International Journal of Applied Biochemistry and Molecular Biology (IJABMB)

Doum Palm (Phoenix dactylifera L.) trees in Saudi Arabia

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Running Title: ***Phoenix dactylifera L*****. trees in Saudi Arabia**

Abstract

Saudi Arabia is the world's top producer of dates, and the country's climate and natural surroundings make it a perfect place to grow palm trees. In several verses, the Holy Qur'an also highlights the value of palm trees and their fruits, emphasizing their importance in human life. One species of flowering plant belonging to the Arecaceae family is the *Phoenix dactylifera* (*P. dactylifera*). It is widely grown and yields dates, which are edible fruits that can be consumed fresh or dried. For thousands of years, the *P. dactylifera* has been cultivated and used as a staple meal in many cultures. In addition to other vitamins and minerals, the fruit is high in fiber, calcium, magnesium, potassium, and antioxidants. P. dactylifera is still growing extensively and is a significant crop in many places, especially in North Africa and the Middle East. Many parts of the tree are still employed for a variety of functions, and the fruits are transported to other countries and consumed domestically. For ages, palm trees—especially date palms, P. dactylifera—have played an important role in Middle Eastern and North African agriculture and are an excellent supplier of vitamins. However, these trees' traditional usage has diminished, resulting in significant waste upon harvest. The bioactive substances found in *P. dactylifera* were the focus of this review.

1. Introduction

Saudi Arabia is the world's top producer of dates, and the country's climate and natural features make it a perfect place to grow palm palms (1). The value of palm trees plus their fruits in human life is also highlighted in the Holy Qur'an, which refers to them in several verses (2). Due to their abundant mineral and vitamin content vital for bodily functions, date fruits are renowned for being highly nutritious (3). Among other minerals, date fruits are rich in fiber, magnesium, calcium, potassium, and antioxidants (4). They have been linked to several health advantages, including better digestion, decreased inflammation, and a decreased chance of developing chronic illnesses (5,6).

In Saudi Arabia, dates hold cultural and social value in addition to being a staple food (7). They play a significant role in religious ceremonies and celebrations, and they are frequently used in traditional cuisine (8). A particular type of flowering plant belonging to the Aceraceae family is *P. dactylifera*. Dates are edible fruits, which are eaten both fresh and dried, and it is widely grown (9, 10). For thousands of years, the *P. dactylifera* has been cultivated and used as a staple meal in many cultures (11). Alongside other vitamins and minerals, the fruit is high in fiber, calcium, magnesium, potassium, and antioxidants (12).

P. dactylifera is still growing extensively and is a significant crop in many places, especially in North Africa and the Middle East (13). The many parts of the tree are still employed for various functions, and the fruits are transported to other countries and consumed domestically (14). For ages, palm trees—especially date palms, *P. dactylifera*—have played an important role in Middle Eastern and North African agriculture and are an excellent supplier of vitamins (15). However, these trees' traditional usage has diminished, resulting in significant waste upon harvest (16).

It is clear from a thorough analysis of the *P. dactylifera* value chain in the Arab world that this region contributes significantly to the production of this prestigious crop worldwide. The vast majority among the world's *P. dactylifera* production occurs in the Arab world, which covers an area of around 1.35 million hectares, according to the United Nations Food and Agricultural Organization (17). This enormous contribution amounts to an astounding 75% or more of the total production of *P. dactyliferas* worldwide, highlighting the critical role the Arab world plays in satisfying the demand for this delicious fruit worldwide.

The growth in the area under cultivation for *P. dactylifera* farming is the most significant element contributing to the increased production levels observed in recent years. This upward trend in production has seen an impressive average annual growth rate of 4%, highlighting the Arab region's persistent efforts and commitment to satisfying the growing demand for P. *dactyliferas* worldwide.

Because of this, the Arab world now accounts for over two-thirds of the world's *P. dactyliferas* exports, making it a major player in the worldwide market. It should be noted that, according to the FAO's 2023 predictions, India and the Islamic nations are the primary recipients of *P. dactyliferas* from the Arabian countries (17).

