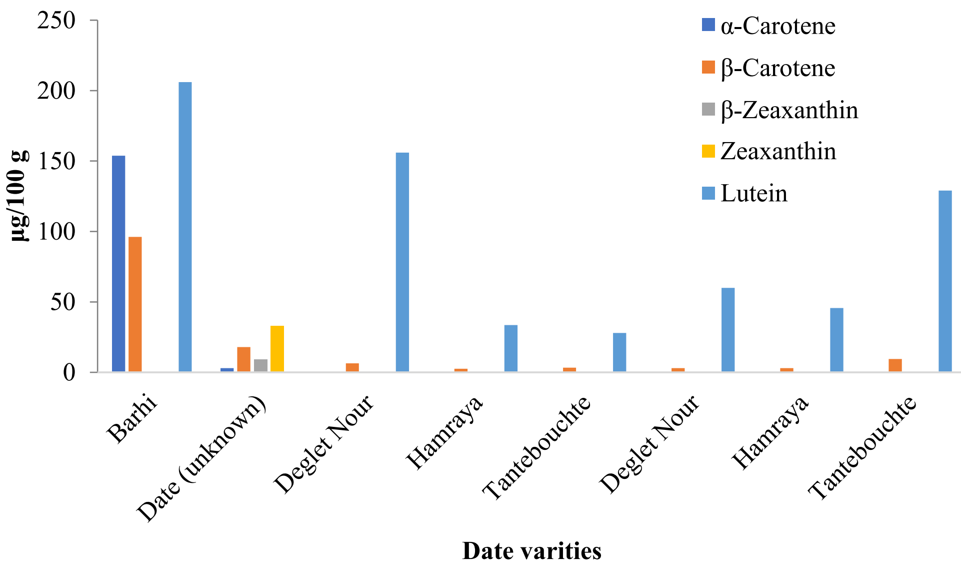

Fig 5. Carotenoid content of different varieties of dates (*Pheonix dactylifera L.*) (Al-Farsi et al., 2005; Boudries et al., 2007).

conditions (Hussain et al., 2020). The amount of carotenoid also depends on the colour whether dates are red or yellow in hue. Given that Khalas has a yellow hue, the high concentration of carotenoids in this variety was predicted. Hydrocarbon carotenoids, including α-, β-, and γ-carotene, as well as lycopene, are found in red dates. Compared to fresh fruit, sun-drying as a postharvest treatment method results in a considerable loss of total carotenoids, according to Al-Farsi et al. (2005). Sun drying may damage 4–30 % of the carotenoids found in dates. This damage was linked to the drying temperature (30 to 50 °C) and method time (7 to 10 days) (Al-Farsi et al., 2005). In comparison to other dried fruits, dates have a moderate level of carotenoids. Dates may help meet the human demand for vitamin A, even though not all carotenoids function as provitamin A (Al-Farsi and Lee 2008b).

According to research, date seeds contain more carotenoids than the fleshy component of the fruit (Vayalil, 2012). Beta-carotene (1.18–2.68 mg/100 g) was the most common carotenoid in the oil of these dates, according to a carotenoids analysis of 18 date seeds cultivars grown in the United Arab Emirates, with total carotenoids ranging from 1.46 to 3.53 mg/100 g (Habib et al., 2013). These values were below 5.51 mg/100 g of fully ripened Tunisian date seeds (Nehdi et al., 2010). Similarly, Habib and Ibrahim (2011) investigated different carotenoids in date seeds made from the Khalas cultivar in the United Arab Emirates. Carotene (314.2 g/100 g), lutein (159.9 g/100 g), lycopene (1.95 g/100 g), zeaxanthin (1.08 g/100 g) and -cryptoxanthin (2.04 g/100 g) were the main carotenoids detected. Carotenoid concentration differences amongst date seeds kinds can be mainly linked to factors such as ripeness, postharvest treatment, and the conditions of storage (Habib and Ibrahim, 2011). Since colour is a key characteristic for evaluating oil quality, the carotenoid pigment is often regarded as an essential indicator of oil quality. date seeds, being a rich source of carotenoids and an underutilized material, could be explored as a sustainable supply of these high-value bioactives with value-added prospects (Al-Farsi and Lee, 2008a).

Dates, in addition to being a traditional dietary staple with a high nutritional profile, show promise as a source of bioactive compounds with potential health benefits. A closer study of the potential nutraceutical applications of dates reveals the complex interactions between these valuable elements, which present opportunities to exploit their bioactive potential in the development of health-improving products. The examination of high-value bioactive and functional components, such as tocopherols, phenolics, antioxidant content, and carotenoids, substantially aids the understanding of functional foods and possible applications of dates in nutraceuticals.

4. Functional food and nutraceutical prospects of dates

Dates, with functional food potential, have long been utilized as a vital component in traditional remedies around the world, especially in Iraq, Algeria, Iran, Morocco, Egypt, and India are amongst them (Khare, 2008. However, due to a lack of cultivation potential and applications, the traditional medicinal benefits of dates are generally overlooked in Western and Eastern states (Vayalil, 2012). Dates have long been used to treat diabetes and hypertension in southern Morocco (Tahraoui et al., 2007). Dates were an important component of several aphrodisiacs in ancient Egypt as it was believed that consuming male flowers and pollen from date palms daily would increase fertility (Khare, 2008). Dates have been used as an anti-hypertensive medicine for millennia. Date phytochemicals have been shown to help reduce the onset and development of cardiovascular illnesses by lowering hypertension, hypercholesterolaemia, and lipoprotein oxidation (Vayalil, 2012). Date syrup, for example, has been shown in numerous recent studies to successfully fight angiogenesis and inflammation (Al-Alawi et al., 2017). According to research conducted in rat models, dates' bioactive components such as polyphenols, fibre, and steroids, are likely to be involved in the fruit's ability to reduce inflammation (Zhang et al., 2013).

Dates were later used for medicinal purposes in India, as fruit was an important element in ancient medicine (Ayurveda). Although there is scant clinical or scientific evidence to back up these purported health benefits, some recent research is beginning to change the picture. Date kernels, for example, have been associated with anti-ageing and decreased wrinkles on women's skin (Bauza et al., 2002). According to other research, boiling dates with cardamom and black pepper can help with headaches, fatigue, dry coughs, mild fevers, and appetite loss (Zaid and De Wet, 1999).

Additionally, dates are claimed to have restorative, expectorant, demulcent, laxative, and diuretic qualities (Khare, 2008). Furthermore, people in Sri Lanka and India consume a traditional cuisine called Idli, which is mostly made with sugar and other components. High sugar levels in this food product are harmful to health because they can lead to a variety of disorders such as dental cavities and diabetes. In this regard, Manickavasagan et al. (2013) conducted a study to offset this additional sugar influence by substituting paste, chopped dates and date syrup and noted a positive effect. It was shown that idli with dates had better overall acceptance and sensory qualities. Furthermore, as compared to idli made with sugar, the idli's total phenol and vitamin C levels increased with the inclusion of dates. As a result, dates can be employed to boost the health benefits of traditional dishes like idli. Several other studies have shown that dates and date by-products as a functional dietary component have a high potential for inclusion in baked products (Al-Amri et al., 2014; Ambigaipalan and Shahidi, 2015; Bouaziz et al., 2010; Platat et al., 2015; Shokrollahi and Taghizadeh, 2016).

4.1. Nutraceutical properties of date fruits

Dates contain significant amounts of phytoestrogens such as coumestrol, daidzein, glycitein, genistein, matairesinol, lariciresinol, pinoresinol and secoisolariciresinol, which exert multiple biological effects (Al-Turki et al., 2010). The presence of such therapeutic substances can be linked to diverse biological and nutraceutical characteristics including anti-inflammatory, anti-cancer, antioxidant, antidiabetic, and antimicrobial of dates, which are highly valued for related nutra-pharmaceutical products development industries (Kchaou et al. 2016; Wang et al., 2008). Thus, dates include a wide range of physiologically active compounds, which are in great demand from consumers and the nutra-pharmaceutical industry. Table 5 presents the detailed classes of various high-value nutraceutical components identified in different varieties of dates.

4.1.1. Antioxidant properties

Dates and date seed powder, in particular, have drawn interest for functional food developments due to their unique antioxidant effects functions attributed to their ability to scavenge free radicals (Martn-Sánchez et al., 2014). Excess free radicals have been linked to a variety of disorders, including Alzheimer's, Parkinson's heart disease and cancer (Kim et al., 2015). Antioxidants found in dates help to lower oxidative stress, which is associated with a variety of disorders (Baliga et al., 2011). The antioxidant potential of dates varies greatly depending on cultivar and origin. This variation must be addressed while determining their viability as nutraceuticals. The antioxidant potential of dates from various varieties, ripening stages, and locations (Algeria, Kuwait, Oman, Bahrain, and the USA) have been studied by researchers (Al-Farsi et al., 2005; Allaith, 2008; Mansouri et al., 2005).

