International Journal of Applied Biochemistry and Molecular Biology (IJABMB)

Bioactive Compounds present in Doum Palm (*Hyphaene thebaica L.*) trees in Saudi Arabia

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Running Title: ***Hyphaene thebaica L.*** **Bioactive Compounds**

Abstract

The doum tree (*Hyphaene thebaica L.*) holds great historical and cultural significance in Saudi Arabia and its neighboring regions. Doum trees are also used in traditional medicine and are a component of the Kingdom of Saudi Arabia's diversified flora. Doum fruit also includes a variety of other chemicals, including flavonoids, glycosides, steroids, tannins, and saponins. Numerous pharmacological substances, flavonoids, hydroxyl cinnamates, coumarins, saponins, and essential oils are found in doum fruit. Compounds with anti-bacterial, anti-inflammatory, and anti-cancer properties are utilized in medicine to lower hypertension and hyperlipidemia.

Keywords

Doum trees, *Hyphaene thebaica L.*, Bioactive compounds.

1. Introduction

Doum palm and its scientific name: Hyphaene thebaica (*H.thebaica*), which is a type of *P.dactylifera* with oval fruit, and it is from the Arecaceae family (1). It is bilateral and of medium height, and the trunk is divided into two branches, and each branch is divided into two other branches. It grows in warm temperate regions—firewood, coal, textiles, etc. (2).

Consumption of doum fruit, like other whole fruits, is linked to a variety of health advantages. These include better gastrointestinal health, weight management, a lower risk of chronic diseases, and increased psychological well-being (3). The World Health Organization recommends consuming five to eight pieces of fruit and vegetables each day, with whole fruits being especially beneficial for health (4).

The doum tree has significant historical and cultural importance in Saudi Arabia and other regions in Saudi Arabia (5). The Dūmat al-Jandal oasis in Saudi Arabia, known for its doum trees, is a major pre-Islamic site (6). Furthermore, doum trees are part of the Kingdom of Saudi Arabia's diverse flora and are utilized in traditional medicine (7).

Doum fruit (*H.thebaica*) has been found to contain high levels of protein and amino acids, such as lysine and cysteine, in addition to fats and fiber. These nutrients make doum fruit a valuable source of nutrition (8, 9).

Doum fruit also contains several chemical compounds, including tannins, saponins, steroids, glycosides, and flavonoids. These compounds have been found to have various biological activities, including antioxidant, anti-inflammatory, and antimicrobial properties (10).

Flavonoids found in doum fruit, such as quercetin, kaempferol, and rutin, have been associated with their antioxidant and health-promoting properties (11). Tannins found in doum fruit have been found to have potential applications in the food and cosmetic industries as natural antioxidants and preservatives (12).

H. thebaica been found to contain polyphenols and phenolics (13) and the presence of these substances suggests that they may have potential as a source of natural antioxidants and other Health-promoting compounds (14, 15).

In doum palm *H.thebaica*, the leaves and fruits have been found to contain high levels of phenolic compounds and flavonoids, including quercetin, kaempferol, and rutin, which have been associated with their antioxidant and health-promoting properties **(**16, 17).

2. Historical of Doum Palm

The *H.thebaica* tree (Figure 1), also known as Doum palm is a highly useful plant with a wide range of applications (18). The *H.thebaica* palm is a versatile plant with various uses.

Its fiber and leaflets are traditionally used for basket weaving, while its fruits contain antioxidants and nutritional trace minerals (10, 19, 20). The tree's nuts are a good source of protein, amino acids, and essential minerals (21). *H.thebaica* flour, made from the tree's fruits, is rich in nutrients and functional compounds (21).

The plant's genetic diversity has been studied, and its potential for use in traditional medicine has been explored (13, 22). Seed priming methods have been developed to improve germination and seedling development (23).

In addition to its traditional uses, *H.thebaica* has also been studied for its potential health benefits. *H.thebaica* fruit in its powder form has been used as a source of fiber, stabilizer, and minerals in food products. Aqueous *H.thebaica* extracts have been found to increase the viability and activity of certain dairy starter cultures used in the manufacture of dairy products, especially probiotics (10).

The assessment of the genetic diversity among 12 *H.thebaica* landrace trees using both phenotypic and molecular analyses and the results from the phenotypic and molecular analyses gave different relationships among the tested landraces. However, when combined, they provided an excellent overview of the genetic diversity among the *H.thebaica* landraces. The information from this study is valuable for further studies on *H.thebaica* improvement and breeding approaches, as it provides a better understanding of the genetic diversity and relationships among different landraces (13).

Figure 1: Photographs of *H.thebaica* tree (by Abrar Alsabi)

2. 1. *H.thebaica*

H.thebaica is a significant plant in Saudi Arabia, with a wide distribution and various uses (10). It is also a versatile plant with a wide range of applications, making it a valuable resource in various industries and fields (24).