One of these trees' principal products, the fruit of *P. dactylifera*, is mostly made up of carbohydrates and fiber and has a variety of potential uses (18). Although *P. dactylifera* being a significant source of food and revenue in the area, it suffers difficulties such pests and low yields (19). Utilizing *P. dactylifera* processed fruit wastes and by-products to create biofuels, biological polymers, and additionally industrial chemicals is one way to try to solve these issues (20, 21). Although the *P. dactylifera* industry in Saudi Arabia has experienced substantial growth, issues with planting, processing, and marketing still exist (22). Research is also being done on the use of additional palm products, like pruning waste from *P. dactylifera*, to produce compost (23).

Most palm debris is typically disposed of in landfills, burnt in boilers to produce steam, or composted (24). However, because of the greenhouse gas emissions that they produce, these solutions are not environmentally benign.

As a result, scientists have been looking at different applications for *P. dactylifera* waste, such as employing the tree's parts as feedstocks to make biofuels and biochar or as precursors to creating active sorbents like carbon (25).

For trash from palm oil mills, Poh et al. (2020) (26) stress the value of environmentally friendly waste management techniques like composting. Hussain et al., 2020 (12) and Mrabet et al., 2019 (27) address the overview of *P. dactylifera* and the preparation and use of the fruits for food purposes, respectively. Wood and wood-derived goods have been a significant substitute for synthetic materials like glass and carbon in recent years (28).

The furniture, automobile industries, and construction are just a few of the industries that use natural fiber extensively (29). The difficulties and possible remedies for *P. dactylifera* degrading and the use of oil palm waste via thermochemical conversion, particularly liquefaction, are discussed by Karkach et al., (2023) (30). An alternate source which has been utilized in place of wood resources is palm trash (31). The potential of *P. dactylifera* waste for engineering applications and the creation of biofuels, biological polymers, and other industrial chemicals is highlighted by Faiad et al. (2022) (15) and Chandrasekaran & Bahkali (2013) (20). The fronds and leaflets of *P. dactylifera* are very common in the Persian Gulf region, which includes Saudi Arabia and Iran, and additionally other nations like Iraq (32).

The Food and Agricultural Organization, better known as the FAO, estimates that there are roughly 105 million *P. dactylifera* worldwide, with most of them found in the Middle East (13).

Large volumes of residues remain on the agricultural grounds following the palm harvest season. Utilizing these wastes can give different companies an environmentally sound source of substitute resources (33).

2.2. Historical Of Date Palm

Because of its substantial nutritional and socioeconomic significance, date palms (*P. dactylifera*) are a fruit tree plant that is commonly grown in severely dry and semi-arid countries (34). With an annual yield of 1.1 million tons, Saudi Arabia's *P. dactylifera* cultivation makes a substantial contribution to the production of *P. dactylifera* worldwide (35). Only a small portion of the manufacturing is sold outside the nation, which presents marketing and exporting issues (36). Higher-value goods such liquid phenolic compounds and activated carbon can be made from the waste from *P. dactylifera* growing (15). Insect pest infestations, soil erosion, and water scarcity also have an impact on the nation's *P. dactylifera* industry (37, 38).

Saudi Arabian *P. dactyliferas* has potential in the worldwide market despite these obstacles, as evidenced by its strengths in several importing nations (39, 40). Fast pyrolysis of P. *dactylifera* garbage is a feasible method for producing biofuel, with possible financial gains and lower emissions of carbon dioxide (41). Around 450 distinct *P.dactylifera* cultivars have been grown in Saudi Arabia's various locations. *P.dactylifera* production and cultivation are vital to the nation's economy and cultural traditions (42).

Mesh fibers, leaves, bunches, rachis, and petioles are among the parts of *P.dactylifera* that have been studied as promising fibers for use in building materials and construction (43).

Because of their inexpensiveness, high availability, and favorable mechanical qualities, these fibers have demonstrated promise as sustainable and environmentally acceptable substitutes for conventional building materials (44). Fibers from *P.dactylifera* have been utilized as insulation, reinforcement in mortar and concrete, and as a timber alternative in lightweight building projects (45). In the regions of the Middle East or northern Africa, P.dactylifera is an essential crop. However, a lack of funding and difficulties with lengthy generation times have hindered genetic research (46). With the creation of a draft genome and the discovery of gender-linked regions, recent developments in *P.dactylifera* genetics have overcome these constraints (47). Genetic variation and the domesticated history of *P.dactylifera* have also been uncovered by studies (48).

