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Review

Date Palm Fruits as a Potential Source of Functional Dietary Fiber: A Review

Abdessalem MRABET[1,2*], Hamza HAMMADI[3], Guillermo RODRÍGUEZ-GUTIÉRREZ[2], Ana JIMÉNEZ-ARAUJO[2] and Marianne SINDIC[1]

[1]*University of Liege - Gembloux Agro-Bio Tech. Department Agro-Bio-Chem. Passage des Déportés, 2. B-5030 Gembloux, Belgium*
[2]*Instituto de la Grasa, Consejo Superior de Investigaciones Científicas (CSIC), Campus Universitario Pablo de Olavide, Edificio 46, Ctra. de Utrera, km. 1 - 41013, Seville, Spain*
[3]*Arid and Oases Cropping Laboratory, Arid Area Institute, Medenine 4119, Tunisia*

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Date palm fruits and their seeds are excellent sources of dietary fiber (DF). Date fruits contain 8.1 - 12.7 % Total DFs (of which 84-94 % is insoluble and 6-16 % soluble DF) and is very rich in phenolic antioxidants (1-2 %). Date fruit fibers are composed of cellulose and NSP. Moreover, date DF has important functional properties, such as water-holding capacity and oil-holding capacity. Date seeds contain about 15 % fiber, characterized by a high level of water-insoluble mannan fibers. It has been suggested that date fruits and seeds can be exploited in some food applications. In order to improve fiber yields, pretreatment procedures can be applied, which give excellent results in the case of date palm fibers. Date fruits are widely available in the global market, but there is still room for improvement, particularly in the revalorization of date processing waste, and secondary cultivars. The incorporation of date fruits and seeds as food ingredients would promote the presence of dates in the modern's consumer shopping basket. Present knowledge about different aspects of date DF, and suitable extraction methods and applications of date fiber (flesh and seed), will be the focus of this report.

Keywords: Date, dietary fiber, composition, food industry

1. Introduction

Date palms (*Phoenix dactylifera* L.) are one of the most extensively cultivated plant families. They have played an important role in human nutrition throughout much of history. The fruits of the date palm are commonly consumed around the world (El Rayes., 2009). Date palm fruit is composed of a flesh (pulp) and seed (or pits). The flesh is a rich source of carbohydrates, dietary fibers (DF), and certain essential vitamins and minerals. The date seeds are also an excellent source of DF (characterized by a high level of water-insoluble mannan fibers), and contain considerable amounts of protein and lipids. Also, date seeds contain high levels of phenolics. It has been suggested that date seeds can be used in some food products to enhance their fiber content.

At present, more than 2000 different cultivars of date palm are known in the world, but only a few important ones have been evaluated for their fruit quality. Despite the lack of commercialization of many varieties, date palm fruits are important marketable crops. According to Vayalil (2012), fresh dates are the most nutritious fruits; in fact they have three to

Abbreviations: DF (dietary fiber); IDF (insoluble dietary fiber); SDF (soluble dietary fiber); WHC (water-holding capacity); OHC (oil-holding capacity); DSF (date seed fiber).

*To whom correspondence should be addressed. E-mail: abdessalem_mr@yahoo.fr

ten times more nutrients than other fruits. The importance of the date in human nutrition comes from its rich composition in bioactive compounds with antioxidant and antimicrobial activities; it is also a valuable source of DF, which can be extracted and used as a value-added ingredient (Cheikhrouhou *et al*., 2006; Elleuch *et al*., 2008). Fresh dates contain 8.1–12.7 % total DF and about 1 % fat, 2 % proteins, and 2 % ash. Moreover, date fruits are very rich in phenolic antioxidants (1–2 %).

DF is defined as the polysaccharides and lignin components of plant foods that are indigestible by enzymes in the human gastrointestinal tract. The physiological effects of DF, in the forms of insoluble and soluble fractions of foods, have a significant role in human nutrition. Numerous researchers have shown the beneficial physiological effects of DF on human health with the prevention of several diseases, such as cardiovascular disease (including coronary heart disease and atherosclerosis), diverticulosis, constipation, irritable colon, and colon cancer, as well as having positive effects for lowering obesity and blood glucose (Rodríguez *et al*., 2006; Al-Farsi *et al*., 2007).