Its wood is used in construction work, while its leaves are used in crafts. The fruits of the *H.thebaica* are also used as food and in medicine. The plant's potential medicinal properties have been highlighted, with different parts of the plant found to have various health benefits (10). The *H.thebaica* is distributed throughout the Sahel region of Africa and some areas of the Arabian Peninsula, and its fruits are rich in nutrients and pharmacological compounds (19).

2.2. Botanical Classification of the H.thebaicav (Table 1)

Table (1): Classification Doum palm (25).

Kingdom	**Plant**
Phylum	Tracheophyta
Class	Equisetopsida
Subclass	Magnoliidae
Order	Arecales
Family	Arecaceae (Palmae)
Genus	*Hyphaene*
Species	*Hyphaene thebaica*

2.3. Geographical Distribution of *H.thebaica*

According to Figure 2, the genus *Hyphaene* is found in arid regions of Arabia, Madagascar, the Red Sea region, the Gulf of Eilat, and continental Africa.

Inland or coastal savannahs, sandy lowlands, and open secondary forests are ideal habitats for *Hyphaene* species, while some are also found in riverine forests. It has been discovered that the genus grows from sea level to 1400 meters. Possibly an invasive palm in Curaçao, West Indies, *H.thebaica*, well-suited to dry and xeric conditions, is located in 21, Additionally, the Red Sea region and the beaches of Arabia's Gulf of Eilat are home to the species (26).

Figure 2: Distribution *H.thebaica* (26).

2.4. The chemical composition of the Doum Palm

2.4.1 Cellulose

Cellulose is an organic polymer that belongs to the polysaccharide family. It is a linear macromolecule built up from simple sugar units called glucose, which are linked together by beta-linkages. Cellulose is the primary constituent of the cell walls of wood fibers (27).

Cellulose is the main component of plant cell walls that provides strength and rigidity to the structure (28). Cellulose is a potential source of value-added products for various industries, such as bioenergy, pulp and paper, and textiles (29).

Studies have focused on the cellulose content of *H.thebaica*, which is an important structural component of the plant cell walls. A study by Garba et al., (30) and Ofori-Boateng and Lee (31) investigated the cellulose content of *H.thebaica* fruit and found that it contained a high amount of cellulose, which has potential applications in the production of biofuels and biomaterials.

Cellulose biosynthesis is a complex process that involves the coordination of multiple enzymes and regulatory factors. Studies have focused on the characterization of genes and proteins involved in cellulose biosynthesis in *H.thebaica* result Showed by Saber et al., (12) investigated the expression of genes involved in cellulose biosynthesis in *H.thebaica* fruit and found that they were regulated by environmental factors such as temperature and water availability. Cellulose is a complex carbohydrate that is difficult to break down and is utilized by many organisms. Recent studies have focused on the characterization of cellulose-degrading enzymes in *H.thebaica* and their potential applications in the production of biofuels and bioproducts.

Nanocellulose is a promising nanomaterial that can be derived from various plant sources, including *H.thebaica* Recent studies have focused on the production and characterization of nanocellulose from *H.thebaica* and its potential applications in various fields, such as biomedicine, energy, and materials science. For example, a study by Norrrahim et al., (32) investigated the production and properties of nanocellulose from *H.thebaica* fruit and found that it had high mechanical strength and thermal stability, which has potential applications in the development of high-performance materials. Recent developments in the study of cellulose in *H.thebaica* have focused on its content, biosynthesis, utilization, and potential applications in various fields. These developments have the potential to promote sustainable development and offer numerous applications in various industries.

2.4.2 Hemicellulose

Together with cellulose and lignin, hemicellulose forms the foundation of the secondary woody cell wall and is made up of glucose, sugars, and derivatives. For hardwoods, hemicellulose mostly consists of two types: xylans, and for softwoods, glucomannans. The primary sugars are glucose-α-(1, 3) galactose, mannose-β-(1, 4) and xylose-β-(1, 4) (33).

Hemicellulose is a complex polysaccharide that is composed of different sugar units and side chains (34). Hemicellulose is a major component of plant cell walls that plays an important role in its structure and function (34). Hemicellulose is a potential source of fermentable sugars to produce biofuels and biochemicals (35).

Recent studies have focused on the utilization of hemicellulose in *H.thebaica* and its potential applications. A study by Trotta, (36) investigated the hydrolysis of hemicellulose in *H.thebaica* fruit and found that it could be efficiently hydrolyzed to produce fermentable sugars. Hemicellulose-based materials have potential applications in various fields, such as packaging, drug delivery, and tissue engineering (37).