The creation of the first chromosomal map of *P. dactylifera* offers comparative genomics and biotechnology as a useful tool (49). Moreover, varietal development and genetic research have been made easier by the discovery of gene-based markers (50). These developments have made it possible to research *P. dactylifera's* resistance to abiotic stress and to improve certain crops (11). However, the application of a sequential reading approach has produced a fine-tuned genome sequence for *P.dactylifera* that is substantially larger and more contiguous than the initial reference genome in the assemblies that were produced using short-read sequencing methods (51). Because of this, scientists have been able to map the entire genome of *P. dactylifera* and find the genes that determine sex, fruit color polymorphism, as well as sugar levels (52). They discovered that evolution coherence in homologous genes across different species drives important domestication and diversification features in *P. dactylifera* (53). It has been discovered that the root cause of the variation in fruit color, not solely in *P. dactylifera* but in other perennial crops from various plant families, including grapes, apples, cacaos, citrus, and more, is mutations in a specific gene that codes for an R2R3-MYB transcription factor. The importance of this gene in domesticated fruit crops has been clarified by this discovery, which highlights its critical function in parallel evolution (47).

Additionally, it has been shown that the sugar content of tomatoes and grapes is directly impacted by the naturally occurring variation of invertase, the enzyme that promotes the breaking down of sugars. This discovery supports the idea that invertase was crucial to the concurrent evolution of domesticated fruit crops (47). The idea that phenotypic alignment and parallelism is a unique feature of crop domestication is thus supported by these findings taken together, highlighting the possibility of conducting a thorough comparative study of genetic architectures throughout the whole range of domesticated taxa. By revealing similarities in the evolutionary paths of various domesticated crops, such a study should help us better understand their shared mechanisms of genetics (47).

Figure 1: Photographs of *P. dactylifera* tree , (by Abrar Alsabi)

2.2.1. *P. dactylifera*

For a good reason, P. dactylifera is referred to as the "tree of life" in many civilizations. Its fruit, seeds, leaves, and stems can all be used in various ways to create a variety of goods (31). For instance, the trunks can be used to build roofs, fences, and other buildings, while the leaves can be woven into mats, baskets, and other domestic items (54). The seeds can be crushed to extract oil or ground into flour, and the fruit can be consumed or processed into a variety of food products (55). In addition to being a historical relic, the technical legacy connected to the use of *P. dactylifera* byproducts serves as a source of inspiration for the creation of novel methods and goods (56).

Building on this legacy, we can find novel, effective, and sustainable uses for *P. dactylifera* byproducts (54). The application of *P. dactylifera* fibers as a source of biofuels and as reinforcement in composites is being investigated by researchers (57). Additional possible uses include using *P. dactylifera* leaves as a base material for papermaking and using the seeds as an antioxidant source (58). Using *P. dactylifera* by-products has significant cultural advantages in addition to environmental ones (31). Many communities' cultural traditions heavily rely on the use of these resources, and conserving this legacy can support social cohesiveness and cultural identity (7).

2.2.2. Botanical Classification of The *P. dactylifera* Table (1)

Table (1): Classification Date palm **(59)**

Kingdom	**Plantae**
Phylum	Streptophyta
Class	Angiospermae
Subclass	Monocotayledonae
Order	Palmalea
Family	Arecaceae (Palmae)
Genus	*Phoenix*
Species	*Phoenix dactylifera*

2.2.3. Geographical Distribution of *P. dactylifera*

Along with the Atlantic islands and Africa, the Middle East, the Caribbean, India, Hong Kong, the islands of Taiwan, the Philippines, Malaysia, Indonesia, Sumatra, and Malaya are home to fourteen distinct species. One huge, commercialized plant that is frequently planted as an ornamental is *P. dactylifera* (Fig. 2). It is a fruit plant that grows in semi-arid areas as well. Most species grow near water courses, oases, or underground water sources in semi-arid areas; however, some can be observed in tropical monsoonal areas (60). Flavonoids, phenolic molecules, and tannins are among the phenolic chemicals that have been discovered to be abundant in date palm fruits (61). Numerous health advantages, including antibacterial, anti-inflammatory, and antioxidant qualities, have been linked to these substances (62). Furthermore, it has been reported that date palm fruits exhibit strong anticancer effects on cells of breast cancer, and an abundance of phenolic chemicals may be the mechanism behind this effect (63).