Date fibers include insoluble DF (IDF) and soluble DF (SDF) types (84–94 % and 6–16 %, respectively), with IDF composed of cellulose, hemicelluloses and lignin, and SDF composed of pectin, gums, and mucilage (Thebaudin and Lefebvre, 1997). The concentrations of these two groups are variable in plant food. DF derived from fruits, vegetables, and legumes are rich in SDF, whereas those derived from grains are rich in IDF. SDFs contribute to the formation of a viscous gel in the intestine that slows the intestinal absorption of nutrients such as glucose and cholesterol.

Nowadays, the demand of consumers for healthier foods has led to the exploration for new sources of DF. In addition to traditional DF sources, such as cereals (Gómez, Moraleja *et al*., 2010), new ones are being developed, such as cactus cladodes (Kim *et al*., 2012), and artichoke by-products (Fissore *et al*., 2014). There is a large potential in this area to develop healthy date products particularly with a focus on the high value fiber and naturally rich phenolic antioxidants found in the date fruit flesh and seeds. Besbes *et al*., 2009 reported that the use of dates' fibers in various functional foods such as bakery, pastry and dairy products, will help to make the palm date an economically viable commodity.

In view of the health benefits of DF, the ratio IDF to SDF is an important index, especially for certain food applications. Spiller (1986) showed that an IDF/SDF ratio from 1 to 2.3 is the most advantageous for the beneficial physiological effects associated with fiber consumption. Furthermore, DF can exhibit unique qualities, such as antioxidant capacity. Recently, Mrabet *et al*. (2012) concluded that some varieties of date could be valuable as a source of antioxidant DF. The antioxidant properties of fibers come from their ability to bind free radicals, which cause damage to membrane proteins, and cellular inactivation (Ubando-Rivera *et al*., 2005). DF also shows, many interesting functional properties, such as water-holding, oil-holding, and swelling capacity.

This review focuses on the recent findings and advances in date palm fiber research. We discuss the nutritional values, chemical composition, functional properties, and antioxidant activity of DF from date palms. Finally, a brief review of the potential industrial applications of date fruit DF and the methods of pretreatment that may be required for the total use of dates are outlined.

2. Nutritional Values and Chemical Composition of DF of Date Flesh and Seed

Carbohydrates, including soluble sugars and DF, are the predominant components in date fruits, followed by moisture, with only small amounts of lipids, proteins, and ash. Many varieties of dates are especially appreciated as rich sources of DF; however, to date, there is no complete information available on the exact constituting fibers of date fruit flesh. The DF of date flesh is a mixture of non-starch polysaccharides (NSP), including insoluble cellulose, partially soluble hemicelluloses and pectin, as well as hydrocolloids, and lignin. Elleuch *et al*. (2008) reported that the neutral sugar of dates' flesh is basically composed of glucose (8.8–9.4 %) and xylose (8.7–9.2 %). However, Mrabet *et al*. (2012) showed that xylose was the major neutral sugar (50 %) in 11 Tunisian date varieties occurring together with arabinose (17–22 %), galactose (8–16 %), mannose (5 %), glucose (5 %), rhamnose (2–3 %) and fucose (1–2 %). Furthermore, Shafiei, Karimi and Taherzadeh (2010) showed that the polysaccharides are composed of glucans (10 %), xylan (5 %), galactan (4 %), arabinan (2 %) and mannan (0.5 %). On the other hand, Elleuch *et al*. (2008) concluded that DF derived from date flesh of Tunisian varieties contained a high proportion of IDF and a low content of SDF (Table 1), supported by the study of Borchani *et al*. (2012) who also observed a higher content of IDF and low content of SDF in date fiber concentrate extracted from date flesh of different Tunisian varieties. This disequilibrium between IDF and SDF is observed in other fruit, such as guava (39.2–50.1 % IDF and 1.8 % SDF) (Jiménez-Escrig *et al*., 2001) and apple pomace (60 % IDF and 15 % SDF) (Shalika *et al*., 2015). DF of the date flesh presents a high content of protein (14 %) (Borchani *et al*., 2010), as compared with other fruit fibers such as mango fiber (4.3 %) (Vergara-valencia *et al*., 2007). However, DF of date flesh presents low contents of lipid (2 %) compared with other fruit fibers such as grape fiber (7 %) (Bravo and Saura-Calixto, 1998). Dietary fiber of the date flesh also contains a low amount of moisture and ash (6 and 2.1 %, respectively) (Borchani *et al*., 2010), with similar results reported for orange fiber and citrus fiber Figuerola *et al*. (2005).