Ajwa dates have been the subject of extensive antioxidant studies. These studies demonstrate that highly active hydrophilic antioxidants are more effective when extracted using aqueous extracts than alcoholic ones (Saleh et al., 2011). According to Zhang et al. (2013), ethyl acetate, methanolic, and aqueous extracts from Ajwa dates have shown strong antioxidant activity and inhibited lipid peroxidation by 88 %, 70 %, and 91 %, respectively. Another study discovered that methanolic and acetone extracts of Ajwa dates had high antioxidant activity, with free radical scavenging being the underlying mechanism (Arshad et al., 2015; Khalid et al., 2017). Moreover, aqueous extracts derived from the Deglet Noor variety, for instance, were demonstrated to offer protection against oxidative stress and hepatotoxicity in rats who were given dimethoate subchronically (Saafi et al., 2011). Previous research has also shown that date seed extract can reduce inflammation by acting as an antioxidant and reducing oxidative stress (Platat et al., 2015).

According to Al-Farsi et al. (2005), the Omani dates exhibited high antioxidant activity. Aqueous extracts derived from the Deglet Noor and Khalas variety had superior antioxidant attributes compared to the Fard and Khasab variety that can be linked to their high phenolic contents. These Omani dates have higher phenolic contents than several other fruits, ranging from 217 to 343 mg of ferulic acid equivalent /100 g. Another study showed that seven different date types in Mauritania showed more antioxidant potential in the Khalal stage than in the Tamar stage (Lemine et al., 2014). According to Mrabet et al. (2016), the Smeti, Garen Gazel, and Eguwa cultivars have total antioxidant activity of 62.5, 46.5, and 43.1 mmol Trolox /kg of fresh dates, respectively. Dates exhibit significant antioxidant capacity across a range of types, indicating potential applications as beneficial ingredients in the development of nutraceuticals and functional foods.

Table 5
Different classes of nutraceutical components found in various date varieties (*Pheonix dactylifera* L.) (Sources: Maqsood et al., 2020).

Date Varieties	Compounds	References
Ougherouss	**Phenolic acids:** *p*-coumaric acid 5-*o*-caffeoylshikimic acid isomer 5-*o*-caffeoylshikimic acid isomer, ferulic acid gallic acid derivative, ginnamic acid, and sinapic acid	Saafi et al. (2010)
Tunisian *P. canariensis*	**Phytosterols:** The main substances detected were campesterol, *β*-sitosterol, and Δ5-avenasterol; smaller amounts were found in cholesterol, Δ7-avenasterol, Δ5,24-stigmastadienol, and Δ7-stigmastenol	Nehdi et al. (2010)
Ghars, Gondeila, Majhoul, Taleese, Tasfert, Adwi, Barakawi, Boufgous, Allig, Dhakki, Dora, Deglet Nour	**Phenolic acids:** Syringic, gallic acid, and protocatechuic	Al Juhaimi et al. (2018)
Adwi, Allig, Barakawi, Boufgous, Dhakki, Dora, Ghars, Deglet Nour, Majhoul, Taleese, Tasfert, and Gondeila	**Tocopherols and Tocotrienols:** Less *α*, *β*, and *δ*-tocopherols were found	Al Juhaimi et al. (2018)
Akerbouche	**Phenolic acids:** 5-*o*-caffeoylshikimic acid isomers, cinnamic acid derivatives, *p*-coumaric acid, ferulic acid, and sinapic acid	Mansouri et al. (2005)
Allig	**Phenolic acids:** Gallic acid, caffeic acid, ferulic acid, and syringic acid	Mansouri et al. (2005); Saafi et al. (2010)
Manifi, Soukari, Barhi, Salaj, Khalas, and Ruzazi	**Tocopherols and Tocotrienols:** The most prevalent tocopherols and tocotrienols were *α*- and *γ*-tocopherols; smaller amounts of *β*- and δ-tocopherols and tocotrienols were found	Nehdi et al. (2010)
Deglet Nour	**Phenolic acids:** Sinapic acid, sinnamic acid derivatives, ferulic acid, syringic acid, *p*-coumaric acid, gallic acid, and *p*-coumaric 5-*o*-caffeoylshikimic acid isomers	Saafi et al. (2010)
Deglet Noor, Fard, Khalas and Khasab	**Carotenoids:** The main substances were carotenoids.; violaxanthin, lycopene, flavoxanthin and leukoxanthin	Al-Farsi et al. (2005); Duke (2017)
Smeti, Eguwa, and Garen Gazel	**Phenolic acids:** Gallic acid, protocatechuic acid, tyrosol, vanillic acid, syringic acid, and *p*-coumaric acid	Mrabet et al. (2016)
Kentichi	**Phenolic acids:** Caffeic acid, syringic acid, gallic acid, *p*-coumaric acid, and ferulic acid	Saafi et al. (2010)
Tamr, Khalal, and Rutab	**Carotenoids:** Antheraxanthin, violaxanthin, neoxanthin, *β*-carotene, and lutein	Boudries et al. (2007)
Khalas	**Carotenoids:** The most common types were lutein and *β*-carotene, with trace amounts of *β*-cryptoxanthin, lycopene, and zeaxanthin	Habib and Ibrahim (2011)
Allig, Deglet Nour, Boufgous, Taleese, Dhakki, Gondeila, Dora, Majhoul, Ghars, Tasfert, Khalas Adwi	**Flavonoids:** Proanthocyanidin, rutin, flavonol, catechin, flavone derivative, quercetin derivative and apigenin derivative	Al Juhaimi et al. (2018); Habib et al. (2014)
Lulu, Barhe, Khalas, Shikat alkahlas, Maghool, Khodary, Sultana,	**Tocopherols and Tocotrienols:** The most	Habib et al. (2013)

(*continued on next page*)

Table 5 (*continued*)

Date Varieties	Compounds	References
Bomaan, Sokkery, Shishi, Shabebe Sagay, Naptit Saif, Fard, Maktoomi, Raziz, Jabri, Dabbas	common was α-tocotrienol, Υ-tocopherol, and tocotrienol	
Khalas, Lulu, Barhe, Shikat alkahlas, Maghool, Sultana, Sokkery, Bomaan, Sagay, Shishi, Khodary, Shabebe, Fard, Naptit Saif, Dabbas, Jabri, Maktoomi, Raziz,	**Carotenoids:** The main component found was β-carotene; smaller levels of lutein, cryptoxanthine, echinenone, lycopene, and α and Υ-carotenes were also found	Habib et al. (2013)
Khouet enta	**Phenolic acids:** Caffeic acid, vanillic acid, gallic acid, syringic acid, *p*-coumaric acid, *o*–coumaric acid, ferulic acid, and *p*-hydroxybenzoic acid	Saafi et al. (2010)
Mabseeli	**Phenolic acids:** ferulic acid, *p*-coumaric acid, *m*-coumaric acid, *o*-coumaric acid, vanillic acid, caffeic acid, protocatechuic acid, *p*-hydroxybenzoic acid, and gallic acid	Al-Farsi and Lee (2008a)
Deglet Noor, Medjoolare	**Carotenoids: The** USDA National Nutrient Database for Standard Reference, (2007) found 81 carotenoids in Medjool and 19 in Deglet Noor	Duke (2017)
Khodry, Ajwa Al Madinah, Mabroom, Sokary, Khlas Al Kharj, Khlas Al Ahsa, Khla Al Qassim, Saffawy, Khals El Shiokh, Rashodia, Nabot Saif, Nabtit Ali	**Phenolic acids:** Caffeic acid, protocatechuic acid, gallic acid, ferulic acid, syringic acid, resorcinol, *p*-coumaric acid, and chlorogenic acid	Hamad et al. (2015)
Ajwa Al Madinah, Rashodia, Nabot Saif, Khodry, Saffawy, Khlas Al Ahsa, Khals El Shiokh Khlas Al Kharj, Khla Al Qassim, Sokary, Mabroom, Nabtit Ali	**Flavonoids:** Rutin, isoquercetrin, luteolin, quercetin, and apigenin	Hamad et al. (2015)
Tazizaout, Akerbouche, Tafizioui ne and Ougherouss	**Flavonoids:** Flavonol glycoside	Mansouri et al. (2005)
Baht, Korkobbi, Bouhattam, Rotbi, Smiti, Kenta, Bekreri, Mermella, Garnghza, Nefzaoui	**Phenolic acids:** Two hydroxybenzoic acids (ellagic acid and gallic acid) were present in all types, but only one hydroxyl-cinnamic acid (*p*-coumaric acid) was detected in Rotbi, Korkobbi, and Garn ghazal varieties	Chaira et al. (2009)
Baht, Korkobbi, Bouhattam, Rotbi, Kenta, Smiti, Mermella, Nefzaoui, Bekreri, Garnghza,	**Flavonoids:** The flavonoid content values that have been observed fall into the following sequence, ranging from 6.41 to 54.46 mg QEQ/100 g FW: Garnghzal > Smiti > Mermella > Nefzaoui > Korkobbi > Bouhattam > Kenta > Baht > Bekreri > Rotbi	Chaira et al. (2009)
Dry date Tamr	**Phenolic acids:** Esculetin, cathechin, tannic acid, ferulic acid, gallic acid, and itaconic acid	El Sohaimy et al. (2015)
Tantbouchte	**Phenolic acids:** Hydrocaffeic acid, caffeoylshikimic acid, cerulic acid, *p*-coumaric acid, cinnamic acid, and caffeic acid derivatives	Mansouri et al. (2005)
Tazizaout	**Phenolic acids:** Sinapic acid, ferulic acid, cinnamic acid derivatives, and cinnamic acid derivatives	Mansouri et al. (2005)
Tunisian date (*P. Conariensis*).	**Tocopherols and Tocotrienols:** The most common tocopherol was α-tocotrienol, which was followed by γ-tocopherol; there were additional traces of other tocopherols (α, β, δ) and tocotrienols (β, δ) found	Nehdi et al. (2010)