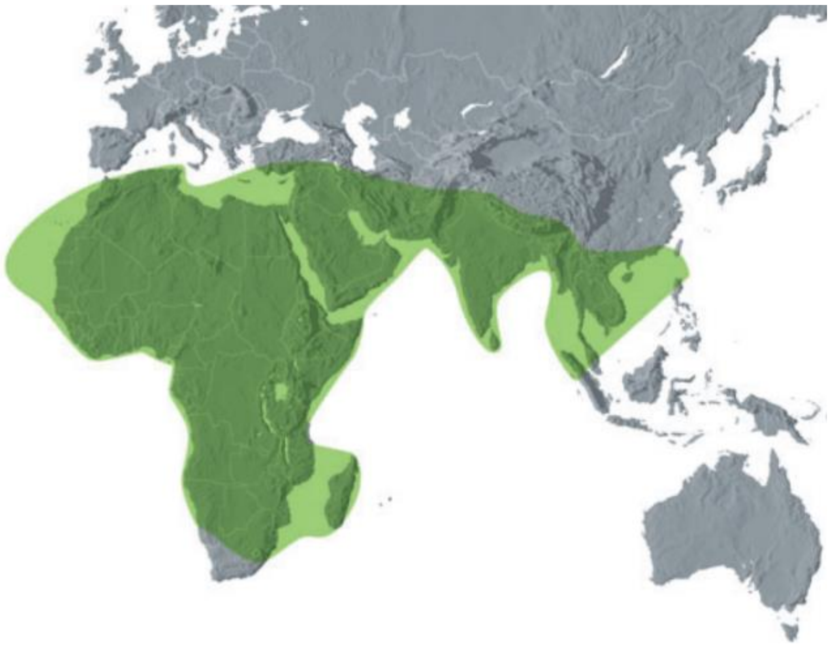

Figure 2: Distribution of *P. dactylifera* **(60)**.

2.4. Bioactive Compounds of the P. dactylifera trees

2.4.1 Cellulose

George (2021) (64) examined the amount of cellulose in various *P. dactylifera* tree parts and discovered that it differed based on the tissues' age and location. Cellulose biosynthesis is a complicated process that requires the cooperation of several enzymes and regulatory elements (65). According to a study by Alam et al. (2023) (66), environmental conditions and developmental phases controlled the expression of the genes responsible for cellulose production in *P. dactylifera* fruit. The use of cellulose of *P. dactylifera* serves distinct purposes. The outcome demonstrated the high output and purity of *P. dactylifera* cellulose and its potential for bacterial cellulose production (67). Applications for cellulose-based nanocomposites could be found in several domains, including environmental engineering, biomedicine, and packaging. The synthesis and characteristics of *P. dactylifera* cellulose-based nanotechnology using nanocellulose were examined by Revin et al., (2022) (68). Their mechanical durability and thermal stability were found to be high (69).

2.4.2 Hemicellulose

The amount of hemicellulose of various *P. dactylifera* tree parts was examined by Djoudi et al., (2021) (70), who discovered that it varied based on the tissues' age and location.

The chemical makeup and configuration of hemicellulose within *P. dactylifera* fiber were examined by Noorbakhsh & Khorasgani (2022) (72) who discovered that it was made up of galacturonic acid, arabinose, and xylose. A possible origin of value-added goods for several industries, including food, medicines, and bioenergy, is hemicellulose (72). The ability of *P. dactylifera* hemicellulose to generate prebiotic oligosaccharides was examined by Alyileili et al. (2020) (73) who discovered that it exhibited both high yield and prebiotic activity. Films made on hemicellulose may find use in several industries, including environmental engineering, biomedicine, or packaging (74).

The manufacture and characteristics of *P. dactylifera* hemicellulose-based film with chitosan were examined by Testa and Tummino (2021) (75), who discovered that they have strong mechanical properties and water vapor barrier qualities. Numerous enzymes and transcription elements control the intricate route involved in the manufacture of hemicellulose in plants (76). The genes' expression responsible for hemicellulose synthesis in *P. dactylifera* was examined by Mohamed et al. (2021) (77), who discovered that these genes were regulated by the phases of development and environmental variables. Hydrogels based on hemicellulose may be used in several areas, including wound healing, tissue engineering, and medication administration (78).