The phenolic content in DF of date flesh is lower. Hasnaoui *et al*. (2012) reported that these compounds varied between varieties (0.55 to 1.06 mg/g), with comparable results reported

Table 1. Nutritional composition and physical properties of Tunisian date flesh fiber (DFF) and date seed fiber (DFS).

	DFF	DSF
Nutritional composition (%)		
TDF	18.4	73.5
IDF	11.7	70
SDF	6.7	3.5
Physical properties (%)		
WHC	15.5	5
OHC	9.75	6

DFF, date flesh fiber; DSF, date seed fiber; TDF, total dietary fiber; IDF, insoluble dietary fiber; SDF, soluble dietary fiber; WHC, water-holding capacity; OHC, oil-holding capacity.

Table 2. The approximate composition of Tunisian date flesh and seed (%)

Component	Date flesh	Date seed	References
Moisture	23.98 – 31.37	11.63 – 13.34	Mrabet *et al*. (2015)
Proteins	2.1 – 3	5 – 6	Elleuch *et al*. (2008); Besbes *et al*. (2004)
Fat	0.35 – 0.52	13.54 – 17.75	Mrabet *et al*. (2015)
Ash	1.5 – 2.52	0.9 – 1.8	Elleuch *et al*. (2008); Al-Farsi *et al*. (2007)
Carbohydrates	79.9 – 88.02	81 – 83.1	Borchani *et al*. (2010); Besbes *et al*. (2004)
DF	14.4 – 18.4	22.5 – 80.2	Elleuch *et al*. (2008); Al-Farsi *et al*. (2007)

by Mrabet *et al*. (2015). Many authors have shown that polyphenols are present in high amounts in DF from mango (16.1 mg/g dry sample) (Vergara-Valencia *et al*., 2007), Mexican and Persian lime peel (10.55 and 19.9 mg/g, respectively), lime peel (10.6 and 19.9 mg/g) (Ubando-Rivera *et al*., 2005), and in commercial grape fiber (20 mg/g) (Bravo and Saura-Calixto, 1998).

Date seeds (also called pits) represents about 10-15 % of the total weight of the date palm fruit (Almana and Mahmoud, 1994). The world production of dates is over 7 million tons, annually, including up to 900 thousand tons of date seeds (FAO, 2010). In many countries, the seeds are used in animal feed. However, date seeds are considered a waste product in many date processing plants, despite their interesting composition of moisture, protein, fat and ash (Table 2) (Al-Farsi *et al*., 2007; Mrabet *et al*., 2015; Besbes *et al*., 2004). High levels of phenolics (1050–5720 mg gallic acid equivalents/100 g) and antioxidants (131–400 mmol Trolox equivalents/kg) have also been reported (Mrabet *et al*., 2015). In addition, date seeds have been recognized as an excellent source of DF. Hamada *et al*. (2002) reported 64.5 to 68.8 g/100 g total DF for three date seed varieties, whereas Al-Farsi *et al*. (2008) reported the content of total dietary fiber as 57.87 g/100 g. These authors concluded that DF derived from date seed contained a high proportion of IDF and a low content of SDF (Table 1). Comparable results were reported by Habib and Ibrahim (2009) who studied the nutritional quality of 18 dates' seeds. These results show that date seeds are excellent sources of DF, an important constituents of functional food.

