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# THESIS

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THEME

# Phytochemical Analysis and Biological Activity Evaluation of the Hydromethanolic Extract of Date Palm (*Phoenix dactylifera* L.) Seeds from the 'Ghars' Cultivar Cultivated in the El Oued Region, Algeria

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Thanks be to **Allah**, for the gift of life and knowledge

To my father, rest his soul

To my mother, for her unwavering love and support

To my professors, for their guidance and wisdom

To my friends, for their encouragement

To the difficult days

This work is dedicated to you

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# ACKNOWLEDGMENT

***In the Name of Allah, the Most Gracious, the Most Merciful.***

*All praise is due to Allah, by Whose grace good deeds are completed and by Whose help hardships are eased. Peace and blessings be upon our* ***Prophet Muhammad*** *ﷺ, upon his family, his companions, and all who follow them in righteousness.*

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*This work emerged from effort and perseverance, from patience and striving, until Allah granted its completion—His favor, first and last. I dedicate this humble achievement to:*

***To my dear father****, my support in hardships and my strength in every trial; your wise advice and unwavering help have guided my steps throughout this journey.*

***To my beloved mother****, the source of tenderness and mercy; your sincere prayers have opened doors of ease and brought blessings into my life. May Allah reward you with the highest ranks of Paradise.*

***To my dear brothers and sisters****, my strength in distress and my comfort in every circumstance; your presence has been a constant source of encouragement and warmth.*

***To my faithful friends and colleagues****, companions in both difficulty and joy, and a light in the darkest nights; thank you for sharing this journey with me.*

***To every hardship*** *endured with patience, and every tear shed in the pursuit of knowledge, I dedicate this work. I pray that Allah accepts it sincerely for His sake, blesses its impact, and makes it a light for us on the Day we meet Him.*

***Abir elayet , Malak, Houyame and Massouda……***

# SUMMARY

The date palm (*Phoenix dactylifera* L., Arecaceae) is a keystone fruit crop of Saharan oasis agro-ecosystems, and its seeds — long discarded as an agro-industrial by-product — are increasingly recognised as a rich yet underexploited reservoir of bioactive secondary metabolites; nevertheless, the phytochemical and biological value of locally grown seeds of the soft cultivar 'Ghars' remains insufficiently documented. The aim of this work was to characterise the hydromethanolic extract of *P. dactylifera* L. seeds of the 'Ghars' cultivar harvested in the El Oued region and to evaluate its *in-vitro* antioxidant, antidiabetic and anti-Alzheimer potential.Cleaned, shade-dried and ground seeds were macerated in methanol/water (75:25, v/v) through three successive 24-hour cycles at room temperature, and the combined macerates were filtered and concentrated under reduced pressure at 40 °C, affording a crude dried extract with a yield of 24.61% (w/w). Total phenolic, total flavonoid and condensed tannin contents were determined by the Folin–Ciocalteu, aluminium chloride and vanillin–HCl methods, respectively, while the phenolic profile was established by reversed-phase high-performance liquid chromatography coupled with photodiode-array detection (HPLC–PDA); biological activities were assessed through DPPH and ABTS-$^{+}$ radical-scavenging assays, the *o*-phenanthroline reducing assay, and inhibition of α-amylase, α-glucosidase and acetylcholinesterase. The extract was particularly rich in polyphenols (284.19 ± 1.40 mg GAE/g), flavonoids (94.33 ± 3.90 mg QE/g) and condensed tannins (68.62 ± 1.20 mg CE/g), and fifteen phenolic and related compounds were targeted by HPLC–PDA, of which ten were detected and quantified, dominated by salicin (6949.30 µg/g extract), caffeic acid (431.74 µg/g extract) and esculin (207.34 µg/g extract). Marked radical-scavenging activity was recorded against DPPH- ($IC_{50}$ = 8.300 ± 0.231 µg/mL) and ABTS-$^{+}$ ($IC_{50}$ = 3.984 ± 0.033 µg/mL), together with an *o*-phenanthroline reducing capacity ($A_{0.5}$ = 5.474 ± 0.156 µg/mL), closely approaching those of Trolox and ascorbic acid. Notably, the extract inhibited α-amylase ($IC_{50}$ = 50.03 ± 3.80 µg/mL) more strongly than the reference inhibitor acarbose ($IC_{50}$ = 60.86 ± 1.58 µg/mL), and exhibited complementary α-glucosidase ($IC_{50}$ = 120.00 ± 2.97 µg/mL) and acetylcholinesterase ($IC_{50}$ = 98.82 ± 5.25 µg/mL) inhibition compared with acarbose ($IC_{50}$ = 62.20 ± 1.38 µg/mL) and galantamine ($IC_{50}$ = 28.00 ± 0.30 µg/mL), respectively. These findings demonstrate that locally cultivated El Oued 'Ghars' date seeds constitute a promising antioxidant, antihyperglycaemic and neuroprotective phytotherapeutic and functional-food resource, valorising a Saharan agro-industrial by-product within a circular-bioeconomy framework; nevertheless, the present results are restricted to *in vitro* models, and further *in vivo*, toxicological and clinical investigations are required to confirm efficacy, safety and optimal conditions of use.



**Keywords:** *Phoenix dactylifera* L.; 'Ghars' cultivar; hydromethanolic extract; HPLC–PDA; antioxidant activity; antidiabetic activity; acetylcholinesterase inhibition.

# SUMMARY IN ARABIC (ملخص)

يُعدّ نخيل التمر ( *Phoenix dactylifera* L. Arecaceae. ) ، محصولاً فاكهيّاً محوريّاً في النظم الزراعية الواحاتية الصحراوية، كما تُعدّ بذوره ـــ التي طالما اعتُبرت من المخلّفات الزراعية المهملة ـــ من أكثر المصادر غنىً بالمستقلبات الثانوية الفعّالة بيولوجيّاً، وإن ظلّت قيمتها الفيتوكيميائية والبيولوجية في الأصناف المحلية، ولا سيّما صنف "غرس"، غير موثّقة بالقدر الكافي. هدفت هذه الدراسة إلى توصيف المستخلص الهيدرو-ميثانولي لبذور *P. dactylifera* L. من الصنف "غرس" التي جُمعت من منطقة الوادي (دوّار الماء، دائرة الطالب العربي، جنوب شرق الجزائر)، وتقييم فاعليّتها المضادّة للأكسدة والمضادّة للسكّري والمضادّة لمرض الزهايمر مخبريّاً (*in vitro*).نُظِّفت البذور وجُفِّفت في الظلّ ثمّ طُحنت، وأُخضعت للنقع في مزيج ميثانول/ماء (75:25، حجم/حجم) خلال ثلاث دورات متتالية مدّة كلٍّ منها 24 ساعة في درجة حرارة الغرفة، ثمّ رُشّحت المنقوعات المجمَّعة وكُثِّفت تحت ضغط مخفَّض عند 40 °م، ممّا أتاح الحصول على مستخلص خام جافّ بمردود قدره 24.61% (وزن/وزن). قُدِّر محتوى الفينولات الكلية والفلافونيدات الكلية والعفص المكثّف باستعمال طرائق Folin–Ciocalteu وكلوريد الألومنيوم و Vanillin–HCl على التوالي، في حين حُدِّد الملمح الفينولي بواسطة الاستشراب السائل عالي الأداء في الطور المعكوس المقترن بالكشف بمصفوفة الثنائيات الضوئية(HPLC–PDA) ؛ وقُيِّمت الفاعليات البيولوجية عبر اختبارَي اقتناص الجذور الحرّة DPPH و $ABTS^{•+}$، واختبار الاختزال بـ *o*-phenanthroline، فضلاً عن تثبيط إنزيمات α-amylase و α-glucosidase وacetylcholinesterase. تميّز المستخلص بغناه بالبوليفينولات (284.19 ± 1.40 mg GAE/g) والفلافونيدات (94.33 ± 3.90 mg QE/g) والعفص المكثّف (68.62 ± 1.20 mg CE/g) ، وأمكن استهداف خمسة عشر مركّباً فينوليّاً بواسطة HPLC–PDA، تمّ الكشف عن عشرة منها وتحديد كميّاتها، يهيمن عليها السالسين (6949.30 ميكروغرام/غ مستخلص)، وحمض الكافييك (431.74 ميكروغرام/غ مستخلص)، والإسكولين (207.34 ميكروغرام/غ مستخلص). وسُجِّلت فاعلية ملحوظة في اقتناص الجذور تجاه DPPH- ($IC_{50}$ = 8.300 ± 0.231 µg/mL) و $ABTS^{•+}$ ($IC_{50}$ = 3.984 ± 0.033 µg/mL)، إلى جانب قدرة اختزالية في اختبار *o*-phenanthroline ($A_{0.5}$ = 5.474 ± 0.156 µg/mL)، وهي قيم تقترب كثيراً من تلك المسجّلة لـ Trolox وحمض الأسكوربيك. واللافت أنّ المستخلص ثبّط إنزيم α-amylase ($IC_{50}$ = 50.03 ± 3.80 µg/mL) بفاعلية أقوى من المثبِّط المرجعي acarbose ($IC_{50}$ = 60.86 ± 1.58 µg/mL)، وأبدى تثبيطاً تكميليّاً لإنزيمَي α-glucosidase ($IC_{50}$ = 120.00 ± 2.97 µg/mL) و acetylcholinesterase ($IC_{50}$ = 98.82 ± 5.25 µg/mL) مقارنةً بـ acarbose ($IC_{50}$ = 62.20 ± 1.38 µg/mL) و galantamine ($IC_{50}$ = 28.00 ± 0.30 µg/mL) على التوالي. تُبيّن هذه النتائج أنّ بذور تمور "غرس" المزروعة محليّاً في منطقة الوادي تمثّل مورداً واعداً للعلاج النباتي والأغذية الوظيفية بخصائص مضادّة للأكسدة وخافضة لفرط سكّر الدم وحامية للأعصاب، ممّا يُسهم في تثمين هذا المخلَّف الصناعي الزراعي الصحراوي ضمن إطار الاقتصاد الحيوي الدائري؛ غير أنّ النتائج المعروضة تقتصر على نماذج *in vitro*، ممّا يستوجب إجراء دراسات تكميلية *in vivo* وسُمّية وسريرية للتحقّق من الفاعلية والسلامة وتحديد الشروط المثلى للاستعمال.