Laifa et al., (38) investigated the production and properties of hemicellulose-based films from *H.thebaica* fruit. They found that they had high mechanical strength and thermal stability, which has potential applications in the development of biodegradable packaging materials.

2.4.3 Lignin

Lignin is a phenolic substance that plays a crucial role in the structure and mechanical properties of wood tissue (39). It is composed of a complex group of hydroxyls and phenylpropane units that are interconnected and distributed throughout the secondary cell wall. Lignin is responsible for providing rigidity to the cell wall, making it less permeable to water and other substances, and contributing to the mechanical strength of wood (40, 41). Additionally, lignin can impact the chemical and physical properties of wood, affecting its durability, color, and decay resistance (42).

Recent studies have further explored the role of lignin in wood tissue and the potential applications of lignin-based materials (43). A study by Wang et al., (44) investigated the impact of lignin content on the mechanical properties of wood and found that increased lignin content led to improved stiffness and strength. Another study by Dessbesell et al., (45) explored the potential of lignin-based materials as sustainable alternative to traditional petroleum-based materials, highlighting the potential of lignin as a valuable renewable resource.

The biosynthesis of lignin in plants involves a complex pathway that is regulated by various enzymes and transcription factors (46). Recent studies have investigated the lignin biosynthesis pathway in *H.thebaica* and its regulation. Results Shown by Saber et al., (12) investigated the expression of genes involved in lignin biosynthesis in *H.thebaica* fruit and found that developmental stages and environmental factors regulated them. Lignin-based nanocomposites have potential applications in various fields, such as packaging, biomedical, and environmental engineering (47).

Recent studies have investigated the production and properties of lignin-based nanocomposites from *H.thebaica* Explained Beisl et al., (48) in his study investigated the production and properties of *H.thebaica* lignin-based nanocomposites with cellulose nanocrystals and found that they had high mechanical strength and thermal stability.

Lignin-derived compounds have potential applications in various fields, such as medicine and agriculture (49). Recent have investigated the production and properties of lignin-derived bioactive compounds from *H.thebaica*, investigated the potential of *H.thebaica* lignin as a source of bioactive compounds and found that it had high antioxidant and antibacterial activity (12).

Lignin-based adsorbents have potential applications in water treatment and environmental remediation (50). Lignin is a complex, three-dimensional polymer that is a vital component of plant cell walls, providing structural support and protection against biotic and abiotic stresses (51).

It is synthesized through the phenylpropanoid pathway, which also produces other phenolic compounds, such as flavonoids and lignans (52).

Lignin is a highly heterogeneous polymer with variations in composition, structure, and properties depending on the plant species, tissue type, and developmental stage (53). It is composed of three main monolignols: p-coumaric alcohol, coniferyl alcohol, and sinapyl alcohol, which can combine to form different types of lignin, including guaiacol, syringyl, and p-hydroxyphenyl lignin (54).

Lignin has various applications in different industries, including the production of biofuels, bioplastics, and building materials (55). It is also a potential source of value-added chemicals, such as vanillin and syringaldehyde, which have applications in the food and pharmaceutical industries (56).

2.5. Pharmacological Properties

2.5.1. Antidiabetic Activity

Diabetes is a chronic disease that affects millions of people worldwide, and it is characterized by impaired insulin secretion and glucose metabolism. There is a growing interest in exploring natural compounds and supplements as potential treatments for diabetes (57). The findings of Shady et al., (58) suggest that the flavonoids present in *H.thebaica* fruits may have the potential as a natural supplement for promoting insulin secretion and managing diabetes.

Flavonoids are bioactive compounds that have been found to have antioxidant, anti-inflammatory, and other health-promoting properties (59).

Myricetin, luteolin, and apigenin are flavonoids that have been previously investigated for their potential health benefits, including their ability to improve insulin sensitivity and glucose metabolism (60). The results of the in vitro insulin secretion assay conducted by Shady et al., (58) suggest that these flavonoids may have the potential to promote insulin secretion and improve glucose metabolism in humans. One of the strategies for managing type 2 diabetes is to regulate blood sugar levels by inhibiting the enzymes involved in the breakdown of carbohydrates into glucose (61).

α-amylase inhibitors are compounds that prevent the breakdown of carbohydrates into glucose by inhibiting the activity of α-amylase, an enzyme that breaks down carbohydrates into simple sugars (62). This inhibition can help regulate blood sugar levels in individuals with type 2 diabetes (44).

2.5.2. Anti-Inflammatory Activity

The anti-inflammatory potential of different parts of the *H.thebaica* plant has been extensively studied. The chloroform extract of *H.thebaica* seeds was found to inhibit kidney muscle stimulation significantly, suggesting its anti-inflammatory activity (63). Similarly, the 80% methanol extract of *H.thebaica* fruit was found to inhibit the cyclooxygenase-1 (COX-1) enzyme, likely mediated by flavonoid conjugates, oxygenated fatty acids, and sphingolipids (12, 64).