The development and characteristics of *P. dactylifera* hemicellulose-based hydrogels using carboxymethyl cellulose were examined by Barhoum et al. (2020) (79), who discovered that they were highly biocompatible and capable of absorbing water. Oligosaccharides produced from hemicellulose may be used in several industries, including food, medicine, and agriculture (80). The ability of *P. dactylifera's* hemicellulose to generate Xylo oligosaccharides was examined by Ataei et al. (2020) (81) who discovered that it exhibited significant yield and prebiotic action. Composites made on hemicellulose may be used in several industries, including construction, packaging, and automobiles (72). The manufacture and characteristics of *P. dactylifera's* hemicellulose-based composites with polyvinyl alcohol were examined by Benallel et al., (2023) (82). They discovered that these composites exhibited great mechanical strength and thermal stability.

2.4.3 Lignin

Latifa et al. (2019) (83) looked at the structural and chemical properties of lignin in *P. dactylifera* fronds. Athinarayanan et al. (2022) (84) discovered that the lignin of *P. dactylifera* was primarily made up of syringyl and guaiacol units, with a smaller percentage of p-hydroxyphenyl units. Coniferyl alcohol, sinapyl alcoholic beverages, and p-coumaric alcohol are the three primary monolignols that make up the lignin in *P. dactylifera* fronds, according to a study by George et al. (2020a) (61).

Apart from its antioxidant qualities, *P. dactylifera* lignin has prospective uses in several sectors, including construction materials, biofuels, and bioplastics (85). The possible use of lignin of *P. dactylifera* waste as a fuel to manufacture biofuels was examined in a study by Bharath et al. (2020) (86). They discovered that the lignin had an elevated energy content and might have been transformed into bio-oil with a high yield and quality.

2.5 Major Uses of the P. dactylifera Tree

In Saudi Arabia, palm trees—especially *P. dactylifera*—are an important crop that supports the agroecosystem (37). Imports of wood can be decreased by using its leftovers, such as the midrib of *P. dactylifera* leaves, in the uncommon wooden industry (87). *The P. dactylifera* tree itself has a variety of uses, including both medicinal and non-medicinal ones (88, 89), and its waste can be processed for possible engineering applications (15).

2.6. Pharmacological Properties

2.6.1. Antidiabetic Activity

It has been discovered that *P. dactylifera* fruits and pits possess several antimicrobial qualities, such as antiviral, antifungal, and antibacterial effects (12).

Because of these characteristics, they are a prospective source of natural antibacterial agents and their derivatives that can be utilized to combat bacteria that are resistant to antibiotics (90). Extracts from various *P. dactylifera* cultivars have been demonstrated in studies to suppress the growth of gram-positive plus gram- negative bacteria (91). It has also been discovered that *P. dactylifera* extracts work well antifungal like Fusarium oxysporum (92). It's interesting to note that *P. dactylifera* pit extracts were found to have antiviral qualities, despite the meat of the plant being thought to have antibacterial and antifungal qualities. They are therefore a viable candidate for *P. dactylifera* in the creation of novel antiviral drugs. *P. dactylifera* fruits and pits have a broad range of antibacterial action, which indicates that they may be a useful tool in protecting against microbial illnesses (12).

2.6.2. Anti-Inflammatory Activity

It is reported that oxidative stress contributes to the onset and advancement of chronic illnesses, such as heart disease (93). Because *P. dactylifera* has anti-inflammatory qualities, it can help lower the body's levels of cyclooxygenase (COX) enzymes and pro-inflammatory cytokines (94). These anti-inflammatory effects are believed to be caused by several compounds found in *P. dactylifera*, including quercetin, rutin, caffeine acidic substances, p-coumaric, and gallic acids (95). Additionally, research has demonstrated how *P. dactylifera* seeds extract (DSE) can eliminate free radicals from nitric oxide, stabilize lysosomal membranes, prevent protein denaturation, and prevent the synthesis of fibrinogen and C-reactive protein.

The reported anti-inflammatory benefits associated with *P. dactylifera* seeds are thought to be caused by these pathways (96).