**الكلمات المفتاحية :** *Phoenix dactylifera* L.؛ الصنف "غرس"؛ المستخلص الهيدرو-ميثانولي؛ HPLC–PDA ؛ الفاعلية المضادّة للأكسدة؛ الفاعلية المضادّة للسكّري؛ تثبيط acetylcholinesterase .

# SUMMARY IN FRENCH (RESUME)

Le palmier dattier (*Phoenix dactylifera* L., Arecaceae) est une culture fruitière emblématique des agro-écosystèmes oasiens sahariens, et ses graines — longtemps considérées comme un sous-produit agro-industriel et écartées en tant que tel — sont aujourd'hui de plus en plus reconnues comme un réservoir riche, mais sous-exploité, de métabolites secondaires bioactifs ; néanmoins, la valeur phytochimique et biologique des graines localement cultivées du cultivar tendre « Ghars » demeure insuffisamment documentée. L'objectif de ce travail était de caractériser l'extrait hydrométhanolique des graines de *P. dactylifera* L. du cultivar « Ghars » récoltées dans la région d'El Oued et d'évaluer son potentiel antioxydant, antidiabétique et anti-Alzheimer *in vitro*.Les graines, nettoyées, séchées à l'ombre et broyées, ont été macérées dans un mélange méthanol/eau (75:25, v/v) au cours de trois cycles successifs de 24 heures à température ambiante ; les macérats combinés ont ensuite été filtrés et concentrés sous pression réduite à 40 °C, ce qui a fourni un extrait brut sec avec un rendement de 24,61% (m/m). Les teneurs en composés phénoliques totaux, en flavonoïdes totaux et en tanins condensés ont été déterminées respectivement par les méthodes de Folin–Ciocalteu, au chlorure d'aluminium et à la vanilline–HCl, tandis que le profil phénolique a été établi par chromatographie liquide haute performance en phase inverse couplée à une détection par barrette de diodes (HPLC–PDA) ; les activités biologiques ont été évaluées par les tests de piégeage des radicaux DPPH et $ABTS\cdot^{+}$, le test de réduction à l'*o*-phénanthroline et l'inhibition de l'α-amylase, de l'α-glucosidase et de l'acétylcholinestérase. L'extrait s'est révélé particulièrement riche en polyphénols (284,19 ± 1,40 mg EAG/g), en flavonoïdes (94,33 ± 3,90 mg EQ/g) et en tanins condensés (68,62 ± 1,20 mg EC/g), et quinze composés phénoliques et apparentés ont été ciblés par HPLC–PDA, parmi lesquels dix ont été détectés et quantifiés, dominés par la salicine (6949,30 µg/g d'extrait), l'acide caféique (431,74 µg/g d'extrait) et l'esculine (207,34 µg/g d'extrait). Une activité antiradicalaire marquée a été enregistrée vis-à-vis du DPPH- ($IC_{50}$ = 8,300 ± 0,231 µg/mL) et de l'$ABTS\cdot^{+}$ ($IC_{50}$ = 3,984 ± 0,033 µg/mL), ainsi qu'une capacité réductrice à l'*o*-phénanthroline ($A_{0,5}$ = 5,474 ± 0,156 µg/mL), des valeurs proches de celles du Trolox et de l'acide ascorbique. De manière notable, l'extrait a inhibé l'α-amylase ($IC_{50}$ = 50,03 ± 3,80 µg/mL) plus puissamment que l'inhibiteur de référence acarbose ($IC_{50}$ = 60,86 ± 1,58 µg/mL), et a présenté une inhibition complémentaire de l'α-glucosidase ($IC_{50}$ = 120,00 ± 2,97 µg/mL) et de l'acétylcholinestérase ($IC_{50}$ = 98,82 ± 5,25 µg/mL) comparativement à l'acarbose ($IC_{50}$ = 62,20 ± 1,38 µg/mL) et à la galantamine ($IC_{50}$ = 28,00 ± 0,30 µg/mL), respectivement.Ces résultats démontrent que les graines de dattes « Ghars » localement cultivées dans la région d'El Oued constituent une ressource phytothérapeutique et alimentaire fonctionnelle prometteuse aux propriétés antioxydantes, antihyperglycémiantes et neuroprotectrices, valorisant un sous-produit agro-industriel saharien dans le cadre d'une bioéconomie circulaire ; néanmoins, les résultats obtenus se limitent à des modèles *in vitro*, et des investigations *in vivo*, toxicologiques et cliniques complémentaires sont nécessaires afin de confirmer l'efficacité, l'innocuité et les conditions optimales d'utilisation.

**Mots-clés :** *Phoenix dactylifera* L. ; cultivar « Ghars » ; extrait hydrométhanolique ; HPLC–PDA ; activité antioxydante ; activité antidiabétique ; inhibition de l'acétylcholinestérase

***Symbol***:

**%** Percentage

**°C** Degree Celsius

***A**** Acetylcholinesterase activity/capacity in the absence of inhibitor

$A_{0.5}$ Concentration giving an absorbance equal to 0.5

**Abs** Absorbance

***B**** Acetylcholinesterase activity/capacity in the presence of inhibitor

**g** Gram

**h** Hour(s)

$IC_{50}$ Half maximal inhibitory concentration

**M** Molar

**m** Metre

**mg** Milligram

**mL** Millilitre

**mm** Millimetre

**min** Minute(s)

**mM** Millimolar

**µg** Microgram

**µL** Microlitre

**µm** Micrometre

***n*** Number of replicates

**nm** Nanometre

***p*** Probability value

**pH** Hydrogen ion potential

**rpm** Revolutions per minute

$R^2$ Coefficient of determination

**Rt** Retention time

**v/v** Volume per volume

**w/v** Weight per volume

**w/w** Weight per weight

**α Alpha** (e.g., α-amylase; α-glucosidase)

**λ** Wavelength

**λmax** Wavelength of maximum absorbance

***Abbreviations:***

**ABTS** 2,2′-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)

**ABTS**$^{-+}$ ABTS radical cation

**AChE** Acetylcholinesterase

**$AlCl_3$** Aluminium chloride

**AUV** Absorbance unit value

**C18** Octadecyl-bonded silica (reversed-phase column)

**CE** Catechin equivalent

**cv.** Cultivar

**DPPH** 2,2-Diphenyl-1-picrylhydrazyl

**DPPH** DPPH radical

**DTNB** 5,5′-Dithiobis(2-nitrobenzoic acid)

**$FeSO_4$** Ferrous sulfate

**GAE** Gallic acid equivalent

**HCl** Hydrochloric acid

**HPLC–PDA** High-performance liquid chromatography coupled with photodiode-array detection

**IPI** Iodine–potassium iodide solution

**$K_2S_2O_8$** Potassium persulfate

**MeOH** Methanol

**$Na_2CO_3$** Sodium carbonate

**PNPG** *p*-Nitrophenyl α-D-glucopyranoside

**QE** Quercetin equivalent

**SD** Standard deviation

**TCT** Total condensed tannin content

**TFC** Total flavonoid content

**TPC** Total phenolic content

**Tris–HCl** Tris(hydroxymethyl)aminomethane hydrochloride

**UV–Visible** Ultraviolet–visible (spectrophotometer/spectrophotometry)

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# GENERAL INTRODUCTION

The valorization of agro-food crops and of their associated by-products has become a central axis of contemporary food and natural-product research, driven by the convergence of nutritional, pharmacological, environmental, and economic concerns (Galanakis, 2012). Beyond their primary role as staple foods, many cultivated species accumulate, in their edible and non-edible fractions, a remarkable diversity of bioactive constituents whose recovery and characterization underpin the development of functional foods, nutraceuticals, and pharmaceutical excipients (Galanakis, 2012). This research orientation is fully aligned with the circular-bioeconomy paradigm, in which agro-industrial residues are no longer treated as waste but as biological reservoirs from which scientific, technological, and economic value can be sustainably extracted (Atanasov et al., 2021). Within this framework, plant-derived matrices that combine high production volumes with chemically rich by-products represent particularly promising targets for systematic phytochemical and pharmacological investigation.