These findings suggest that the *H.thebaica* tree, from which *H.thebaica* is derived, may have potential as a natural anti-inflammatory agent.

2.5.3. Antimicrobial Activity

H.thebaica fruits were found to have antibacterial activity against K. pneumoniae, P. aeruginosa, and S. Typhi when extracted in n-hexane. The diameter zone of inhibition (DZI) varied depending on the bacteria: 15.10 ± 0.51 to 2.0 ± 0.55 mm for K. pneumoniae, 10.20 ± 0.57 to 2.00 ± 0.35 mm for P. aeruginosa, and 8.00 ± 0.35 to 1.00 ± 0.55 mm for S. typhi. The DZI values of the aqueous extract demonstrated antibacterial activity against K. pneumoniae, S. typhi, and P. aeruginosa, respectively, ranging from 7.10 ± 0.23 to 2.0 ± 0.35 mm, 6.20 ± 0.31 to 2.00 ± 0.35 mm, and 5.42 ± 0.55 to 2.05 ± 0.75 mm. 100 mg/mL was the extracts' minimum inhibitory concentration (MIC) while 200 mg/mL was its minimum bactericidal concentration (MBC).

These findings suggest that the fruits of *H.thebaica* may have potential as a natural antibacterial agent **(65)**. The aqueous extract of fruits of *H.thebaica* was found to have high antimicrobial activity against S. aureus and *E. coli.* The extract showed the highest diameter zone of inhibition (DZI) of 20.33 mm against S. aureus and a DZI of 16.00 mm against E. coli. These findings suggest that the aqueous extract of *H.thebaica* fruits may have the potential as a natural antimicrobial agent, particularly against S. aureus and E. coli, for the treatment of bacterial infections caused by these microorganisms (12).

According to Taha et al. (20), the fruit extract of *H.thebaica* demonstrated antimicrobial activity against *Candida albicans* with an inhibition zone of 9.0 ± 0.0 mm. The fruit extract likely contains secondary metabolites such as anthocyanins, saponins, phenolics, flavonoids, and tannins, which are known for their antimicrobial properties against a wide range of Gram-positive and negative bacteria.

The antimicrobial activity of the fruit extract may be attributed to the presence of these secondary metabolites, which can disrupt the cell membrane of microorganisms and inhibit their growth (66). Furthermore, the fruit extract may have potential as a natural antifungal agent, particularly against Candida albicans. Overall, the fruit extract of *H.thebaica* shows promise as a natural antimicrobial agent. Millions of individuals worldwide suffer from type 2 diabetes, a chronic condition marked by elevated blood sugar levels brought on by decreased insulin production or insulin resistance (67).

The findings of Atito et al., (68) suggest that the mesocarp extract of *H.thebaica* fruits may have the potential to be a natural supplement for managing blood sugar levels in individuals with type 2 diabetes.

Further research is needed to investigate the specific mechanisms of action of the mesocarp extract and its potential applications in the management of type 2 diabetes. In addition to its potential α-amylase inhibitory activity, *H.thebaica* fruits have been found to contain other bioactive compounds with potential health benefits, such as flavonoids and phenolic acids (12).

These compounds have been found to have antioxidant, anti-inflammatory, and other health-promoting properties, which may make *H.thebaica* fruits a promising natural supplement for managing type 2 diabetes and other chronic diseases (58).

Saber et al., (12) investigated the α-glucosidase inhibitory activity of various fractions obtained by different solvents from the total ethanolic extract of *H.thebaica* They found that the dichloromethane fraction exerted potent inhibition with an IC50 value of 52.40 μg/mL. The subsequent fractions from the dichloromethane showed even more powerful inhibition compared to acarbose, a commonly used medication for managing blood sugar levels in individuals with type 2 diabetes.

However, El-Manawaty and Gohar (69) tested the inhibitory effect of the methanol extract of *H.thebaica* flowers on the enzymatic activity of α-glucosidase. They showed that the extract exhibited very low inhibitory activity with only 2% inhibition on α-glucosidase at the tested concentration of 25 ppm.

These findings suggest that the α-glucosidase inhibitory activity of *H.thebaica* may vary depending on the specific part of the plant, the extraction method, and the solvent used.

2.5.4. Anticancer Activity

Saber et al., (12) results indicate that *H.thebaica* has been found to exhibit potent cytotoxic potential against HepG2 and A549 cancer cell lines.