Hamada *et al*. (2002) further classified the date seed fiber (DSF) into 46–51 % acid detergent fiber (principally; arabinose, rhamnose, galactose, and glucose), and 65–69 % neutral detergent fiber (principally; mannose, glucose, arabinose, and rhamnose). The high content of neutral detergent fiber indicates the presence of a large amount of lignin probably some resistant starch. Mrabet *et al*. (2012) quantified between 19.6 and 25.4 % lignin in date seeds from different Tunisian varieties, although, Bouaziz *et al*. (2010), recorded a higher value of neutral detergent fibers (70 %). DSF contains a high percentage of cellulose and hemicelluloses. In the case of Tunisian varieties, the cellulose content is 17.0–20.5 % while that of hemicelluloses is 10.8–20.5 % (Mrabet *et al*., 2015). Indeed, different hemicellulose fractions have been identified in date seeds (gluco-mannans and galacto-mannans and heteroxylan). Ishrud *et al*. (2001) described one such galactomannan (from the seeds of Libyan dates) showed that hydrolysis to glucomannan gave mannose, glucose, arabinose, and galactose. Besbes *et al*. (2004), concluded that date seed contain higher amount of DF compared to date flesh. Date seed fiber is a particularly good candidate for consideration as a DF enriched food product due to its nutritional properties as well as the optimization of a generally discarded component of dates.

3. Functional Properties and Antioxidant Activity of the DF of Date Palm Fruit

Besides their important nutritional properties, DF of date palm fruit has very interesting functional and technological properties, such as water-holding capacity (WHC) and oil-holding capacity (OHC).

3.1. Water and oil holding capacity (WHC and OHC) WHC is a property that refers to the ability to retain water within a porous matrix, and is a property related to the chemical and physical structure of polysaccharides (Kethireddipalli *et al*., 2002). The ability to trap water by adsorption and absorption phenomena is an important characteristic of fibers from both physiological and technological point of view. Some water is also retained outside the fiber matrix (free water) (Sanchez *et al*., 2011). Thus, fiber with strong hydration properties could increase stool weight, slow nutrient absorption from the intestine and facilitate waste removal from the gut. Many methods have been used to estimate the WHC, which is expressed as the amount of water that is retained by one gram of dry fiber under specific conditions; however, several drawbacks of these methods have been demonstrated. The most efficient method to date is the one described by Jiménez *et al*. (2000). In this protocol, samples are suspended for 24 h and then the suspension is centrifuged and the hydrated fibers weighed.

The proportion of IDF and SDF, the particle size, the drying method the plant sources and the drying temperature all affect the WHC of DF of date. Indeed, Borchani *et al*. (2012) studied the influence of drying temperatures (40℃, 50℃, 60℃) on the hydration properties of date fiber. The results showed that the WHC decreases with increased drying temperatures (drying temperature affects the structure and functional properties of the fiber). The same authors also observed a higher WHC in freeze-dried date fiber concentrate (6.3 g water/g dry fiber) extracted from different date varieties in comparison to sun and oven drying method (3.5 and 4 g water/g dry fiber respectively) (Borchani *et al*., 2011a). In contrast, Monsoor (2005), reported that various drying methods (freeze drying, spray drying and vacuum drying), had very little or no effect on the WHC of soy hull.

Numerous studies have focused on the WHC content of DF from date flesh. Borchani *et al*. (2010) found that the WHC contents of DF from 11 Tunisian varieties ranged between 3.97 and 6.20 g/g dry fiber, and the best holding capacity was found in dates of the Alligh variety. Elleuch *et al*. (2008) recorded the highest value of WHC of DF from date flesh in Tunisian varieties (Table 1). similar results were obtained by Jasim *et al*. (2012) in Kuwaiti varieties.

DF derived from date flesh has high WHC values in comparison with DF from other agricultural by-products (Femenia *et al*., 1997; Gan and Latiff, 2011). These proprieties show that this material can be used as a functional ingredient to avoid syneresis, modify the viscosity and texture of some formulated food, reduce calories in food formulations, stabilize high fat food and emulsions and improve shelf-life (Lario *et al*., 2004; Elleuch *et al*., 2008).

The WHC of fiber extracted from date seeds was also evaluated for the Tunisian date palm (Bouaziz *et al*., 2011) (Table 1). However, studies of the WHC of DF extracted from date seed are limited.