The biological activities reported for plant-derived matrices are largely attributable to specialized (secondary) metabolites, biosynthesized in response to ecological constraints rather than for primary growth (Cushnie & Lamb, 2005). Among these compounds, polyphenols—including phenolic acids, flavonoids, and condensed tannins—occupy a central position because they combine direct radical-scavenging properties with the capacity to modulate enzymatic activities and signaling pathways implicated in oxidative stress, postprandial hyperglycaemia, and neurodegeneration (Pietta, 2000). Their structural diversity and chemical reactivity, together with their ability to interact with biological targets through hydrogen-bond donation, single-electron transfer, and $\pi$–$\pi$ stacking, account for the breadth of their reported bioactivities (Pietta, 2000). The pharmacological relevance of polyphenol-rich food matrices is further supported by recent advances in analytical chemistry, which allow the precise fingerprinting of complex extracts and the rational interpretation of their *in vitro* bioactivities, thereby strengthening the translational potential of by-product-derived ingredients (Atanasov et al., 2021).

Within arid and semi-arid agro-ecosystems, the date palm, *Phoenix dactylifera* L. (Arecaceae), is one of the oldest cultivated fruit trees and a keystone crop of oasis agriculture across North Africa and the Middle East (Chao & Krueger, 2007). Its dates are recognized as an energy-dense functional food, characterized by a high content of simple sugars, dietary fiber, minerals, and phenolic antioxidants (Al-Farsi & Lee, 2008). Beyond its agronomic centrality, *P. dactylifera* structures the cultural and socioeconomic identity of Saharan populations, where it sustains both subsistence agriculture and export-oriented value chains (Chao & Krueger, 2007). It is therefore on the basis of its status as a major fruit crop—and not as a medicinal plant *sensu stricto*—that the species is examined in the present work, with particular attention directed to the bioactive potential of its seed fraction, which represents a substantial yet underexploited co-product of the date industry (Al-Farsi & Lee, 2008).

Algeria ranks among the leading date-producing countries worldwide and is distinguished by an exceptional intraspecific diversity, with hundreds of named cultivars maintained across its Saharan and pre-Saharan oases (Chao & Krueger, 2007). In southeastern Algeria, the El Oued (Souf) region constitutes a distinctive oasis agro-ecosystem, shaped by hyper-arid climatic conditions, sandy soils, and locally adapted cultivation practices that have allowed phoeniciculture to remain the structuring activity of the regional economy. Within this landscape, the 'Ghars' cultivar holds particular economic and cultural significance: it is a soft, sugar-rich variety, widely consumed locally and traditionally processed into date paste ( *Btana*), and it is closely associated with the alimentary identity of the Souf. Despite its regional prominence and its high level of fruit consumption, the chemical and biological characterization of its non-edible fractions—particularly the seeds—remains comparatively limited, leaving a clear scientific and industrial gap to be addressed.

Date seeds (pits) represent a major by-product of the date-processing industry, accounting for a substantial proportion of fruit mass and generated in considerable quantities wherever dates are industrially transformed (Al-Farsi & Lee, 2008). Long discarded or directed to low-added-value uses such as animal feed, these seeds are now recognized as a concentrated reservoir of dietary fiber, lipids, proteins, and phenolic constituents, with composition profiles that often surpass those of the edible flesh on a per-mass basis (Al-Farsi & Lee, 2008). Their valorization as a source of functional ingredients, of nutraceutical extracts, and of pharmaceutical-grade actives is therefore both a scientific and an economic imperative, and is fully consistent with the circular-bioeconomy framework applied to agro-food residues (Atanasov et al., 2021). Such valorization, however, requires a robust and cultivar-resolved phytochemical and pharmacological characterization, since composition and bioactivity are strongly dependent on genotype, ripening stage, and growing environment (Chao & Krueger, 2007).

In this context, phytochemical profiling of date seed extracts—coupled to targeted bioassays—has emerged as a rational strategy to connect chemical composition with biological function and to identify extracts of potential nutraceutical and pharmaceutical interest. Hydro-alcoholic systems, and in particular hydromethanolic mixtures, are widely adopted because they solubilize a broad spectrum of phenolic classes and yield extracts amenable to spectrophotometric quantification, chromatographic fingerprinting, and *in vitro* bioactivity screening (Al-Farsi & Lee, 2008). Nevertheless, locally resolved data on Algerian cultivars remain comparatively scarce, and dedicated studies on the seeds of the 'Ghars' cultivar from El Oued are still limited despite the cultural, agronomic, and economic prominence of this variety. Filling this gap directly contributes to the broader effort of valorizing the genetic resources of the Algerian Sahara and of providing a scientific basis for the integral exploitation of *P. dactylifera*, in which no part of the fruit is treated as residual.

The present dissertation therefore aims to characterize the phytochemical composition and to evaluate selected *in vitro* biological activities of the hydromethanolic extract of *Phoenix dactylifera* L. seeds from the 'Ghars' cultivar cultivated in the El Oued region (southeastern Algeria). To this end, cleaned, dried, and ground seeds were subjected to hydromethanolic maceration in order to prepare the crude extract and to determine its corresponding yield. The extract was subsequently analyzed for total phenolic, total flavonoid, and condensed tannin contents, and its phenolic profile was established by reversed-phase HPLC. The *in vitro* antioxidant activity was assessed through three complementary assays (DPPH, ABTS, and o-phenanthroline), while the inhibitory potential of the extract was evaluated against three biomedically relevant enzymes—α-amylase, α-glucosidase, and acetylcholinesterase—in order to explore its plausible antidiabetic and neuroprotective relevance. The thesis is structured into three chapters:

**First chapter** presents a bibliographic review of *P. dactylifera*, with emphasis on the seed fraction, its phytochemistry, and its reported biological activities.

**Second chapter** describes the experimental procedures applied to the El Oued seed material, from plant collection and extract preparation to phytochemical quantification, chromatographic profiling, and bioactivity assays;

**Third chapter** reports and discusses the results obtained, before drawing a general conclusion and outlining perspectives for the further valorization of 'Ghars' date seeds as a Saharan agro-industrial resource.

# CHAPTER I

**_Phoenix dactylifera_ L. Date Palm Seeds: Botanical, Phytochemical and Biological Activity**

## 1. Introduction

The date palm (*Phoenix dactylifera* L., Arecaceae) is among the oldest cultivated fruit trees of the human species and remains the keystone crop of arid and hyper-arid agro-ecosystems stretching from the Atlantic coast of Mauritania to the Indus Valley. For more than six millennia its sweet, energy-dense fruit has provided populations of North Africa and the Middle East with a staple food, a portable trade commodity and a culturally central element of religious and social life (Chao & Krueger, 2007; Al-Shahib & Marshall, 2003). Dates are exceptionally rich in simple sugars (60–80 % of dry weight), dietary fibre, minerals (notably potassium, magnesium and selenium), B-group vitamins and a diversified pool of phenolic antioxidants, a composition which underlies their persistent reputation as a functional food and which has been amply confirmed by modern nutritional and clinical studies (Al-Farsi & Lee, 2008; Vayalil, 2012; Hamad et al., 2015). World production today exceeds nine million tonnes per year and is concentrated in a small number of producing countries — Egypt, Saudi Arabia, Iran, Algeria, Iraq and the United Arab Emirates — in which the date palm continues to support both subsistence agriculture and an export-oriented value chain (FAO, 2022; Salomón-Torres et al., 2021).

Algeria occupies a singular place in this global landscape. With approximately one million tonnes of dates produced annually, the country ranks fourth worldwide and first in North Africa, and its phoenicicultural heritage is sustained by an exceptional intra-specific diversity: close to one thousand named cultivars are still recognised across the Saharan and pre-Saharan oases (Matallah et al., 2016; Rekis & Laiadi, 2020). Among these, four cultivars dominate the cultivated area and the domestic market and define the typology of Algerian dates: Deglet Nour ("finger of light"), the flagship semi-dry cultivar exported worldwide, prized for its translucent flesh, balanced sugar profile and long shelf life; Ghars, a soft, melting and highly sugary cultivar produced chiefly in the southeast and consumed predominantly on the domestic market and in traditional preparations; Mech-Degla, a dry to semi-dry cultivar of intermediate quality, widely grown for storage and as a source of date flour; and Degla Beïda ("white date"), a dry, hard, low-moisture cultivar destined for storage, animal feed and the preparation of date paste (Acourene & Tama, 1997; Benziouche & Cheriet, 2012; Boudries et al., 2007). Together these four cultivars structure the Algerian production landscape and underpin most of the phytochemical and nutritional studies reported on Algerian material.