4.1.2. Antimicrobial properties

The use of natural antimicrobial agents and their derivatives is seen as a promising solution to antibiotic-resistant bacteria due to their cost-effectiveness and lack of side effects (Al-Daihan and Bhat, 2012). Various date cultivars have shown significant antibacterial properties in both in vitro and in vivo studies. For example, methanolic and acetone extracts from Ajwa dates have been found to inhibit both Gram-positive and Gram-negative bacteria (Aamir et al., 2013; Jassim and Naji, 2010). Following an initial study that demonstrated the antiviral activity of dates extracts (Jassim and Naji, 2010), numerous other reports have confirmed the strong antimicrobial potential of dates. Ethanol and aqueous extracts of Egyptian dates showed strong antimicrobial activity against five pathogenic bacterial strains (El Sohaimy et al., 2015). Additionally, methanolic extracts of Ajwa dates were effective against *Escherichia coli, Bacillus cereus, Staphylococcus aureus,* and *Serratia marcescens* (Samad et al., 2016). Given the significant implications for human health, further research is required to confirm the antiviral properties of date fruit and seed extracts. However, the current data consistently show that dates possess broad-spectrum antimicrobial activity, indicating that this fruit could provide an affordable means of protecting humans against various microbial infections.

4.1.3. Anticancer activity

Oxidative stress contributes to the incidence of cancer by changing various signalling pathways in human tissues; combatting oxidative stress is a major preventative step against cancer's early pathogenesis. In this context, plant polyphenols including phenolic acids and flavonoids play a crucial part in preventing cancer by regulating molecular/genetic pathways. The bioactive compounds in dates show great promise, as experimental trials have demonstrated their effectiveness against various cancers (Al-Alawi et al., 2017). For example, methanolic extracts of Ajwa dates have been shown to inhibit cell proliferation in gastric, prostate, colon, breast, and lung tumour lines (Zhang et al., 2013). Additionally, consuming dates has been found to significantly improve colon health, likely due to the increased growth of beneficial gut bacteria and reduced tumour cell proliferation (Eid et al., 2014). While the exact mechanisms behind this anti-cancer activity are not fully understood, it is believed that polyphenols and dietary fibre (such as β-glucan) play a key role. Irradiated β–glucan has demonstrated anti-proliferative potential against three cancer cell lines: Colo-205, T47D, and MCF7 (Shah et al., 2015).

Dates are rich in dietary fibre and a variety of polyphenolic chemicals, including β-glucan, which has anti-cancer characteristics. However, the specific mechanism of anticancer action of these compounds still needs to be elucidated. Libyan dates have been shown to have anti-tumour properties (Ishurd and Kennedy, 2005). Dates offer protection against cancer, according to research trials and clinical evidence (Al-Alawi et al., 2017). Furthermore, because of these antioxidant characteristics, dietary fibre and polyphenolic extracts from dates have an opportunity to be investigated as natural alternatives in the nutraceutical and food-pharma industries (Al-Farsi and Lee, 2008a). The preliminary data reviewed here suggest a significant potential for further detailed exploration of the anticancer properties of dates and their by-products. In the future, further research is needed towards investigating dates and pits' anticancer properties against various cancer cell types, and additionally in the animal model system.

4.1.4. Antidiabetic activity

Diabetic drugs are helpful, but like modern cancer treatments, they might have unfavourable side effects, such as changes to genetic and metabolic pathways. Natural plant extracts can enhance insulin production and inhibit intestinal glucose absorption, playing a significant role in diabetes management (Malviya et al., 2010). Dates contain active compounds such as flavonoids, steroids, phenols, and saponins, which act as antidiabetic agents. Whether extracted from dates or other sources, these compounds benefit diabetes management through their free-radical scavenging abilities, as demonstrated in multiple diabetic rat studies (Hasan and Mohieldein, 2016; Zhang et al., 2013). Extended ingestion of Ajwa seed extract promotes healthy liver and renal function and lowers oxidative stress (Hasan and Mohieldein, 2016). The inhibitory properties of α-glucosidase, which affects the absorption of glucose in the kidneys and small intestines, may be partially responsible for this impact in dates (Khalid et al., 2017).

Although the precise mechanism underlying the antidiabetic effect of date products is unclear, it might involve decreased intestinal glucose absorption and improved insulin production (Michael et al., 2013). According to Singh et al. (2012), dates-derived diosmetin glycosides appear to increase insulin secretion and induce glycogen synthase, helping to maintain blood glucose homoeostasis. Furthermore, this study revealed that giving date-derived diosmetin glycosides to male diabetic rats resulted in a considerable increase in serum testosterone levels as well as a decrease in total and prostatic acid phosphate activity (Singh et al., 2012).

4.2. Use of date fruit as functional ingredients in food products

Over the last few decades, research into date functional content and phytochemistry has improved our understanding of the processes that may have underlying previous health claims. Dates are found to possess multiple functional food and nutraceutical benefits because a variety of high-value components such as phenolics (phenolic acids and polyphenols), carotenoids, vitamins, tocols and phytosterols with antioxidant properties are present (Mansouri et al., 2005).

Dates contain a distinct variety of high-value compounds (functional components) including phenolic acids volatile compounds, tannins (Guido et al., 2011), phytosterols (campesterol, β-sitosterol, stigmasterol, isofucosterol), carotenoids (β-carotene, violoxanthin, lutein, antheraxanthin and neoxanthin) which and flavonoids (apigenin, anthocyanin, quercetin, luteolin), distinguishes them from fruits (Al-Farsi et al., 2005; Hong et al., 2006; Mansouri et al., 2005). Typically, Matloob and Balakita (2016) investigated the total phenolic content in several date cultivars and found that it was extremely high between 331 and 475 mg GAE/100 g. These levels were higher than those found in apples, blueberries, apricots, oranges, pomegranates, papayas, bananas, pineapples, and red grapes (Gonzalez-Aguilar et al., 2008; Matloob and Balakita, 2016). Dates possess a higher nutraceutical value than other fruits because of their high phenolic content. Date seeds contain a high concentration of phytochemicals that can be incorporated as a functional food ingredient.

Date seeds are high in bioactive phytochemicals and are currently used as an ingredient in functional foods. They have phytonutrients that can be used as inhibitors of angiotensin-converting enzyme, or ACE inhibitors. Various allergic responses, skin rashes, and cough have been documented as side effects of synthetic ACE inhibitors (Bougatef et al., 2008). As a result, there is a greater search for naturally occurring ACE inhibitors in agricultural products and byproducts. Date seeds are a notable source of protein (ca. 5.1 g/100 g); biopeptides from the seed with potent antioxidant activity can be used as natural ACE inhibitors to control blood pressure (Al-Farsi and Lee, 2008a). Adding date seeds flour and protein hydrolysates to baked products such as muffins meaningfully increased DPPH radical scavenging and ACE inhibitory action (Ambigaipalan and Shahidi, 2015). As date seeds flour and hydrolysates have higher levels of antioxidant and ACE inhibitory properties, they could be used as natural antioxidants and ACE inhibitors in baked goods (Ambigaipalan and Shahidi, 2015). As a result, the addition of date-beneficial components during the baking process can be employed to enhance the products' nutritional and nutraceutical properties.