2.6.3. Antimicrobial Activity

It has been discovered that *P. dactylifera* possesses antibacterial qualities and can penetrate bacterial cytoplasmic membranes (97). The growth of certain bacteria, such as Staphylococcus aureus with resistance to methicillin (MRSA), Proteus mirabilis, Escherichia coli, Klebsiella pneumonia, Pseudomonas aeruginosa, and Enterococcus faecalis, can be inhibited by *P. dactylifera* extract, according to studies (98). Furthermore, it has been discovered that *P. dactylifera* seeds have antiviral properties, as they can prevent Pseudomonas phage ATCC 14209-B1 from infecting P. aeruginosa (99). Pollen extracts from *P. dactylifera* were tested for their antibacterial efficacy against dangerous bacteria and fungi. According to the study, *P. dactylifera* pollen extracts have potent antibacterial properties that could increase its usage as a natural component in the production of antibiotics and antifungal drugs (100).

2.6.4. Anticancer Activity

Breast cancer is one of the most common types of cancer discovered in women and a major cause of cancer-related fatalities worldwide (101). Although there are several treatment options for breast cancer, such as radiation therapy and chemotherapy, these can sometimes be less effective and can have serious adverse effects (102).

The consequences of extract from three distinct *P. dactylifera's* types on MDA-MB-231 breast carcinoma cells were carefully investigated. The findings demonstrated that the extracts changed the shape of the cells with cancer and had lethal effects on them (103).

2.7. Chemical/Industrial Applications

It is crucial to remember that foliar fertilization is not a substitute for soil fertilizer. Basic nutrition for plants and increasing soil fertility still depend on fertilizing the soil with inorganic or organic fertilizers (104). According to studies, *P. dactylifera* may benefit from foliar fertilization to enhance plant development and boost yield in addition to compensating for shortages in certain elements (105). The physico-mechanical properties of fibers extracted from different parts of a *P. dactylifera* ripe palm, and the composite materials formed from these fibers varied noticeably, as reported by Djoudi et al., 2021 (70) results. Because of the complex structure of the palms and the extraction zone of the tested fiber, the results of X-ray diffraction analysis and the values of the modulus of elasticity and maximum stress obtained from the tensile test differ among fibers taken from different sections of the palm.

2.8. Food Industry Applications

According to a study, *P. dactylifera* fruit powder's excellent antioxidant properties, fiber content, and possible prebiotic effects may make it a useful addition for food items (106).

Each component of the palm, involving its seeds, fruits, pollen grains, and leaves, can be used in a variety of food industry applications, according to a research report by Salomón-Torres et al., 2021 (55) that suggests *P. dactylifera* fruit powder can be added to a variety of food products, including dairy products, beverages, and bakery goods. The findings indicated that *P. dactylifera* seeds are a source of bioactive chemicals. The bioactive compounds found in *P. dactylifera* seeds were examined, along with their possible uses in the food sector (107).

They discovered that *P. dactylifera* seeds have a variety of bioactive substances with potent antibacterial, anti-inflammatory, and antioxidant properties, including tannins, flavonoids, and phenolic acids (77). This implies that extracts from *P. dactylifera* seeds might be utilized as functional additives and natural preservatives in food items (108). They have been making food packaging materials out of *P. dactylifera* leaves. They discovered that *P. dactylifera* leaflets can be utilized to create packaging materials that are both compostable and biodegradable, and that have superior mechanical and barrier qualities (109). According to the study, P. dactylifera leaves may offer a sustainable substitute for artificial packaging substances in the food sector (110).

Using the sap of *P. dactylifera* as a natural food sweetener. *P. dactylifera* sap includes a variety of sugars, including glucose, fructose, and sucrose, which can be utilized as natural sweeteners in food products, according to a report of Sayas-Barberá et al., (2023) (111). This implies that *P. dactylifera* spa may one day replace artificial sweeteners in the food business. According to the study, *P. dactylifera* fibers have a high dietary fiber content, which can help with weight control, better digestion, and a lower chance of developing chronic illnesses. This implies that *P. dactylifera* fibers may be added to food products as a functional component to increase their nutritional content (112).

2.9. Polyphonic Compound in Palm Tree

The plant kingdom contains many secondary metabolites called polyphenolic chemicals, which have a variety of biological activities such as antibacterial, anti-inflammatory, and antioxidant qualities (113). Numerous polyphenolic chemicals, including phenolic acids, flavonoids, and tannins, are known to be present in palm trees, especially *P. dactylifera*. These substances primarily located in the palm tree's fruit, leaves, and bark, may be used in several sectors, such as food, medicine, and cosmetics. According to studies, the polyphenolic chemicals found in *P. dactylifera* fruit have potent anti-inflammatory and antioxidant qualities and may help prevent chronic illnesses like cancer, diabetes, and cardiovascular disease (12,114,115). Furthermore, studies have demonstrated the potential of polyphenolic chemicals derived from palm leaves as natural food preservatives and antimicrobials (100).