The leaves, male parts, and fruits of *H.thebaica* were tested for their anticancer activity, and all three parts showed significant effects on the viability of the cancer cell lines (20). Male parts of *H.thebaica* exhibited stronger antiproliferative activity against HepG2 (IC50 = 1.14 µg/mL) and A549 (IC50 = 1.15 µg/mL) cancer cell lines compared to the leaves and fruits. Chrysin, a flavonoid found in *H.thebaica*, was found to have non-detectable anticancer activity (20). These findings suggest that *H.thebaica* has the potential as a natural source of compounds with anticancer activity, particularly in the male parts of the plant. One of the most prevalent forms of cancer in women and a leading cause of cancer-related deaths globally is breast cancer (70). While there are several treatment options available for breast cancer, including chemotherapy and radiation therapy, these treatments can be associated with significant side effects and may not always be effective (71).

2.6. Chemical/Industrial Applications

Mannan polysaccharides are considered safe and have various applications in industries such as pharmaceuticals, food, cosmetics, and textiles (72). Gibril et al., (73) found that, when compared to commercial mannan, powdered *H.thebaica* seed are a great source of mannan production. Mannan was extracted using an alkaline NaOH solution. In addition, Benhamou et al., (74) were able to extract cellulose from *H.thebaica* leave and chemically convert it to carboxymethyl cellulose, which offers good stability and appropriate production yield compared to other conventional methods.

These findings suggest that *H.thebaica* has the potential to be a source of valuable polysaccharides and can be used in various industries.

2.7. Food Industry Applications

Fortification of food with healthy ingredients has gained more attention in recent years to improve the nutritional quality of food and prevent malnutrition and vitamin and mineral deficiencies, especially in vulnerable populations such as children and women (75). *H.thebaica* fruit has been used as an ingredient in various food products for fortification, including bread, cakes, tahini, biscuits, crackers, syrups, jellies, and ice creams (12). *H.thebaica* fruit powder has been found to be an excellent source of several important nutrients, such as protein, carbohydrates, minerals, and vitamins, as well as antioxidant and antimicrobial compounds (76).

Aboshora et al. (77) and Saber et al. (12) reported that bread made with *H.thebaica* fruit powder was superior to plain white flour bread in terms of nutritional value. Incorporating *H.thebaica* fruit powder in cake and tahini has also been found to improve their sensory, nutritive, and healthy properties (12, 78).

However, Ismail et al. (79) reported that the incorporation of *H.thebaica* fruit in some food products, such as ice creams, may affect their acceptability, lower acceptability in the sensory evaluation of ice creams with increasing the percentage of *H.thebaica* fruit syrups and pomegranate peels.

2.8. Bioactive components of *H.thebaica*

1-Phenplic Compound

2-Flavonoids

2.8.1. Polyphonic Compound in Dum Tree

H.thebaica contains various polyphenolic compounds that have potential health benefits and other applications (12). Studies have shown that *H.thebaica* fruit is a rich source of polyphenolic compounds, including flavonoids, phenolic acids, and tannins, which have antioxidant, anti-inflammatory, and antimicrobial properties (20). In addition, *H.thebaica* fruit has been traditionally used in African and Middle Eastern cultures for its medicinal properties, such as for the treatment of gastrointestinal disorders, fever, and diabetes (80). Polyphenolic compounds from *H.thebaica* fruit have also been shown to have potential as natural preservatives for food products due to their antimicrobial activity against foodborne pathogens (14).

2.8. 2. Phenolic Compound and Their Classification

Phenolic compounds, a diverse group of secondary metabolites, are abundant in the plant kingdom and are known for their antioxidant, antimicrobial, and anti-inflammatory properties (81).

They are classified into different groups based on their chemical structure, including flavonoids, phenolic acids, tannins, and lignans (82). These compounds are not distributed uniformly in plants, with insoluble phenolics found in cell walls and soluble ones in vacuoles (83). Phenolic compounds are important for the quality of plant-based foods, contributing to their color, flavor, and health benefits (84). They are also found in the family Sapotaceae, with various biological activities (85).

Techniques for analyzing these compounds have evolved over the years, with organic solvent extraction being the main method (86). However, the bioavailability and absorption of plant phenolics remain areas of ongoing research (83). In *H.thebaica*, phenolic compounds are mainly present in fruit, seed, and bark, where they have been traditionally used for medicinal and other purposes. The phenolic compounds in *H.thebaica* fruit are mainly flavonoids, phenolic acids, and tannins, with variations in composition depending on the geographic location and ripening stage (12,66).

2.8.3. Major Phenolic Compound in the Palm Tree

These phenolic compounds, along with other secondary metabolites, play a role in the plant's resistance to stress and defense against external threats (88). The presence of flavonoids, such as tricin, glycoflavones, and proanthocyanidins, further contributes to the plant's chemical makeup (88). The phenolic constituents in the palm tree are influenced by factors such as light exposure and tree health (89).