Moreover, a date seed powder-based product has been recently launched in the market as a coffee alternative (Rahman et al., 2007). Because of their high dietary fibre content, date seeds have a high nutritional value and are perfect for the production of fibre-based foods and nutritional supplements. Dates fibre concentrate (DFC) from Tunisian dates was used to improve the overall quality of muffins at two distinct levels (2.5 and 5.0 %). The inclusion of DFC markedly increased the level of antioxidant activity and reduced the magnitude of secondary oxidation in the muffin cooked at 165 °C. The high phenolic content of DFC was found to be responsible for the improved antioxidant and oxidative stability of DFC-enriched muffins (Mrabet et al., 2015). Another study on functional pita bread made with varied amounts of date seed powder (5, 10, and 20 %) discovered that higher levels (15 and 20 %) of date seeds resulted in higher phenolic and antioxidant activity when compared to conventional and whole wheat bread (Platat et al., 2015). It has been discovered that flavon-3-ols were the most prevalent polyphenols in date seed-formulated bread (Platat et al., 2015). As a result, date seeds' high polyphenolic content may contribute to the strong antioxidant activity reported in date seed-formulated baked meals, supporting the prospective uses of date seeds as a functional component.

Several studies have also demonstrated increased dietary fibres in baked items fortified with various types of date seeds (Al-Dalali et al., 2018; Bouaziz et al., 2010). Date pits have also been employed in model meat products as functional additives (Amany et al., 2012). In another study, date seed antioxidant extracts were found to boost the oxidative stability of ground beef by lowering the product's TBARS (Thiobarbituric acid reactive substances) when compared to a reference. The TBARS value was considerably higher than that of BHT-containing ground beef. Such findings also encourage the use of date seeds as a useful component in the creation of novel designer foods.

Several studies have shown that the date palm fruit contains a great deal of polyphenols that can be used in producing functional food products. For example, Gad et al. (2010), studied the influence of substituting a portion of the water that was utilized for reconstituting skim milk powder with varying volumes of date palm syrup during the yoghurt-making process. They discovered that yoghurt supplemented with a substantial 10 % date syrup raised the phenolics content and ferric reducing antioxidant activity, improving the health benefits of the yoghurt. Date's phenolic compounds have been connected to high antioxidant action (Allaith, 2008; Ishurd and Kennedy, 2005). Furthermore, phytochemical investigations revealed that dates have a high concentration of alkaloids, flavonoids, anthraquinones, saponins, terpenoids, and tannins (Anderson et al., 2004). Dates contain numerous active compounds that have been demonstrated in various studies to possess antioxidants, antidiabetic, antibacterial, antimicrobial, anti-nephrotoxic, and immunostimulant activities (Bentrad et al., 2017; El-Far et al., 2016; Saryono et al., 2018).

Dates are widely recognised for their numerous culinary and functional uses (Hussain et al., 2020; Khalid et al., 2017). Its fruits are recognized to provide an abundance of important nutrients and are regarded as a complete food, containing considerable amounts of carbohydrates, fibre, and other functional components. Furthermore, dates have been proven to have a significant antioxidant capacity (Biglari et al., 2008; Hussain et al., 2020) as well as diabetes-lowering effects (Younas et al., 2020). All of this indicates that dates are necessary for a balanced diet and boost human health. With such a broad profile of high-value phytochemical and nutraceutical components, dates and its seed have enormous potential for developing innovative functional foods and nutra-pharmaceuticals.

5. Microorganisms in dates

It is crucial to evaluate the effect of microorganisms on dates to ensure their quality and safety. Matured dates typically have low moisture content as they have been dried and contain a high sugar content of more than 60 % and thus can less vulnerable to microbial invasion (Sarraf et al., 2021). However, dates, can undergo microbial deterioration under vulnerable conditions (Risiquat, 2013). The types and volume of microorganisms associated with dates have an impact on their nutritional quality and shelf-life.Microbial contamination has been linked to a high annual loss of date quality. A number of important factors, including cultivation weather, size, ripening stage, and post-harvest conditions like unhygienic handling, storage, and transportation procedures, influence the rate of contamination (Farag et al., 2013; Zamir et al., 2018). From the perspective of food safety, dates may contain microoragisims/pathogens such as *Salmonella* spp., *Fusarium* spp., *Bacillus cereus, Aspergillus* spp., *Alternaria* spp., and *E. coli.* could pose a risk to public health (Risiquat, 2013; Al Hazzani et al., 2014; Atharinia and Nojoumi, 2014; Zamir et al., 2018).

Apart from bacteria and moulds, osmotolerant yeast species are also present in dates even after packing and cooling, and have been identified as another key reason that might deteriorate date quality (Risiquat, 2013). Bacterial growth is aided by the high level of moisture in date flesh; nevertheless, mould growth becomes apparent when the dates are dried and kept (Lobo et al., 2013). Fresh fruit spoilage, including dates, can happen when these microorganisms multiply on the fruit's surface or inside it at quantities as high as 6.0 Log CFU/g.

Microbial contamination by moulds is the most significant issue with the global marketing of dates. As a result, dates are more durable to microbial spoilage. Nevertheless, osmotolerant yeasts and mould can live for longer, even after packaging and refrigeration, or grow on the fruit's flesh (Hamad, 2008). Physicochemical factors (pH, water activity, moisture content, type, and quantity of carbohydrates) and extrinsic contexts such as temperature, humidity, and conditions for storage influence microbial load inherent qualities of dates. Methods of production, for instance partly treated manure, irrigation with contaminated water, and improper post-harvest and processing of dates may lead to microbiological contamination (Kalia and Gupta, 2012). Some of the microbes that can be detected in dates are yeast, mould, lactic acid bacteria, and other possible microorganisms (Hamad et al., 2012). Temperature and moisture content are the aspects that may affect the growth of microorganisms and the spoilage of dates (Umar et al., 2014).

High sugar and low moisture content in dates can reduce microorganism growth, however microbial deterioration can take place. It may result from improper storage of dates, such as inaccurate temperature and relative humidity in the storage facility. Poor handling can also lead to temperature fluctuations as it can cause condensation of moisture on dates, which stimulates bacterial microorganisms to grow. The bacteria present on the dates are *Bacillus cereus, Salmonella* spp.*, E. coli, Staphylococcus aureus*, and *Streptococcus* spp. (Zamir et al., 2018).

The fungal growth can be seen when the dates have been dried and kept at an inappropriate temperature or storage conditions. Fungal growth can also be caused by an inadequate handling system from harvesting to storage. Yeast, mould, *Aspergillus flavus, Aspergillus niger*, and *Aspergillus parasiticus* are types of fungi commonly found on dates (Shenasi et al., 2002). If the pre- and post-harvest processes are not controlled, yeast and mould can be present in the dates. The osmotolerant yeasts and mould can live for longer, even after packaging and refrigeration (Elsharawy et al., 2019).

Water activity (a_w) has a major influence on the microbiological load in dates. Navarro (2006), on the other hand, stated that *Aspergillus* species can grow at a_w values somewhat greater than 0.65. Al-Bulushi et al. (2017) employed a metagenomic approach to examine the microbial makeup of two widely grown date cultivars in Oman, 'Burny' and 'Kheniz'. At the Tamer stage, they detected the fungal species associated with various fruit components and found that *Ascomycota* (94 %), *Chytridiomycota* (4 %), and *Zygomycota* (2 %), were the fungi that both cultivars shared. Over 60 % of the fungal operational taxanomic units (OTUs) were represented by the 54 fungal species discovered, including species from the genera *Alternaria, Penicillium, Aspergillus* and *Cladosporium*. The species such as *Aspergillus versicolor, Aspergillus flavus* and *Penicillium citrinum* were amongst the fungi that may produce mycotoxin in the stored dates, although their relative abundance was extremely low (0.5 %). There were no variations in the fungal populations of the distinct components (skin and pulp) parts of the dates (Al-Bulushi et al., 2017)

Microbial load in date varieties is mainly reported in Middle Eastern countries, for instance, Saudi Arabia and Tunisia, a few countries in African regions including Nigeria, followed by Bangladesh and Pakistan, as shown in Table 6. This study primarily concentrates on assessing the microbial load, specifically targeting bacterial and fungal loads. The research was predominantly conducted in Middle Eastern countries, which are major producers of dates with a high consumption rate compared to other nations.

Shenasi and colleagues (Shenasi et al., 2002) tested 25 different types of fresh dates those were kept at high relative humidity using conventional culture-based methods and analysed the for microbial load. The primary findings of the study revealed that overall microbial counts were high during the first maturation stage (Kimri), rapidly increased during the second maturity stage (Rutab), and then

Table 6
Microbiological load in different varieties of dates (*Pheonix dactylifera* L.).