Within this typology, the soft-fleshed variety Ghars holds a particular position. Originally selected in the palm groves of the Oued Righ and now widely cultivated in the El Oued - Souf area - of southeastern Algeria, Ghars is the most economically and culturally significant soft cultivar of the region. It owes its prominence to a combination of agronomic and organoleptic features rarely found together in a single cultivar: a high yield per palm, an early ripening period that fits the climatic window of the Souf, a melting and sticky texture at full maturity, a very high sugar content with a dominant fructose–glucose pattern, and excellent suitability for traditional preservation as date paste (*btana*) — a preparation that has historically served Saharan populations as a compact, storable food reserve through the dry season (Benziouche & Cheriet, 2012; Acourene & Tama, 1997). Beyond its commercial importance, Ghars is deeply embedded in the alimentary and ceremonial life of the Souf: it features prominently in the breaking of the Ramadan fast, in hospitality rituals and in traditional confectionery and is, for the inhabitants of the southeastern Algerian Sahara, the variety most readily associated with daily consumption. These attributes explain why Ghars has long attracted the attention of local producers, traders and, more recently, of researchers seeking to characterise the chemical basis of its sensory and nutritional profile (Benchikh & Louaileche, 2014; Bouhlali et al., 2017).

The very intensity of date production in Algeria, however, generates an under-recognised mass of by-products. Each kilogram of dates processed for the food industry yields roughly 100–150 g of seeds, which means that several tens of thousands of tonnes of date pits are produced each year in Algeria alone, the majority of which are still discarded, burned or used at low value as animal feed (Ghnimi et al., 2017; Hossain et al., 2014). Yet the date pit is not a waste: it is a compact biological reservoir of dietary fibre, lipids, proteins, mannans and galactomannans, and a remarkably rich pool of phenolic antioxidants, tocopherols and phytosterols (Habib & Ibrahim, 2009; Bouhlali et al., 2017; Alkhoori et al., 2022). Its rational valorisation — as a source of functional ingredients, of nutraceutical extracts, of cosmetic actives and of pharmacologically interesting molecules — is therefore both an economic and an environmental imperative, fully aligned with the contemporary paradigm of circular bioeconomy applied to agro-food residues. It is precisely this perspective that motivates the present work: by characterising in detail the phytochemistry and biological activities of the seeds of the Ghars cultivar from El Oued, we aim to contribute to the scientific case for the integral exploitation of *Phoenix dactylifera* L., in which no part of the fruit is treated as residual and every component is examined for its potential to deliver nutritional, therapeutic or industrial value.

## 2. Taxonomy and Botanical Description

### 2.1. Morphology and anatomy of the date palm

*Phoenix dactylifera* L. is a long-lived, dioecious, monocotyledonous tree characteristic of the family Arecaceae (Palmae). Mature individuals typically reach 15–25 m in height under cultivation, occasionally up to 30 m in old specimens, and may live productively for more than a century, with some palms reported to remain fruitful for two hundred years (Chao & Krueger, 2007; Salomón-Torres et al., 2021). The aerial axis is a non-branching, columnar trunk known botanically as a *stipe*, formed by the persistent leaf bases that gradually accumulate as the apical meristem advances upwards. The stipe is generally cylindrical, 30–50 cm in diameter, and exhibits a characteristic fibrous-lignified texture without true secondary growth, since palms lack a vascular cambium and instead rely on diffuse atactostelic vascular bundles distributed throughout the cortex.

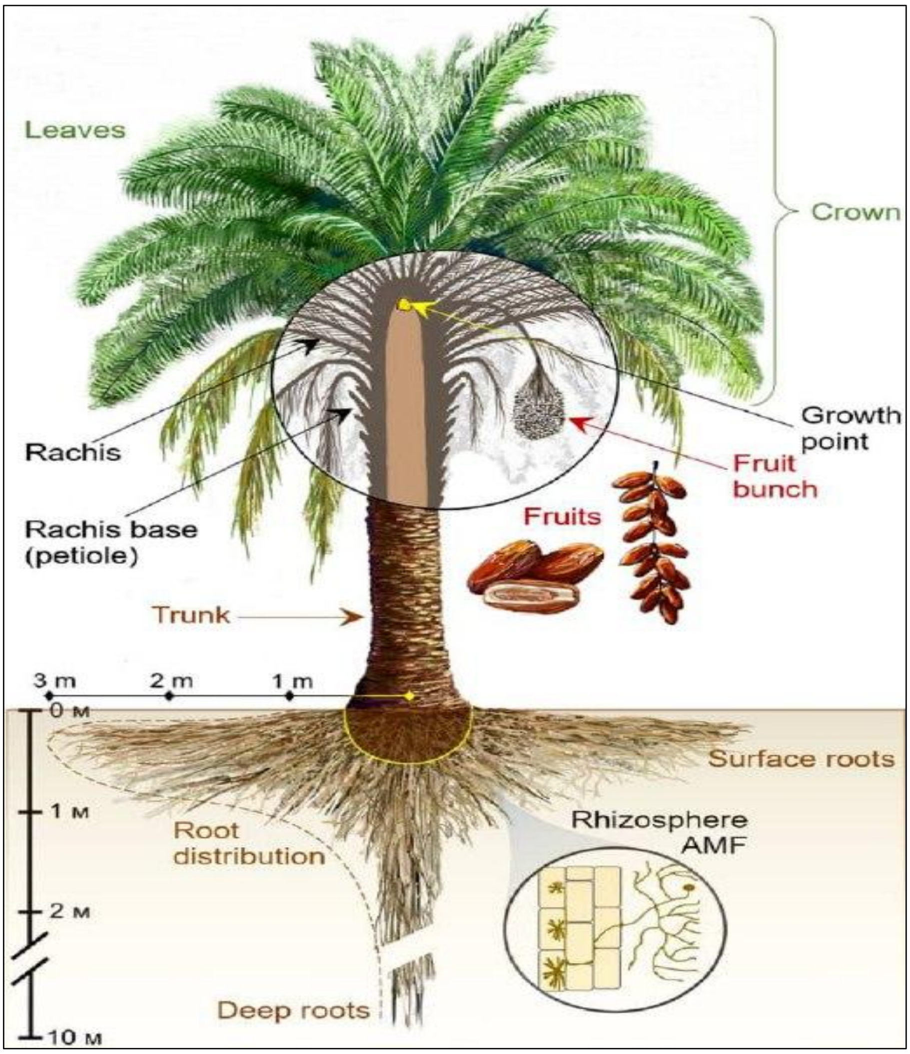


**Figure 1.** General morphology of the date palm (*Phoenix dactylifera* L., Arecaceae) showing the principal vegetative and reproductive organs: the crown of pinnate leaves with rachis and leaflets

(pinnae), the columnar trunk or stipe formed by persistent leaf bases, the pendulous fruit bunches (regimes) borne on long peduncles, and the root system composed of an extensive network of surface respiratory roots together with deep penetrating roots that reach phreatic water reserves typical of oasis hydrology. Schematic redrawn after Alotaibi et al. (2023).

Crowning the stipe is a rosette of 50–150 large pinnate leaves, technically called *fronds*, each measuring 3–6 m in length. Each frond consists of a stout, semi-rigid central axis (rachis) bearing on either side numerous lanceolate leaflets (pinnae) folded in V-shape and arranged in spiral pairs, with the basal leaflets transformed into rigid, sharp spines that are diagnostic of the genus *Phoenix* (Barrow, 1998; Salomón-Torres et al., 2021). The leaf base is broad, fibrous and persistently attached to the stipe; this structure, together with the imbricated leaf scars, gives the trunk its typical sculpted appearance. New fronds are produced apically at a rate of 10–20 per year, while the oldest are pruned away as they senesce; a productive palm therefore maintains, on average, 100–125 active fronds organised in helical phyllotaxis.

The date palm is strictly dioecious: male and female reproductive structures are borne on separate individuals. Inflorescences emerge in the leaf axils as compact, intrafoliar structures enclosed in a tough, spathe-like bract that splits longitudinally to release a much-branched panicle at anthesis (Salomón-Torres et al., 2017, 2021). Female inflorescences carry several thousand small, creamy-white flowers, each consisting of a tripartite calyx, three free petals and a tricarpellate gynoecium of which usually only one carpel develops into the mature fruit. Male flowers are smaller and produce abundant powdery pollen. In commercial cultivation, natural anemophilous pollination is largely replaced by manual or mechanical pollination, since a single male tree produces enough pollen to fertilise 50 or more females, and breeders prefer to maximise the proportion of fruit-bearing individuals in the orchard.