The OHC is also an important property. OHC is determined by the amount of oil retained by fibers after incubation with oil and centrifugation (Elleuch *et al*., 2008). It is, related mainly to the composition and structure of the absorbent components of DF (chemical and physical structure of polysaccharides), their surface properties (the lower the particle size, the higher the OHC), porosity, and drying (dehydration promotes a general decrease in fiber OHC) (Lopez *et al*., 1996; Femenia *et al*., 1997). Elleuch *et al*. (2008), found that DF from date flesh in Tunisian varieties has a high OHC value. In fact, date fibers possess a higher capacity to hold oil in comparison with the fiber of other fruits (Elleuch *et al*., 2008), such as apples and orange (0.60–1.81 g oil/g fiber, respectively) (Figuerola *et al*., 2005). Thus, the use of date DF may be appropriate in products that require emulsifying properties. Borchani *et al*. (2012), studied the influence of drying temperatures (40℃, 50℃, 60℃) on the OHC of date fiber, and the results showed that high drying temperature didn't affect the OHC of date fiber. Similar results were obtained by Lou *et al*. (2009) who reported that high drying temperatures had very little or no effect on the OHC of burdock root.

In another study, Bouaziz *et al*. (2011) studied the OHC of DSF from Tunisian varieties. The seed OHC varied between 5 and 6 g of oil/g of the sample (Table 1). In general, fibers with a high OHC allows the stabilization of foods with a high-fat content as well as flavor preservation and food product yield (especially meat products).

3.2. Antioxidant activity Nowadays, natural antioxidants have an important place in the food industry as consumers seek to avoid synthetic food additives, but also increasingly demand foods containing these bioactive ingredients due to their proven role in protecting against illnesses like cancer and cardiovascular disease. Many antioxidant extracts obtained from natural sources like fruits and agro-industrial wastes have been studied to establish their potential antioxidant activity. In some cases, the extraction of these components helps to revalorize wastes or even secondary cultivars that are at risk of disappearing. Fruits are a promising source of antioxidant compounds, mainly phenols, associated with DF. This is the characteristic that could ultimately promote the use of fruit and their corresponding fibers as antioxidant fibers in the market of healthy ingredients for functional food formulations. DFs are promising dietary supplements for gastrointestinal health and the mitigation of chronic disease risk factors, and can be used as functional ingredients to prevent lipid peroxidation of food products. Antioxidant dietary fiber is a specific type of fiber with exceptional antioxidant capacity, which combines the physiological effects of both DF and natural antioxidants in a single material (Saura-Calixto, 1998).

Antioxidant activities are mainly caused by polyphenols, compound abundant in our diet. The majority of polyphenols are linked to the cell wall and/or indigestible compounds of plant foods, providing DF with antioxidant, and other biological properties. Date fruits are known to contain high levels and a wide range of phenolic antioxidants. The total antioxidant activity of dates was found to be higher than other fruits, such as berries well-known for being rich in antioxidants including elderberry and bilberry (Ou *et al*., 2001). In fact, date fruits were found to have the second highest antioxidant activity among 28 fruits commonly consumed in China (Guo *et al*., 2003). Phenolic compounds of dates, as either soluble or linked to fiber with considerable variations between varieties (Mrabet *et al*., 2012). The phenolic acids in date fruits include derivatives of benzoic acid (gallic, protocatechuic, p-hydroxybenzoic, vanillic, sinapic and syringic acids) and cinnamic acid (caffeic, hydrocaffeic, ferulic, p-coumaric and syringic acids), with ferulic acid as the major phenolic acid.

Date seeds contain very high levels of phenolic antioxidants (3100–4400 mg gallic acid equivalents/100 g) giving 580–930 µM trolox equivalents antioxidant activity (TEAC) (Larrauri *et al*., 1995). Thus date DF is considered a good source of natural antioxidants due to its richness in phenolic compounds. Indeed, the studies carried by Mrabet *et al*. (2015) on date DF concentrate indicated the presence of significant amount of bound phenolics in dietary fiber, which adds additional health benefits to the antioxidant properties of date. These results suggested that date DF concentrate may not only be an excellent source of DF but a suitable ingredient in the formulation of fiber and antioxidant enriched foods.