Country	Dates Varieties	Microbiological Analysis		References
		Mesophilic aerobic bacteria (log CFU/g)	Fungal count, yeast, and mould (log CFU/g)	
Pakistan	Begumjangi	114.33	2169.00	Aslam et al. (2019)
	Haleeni	334.33	2209.33	
	Dashtri	643.33	4879.00	
	Peshnah	756.67	6142.67	
Tunisia	Deglet Nour	3.75	3.90	Jemni et al. (2019)
Bangladesh (New Market)	Nagal	5.65	5.36	Zamir et al. (2018)
	Dhapas	5.23	3.60	
	Boroi	4.00	3.78	
	Morium	4.34	3.48	
	Tunisia (Deglet Nour)	4.81	3.78	
Nigeria				
Maraba market	Various	–	4600.00	Orole et al. (2017)
Lafia old market		–	3600.00	
Shinge market		–	12,500.00	
Modern market		–	3800.00	
Shabu market		–	10,200.00	
Koro market		–	2800.00	
Saudi Arabia	Rezizi	3.51 ± 0.07	2.12 ± 0.08	Al Jasser (2010)
	Khlas	3.69 ± 0.03	2.27 ± 0.01	
	Sukri	2.55 ± 0.07	2.41 ± 0.01	
	Sefri	3.25 ± 0.02	2.26 ± 0.03	
	Sukkary	20.00	0.00	Aleid et al. (2014)
	Khalas	100.00	175.0	
	Sugai	110.00	0.00	
	Anbara	20.00	350.0	
	Khulas	**3.77**	2.39	Hamad (2012)
	Um-Ruhaim	3.88	2.70	
	Shahal	4.24	2.92	
	Hilali	4.54	2.82	
	Tiar	3.75	2.41	
	Megnaz	3.78	2.43	

dramatically dropped during the final drying stage of maturation (Tamer). In 12 % of the samples, aflatoxins were discovered, however, aflatoxigenic *Aspergillus* was found in 40 % of the types tested, only during the Kimri stage of growth. Moreover, lactic acid bacteria were found on a number of date fruits at the Rutab stage, including every varieties in which aflatoxins or aflatoxigenic *Aspergillus* spp. were discovered (Shenasi et al., 2002).

Hamad (2012) investigated the microbiological load at Rutab stages from various date cultivars produced in Saudi Arabia and the Persian Gulf region. They discovered that the tested six cultivars' fruit samples were infected with aerobic mesophilic bacteria at concentrations ranging from 10^2 to 10^5 CFU/cm^2. Notably, different moulds and yeasts were also present in all the tested samples along with coliform bacteria and the food-poisoning bacterium, *Staphylococcus aureus*. Only a small portion of the samples included the mycotoxigenic fungus *A. flavus* and *A. parasiticus*. The authors predicted the fruit's anticipated shelf life and suggested that the amounts of bacterial, mould, and yeast contamination were indicative of the fruit's overall microbiological safety and quality (Hamad et al., 2012). Microbial damage, particularly mould infection, is a significant barrier to the international marketting of Saudi dates (Hamad, 2012).

Rausan et al. (2018) examined the microbiological properties of five different types of dates bought from different local stores in Bangladesh and found that none of the samples were safe to consume, except for two cultivars that were purchased from Mohammadpur and Mirpur. In another research, Umar et al. (2014) examined the bacterial quality of dates collected from five distinct sites in Katsina, Nigeria, and found significant level of Salmonella/Shigella and coliform bacterial contamination. The poor quality of the fruit and unhygienic procedures adopted by the local sellers were the main causes of contamination in this investigation. According to Risiquat (2013), the different examined from Nigerian marketplaces were heavily infected by harmful bacteria, moulds, and yeasts that might be linked to poor handling and storage circumstances. The microbiological quality of pre-packaged dates sold in the greater Glasgow area (Scotland) was examined by Aidoo et al. (1996). The results revealed high amounts of yeast, coliforms, and moulds, but very low levels of *Staphylococcus*. Moisture content was found to be the crucial indicator that adversely affected the microbiological properties of the dates.

The interaction between microbes and mycotoxin contamination in dates is an important factor that needs to be studied. Dates are particularly prone to contamination by a variety of microorganisms during cultivation, ripening, and storage due to their susceptibility to diverse agroclimatic conditions. It is possible for certain fungal species—like *Aspergillus* and *Penicillium*—to flourish in specific climate-related conditions and produce mycotoxins, such as ochratoxin A. Determining the variables affecting the production of mycotoxin requires an understanding of the dynamics of microorganism interactions at various phases of the date's lifecycle. This information is essential for putting into practical methods to reduce mycotoxin contamination in dates, protecting the quality and safety of this nutrient-dense fruit. As there is still much to learn about the precise mechanisms and environmental factors impacting the relationship between microorganisms and mycotoxin contamination in dates, continued research is essential to improving food safety regulations and developing preventive measures.

6. Mycotoxin in dates

Mycotoxins are generally described as fungal metabolites that evoke pathological changes in humans and animals. Mycotoxins are a chemical group of secondary toxic metabolites produced by *Aspergillus, Alternaria, Penicillium,* and *Fusarium*. The first three of these genera are the major contributors to the production of mycotoxins in fruits (Iqbal et al., 2014). Fungi that can produce mycotoxin are prevalent microbes that can contaminate the fruit because of the high sugar levels (Jackson and Al-Taher, 2008). Furthermore, the presence of fungi on dates does not necessarily imply the presence of mycotoxins, as many different factors can influence the production of toxins (Drusch and Ragab, 2003; Jackson and Al-Taher, 2008). These fungi are the main causes of the spoilage of fruit and the major cause of financial losses in the food industry. Based on the pre- and post- harvesting conditions, and varieties different types of mycotoxins have been detected in dates.

6.1. *Aflatoxins*

Aflatoxin is a mycotoxin that mainly occurs in various dates and dried fruits. Polyketide mycotoxins are the family of aflatoxins produced in agricultural commodities mainly by *Aspergillus flavus, Aspergillus nomius* strains, and *Aspergillus parasiticus*. Besides, four main aflatoxins that can be found in agricultural products are: aflatoxin B_1 (AFB_1), B_2 (AFB_2), G_1 (AFG_1), and G_2 (AFG_2). AFB_1 is the most potent and it is categorised as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) (Mukherjee et al., 2018).

Aflatoxin is regarded as a highly toxic substance and may cause toxicity in humans, both acute and chronic (Sanzani et al., 2016). Moreover, aflatoxin may affect babies' congenital disabilities and stuntedness. Besides, high doses of aflatoxin can cause acute human poisoning due to liver damage. Acute liver disease may also cause nausea and death, known as aflatoxicosis in humans (Benkerroum, 2020). Hence, aflatoxin contamination of dates may cause a serious health hazard to the consumers.

The occurrence of aflatoxin in dates has been reported worldwide, primarily in Middle Eastern countries. The prevalence of aflatoxins has been observed in many countries, such as Pakistan, Italy, Iran, Egypt, Tunisia, and Spain. However, data on these contaminants in dates from Malaysian markets is pretty limited and outdated. Isolation of mycotoxigenic fungi and incidence of related mycotoxin contamination have been reported in various varieties of dates, either fresh or dried forms (Abdallah et al., 2018). Table 7 shows the contamination and levels of mycotoxin detected in several date varieties from different countries.

For instance, aflatoxin content in dates from Pakistan has been investigated. In Punjab and Khyber Pakhtunkhwa, the incidence of AFB_1 and total aflatoxins (AFs) has been documented by Iqbal et al. in 2014 and 2018. Aflatoxins were identified in 39.6 % of the various date types analysed, with average levels of 2.13 g/kg for AFB_1 and 4.11 g/kg for total AFs (Iqbal et al., 2018). Aflatoxin was found in just 10 % of samples in another study carried out in Khyber Pakhtunkhwa, Pakistan, with an average of 2.5 μg/kg (Luttfullah and Hussain, 2011). Masood et al. (2015) discovered incredibly high occurrence rates in Khyber Pakhtunkhwa, where an average of 4.50 g/kg of total AFs and 6.32 g/kg of AFB_1 contamination were observed in 60 % of tested date samples. In another similar investigation, 25 out of 170 samples were found to be contaminated with aflatoxins with average total AFs being 0.24 μg/kg (Ghnimi et al., 2017).

Similarly, Iranian dates have aflatoxin contamination levels comparable to those discovered in dates sold in Riyadh, Saudi Arabia, where the average amount is approximately 2 g/kg (Ibrahim et al., 2013; Heshmati et al., 2017). However, Saudi Arabia had higher frequency records with 80 % contamination. In Shanghai, China, 40 date samples tested revealed the absence of any AFs types (Han et al., 2016). Dates analysed from Spain and Italy did not contain any aflatoxins (Azaiez et al., 2014; Quaglia et al., 2020). Furthermore, the results of the research conducted by Azaiez et al. (2015), revealed that none of the date types sold in Spain had any evidence of aflatoxin contamination. Additionally, the prevalence of aflatoxins in dates from Africa has not been extensively investigated. Aflatoxin-free dates (Rutab and Sukkary) were discovered by Hegazy and El Sayed (2014) during their studies. The findings were in accordance to research by Han et al. (2016), who discovered that a single sample from 40 samples was contaminated at levels of 14.4 μg/kg for AFB_1 and 2.44 μg/kg for AFB_2. Several date types (48 samples) were gathered and examined in Tunisian markets; with 22 were found to be positive with an average amount of AF contamination

Table 7
Occurrence and levels of aflatoxins (AFs) and ochratoxin A (OTA) in different varieties of dates (*Pheonix dactylifera* L.).