2.10. Phenolic Compounds and Their Classification

Phenolic chemicals are mostly found in *P. dactylifera* fruit that enhance the fruit's anti-inflammatory and antioxidant properties. Flavonoids, phenolic molecules, and tannins make up most of the phenolic chemicals found in *P. dactylifera's* fruit; the exact composition varies based on the cultivar and stage of ripening (115,116).

2.11. Major Phenolic Compound in The Palm Tree

P. dactyliferas contains phenolic acid (ferulic acid) which is abundant in palm trees (14, 117). Flavonoids are mostly found in *P. dactylifera* fruit, enhance the fruit's anti-inflammatory and antioxidant qualities. The cultivars, maturation stage, and processing techniques all affect the flavonoid content of *P. dactylifera* fruit. Numerous flavonoids, such as kaempferol, quercetin, apigenin, luteolin, and their glycosides have been found in P. *dactylifera* fruit in recent studies. These flavonoids have been linked to several health advantages, including a lower risk of cancer, cardiovascular disease, and neurodegenerative diseases (77, 115).

2.11.2 Tannins

The fruit of *P. dactylifera* mostly contains tannins giving it the astringent flavor and antioxidant qualities. Many tannins, such as ellagitannins, proanthocyanidins, and gallic acid derivatives are found in *P. dactylifera* fruit. These tannins have been linked to several health advantages, including a lower risk of obesity, cancer, and cardiovascular disease (115, 118). *P. dactylifera* fruit tannins have been utilized as natural antioxidants and coloring agents in food products (119, 120).

2.11.2.1 Condensed Tannins

According to a 2020 study that examined the condensed tannin levels in *P. dactylifera* fruits, these substances were present in significant concentrations and may offer potential health advantages (121). Condensed tannins' complicated structure and diversity make it difficult to determine their presence in plant materials (122).

2.11.2.2 Hydrolyzable Tannin Content

In comparison to condensed tannins, *P. dactylifera* fruits have lower amounts of hydrolyzable tannins, according to a 2023 study that examined their concentration (10).

2.11.3 Lignans

Several lignan types, such as pinoresinol diglucoside, secoisolariciresinol diglucoside, and lariciresinol diglucoside, have been found in *P. dactylifera* fruit in recent investigations. Potential health benefits of these lignans have been discovered, including a decreased risk of osteoporosis and breast cancer (123, 124). Furthermore, lignans from *P. dactylifera* have been shown in a recent study to have anti-inflammatory properties and may be employed as a naturally occurring anti-inflammatory agent (10).

2.12. Phenolic Antioxidants Properties and Their Action Mechanism

Flavonoids, phenolic acids, and tannins are among the phenolic compounds with antioxidant qualities found in *P. dactylifera* trees, according to studies (61, 125). According to research, these substances can prevent lipid peroxidation and scavenge free radicals, both of which can lead to oxidative injury and cell damage (126, 127).

2.13. Soluble And Insoluble Bound Phenolics Compounds

According to a study on *P. dactylifera* fruit, both insoluble and soluble bound phenolics made up the fruit's total phenolic content, with the insoluble bound phenolics accounting for the majority (95).

2.14. Natural Antioxidants

Natural antioxidants, such as phenolic substances including flavonoids, phenolic acids, and tannins, are abundant in P. dactylifera plants. It has been demonstrated that these antioxidants scavenging free radicals and guard against oxidative damage, which can lead to the onset of chronic illnesses (62, 128).

2.15. Dietary Fibers

Research has indicated that the dietary fibers found in *P. dactylifera* fruits may offer possible health advantages, such as better blood glucose regulation and digestive health. For instance, *P. dactylifera* fiber supplementation enhanced fecal production and decreased glycemic reaction to a meal in a study conducted on rats (129, 130). The potential of *P. dactylifera* dietary fibers as useful components in food items have been examined in recent studies. For instance, a study discovered that including *P. dactylifera* fiber into bread dough enhanced the bread's sensory qualities and fiber content (131).

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