4. By-products of Date Processing

The date palm fruit process is accompanied by a loss of dates which could be a considerable by-product (Sánchez-Zapata *et al*., 2011). In Tunisia non commercialized varieties, commonly named ‘‘date by-products”, constitute about 30 000 tones/year, and can reach around 30 % of the whole production. Owing to their important nutritional composition, some attempts have been carried out to develop new products with high added-value, such as date pastes for different uses (e.g. bakery and confectionary) and date juice concentrates (spreads, syrup and liquid sugar). They could also be used as substrates for fermented products.

Date paste is obtained by the steaming of pitted and macerated dates and converted into a semi-solid form with 20 to 23 % of moisture and low water activity (Ahmed *et al*., 2005). These characteristics allow date paste to be used in many food industries as a sugar substitute (Alhamdan and Hassan, 1999). Date paste has a potential application as a functional ingredient in meat products. The addition of up to 15 % date paste in the formulation of bologna-type products led to the enhancement of the nutritional quality (Manickavasagan *et al*., 2012). In addition, date syrup is one of the most common date fruit derivatives. It is used as a sweetening agent, with a characteristic flavor of mature date fruit, to substitute malt syrup, molasses, glucose syrup, invert sugar, high fructose syrup, and all forms of crystalline sugars. Date syrup has been also used to replace sucrose in yellow and chocolate-flavored layer cakes.

Powdered date seeds are used by some rural communities as coffee substitutes and coffee-like preparations made from date seeds are commonly available in some Arabian markets in the Kingdom of Saudi Arabia (KSA) and United Arab Emirates (UAE). In addition, the chemical modifications of date seeds have been practiced, yielding many products such as polyols. This product is obtained after date seeds oxypropylation and liquefaction in organic solvents with catalyzation (Briones *et al*., 2011). Nevertheless, date seeds have a high potential for many other functions, since they show antimicrobial and antioxidant activity (Perveen *et al*., 2012).

5. Methods of Pretreatments

Pretreatment is a general term describing several different physical, chemical or biological processes that prepare biomass for subsequent enzymatic hydrolysis to improve fiber yields. They consist of disrupting or removing lignin, removing hemicellulose, and disrupting the crystalline structure of cellulose (Mosier *et al*., 2005).

We give a brief summary of some different pretreatment technologies (Table 3). Not all of these technologies have been applied to date palm fruits; however, applying them could open up an important research direction.

Biological pretreatments These methods cause the partial degradation of lignin by using microorganisms such as fungi and bacteria (Ghosh and Syngh, 1993), The process is very slow and is only economically viable through its combined use with other physical and/or chemical methods.

Physical pretreatments Milling and microwave irradiation have been used to facilitate the hydrolysis of lignocellulosic material as they cause a decrease in crystallinity and the degree of polymerization of cellulose (Zhu *et al*., 2006, Furcht and Silla, 1990).

Chemical pretreatments Hemicelluloses and lignin must be solubilized to expose the cellulose to acid and/or enzymatic hydrolysis. This pretreatment can be carried out with acid at room temperature, which solubilizes hemicelluloses and makes cellulose more accessible. The use of oxidative species, such as hydrogen peroxide, facilitates the removal of lignin and hemicellulose and increases cellulose accessibility (Liu and Wyman, 2003).

Pretreatment with eutectic solvents Deep eutectic solvents are a new class of ionic solvents, which are formed of a mixture of an ammonium salt with a hydrogen bond donor

Table 3. Pretreatments methods

Methods' type	Characteristic	References
Biological pretreatments	Partial degradation of lignin by using microorganisms such as fungi and bacteria.	Ghosh & Syngh, 1993,
Physical pretreatments	Decrease in crystallinity and the degree of polymerization of cellulose	Zhu *et al*. 2006, Furcht & Silla, 1990.
Chemical pretreatments	Solubilizes hemicelluloses and makes cellulose more accessible and facilitates the removal of lignin	Liu & Wyman, 2003
Eutectic solvents	Application profitable in industry processes, currently being employed for the pretreatment of lignocellulosic materials, able to separate lignin and hemicellulose from cellulose.	Paul-Domínguez, 2014).
Physicochemical pretreatments	It is based on steam treatment. It is a frequent method to fractionate the biomass and to assist in delignification and release of sugars trapped in the lignin-hemicellulose network and frail the lignocellulosic part which facilitate the enzyme accessibility.	Fernández-Bolaños *et al*., 2001