Country	Dates Varieties	Mycotoxins	Samples n	Positive N (%)	Mean μg/kg	Concentration Range (μg/kg)	References
Pakistan	Various	Total AFs	170	25 (15)	0.24	0.24–5.87	Asghar et al. (2017)
	Azadi	AFB_1	16	5 (31.3)	21.4	LOD-18.50	Iqbal et al. (2018)
		Total AFs			3.08		
	Badami	AFB_1	22	11 (50)	1.20	LOD-11.80	
		Total AFs			2.90		
	Dhakki	AFB_1	19	5 (26.3)	2.14	LOD-7.90	
		Total AFs			4.56		
	Bashra	AFB_1	18	8 (44.4)	2.57	LOD-21.45	
		Total AFs			4.34		
	Tikala	AFB_1	21	9 (42.9)	2.78	LOD-26.60	
		Total AFs			4.96		
	Dried dates	Total AFs	15	9 (60)	6.32	LOD-18.79	Masood et al. (2015)
		AFB_1			4.50	LOD-9.80	
	Dried dates	Total AFs	20	2 (10)	2.5	2.1–2.9	Luttfullah and Hussain (2011)
	Dates	AFB_1	15	6 (40)	4.80	LOD-10.20	Iqbal et al. (2018)
		Total AFs			5.30		
Pakistan	Dried dates	AFB_1	17	5 (29.4)	3.20	LOD-15.50	
		Total AFs			3.90		
Egypt	Dried dates	AFB_1	28	1 (3.57)	Abs	14.4	Abdallah et al. (2018)
		AFB_2		1 (3.57)	Abs	2.44	
	Rutab and Sukkary	Total AFs	5	0 (0)	Abs	Abs	Hegazy and El Sayed (2014)
Spain	Dried dates	Total AFs	3	0 (0)	Abs	Abs	Azaiez et al. (2014)
	Different date varieties	Total AFs	27	0 (0)	Abs	Abs	Azaiez et al. (2015)
Tunisia	Different date varieties	AFB_1	48	22 (45.8)	n.d.	Abs	Azaiez et al. (2015)
		AFB_2			1.14	1.1–1.3	
		AFG_1			1.40	<LOQ–1.8	
		AFG_2			1.70	<LOQ–2.2	
Iran	Dried dates	AFB_1	22	9 (40.9)	2.1	0.6–6	Heshmati et al. (2017)
		AFB_2		5 (22.7)	0.7	0.4–0.7	
		AFG_1		3 (13.6)	0.3	0.29–0.41	
		AFG_2		1 (4.5)	0.3	–	
		Total AFs		9 (40.9)	2.6	0.9–8.1	
Saudi Arabia	Semi-dry dates	AFB1	12	10 (83.3)	1.39	0.00–5.92	Ibrahim et al. (2013)
		Total AFs			2.01		
China	Dried dates	Total AFs	40	0 (0)	Abs	Abs	Han et al. (2016)
Italy	Dried dates	Total AFs	20	0 (0)	Abs	Abs	Quaglia et al. (2020)
Egypt	Various	OTA	28	3 (11)	58.7	1.48–6070	Abdallah et al. (2018)
Tunisia and Spanish	Dates	OTA	75	18 (24)	1.3	0.57–3.3	Azaiez et al. (2015)
Iran	Various		22	5 (22.7)	1.2	0.5–2.1	Heshmati et al. (2017)
			20	2 (10)	2.5	1.4 – 3.6	Rahimi et al. (2013)

Abs: Absence.

of 1.14 μg/kg, 1.4 μg/kg, and 1.7 μg/kg for AFB_2, AFG_1, and AFG_2, respectively (Azaiez et al., 2015).

Generally, dates are cultivated in regions that are relatively high in temperatures and relative humidity, that may lead to aflatoxin contamination. The colour, flavour, chemical changes, and climatic conditions may also contribute to dates' susceptibility to aflatoxin contamination (Mukherjee et al., 2018; Wang et al., 2018). Other than the environmental factors, the most crucial indicator for aflatoxin contamination is handling practices in the food production chain. The most influencing and contributing factors include the cultivation stage, processing, transport, and storage (Elsharawy et al., 2019).

Aflatoxin contamination of dates may have begun when fungi contaminated the trees during the cultivation stage. Afterwards, the level of aflatoxins continuously increased through the harvesting of dates (Drusch and Ragab, 2003). The time for date harvesting at different cultivation stages might also affect the aflatoxin formation (Elsharawy et al., 2019). Based on the research by Elsharawy et al. (2019), in the early stage of maturation, aflatoxin formation was the highest in artificially inoculated dates with *A. parasiticus*, at maximum total aflatoxin levels greater than 300 mg/g. In contrast, total aflatoxins have been detected at levels below 100 mg/g in the ripening stages. The late ripening of dates generally can be linked to lower chances of aflatoxin formation than early ripening (Jackson and Al-Taher, 2008). The observed phenomenon of lower aflatoxin formation in late-ripening dates compared to early-ripening dates may be attributed to the extended maturation period. Extended ripening may allow the fruit to develop stronger natural defenses and mitigation mechanisms against aflatoxin infection. The observed decrease in aflatoxin production may be explained by a number of factors, such as enhanced biochemical composition, higher synthesis of antifungal chemicals, and greater resistance to fungal invasion over the extended ripening phase (Shenasi et al., 2002). Hence, if the fruits are harvested in the earlier stages of maturation, the dates may contain a higher level of aflatoxin.

Furthermore, high aflatoxin levels have also been associated with prolonged storage and contamination during storage or transport. Inappropriate moisture content and temperature during transportation may result in exponentially increased levels of aflatoxins (Agriopoulou et al., 2020). Consequently, it is imperative to devise preventive measures to avert aflatoxin contamination in dates besides applying effective analytical tools for their reliable detection. Some analytical techniques including HPLC, LC, LC-MS/MS and ELISA can be used to determine the magnitude and types of aflatoxins (B_1, B_2, G_1, G_2) in date palm fruits.

6.1.1. *Techniques for aflatoxins determination in dates*

Considering the possible health implications of aflatoxins, accurately detecting aflatoxins in dates is essential to maintaining food safety and quality. As some moulds produce aflatoxins, which are dangerous for human health, it is important to use effective detection methods while dealing with dates. As a result of the pressing need to protect public health, scientists have worked hard to develop sophisticated techniques for identifying aflatoxins in datesThere is a need to increase understanding of aflatoxin exposure prevention strategies for dates while preserving their quality and safety by conducting a thorough analysis of detection techniques ranging from conventional to innovative and cutting-edge technologies. Table 8 presents the overview of different analytical techniques and analysis conditions used for the determination of aflatoxins in date fruits.

Whether utilizing chromatography or immunoassay techniques, it is imperative to eliminate toxins from the samples and undergo a purification process to enable the accurate detection and quantification of aflatoxins while mitigating matrix interference from food sources (Krska et al., 2008). LC has been frequently used for aflatoxins determination regardless of some limitations of this technique (Mahfuz et al., 2018). (Alternatively, ELISA, due to its simplicity, speed, and sensitivity, is recognized as a viable immunochemical method, providing an alternative to chromatographic methods for determination of aflatoxins. These attributes stem from antibody–antigen interactions; however, ELISA may encounter limitations attributed to its potential cross-reactivity with analogous toxins (Pal et al., 2004).

Currently aflatoxin quantification is in practice using LC combined with fluorescence detection (LC-FD), mass spectrometry (LC-MS), or tandem mass spectrometry (LC-MS/MS) (EFSA, 2020). LC-FD samples are typically extracted with methanol or mixtures of methanol and water. Subsequently, quantification by FD, post-column derivatization, and cleanup can be achieved through the utilization of an immunoaffinity column (IAC) before separation by LC. Unlike LC-FD, derivatization is unnecessary for LC–MS and LC–MS/MS. Acetonitrile is typically employed for sample extraction in LC–MS or LC–MS/MS analysis. Because of its capacity to identify several toxins in a single run with excellent reliability and sensitivity, LC-MS/MS is becoming increasingly popular in aflatoxin analysis (EFSA, 2020; Ouakhssase et al., 2019; Woo et al., 2019).

6.2. *Ochratoxin A*

Ochratoxin A (OTA), a mycotoxin predominantly synthesized by *Penicillium* and *Aspergillus* spp., poses a significant threat to food safety and human health. Heshmati et al. (2017) highlighted the climatic preferences of these fungi, with *Aspergillus* spp. thriving in warmer environments and *Penicillium* spp. flourishing in cooler climates. The environmental conditions conducive to *Aspergillus* spp. proliferation may raise the possibility of OTA exposure in regions characterized by elevated temperatures.