The presence of these compounds in the palm tree's sap and heartwood suggests a potential for their extraction and utilization (90). Flavonoids are a major group of phenolic compounds that are further classified into several subgroups, including flavones, flavonols, flavanones, flavan-3-ols (catechins), and anthocyanins. Flavonoids are known for their antioxidant properties and have been associated with various health benefits in humans, such as reducing the risk of cardiovascular disease, cancer, and neurodegenerative disorders (91).

Another significant family of phenolic chemicals is phenolic acids, which are further divided into two subclasses: hydroxybenzoic acids and hydroxycinnamic acids. Phenolic acids are well-known for their antioxidant and anti-inflammatory characteristics, and they have been linked to a variety of health advantages in humans, including a lower risk of cardiovascular disease, cancer, and diabetes (92).

Tannins are another significant family of phenolic chemicals that are further subdivided into hydrolyzable tannins and condensed tannins. Tannins are recognized for their astringent characteristics and have been linked to a variety of health advantages in humans, including a lower risk of cardiovascular disease, cancer, and obesity (44).

2.8.4. Flavonoids

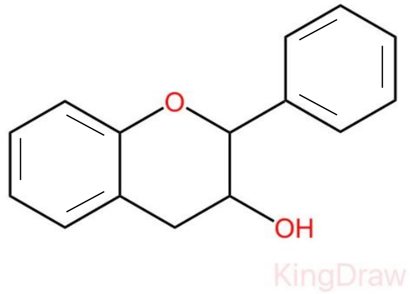

Figure 3: Chemical structure of Flavonoid

Flavonoids (Fig: 3), a subclass of phenolic compounds, are known for their antioxidant and anti-inflammatory properties (93). They are found in various plants, including *H.thebaica*, and have potential health benefits and other applications (94). These compounds have been extensively studied for their biomedical applications, including their role in chronic inflammation, cancer, cardiovascular complications, and hypoglycemia (93). They also exhibit antibacterial, antiviral, and anticarcinogenic properties (95).

Flavonoids have been shown to have a range of health benefits, including anti-inflammatory, antioxidant, antiproliferative, and anticancer effects (96). They are being investigated for their potential use in anti-cancer therapy (97) and as chemoprotective agents in civilization diseases (98). Their beneficial effects on health have led to their use in nutraceutical, pharmaceutical, medicinal, and cosmetic applications (99) .

In *H.thebaica*, flavonoids are mainly present in the fruit, seed, and bark, where they have been traditionally used for medicinal and other purposes. The flavonoid content in *H.thebaica* fruit varies depending on the geographic location, ripening stage, and processing methods. Recent studies have identified several flavonoids in *H.thebaica* fruit, including quercetin, kaempferol, myricetin, and their glycosides, which have been associated with various health benefits, such as reducing the risk of cancer and diabetes (100).

2.8.5. Tannins

Figure 4: Chemical structure of Tannins

Tannins (Fig: 4) are a group of polyphenolic compounds that are widely distributed in the plant kingdom and are known for their astringent properties (101). They are classified into two main types: hydrolyzable tannins and condensed tannins. *H.thebaica* is a species of palm trees that are known to contain various tannins with potential health benefits and other applications. In *H.thebaica*, tannins are mainly present in the fruit, seed, and bark, where they have been traditionally used for medicinal and other purposes (12).

Another study reported the presence of hydrolyzable tannins in *H.thebaica* fruit and their potential use as natural antioxidants (102). Tannins from *H.thebaica* has potential applications in various fields, including food, pharmaceuticals, and cosmetics.

2.8.5.1. Condensed Tannins

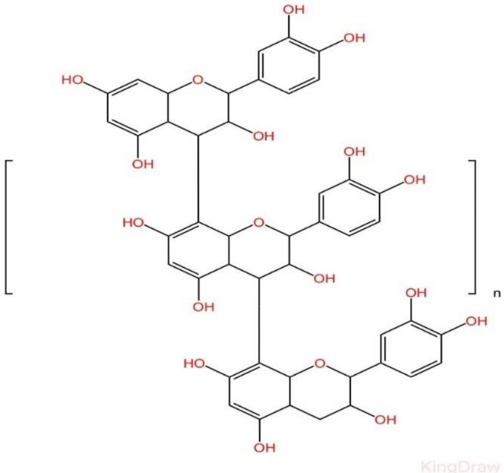

Figure 5: Diagrammatic representation of condensed Tannin

Condensed tannins (Fig: 5), also known as proanthocyanidins, are a type of polyphenol found in many plant species (103), including *H.thebaica* trees.