(HBD). In these solvents, the anion interacts with the HBD, inducing a decrease in the melting point of the mixture to a temperature close to room temperature, but retaining the same properties of ionic solvents such as low volatility, high thermal stability and high polarity. Their main advantages are their low cost, and the fact that they are considered "green solvents", which can make their application profitable in industry processes. Eutetic solvents are currently being employed for the pretreatment of lignocellulosic materials, because they are able to separate lignin and hemicellulose from cellulose (Paul-Domínguez, 2014).

Physicochemical pretreatments The most commonly used methods are thermal pretreatment with steam and pretreatments with explosive decompression, "steam explosion" (Rodríguez-Gutiérrez *et al*., 2012). These processes combine chemical and physical effects on lignocellulosic materials to fractionate the biomass and assist in delignification and release of sugars trapped in the lignin-hemicellulose network, which facilitate enzyme accessibility. Physical modifications are the result of rapid depressurization, causing a breakdown in the weakest lignocellulosic regions (amorphous cellulose) and the separation of cellulose fibers, which reduces the particle size. The disruption of fibrils increases the accessibility of the cellulose to enzymes during hydrolysis (Ballesteros *et al*., 2002). Chemical modifications separate the cellulose from matrix polymers and make it more accessible to enzymatic hydrolysis (Fig. 1).

Steam explosion pretreatment requires two steps in order to create an optimum cellulose fraction during hydrolysis: the first is done at a high temperature (up to 180℃) in order to solubilize and remove the hemicelluloses, and the second occurs at high pressure with temperatures up to 210℃ (not exceeding 240℃) to break carbohydrate linkages in the cellulose fraction. For example, this method can be applied to a variety of plant biomass types. This pretreatment is applied to increase the susceptibility of olive pit cellulose to enzymatic attack and to increase the solubility of hemicelluloses (Fernandez-Bolaños *et al*., 2001) in order to recover phenolic compounds of interest by solubilization, and to recover lignin and cellulose that become part of the soluble fraction (Fernandez-Bolaños *et al*., 2001). Despite the advantages that steam explosion pretreatment provides, this pretreatment methods was further developed (Fernández-Bolaños *et al*., 2011). The new method is also based on steam treatment, but without explosive decompression, working at lower pressures and temperatures (9 kg/cm^2 and 140–180℃) for longer periods of time (15–90 min). Thus, the treatment conditions and the contact of steam with the sample are improved, avoiding the technical complications and the high costs of steam explosion treatment.

Recently, both pretreatments have been applied to Tunisian date varieties that are not profitable for human consumption (Mrabet *et al*., 2015). Steam treatment of these secondary date varieties under the optimized conditions could be an interesting alternative for date growers, because this technology can be easily applied. The authors showed that the date DF obtained has a similar chemical composition and functional characteristics to that obtained by steam explosion treatment, and could be a valuable ingredient for the formulation of healthier foods (fiber- or antioxidant-enriched). The products have a balanced nutritional composition (around 6 % fat, 10 % protein and 70–80 % dietary fiber). Additionally, this DF has very high antioxidant activity (230–580 mmol Trolox/kg DF), similar to the highest antioxidant agricultural by-products, i.e. citrus by-products and Manto Negro red grape pomace (Marín *et al*., 2007). The pleasant chocolate/coffee flavor of the solids is another positive characteristic for their use in food formulations, especially in dairy or bakery products.