The fruit of *Phoenix dactylifera* is a one-seeded, fleshy berry developing from a single carpel, classified pomologically as a drupaceous berry rather than a true drupe because the lignified endocarp is not as discrete as in classical stone fruits. The mature fruit is oblong-ellipsoidal, 2–8 cm long and 1.5–3 cm wide depending on the cultivar, and ripens through four well-defined developmental stages traditionally known by their Arabic names: *kimri* (green, immature), *khalal* (full-size, hard, yellow or red), *rutab* (soft, partially translucent, beginning of ripening) and *tamr* (fully ripe, brown, with low water activity) (Chao & Krueger, 2007; Vayalil, 2012). The internal anatomy of the ripe fruit displays a thin, glossy *exocarp* (skin), a fleshy, sugary *mesocarp* that constitutes the edible part, and a thin, papery *endocarp* that wraps the single seed in close apposition.

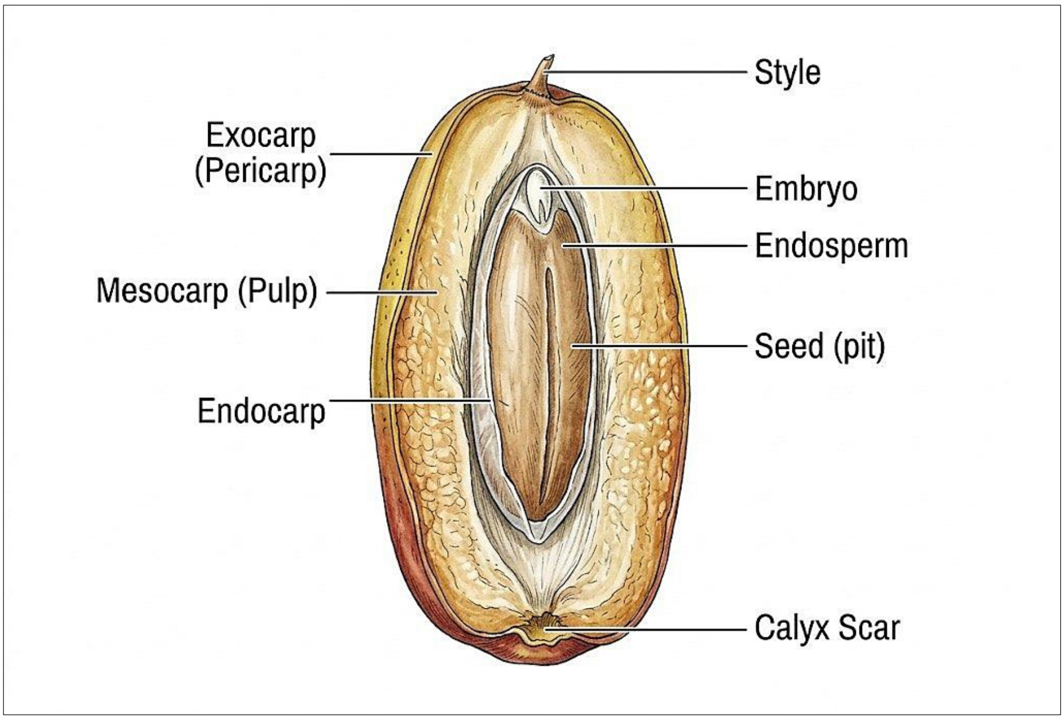


**Figure 2.** Internal anatomy of the date fruit (*Phoenix dactylifera* L.) shown in longitudinal section, with labelling of the four functional layers: the thin glossy exocarp (skin), the sugary fleshy mesocarp constituting the edible portion, the papery endocarp adherent to the seed, and the seed proper containing the lateral embryo embedded in a hard horny endosperm. After Chao and Krueger (2007); Alkhoori et al. (2022).

The seed itself, often referred to in the agronomic and food-science literature as the date pit or date stone, is a hard, oblong-ellipsoidal structure 1.5–3.0 cm long, 0.6–1.2 cm wide, weighing 0.5–1.5 g and accounting for roughly 6–15 % of the fresh fruit weight depending on cultivar and ripening stage (Alkhoori et al., 2022; Habib & Ibrahim, 2009). Externally, the seed bears a longitudinal *ventral furrow* running its full length, opposite to which a small, lateral, slightly depressed *micropyle* marks the position of the embryo. Internally, the bulk of the seed is occupied by a hard, horny *endosperm* composed of thick-walled cells with abundant cell-wall storage polysaccharides — chiefly mannans and galactomannans — and storage lipids and proteins. The embryo is small and lateral, embedded in a depression of the endosperm near the micropyle (Ishrud et al., 2001; Mrabet et al., 2020). The hardness of date seeds, much greater than that of most legume or oilseed crops, is largely due to the unusually thick mannan-rich endospermic cell walls.

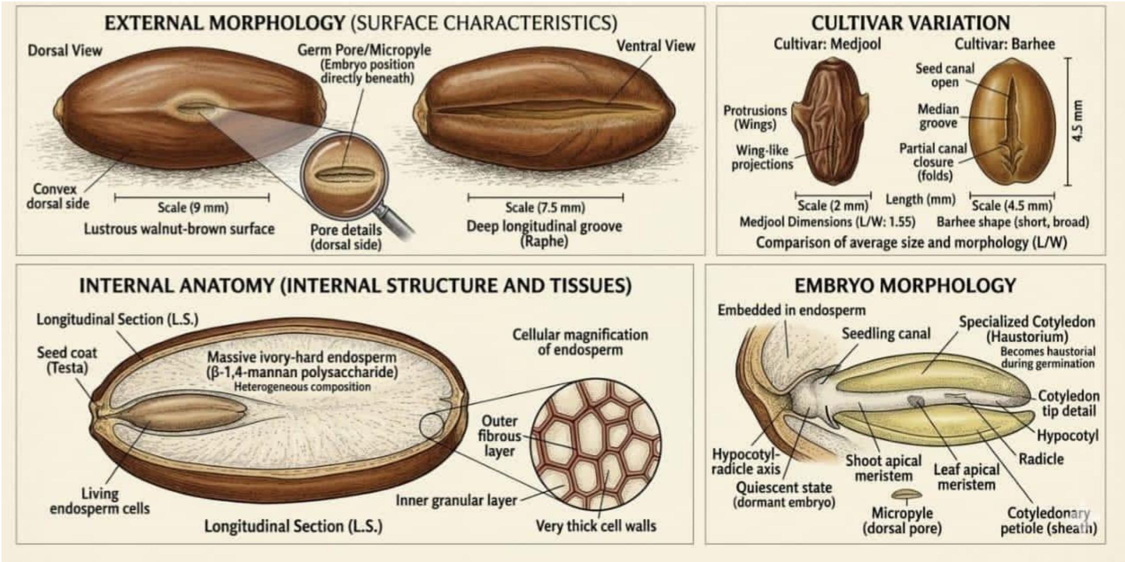


**Figure 3.** Morphology and internal anatomy of the date palm seed (*Phoenix dactylifera* L.). External view showing the elongated, oblong-ellipsoidal shape, ventral furrow and lateral micropyle (left); longitudinal section showing the hard horny endosperm composed of thick-walled mannan- and galactomannan-rich cells, the lateral embryo embedded near the micropyle, and the thin adherent endocarp (right). After Chao and Krueger (2007); Mrabet et al. (2020); Alkhoori et al. (2022).

The root system of the date palm is *fasciculate*, lacking a true taproot. Anatomically and functionally it is divided into four overlapping zones: a network of superficial *respiratory roots* in the upper 25 cm of soil that ensures gas exchange and absorbs surface irrigation; a denser zone of *nutritive roots* between 25 and 100 cm depth, where most uptake of mineralised water occurs; a deep system of *aquatic* or *piercing roots* that may reach the phreatic water table at 5–15 m, ensuring drought resistance even when surface soil is severely desiccated; and an *absorbing/transporting* zone with finer rootlets responsible for water and nutrient capture (Chao & Krueger, 2007). This dual architecture — extensive shallow uptake combined with deep phreatic anchorage — is the morphological key to the date palm's capacity to thrive in hyper-arid environments such as the Algerian Souf, where surface rainfall is minimal but groundwater is accessible at moderate depth.

Several xeromorphic anatomical adaptations explain the palm's notorious tolerance to heat, drought and saline soils. The leaflets are coated with a thick wax cuticle and bear sunken stomata in epidermal grooves; the leaf bases retain water-storing parenchyma; the trunk is heavily lignified yet hygroscopic; and the seed coat is mechanically reinforced by sclerenchymatous fibres and impregnated with phenolic polymers that delay imbibition and protect the embryo against rapid temperature and moisture variation (Vayalil, 2012; Chao & Krueger, 2007). Together, these features explain why *P. dactylifera* has remained the dominant fruit species of the Saharan oasis system for millennia and why its cultivation has played a structuring role in the human geography of arid lands.