The International Agency for Research on Cancer (IARC) classifies OTA as a Group 2B probable human carcinogen (IARC, 1993). This designation underscores the need for stringent monitoring and regulation of OTA levels in food commodities including different types of dates. Chronic exposure to this mycotoxin has been associated with renal toxicity and an elevated risk of renal carcinoma in humans. Moreover, OTA has been implicated in other adverse health effects, including nephrotoxicity, immunosuppression, and developmental abnormalities, amplifying its significance as a food safety concern (Pfohl-Leszkowicz and Manderville, 2007).

6.3. *Alternaria toxins*

Additionally, *Alternaria* toxins may contaminate dates during storage as *Alternaria* spp. can grow at low temperatures. Therefore, during refrigerated storage, they are mainly involved in fruit spoilage. The competition between fungal genera during development affects the growth of *Alternaria* species (Sanzani et al., 2016). Although *Alternaria* spp. may yield more than 70 hazardous secondary metabolites, only a few of them have been physically recognized and classified as mycotoxins. *Alternaria* toxins include alternariol monomethyl ether (AME), tentoxin (TEN), alternariol (AOH), tenuazonic acid (TeA) and altenuene (ALT) (Wei et al., 2019).

6.4. *Mitigation strategies for microbial contamination of dates*

Dates are one of the most traded food commodities worldover. In this

Table 8
Analytical techniques used for aflatoxin determination in date fruits from different countries (Sources: Almaghrabi, 2022).

Country	Extraction	Clean-up	Tech	Derivatization	Limit of detection µg/ kg				References
					B1	B2	G1	G2	
China (Shanghai)	Acetonitrile: water	–	LC-MS/MS	–	0.1	0.1	0.3	0.3	Han et al. (2016)
Egypt (Assiut)	Acetonitrile: water: acetic acid	–	LC-MS/MS	–	0.05	0.03	–	–	Abdallah et al. (2018)
Egypt (Cairo)	Methanol: water	–	ELISA	–	1.0				Hegazy and El Sayed (2014)
Iran (Hamadan)	Methanol: water	Immunoaffinity column	HPLC	–	0.06	0.05	0.08	0.02	Iqbal et al. (2018)
Italy (Perugia)	Acetonitrile: water: acetic acid	–	LC-MS/MS	–	–	–	–	–	Quaglia et al. (2020)
Pakistan (different areas of Pakistan)	Methanol: water	Immunoaffinity column	HPLC	Kobra Cell™	0.12				Asghar et al. (2017)
Pakistan (Khyber Pakhtunkhwa)	Methanol: water	Immunoaffinity column	LC	TFA	0.5	1.0	0.5	1.0	Luttfullah and Hussain (2011)
Pakistan (Khyber Pakhtunkhwa)	Acetonitrile: water	Immunoaffinity column	HPLC	TFA	0.04	0.07	0.04	0.07	Heshmati et al. (2017)
Pakistan (Khyber Pakhtunkhwa and Punjab)	Acetonitrile: water	Immunoaffinity column	HPLC	TFA	0.05	0.06	0.05	0.06	Iqbal et al. (2014)
Pakistan (Punjab and Khyber Pakhtunkhwa)	Acetonitrile: water	Immunoaffinity column	HPLC	TFA	0.04	0.07	0.04	0.07	Iqbal et al. (2018)
Saudi Arabia (Riyadh)	Methanol: water	Immunoaffinity column	HPLC	PBPB	–	–	–	–	Quaglia et al. (2020)
Spain (Valencia)	Acetonitrile: water: acetic acid	–	LC-MS/MS	–	0.08	0.08	0.16	0.3	Azaiez et al. (2014)
Spain (Valencia)	Acetonitrile: water: acetic acid	–	LC-MS/MS	–	–	–	–	–	Azaiez et al. (2015)
Tunisia (Tunis)	Acetonitrile: water: acetic acid	–	LC-MS/MS	–	–	–	–	–	Azaiez et al. (2015)

HPLC: high-performance liquid chromatography; MS: liquid chromatography with tandem mass spectrometry; ELISA: enzyme-linked immunosorbent assay; PBPB: pyridinium hydrobromide perbromide: TFA: trifluoroacetic acid.

direction, Saudi Arabia's bid to declare 2027 the International Year of Dates has been granted by the Food and Agriculture Organization (FAO). Typically, dates are a sustainable crop that can be cultivated in a variety of climates, therefore the request was made in response to worries about the possible impact of climate change on global food security (Aslam et al., 2019). Microbial contamination, especially involving aflatoxins can have serious health effects, thus it is important to undestand the effectiveness of some mitigation strategies to control such contaminations for the sake of dates food quality and safety.

To minimise microbial contamination in dates, it is crucial to enhance the quality at each processing step, from manufacturing to processing and storage (Jdaini et al., 2022). The methods can be listed as either conventional or innovative as shown in Fig. 6. Implementing good agricultural practices (GAP), encompassing fumigation, sorting, washing, heat treatments, and appropriate packaging, are a few mitigation steps to reduce microbial contamination in dates (Elhadi et al., 2013).

Appropriate preharvest-management steps can avoid moulds growth at different growth and maturity stage of dates by using suitable cultivation methods and proper use of insecticides and fungicides. For example, dates can also be harvested in hot weather to ensure the fruit is free from mycotoxins (Drusch and Ragab, 2003; Sarraf et al., 2021). Besides, Shenasi et al. (2002) stated some essential control practices to control fungi in the following harvesting phases. They are first harvested at the right time, at or near maturity. Hence, early harvesting is commonly practised to prevent bad weather, excessive fruit dehydration, bug infestation, and attacks by microorganisms. Then, these dates can be further ripened indoors with equipped devices to control humidity, air circulation, and temperature. Secondly, the fruit should be handled gently to prevent the entry of fungi through potential bruises. Thirdly, good hygienic practices should be maintained to reduce the accumulation of moulds on surfaces in contact with the fruit (Sarraf et al., 2021). Moreover, microbial contamination also can be decreased by using appropriate sanitation techniques in the packing house and storage areas (Sanzani et al., 2016; Yahia et al., 2013). After that, dates undergo a sorting and grading process, wherein mouldy dates, skin breaks, and bruises are removed. Hence, the incidence of aflatoxin contamination can be minimised (Drusch and Ragab, 2003). After that, the dates must be dried until the moisture content reaches 25 % or preventing mould growth at each production level, from harvesting until storage. This can be the viable strategy to remove mycotoxins from different foods and dates (Yahia et al., 2013; Carla et al., 2011). Drying is a critical step as it prevents the growth of microorganisms that cause spoilage and deterioration due to moisture (Jdaini et al., 2022).

Other physical treatments, such as radiation and cold plasma treatment, may also be used to minimise mycotoxins on dates. The utilization of radiation entails the application of natural detoxifying agents, leading to the reduction of pathogenic microorganisms and the removal of mycotoxins present in dates. This process effectively detoxifies dates and diminishes the presence of harmful microorganisms and mycotoxins (Jemni et al., 2015). In addition, to addressing microbiological contamination, cleaning the dates with food-grade sanitisers and γ-radiation techniques is also applicable (Zamir et al., 2018). Besides, cold atmospheric pressure plasma technology is one of the efficient green techniques used for the decontamination of mycotoxins because it is environmentally friendly and cheaper. This technique can reduce more than 90 % of aflatoxins after eight minutes of exposure. Plus, plasma treatment can also minimise AFB_1 to 100 % for five seconds (Agripoulou et al., 2020). Furthermore, date palm preservation has reportedly been successful with the application of recent advances in nanotechnology. Dates, for example, can be preserved longer when edible coatings and films comprising chitosan nanoparticles are utilized as antifungal agents (Al Jasser, 2010; Orole et al., 2017)

Consequently, the dates must be stored at hygienic and recommended conditions to protect them from various contaminants during storage. As mycotoxin contamination is directly linked with temperature, low-temperature storage should be preferred (Mukherjee et al., 2018). Typically, the dates can be stored at −3 °C for one year, or it can be safely stored even up to two years at 25 °C after the dates are properly packaged and marketed (Biglari, 2009; Sarraf et al., 2021). Hamad (2012) investigated that refrigeration inhibits microbial growth by lowering temperature, reducing water activity, and increasing the sugar content in fruit packaging. Maintaining cold storage conditions during delivery, distribution, and transportation is also critical for protecting date quality and minimizing microbial contamination (Al Jawally, 2010). Furthermore, mesophilic aerobic bacteria are sensitive to low oxygen levels, high sugar content, low water activity, and low temperatures during storage hence taking care of these factors gradually reduce such contamination (Al Hazzani et al., 2014). In fact, proper storage and preservation techniques are essential, including packing and refrigeration at low temperatures, utilising specialised packhouses with private cold storage and advanced harvesting methods (Chapron et al., 2014; Risquat, 2013). Better packaging also can control the amount and water activity and humidity to maintain the microbial load within minimum permitted level (Jdaini et al., 2022).