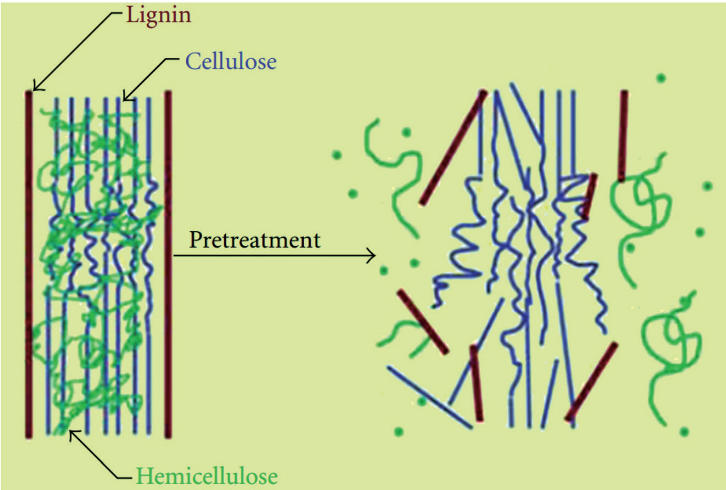

Fig. 1. Schematic representation of the effect of physicochemical pretreatments (steam explosion) on lignocellulose materials (Mosier *et al*., 2005).

6. Applications of Date Fruit DF as an Ingredient in Food Products

Considering the fiber content in date flesh as well as in date seed, it can be concluded that dates are a good candidate for use in value-added applications. The chemical composition and functional properties of date fiber means to would be an excellent ingredient in the food industry. Nowadays, an increased daily intake of fiber is recommended. The literature contains many reports regarding the addition of date DF to food products such as baked goods, beverages, confectionary, dairy, meat and pasta (Elleuch *et al*., 2008; Bourcheni *et al*., 2011b; Mrabet *et al*., 2016). In this section, we will attempt to summarize the investigations done on date DF and its use in food products and dietetic formulations.

Addition of date DF in beef burger formulations did not affect the sensory properties of the meat, whereas it led to, a decrease in the ash content and an increase in the WHC of the burgers (Besbes *et al*., 2010). This was because the added DF decreased cooking loss due to its ability to maintain moisture and fat in the food medium. The same effect was observed when lemon albedo fibers, wheat fibers and hazelnut pellicles were incorporated into beef burger formulations (Aleson-Carbonell *et al*., 2005; Mansour and Khalil, 1997).

In another study, Borchani *et al*. (2011b), incorporated date DF into baked products and analyzed (discussed the performance of DF on bread quality). The authors concluded that the addition of date DF increased the water absorption of the dough. They also noted an increase in dough stability, the yield of bread and the quality index without any modification to softening. This was explained by the interactions between DF, water and flour protein. Moreover, the fortification of wheat flours with steam extracted date DF in the formulation of muffins was studied (Mrabet *et al*., 2016). This enrichment led to dough with a higher baking yield than the control. Although the date muffin volume decreased and its density increased, this did not imply higher values in the instrumental texture parameters. The fortified muffins also showed good acceptability by untrained panelists, similar to that of the control. From the nutritional and functional points of view, the addition of date DF was very interesting because, besides the increase in DF content, the antioxidant activity tested by two in vitro assays was much higher than that of the unfortified muffins, which would help delay muffin rancidity.

Date seeds can be used as an enrichment agent due to their high nutritional value. The rheological proprieties of dough with date seeds' DF incorporated are similar to those of dough, containing wheat bran, but the bread containing the date fine fiber core had a higher DF content than the wheat bran controls (Almana and Mahmoud, 1994). In addition, Al-Farsi and Lee (2014) enriched date paste with seed powder. This enrichment led to an increase in the moisture content of date paste. This increase in the moisture content was mainly due to the high content of DF in the seed powder, which has the ability to hold a higher content of water. The fortified paste also showed higher levels of DF and antioxidant activity, than the unfortified paste. Hence, these agricultural wastes could be successfully used in baked products to improve for their functional and nutritional properties.

These results support the use of secondary date varieties (flesh and seed) as a valuable source of antioxidant dietary fiber and provide important support for their valorization.

7. Conclusion

Date fruits are widely produced and represented rich sources of sugar, fiber and phenolic antioxidants that can function as natural therapeutic agents. The data presented in this review show that the fiber content in date flesh as well as in date seed can serve as an important food ingredient and can play a major role in improving human health and nutrition. Compared to other fruits, dates can be regarded as valuable functional foods due to their DF constituents. For this reason, the employment of the new processing technologies (e.g., steam explosion) of the whole date fruit (flesh and seed) would be necessary, in order to improve the physicochemical composition, functional properties, and to decrease the IDF/SDF ratio for their subsequent use in food products.

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