### 2.2. Taxonomic position and nomenclature

The genus *Phoenix* L. comprises 14 currently accepted species distributed across the warm regions of the Old World, from the Canary Islands and the Mediterranean basin through tropical Africa and the Arabian Peninsula to South Asia and the Indo-Pacific (Barrow, 1998). Within this genus, *Phoenix dactylifera* L. is set apart by the conjunction of an arborescent habit, a true edible drupaceous berry, abundant manual or mechanical pollination requirements and extensive vegetative propagation by offshoots — features that have contributed to its early domestication. The species was formally described by Carl Linnaeus in *Species Plantarum* (1753), and the binomial *Phoenix dactylifera* L. has been retained without modification since.

Modern molecular phylogenies, anchored in plastid and nuclear markers, confirm the placement of *Phoenix* within the subfamily Coryphoideae, tribe Phoeniceae, of the family Arecaceae, in the monocot order Arecales of the angiosperm clade as defined by the APG IV system (Barrow, 1998; Sallon et al., 2020). Whole-genome analyses of cultivated and ancient *P. dactylifera* accessions, including the celebrated 2,000-year-old "Methuselah" seed germinated from material recovered at Masada, have further demonstrated that the species harbours both North African and Middle Eastern genetic contributions, consistent with long-standing gene flow across the Saharo-Arabian belt (Sallon et al., 2020). The complete taxonomic hierarchy, organised according to APG IV, is summarised in Table 1.

**Table 1.** Taxonomic classification of *Phoenix dactylifera* L. according to the APG IV system. ( Barrow, 1998; Chao and Krueger, 2007 ; Sallon et al., 2020 ; Hammiche and Maiza, 2006 ; Beloued, 2009)

| Rank | Scientific name |
|---|---|
| Domain | Eukaryota |
| Kingdom | Plantae |
| Superdivision | Spermatophyta |
| Division | Magnoliophyta (Angiospermae) |
| Class | Liliopsida (Monocotyledons) |
| Order | Arecales |
| Family | Arecaceae (Palmae) |
| Subfamily | Coryphoideae |
| Tribe | Phoeniceae |
| Genus | *Phoenix* L. |
| Species | *Phoenix dactylifera* L. |
| Common names | Date palm, *nakhla* (Arabic), *tamr*, *dattier*, *palmera datilera* |

The common names of the species reflect its remarkable cultural footprint. In classical and Maghrebi Arabic the tree is called نخلة (*nakhla*) and the fruit تمر (*tamr*); in Berber dialects of southern Algeria *tazdayt* is widely used; in French *dattier* designates the tree and *datte* the fruit; in English *date palm* is universal; in Persian and Urdu *khurma* is preferred; while the Latin epithet *dactylifera* — literally "finger-bearing" — refers metaphorically to the elongated shape of the fruit (Chao & Krueger, 2007; Beloued, 2009). It should be emphasised that several closely related but distinct *Phoenix* species occur in cultivation or in the wild and must not be confused with *P. dactylifera*: most notably *P. canariensis* H. Wildpret (Canary Island date palm, ornamental, with smaller, non-palatable fruit), *P. sylvestris* (L.) Roxb. (Indian wild date, used for sap and sugar production), *P. reclinata* Jacq. (Senegal date palm, sub-Saharan Africa) and *P. theophrasti* Greuter (Cretan date palm, native to the eastern Mediterranean) (Barrow, 1998; Nehdi et al., 2010). Comparative compositional studies on these congeneric species, although outside the main scope of the present chapter, provide useful interspecific reference points and confirm that the lipid profile and phytochemical signature of *P. dactylifera* seeds are clearly distinguishable from those of, for instance, *P. canariensis* (Nehdi et al., 2010).

### 2.3. Geographic origin, distribution and cultivation

The exact geographic origin of *Phoenix dactylifera* has been debated since the nineteenth century. Most contemporary accounts converge on a centre of origin in the lower Mesopotamian basin and the Persian Gulf coast, where archaeological remains attest to date consumption and cultivation as early as 6,000 BCE, with subsequent domestication corridors extending westwards into Egypt, the Maghreb and the Sahara, and eastwards into the Indus Valley (Chao & Krueger, 2007; Sallon et al., 2020). Population-genomic data on extant cultivars and on ancient germinated seeds support a more nuanced model in which two principal genetic pools — North African and Middle Eastern — diverged early and subsequently exchanged genes via long-distance trade and migration along the Saharo-Arabian belt; cultivars from the Algerian Sahara show clear affinity with the North African pool while retaining detectable Middle Eastern admixture (Sallon et al., 2020).

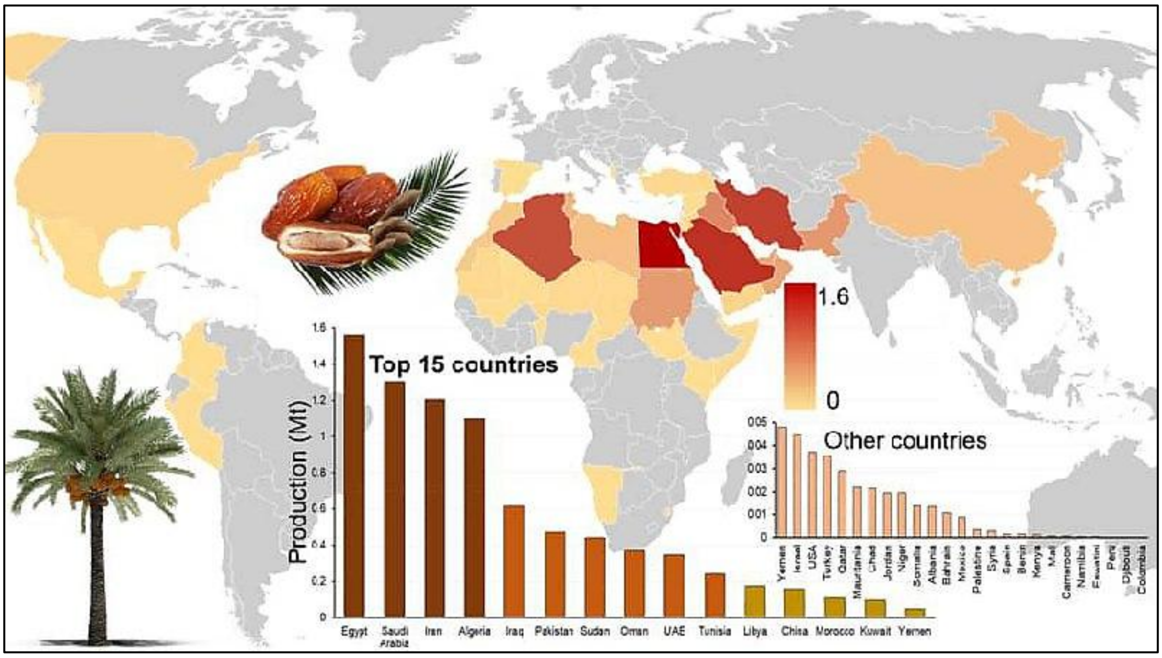


**Figure 4.** Global distribution of date palm (*Phoenix dactylifera* L.) production. The map indicates the top-fifteen producing countries together with secondary producers; symbol size encodes relative production volume in tonnes per year. Egypt, Saudi Arabia, Iran, Algeria, Iraq, Pakistan and the United Arab Emirates dominate world output, while Tunisia, Morocco, Sudan, Oman, Libya, Yemen, Turkey and the United States complete the top fifteen. Adapted from Alotaibi et al. (2023).

At present, the date palm is cultivated commercially across the warm-arid belt of the Old World and, on a smaller scale, in California, Arizona and northern Mexico (Salomón-Torres et al., 2017). According to FAO statistics summarised in recent reviews, world annual production exceeds nine million tonnes of fresh dates, with Egypt, Saudi Arabia, Iran, Algeria and Iraq accounting for more than 60 % of the total. Algeria alone produces approximately one million tonnes per year, ranking fourth globally and first in North Africa, with the bulk of production concentrated in the southeastern wilayas of Biskra, El Oued, Ouargla, Touggourt and Ghardaïa (Djaoudene et al., 2019; Ould El Hadj, Sebihi, & Zerrouk, 2003). Within Algeria, the Souf region and the Oued Righ valley, both situated in the eastern Bas-Sahara, host distinctive oasis systems characterised by hyper-arid climate, very high summer temperatures (often above 45 °C), negligible rainfall (< 80 mm per year) and reliance on phreatic groundwater for irrigation. The Souf in particular is famous for the *ghout* system, in which palm groves are sunk into shallow craters dug to bring root systems closer to the water table — an agro-engineering tradition unique to the region.