6.5. Regulations on mycotoxin in dates

The permissible levels of aflatoxins, ochratoxin A and *Alternaria* toxins vary with governmental jurisdictions in human foods. Aflatoxins' hazardous nature to humans and animals has required national and international authorities to establish monitoring measures and tolerance levels (Carla et al., 2011). However, there is no specific data on the maximum limit of aflatoxins, ochratoxin A and *Alternaria* toxin in dates.

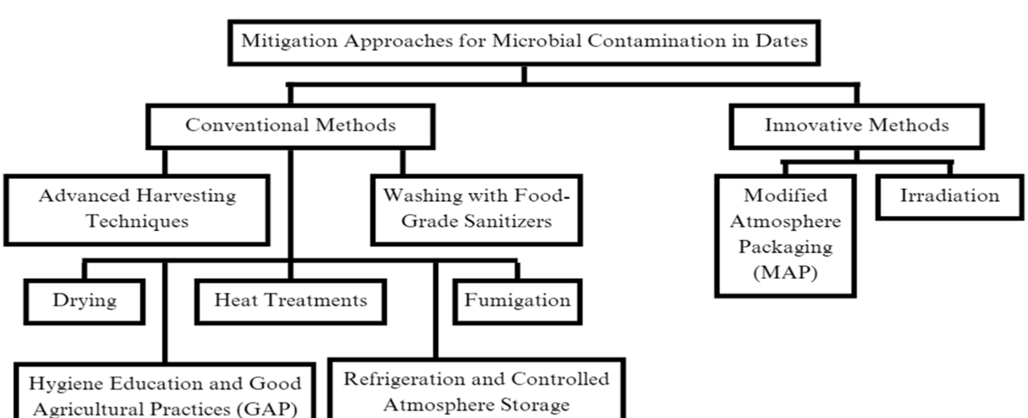

Fig. 6. Conventional and innovative methods for mitigation of microbial contamination in dates (*Pheonix dactylifera* L.).

Most of the studies refer to dates as dried foods or fruits. So, the data obtained was limited. Hence, a few regulations on the limits of aflatoxins and ochratoxin A from different countries are listed in Table 9.

7. Conclusions

Dates are valued as a highly nutritious and healthy food because of containing r variety of nutritional and nutraceutical benefits. The food quality of dates also varies with the colour, weight, and size of the varieties. Dates fruit and seed include a diverse range of high-value components and nutraceuticals. Hence, dates can be used as useful components in the development of nutraceuticals and functional foods since they exhibit appreciable antioxidant capacity across various types. Innovative functional food products can be formulated by incorporating high-value ingredients of date fruit and the seeds. However, dosage standarization, sensory properties, and consumer acceptance of such products needs to be further evaluated and monitored. The date seed, in particular, is proving to be an incredibly medicinally useful material due to a broad spectrum of bioactives. The quantitative structure-activity relationships as well as mechanism of biological actions of various bioactive components of dates needs to be further elucidated with the aid of modern molecular docking approaches. Although high-value phytochemicals and nutrients in dates and the date seeds have been linked to a variety of biological and medicinal properties, clinical investigations using human models to extend and maximise therapeutic applications of this valuable food are still rare. Especially, there is need to focus on the ACE inhibitory, blood pressure lowering, and anti-diabetic potential of date seeds through the applications of in vivo, in *situ*, followed by *human clinical trials.* Future studies should also be focussed on the evaluation of anticancer properties of dates andthe seeds (pits) employing different cell lines /cancer types as well animal model systems. Although, date contain appreciable antimicrobial activities due to presence of wide array of bioactives, especially the phenolics. Assessment of broad spectrum antiviral and antimicorbial properties of dates and seed extracts against various microbial strains needs to be further probed in order to explore their potential uses as natural preservatives and safer antmicrobial agents. Meanwhile, in line with the growng demand from food and nutra-pharmaceutical sector for safer and pure natural products or extracts, it is crucial to develop optimised protocols involving green extraction techniques such as supercritical CO_2 extraction, bio solvent extraction, and sub-critical water extractions, amongst others, for efficient recovery of food-grade functional/ bioactive extracts from date fruits and seeds.

Furthermore, dates can be contaminated with fungi that produce mycotoxins, such as aflatoxin, ochratoxin A, and *Alternaria* toxins, which can be harmful to humans' health. Hence, high-standard pre-, and post-harvesting technologies with mechanized agricultural and processing practices are recommended to control and mitigate microbial contamination of dates with the purposes of retaining optimal nutritional and nutraceutical benefits of dates. The shelf-life of date fruits can be

Table 9
Maximum limits for aflatoxins B_1, B_2, G_1 and G_2 in dried fruits including the dates in different countries.

Countries	Aflatoxins	Limits (μg/kg)	Maximum acceptable levels (μg/kg) (Food and Drug Administration (FDA) 2018)	Maximum acceptable limit in European Union (μg/kg) (European Commission, 2010)	Reference
	B_1	2	–	2* 5**	
	AFs (B_1, B_2, G_1, G_2)	2–4	20	4* 10**	
Iran: Iranian National Standard	AFs	15	< FDA MLL	>10 EU MLL	Institute of Standard and Industrial Research of Iran (2002)
	B_1	5	–	=5 EU MLL	
India	AFs	30	> FDA MLL	>10 EU MLL	Mukerjee et al. (2018)
Pakistan	AFs	2.5	< FDA MLL	<4 EU MLL	Lutfullah and Hussain (2011)
Saudi Arabia	B_1	1.39	–	<2 EU MLL	Ibrahim et al. (2013)
	AFs	2.01	< FDA MLL	<4 EU MLL	
Tunisia	AFs	4.24	< FDA MLL	≥4, <10 EU MLL	Azaeiz et al. (2015)
Canada: Maximum and Guidance Level	B_1	15	–	>5 EU MLL	Charmley and Trenholme (2020)
Pakistan	B_1	4.50	–	>2, <5 EU MLL	Masood et al. (2015)
	AFs	6.32	< FDA MLL	>4, <10 EU MLL	
Iran	B_1	2.1	–	≥2, <5 EU MLL	Heshmati et al. (2017)
	AFs	2.6	< FDA MLL	<4 EU MLL	
Japan: Maximum and provisional maximum levels	B_1	10	–	>5 EU MLL	Anukul et al. (2012)
Pakistan	AFs	0.24	< FDA MLL	<4 EU MLL	Asghar et al. (2017)
Egypt	B_1	14.4	–	>5 EU MLL	Abdallah et al. (2018)
	AFs	16.84	< FDA MLL	>10 EU MLL	
Pakistan	B_1	3.20	–	>2, <5 EU MLL	Iqbal et al. (2018)
	AFs	5.30	< FDA MLL	>4, <10 EU MLL	
Malaysia	AFs	15**	< FDA MLL	>10 EU MLL	Food Act 1983 (Act 281) and Regulations (2020)
		10*	< FDA MLL	>4, <10 EU MLL	

Studies compared average AFB_1 and AFs (μg/kg) to maximum legal limits (MLL).
*Dried fruit and processed fruit products intended for direct consumption by humans or use as a food ingredient.
*Dried fruit must be sorted or undergo extra physical treatment before being consumed or used as a component in foodstuffs.

extended by the use of both conventional (refrigeration) and unconventional (fumigation and irradiation) preservation techniques; however, these technologies have reached their limits and their viability is currently being debated. Other cutting-edge and modern technologies, such as MAP (Modified Atmosphere packing), HP (high pressures or hyperbaric treatments), edible coatings (EC), and PEF (Pulsed Electric Field) sparked the interest of date producers and processors. Such innovative approaches need to be further evaluated on a broader spectrum by employing diverse varieties and varying storage environment conditions.

Overall, the comprehensive scientific information and data offered in this review might be useful towards exploring the functional food and nutraceutical prospects of dates with innovative products development potential as well as to resolve food safety issues for future research on the risk assessment of microbial contamination. This review also emphasised the importance of improving public knowledge about dates consumption based on its variety. For recommendations, the relevant health and trade authorities should implement stronger regulations limiting the maximum limit of aflatoxins and ochratoxin A on imported dates to less than 5 µg/kg. As a result, this review can be valuable to researchers, society, food and industry, government and regulatory organizations, and consumers in general.

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Ethical approval of experiments

This work did not involve the use of human and animal subjects.

CRediT authorship contribution statement

Aimie Syahirah Ibrahim: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rashidah Sukor:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Conceptualization. **Farooq Anwar:** Writing – review & editing, Validation, Supervision, Data curation. **Suganya Murugesu:** Writing – review & editing, Supervision. **Jinap Selamat:** Validation, Supervision. **Siva Raseetha:** Writing – review & editing, Supervision, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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