2.8.5.2. Hydrolyzable Tannin Content

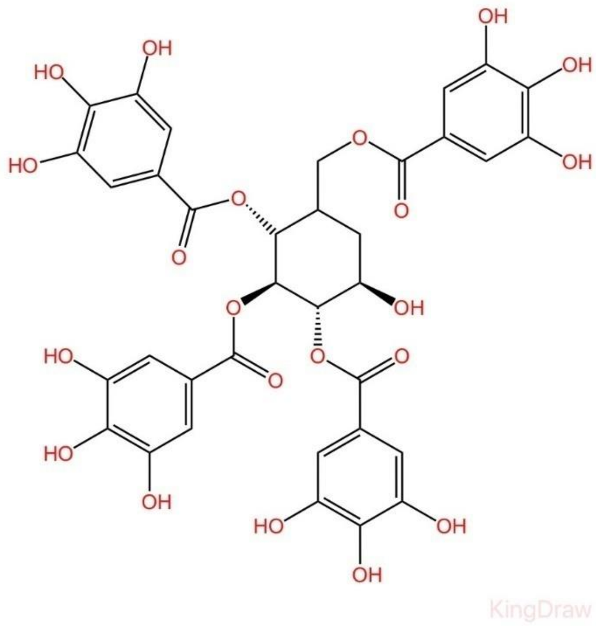

Figure 6: Diagrammatic representation of hydrolyzable Tannin

Hydrolyzable tannins (Fig: 6) are a type of polyphenol found in many plant species (104). The review summarized various studies that have reported the presence of hydrolyzable tannins in different parts of the *H.thebaica* tree, including the fruit, leaves, and roots (102).

2.8.6. Lignans

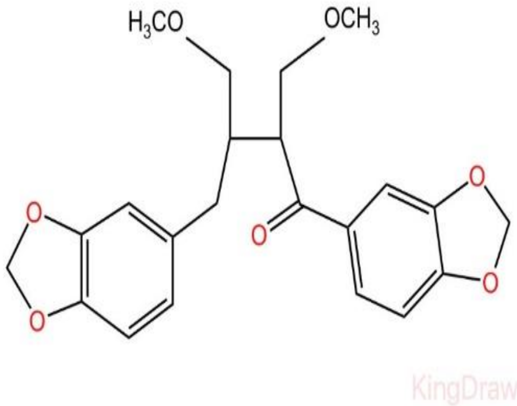

Figure 7: Basic chemical structure of Lignans.

Lignans (Fig: 7) are a class of polyphenolic compounds that are widely distributed in the plant kingdom and have been associated with various health benefits, including antioxidant and anti-cancer effects (105). *H.thebaica* fruit has been found to contain various lignans (106). These lignans have been shown to have potential health benefits, such as reducing the risk of cancer and cardiovascular disease (78).

2.8.7. Soluble and Insoluble Bound Phenolics Compounds

Phenolic compounds in plants can be classified into different types based on their solubility and chemical interactions: free, esterified, and insoluble-bound phenolics (107). Free phenolics are not chemically linked to other molecules, whereas esterified phenolics are linked to fatty acids and glucuronic acids through ester bonds. Both free and esterified phenolics are soluble in water and organic solvents and can be easily extracted using an extraction medium (108). In contrast, insoluble-bound phenolics are covalently linked to macromolecules, such as cellulose, hemicellulose, pectin, and structural proteins in the plant cell wall.

These phenolics cannot be extracted using solvents and require hydrolysis, either chemically or enzymatically, to release them from the food matrix. The presence of insoluble-bound phenolics in plant-based foods can contribute to their health-promoting effects. However, their bioavailability is generally lower than that of soluble phenolics due to their tight binding to cell wall components (110).

These palm trees are known to produce fruits that are rich in phenolic compounds, including both soluble and insoluble bound phenolics (111). Soluble phenolics are those that are present in the free or conjugated form in plant tissues and can be easily extracted using solvents (112). In contrast, insoluble-bound phenolics are those that are covalently bound to cell wall components, such as cellulose and lignin, and are not easily extractable using solvents (113). Recent studies have investigated the phenolic profiles of *H.thebaica* fruit, with both soluble and insoluble bound phenolics being identified.

2.8.8. Phenolic Antioxidants Properties and Their Action Mechanism

Phenolic antioxidants are a diverse group of compounds found in plant-based foods that have been associated with various health benefits (114). These compounds are known for their ability to scavenge free radicals and other reactive oxygen species (ROS), which can cause damage to cells and tissues and contribute to the development of chronic diseases such as cancer, cardiovascular disease, and neurodegenerative disorders (115).

Phenolic antioxidants act by donating an electron or hydrogen atom to the free radicals or ROS, which neutralizes their reactivity and prevents them from causing further damage. In addition to their direct antioxidant activity, some phenolic compounds can also stimulate the body's antioxidant defenses by upregulating the expression of antioxidant enzymes and reducing oxidative stress (116).