Agro-ecologically, the date palm is exceptionally well adapted to hot-arid conditions. Optimum growth occurs at mean annual temperatures of 20–30 °C, summer maxima of 40–48 °C and winter minima above 0 °C; the species tolerates short frosts down to −6 °C without lasting damage but suffers fruit losses below freezing during ripening (Chao & Krueger, 2007). It thrives on deep, well-drained sandy or sandy-loam soils of neutral to alkaline pH (7.5–8.5), tolerates high salinity (electrical conductivity up to 12 dS $m^{-1}$) and shows remarkable resistance to wind and ground-level dust. Crucially, the species is poorly adapted to humid tropical climates, where pollen germination is impaired and fruit ripening is incomplete; the highest-quality dates are therefore obtained in continental hyper-arid climates with very dry summers, such as those of the Algerian Sahara (Djaoudene et al., 2019; Salomón-Torres et al., 2021). Under such conditions, a mature productive palm yields 50–150 kg of fresh fruit per year over a productive life of 60–80 years, although yields of 200 kg or more are reported for elite cultivars under intensive management.

**Table 2.** Major date-producing regions, dominant climate types and main commercial uses of date palm (*Phoenix dactylifera* L.) products (original).

| Region / country | Climate | Main uses | References |
|---|---|---|---|
| Egypt (Nile Valley, New Valley) | Arid Saharan, irrigated | Fresh and semi-dry dates, syrup, confectionery, animal feed | Chao and Krueger (2007); Djaoudene et al. (2019) |
| Saudi Arabia (Al-Qassim, Al-Madinah) | Hyper-arid desert | Premium dry/semi-dry dates (Ajwa, Sukkari, Khalas), nutraceutical seed extracts | Hamad et al. (2015); Al-Yahya et al. (2016) |
| Iran (Khuzestan, Fars, Kerman) | Continental arid | Soft and semi-dry dates, syrup (*shireh*), traditional medicine | Aoudeh et al. (2023); Vayalil (2012) |
| Algeria — Biskra, El Oued, Oued Righ, Ouargla, Ghardaïa | Saharan hyper-arid, phreatic irrigation, oasis (*ghout*) system | Premium dry dates (Deglet Nour), soft dates (Ghars), syrup, traditional medicine, seed valorisation | Djaoudene et al. (2019); Ould El Hadj, Sebihi, and Zerrouk (2003); Bentrad et al. (2017); Boudries et al. (2012) |
| Iraq (Basra, Diyala) | Continental hot-arid | Diverse cultivars, syrup, fermented products | Chao and Krueger (2007); Aoudeh et al. (2023) |
| Pakistan (Sindh, Balochistan) | Hot-arid | Fresh and semi-dry dates, vinegar, animal feed | Chao and Krueger (2007); Vayalil (2012) |
| United Arab Emirates | Hyper-arid coastal desert | Premium fresh dates, seed coffee, functional foods | Habib and Ibrahim (2009); Hilary et al. (2020); Platat et al. (2019) |
| Tunisia (Djerid, Nefzaoua) | Saharan arid | Premium dry dates (Deglet Nour, Allig), syrup, seed oil | Besbes et al. (2004); Kchaou et al. (2013); Chaira et al. (2013) |

| | | | |
|---|---|---|---|
| Morocco (Tafilalet, Drâa) | Pre-Saharan arid | Semi-dry dates, seed extracts, traditional remedies | Bouhlali et al. (2017, 2020) |
| United States (California, Arizona) | Mediterranean–arid (Coachella) | Premium Medjool, Deglet Nour | Salomón-Torres et al. (2017, 2021) |

### 2.4. Date palm cultivars with emphasis on Ghars

The intra-specific diversity of *Phoenix dactylifera* is exceptional. More than 3,000 cultivars are recognised worldwide on the basis of fruit morphology, texture, sugar composition, ripening behaviour, agronomic performance and resistance to abiotic and biotic stresses, of which several hundred are considered commercially important (Chao & Krueger, 2007). Algeria alone harbours approximately 1,000 named cultivars, often locally distributed and frequently undergoing erosion as oases are converted to monoculture of the high-value cultivar Deglet Nour for the export market (Djaoudene et al., 2019; Matallah et al., 2016; Rekis & Laiadi, 2020). Three pomological categories are conventionally distinguished according to the moisture content of the ripe fruit: soft dates (> 30 % moisture, as Ghars and Medjool); semi-dry dates (15–30 % moisture, as Deglet Nour); and dry dates (< 15 % moisture, as Degla Beïda and Mech-Degla). The same triad structures the Algerian production landscape, with Deglet Nour exported globally as the flagship semi-dry cultivar, and Ghars and Degla Beïda primarily destined for the domestic market and traditional preparations (Ould El Hadj, Sebihi, & Zerrouk, 2003).

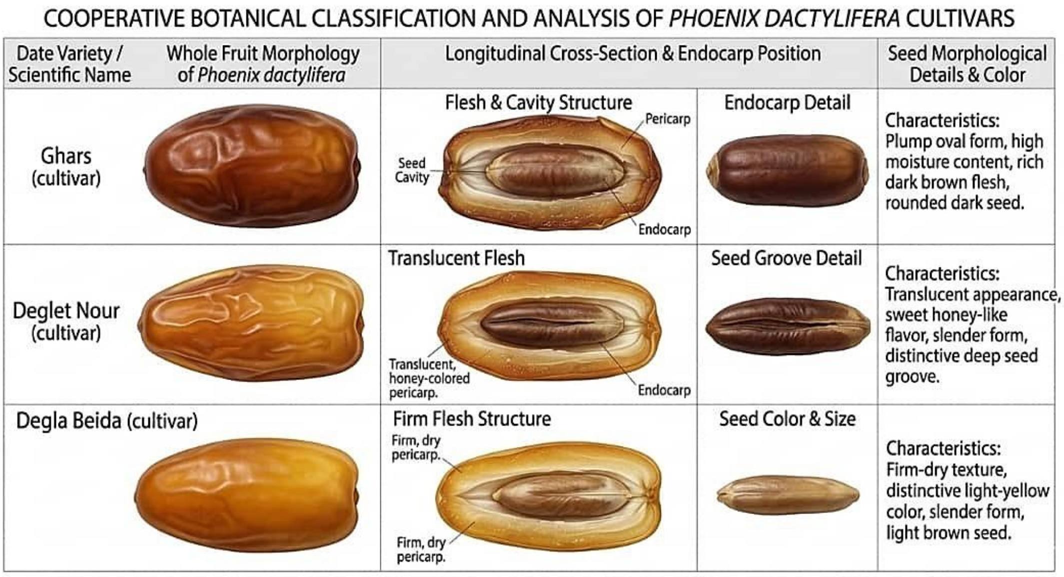


**Figure 5.** Comparative botanical characterisation of three representative Algerian date palm cultivars: Ghars (soft), Deglet Nour (semi-dry, "finger of light") and Degla Beïda (dry, "white date"). For each cultivar are shown the whole fruit morphology, longitudinal section illustrating the relative position and adherence of the endocarp, and the seed in dorsal and ventral views. Compiled from

Ould El Hadj, Sebihi, and Zerrouk (2003); Matallah et al. (2016); Rekis and Laiadi (2020); Boudries et al. (2012).

The cultivar Ghars occupies a particular place in the present dissertation and merits a dedicated description. Originally selected in the Oued Righ palm groves and now widely cultivated in the El Oued/Oued Souf area of southeastern Algeria, Ghars is a soft date with high moisture content at the *rutab* and *tamr* stages and a characteristically tender, sticky, melting texture that places it organoleptically among the prized varieties of the Maghreb (Ould El Hadj, Sebihi, & Zerrouk, 2003; Boudries et al., 2012). The fruit is typically oblong-ellipsoidal, 4.0–4.5 cm long (mean 4.35 cm) and 1.8–2.2 cm wide, with a fresh weight of 8–12 g; the skin is thin, and the colour evolves from greenish-yellow at *khalal* to amber and finally light brown at full maturity. The mesocarp is highly sugary with a dominant fructose–glucose pattern typical of soft dates, and is particularly appreciated in traditional Algerian cuisine and in the preparation of *btana* (preserved dates) and date paste (Djaoudene et al., 2019).

The seed of Ghars is itself one of the most lipid-rich among Algerian cultivars. Boukouada and Yousfi (2009), Boudries et al. (2012) and Amir Hamzah et al. (2022) consistently report that Ghars seeds contain approximately 4.5–5.5 % oil on a dry weight basis, with a fatty-acid profile dominated by oleic acid (42–50 %) and lauric acid (18–22 %). Phenolic content is also notable, with values reported in the upper part of the range observed across Algerian cultivars (Benchikh, Louaileche, George, & Merlin, 2014; Benmeddour et al., 2013). Bentrad et al. (2017) further demonstrated that organic extracts of Ghars seeds display antimicrobial activity against several human pathogens, while Benali et al. (2025) provided the first integrated phytochemical and biological evaluation of an ethanolic extract of Ghars seeds, including formulation as a cosmetic cream with antioxidant and anti-inflammatory activity. These findings, taken together, position Ghars not only as a culturally important cultivar of the Souf and Oued Righ but as a chemically interesting source of bioactive compounds whose systematic study is still incomplete.