Studies have shown that *H.thebaica* tree contains several phenolic compounds with antioxidant properties, including flavonoids, phenolic acids, and tannins (10, 117). These compounds have been shown to scavenge free radicals and inhibit lipid peroxidation, which can contribute to oxidative stress and cellular damage (118).

2.8.9. Natural Antioxidants

Natural antioxidants can be found in a variety of plant-based foods, including fruits, vegetables, nuts, and whole grains (119). These compounds have been shown to scavenge free radicals and other reactive oxygen species, which can cause cellular damage and contribute to the development of chronic diseases (115).

Some natural antioxidants, such as carotenoids and tocopherols, can also act as pro-vitamins and have other functions in the body beyond their antioxidant activity (120). For example, some carotenoids are important for vision and immune function, while tocopherols have been shown to have anti-inflammatory properties (121).

H.thebaica tree is rich in sources of natural antioxidants, including phenolic compounds such as flavonoids, phenolic acids, and tannins. These antioxidants have been shown to scavenge free radicals and protect against oxidative stress, which can contribute to the development of chronic diseases (21).

2.8.10. Dietary Fibers

Dietary fibers are a group of carbohydrates that are resistant to digestion in the small intestine and reach the large intestine intact, where the gut microbiota can ferment those (122). These fibers are found in various plant-based foods, such as whole grains, fruits, vegetables, legumes, and nuts. Fiber intake has been associated with numerous health benefits, including improved digestive health, blood glucose control, lipid metabolism, and weight management (123).

Different types of dietary fibers have different physicochemical properties and physiological effects (124). Soluble fibers, such as beta-glucans and pectins, form viscous solutions in the gut and can slow down the digestion and absorption of nutrients, whereas insoluble fibers, such as cellulose and lignin, increase stool bulk and promote bowel movements (125). Recent research has investigated the potential health benefits of specific dietary fibers, as well as their mechanisms of action.

A study found that supplementation with resistant starch, a type of fiber that resists digestion in the small intestine, improved insulin sensitivity and reduced inflammation in individuals with metabolic syndrome (126). Another study found that inulin, a prebiotic fiber, increased the abundance of beneficial gut bacteria and improved gut barrier function in individuals with irritable bowel syndrome (127).

H.thebaica tree is a source of dietary fiber, which can contribute to the health-promoting properties of these fruits. Dietary fiber in *H.thebaica* fruit includes both soluble and insoluble fibers, such as pectin, cellulose, and hemicellulose (128). The dietary fiber content of *H.thebaica* fruits can vary depending on factors such as cultivar, maturity stage, and processing. A study found that the total dietary fiber content of *P.dactylifera* fruits ranged from 5.5% to 9.5%, depending on the cultivar (66).

The gut microbiota can play an important role in the fermentation of dietary fibers and the production of short-chain fatty acids, which have been associated with various health benefits. A study on *H.thebaica* fruit found that it has prebiotic potential, as it increased the abundance of beneficial gut bacteria and the production of short-chain fatty acids in vitro (22).

2.8.11. Soluble and Insoluble Dietary Fibers

Soluble dietary fiber dissolves in water and forms a gel-like substance in the gut. Soluble fiber can help lower blood cholesterol levels and regulate blood sugar levels (129). Insoluble dietary fiber does not dissolve in water and adds bulk to the stool, promoting regular bowel movements. It is found in foods such as whole grains, nuts, and seeds. Insoluble fiber can also help lower the risk of certain diseases, such as colon cancer (130).

Consuming dietary fiber is beneficial to general health and has been linked to a lower chance of developing chronic illnesses including diabetes, heart disease, and some kinds of cancer. However, many people do not consume enough dietary fiber. Increasing the intake of fruits, vegetables, whole grains, and legumes can help increase dietary fiber intake (131). Binds to cholesterol in the stomach and stops it from being taken into the circulation, soluble fiber can help decrease blood cholesterol levels (132). Insoluble fiber can help promote regular bowel movements by adding bulk to the stool and reducing the risk of constipation (133).

2.8.12. Dietary Fibers Analysis Techniques

AOAC International has established several methods for analyzing dietary fiber, including gravimetric methods and enzymatic-gravimetric methods. The most used method for analyzing total dietary fiber is the enzymatic-gravimetric method, which involves enzymatic digestion of the sample to remove non-fiber components, followed by gravimetric analysis of the remaining fiber (AOAC International, 2017). Newer techniques for analyzing dietary fiber include near-infrared spectroscopy (NIRS), which can provide rapid and accurate analysis of fiber content in a variety of foods (134). Other emerging techniques include Fourier transform infrared (FTIR) spectroscopy and high-performance liquid chromatography (HPLC) (135).

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