For comparison, Deglet Nour ("finger of light"), the flagship Algerian cultivar exported worldwide, is a semi-dry date with translucent flesh, elongated shape (4.5–6.5 cm long), low moisture (< 25 %) at full maturity, and a characteristic light amber colour. Its seed is smaller, denser and contains slightly less oil than that of Ghars, with a fatty-acid profile broadly similar but variable inter-cultivar differences in polyphenols (Besbes et al., 2004; Benchikh, Louaileche, George, & Merlin, 2014; Benmeddour et al., 2013). Degla Beïda ("white date") is a dry, hard, low-moisture cultivar widely grown in the same regions as Ghars and used principally for storage and animal feed; its seed has been included in several comparative studies of Algerian seed oils and shows compositional patterns consistent with the broad *P. dactylifera* template, with no major qualitative deviation (Boukouada & Yousfi, 2009; Nouri et al., 2015). Beyond these three principal cultivars, dozens of secondary varieties — including Tantboucht, Hamraia, Tafezouine, Mech-Degla, Ourous and others — contribute to the genetic and chemical mosaic of the Algerian Sahara (Boudries et al., 2007; Matallah et al., 2016; Djaoudene et al., 2022).

**Table 3.** Comparative morphological and biochemical traits of three representative Algerian date palm cultivars (Ghars, Deglet Nour, Degla Beïda).

| Cultivar | Fruit weight (g) | Length (cm) | Texture | Colour at maturity | Maturity period | References |
|---|---|---|---|---|---|---|
| **Ghars** | 8–12 | 4.0–4.5 | Soft, melting, sticky | Greenish-yellow → amber → light brown | Late October – November | Ould El Hadj, Sebihi, and Zerrouk (2003); Boudries et al. (2012); Amir Hamzah et al. (2022); Djaoudene et al. (2019) |
| **Deglet Nour** | 9–14 | 4.5–6.5 | Semi-dry, translucent, firm-tender | Translucent light amber to honey-brown | November – December | Besbes et al. (2004); Benmeddour et al. (2013); Djaoudene et al. (2019); Matallah et al. (2016) |
| **Degla Beïda** | 6–10 | 3.0–4.0 | Dry, hard | Pale yellow to whitish-tan | Late November – December | Boukouada and Yousfi (2009); Nouri et al. (2015); Matallah et al. (2016) |
| **Tantboucht** | 7–11 | 3.5–4.2 | Soft to semi-dry | Reddish-brown | November | Boudries et al. (2007); Djaoudene et al. (2022) |
| **Hamraia** | 6–9 | 3.2–4.0 | Semi-dry | Dark red to brown | November | Boudries et al. (2007); Mansouri et al. (2005) |
| **Tafezouine** | 7–10 | 3.5–4.3 | Semi-dry | Reddish-brown | November | Boukouada and Yousfi (2009); Nouri et al. (2015) |

The morphological and biochemical diversity captured in Table 3 has direct consequences for the seeds. Soft cultivars such as Ghars and Tantboucht generally yield seeds with slightly higher lipid content and a softer, less compact endocarp than dry cultivars such as Degla Beïda, while polyphenol content is more strongly determined by genotype × environment interactions and ripening stage than by fruit-flesh texture *per se* (Benchikh, Louaileche, George, & Merlin, 2014; Benmeddour et al., 2013; Yaiche Achour et al., 2022). This diversity is one of the principal reasons why systematic, cultivar-resolved phytochemical and pharmacological studies on Algerian date palm seeds — particularly on Ghars from El Oued — are needed, and constitute the broader scientific context of the present work.

## 3. Nutritional Composition of Date Palm Seeds

Date palm seeds were long regarded as an inedible by-product of date processing and were used principally as fodder for camels, cattle and small ruminants, or as raw material for charcoal-like roasted "date-seed coffee" prepared in traditional Saharan and Arabian households (Al-Shahib & Marshall, 2003; Alkhoori et al., 2022). Modern analytical work has, however, transformed this image. The seeds are now recognised as a uniquely concentrated source of dietary fibre, lipids and bioactive phytochemicals, with a nutrient density that, gram for gram, exceeds that of most other agro-industrial residues. Gram for gram, date seeds offer a higher proportion of polyphenols and a more diversified lipid profile than the edible flesh, which has motivated their incorporation into bakery, dairy and beverage formulations as a functional ingredient (Habib & Ibrahim, 2009; Platat et al., 2015; Muñoz-Tebar et al., 2023; Benchikh & Louaileche, 2014). The following sections summarise the present state of knowledge on the proximate, micronutrient, amino-acid, fatty-acid and structural-carbohydrate composition of date palm seeds, with emphasis on Algerian cultivars where data are available.

### 3.1. Proximate composition

The proximate composition of *Phoenix dactylifera* seeds has been characterised in numerous studies covering cultivars from the Maghreb, the Middle East and South Asia. Despite differences in analytical methodology and reporting conventions (dry weight versus fresh weight), the published data converge on a coherent compositional template. Total carbohydrates, of which the overwhelming majority is dietary fibre, dominate the seed and account for 65–85 % of dry weight; crude lipids represent 5–13 %; crude protein 5–9 %; ash 1.0–2.0 %; and moisture in fully dried seeds 5–10 % (Besbes et al., 2004; Habib & Ibrahim, 2009; Alhaj et al., 2010; Bouhlali et al., 2017; Alkhoori et al., 2022). These values place date seeds among the most fibre-rich plant materials known, with total dietary fibre frequently exceeding 70 % of dry mass and reaching 80–84 % in some Emirati cultivars (Habib & Ibrahim, 2009; Hilary et al., 2020).

The crude protein content of date seeds is modest in absolute terms (5–9 %) but corresponds to a meaningful contribution when seeds are incorporated into staple foods such as bread or yoghurt

(Platat et al., 2015; Benchikh & Louaileche, 2014). Importantly, this protein is well-balanced in essential amino acids, as detailed in Section 3.3. The lipid content (5–13 %) is notable for an endosperm-storage tissue and confers genuine industrial value: extracted seed oil shows physicochemical properties — peroxide value, free acidity, refractive index — broadly comparable to those of sub-tropical edible oils such as palm-kernel and coconut oil, and a fatty-acid profile combining the saturated medium-chain pattern of those oils with a substantial unsaturated fraction dominated by oleic acid (Besbes et al., 2004; Zaaboul & Liu, 2022; Amir Hamzah et al., 2022). Algerian cultivars reported by Boukouada and Yousfi (2009), Nouri et al. (2015), Boudries et al. (2012) and Amir Hamzah et al. (2022) fall within these ranges, with Ghars in the upper part of the lipid distribution (4.5–5.5 %, sometimes higher), Deglet Nour intermediate, and Degla Beïda at the lower end. The very low ash content (typically 1.0–1.8 %) reflects the parsimonious mineralisation of the endosperm storage tissue compared with leafy or legume tissues.

**Table 4.** Proximate composition of date palm (*Phoenix dactylifera* L.) seeds (g/100 g dry weight).

| Constituent / Cultivar(s) studied | Range (g/100 g DW) | Mean ± SD | References |
|---|---|---|---|
| Moisture — Deglet Nour and Allig (Tunisia, Besbes); 18 UAE cultivars including Khalas, Lulu, Barhi (Habib & Ibrahim); 14 Algerian cultivars (Alhaj) | 5.0 – 10.0 | 7.4 ± 1.4 | Besbes et al. (2004); Habib and Ibrahim (2009); Alhaj et al. (2010) |
| Crude protein — Deglet Nour and Allig; 14 Algerian cultivars (Alhaj); three Moroccan cultivars Bouskri, Aziza, Boufeggous (Bouhlali); four Indian cultivars Hillawi, Khadrawi, Shamran, Medjool (Singh & Singh) | 5.0 – 9.0 | 6.4 ± 1.0 | Besbes et al. (2004); Alhaj et al. (2010); Bouhlali et al. (2017); Singh and Singh (2012) |
| Crude lipids — Deglet Nour and Allig; three Algerian cultivars Ghars, Degla Beïda, Tafezouine (Boukouada & Yousfi; Nouri); Algerian Ghars and Tafezouine seed oils (Amir Hamzah); review on lipid fraction (Zaaboul & Liu) | 5.0 – 13.0 | 9.1 ± 2.1 | Besbes et al. (2004); Boukouada and Yousfi (2009); Nouri et al. (2015); Amir Hamzah et al. (2022); Zaaboul and Liu (2022) |
| Total carbohydrates — Deglet Nour and Allig; 18 UAE cultivars; 14 Algerian cultivars; UAE Khalas seed (Hilary) | 65.0 – 85.0 | 78.0 ± 4.6 | Besbes et al. (2004); Habib and Ibrahim (2009); Alhaj et al. (2010); Hilary et al. (2020) |
| Total dietary fibre — review of Omani Khalas, Khasab, Fardh (Al-Farsi & Lee, 2008b); 18 UAE | 55.0 – 84.0 | 73.1 ± 6.7 | Al-Farsi and Lee (2008b); Habib and Ibrahim (2009); Hilary |

| | | | |
|---|---|---|---|
| cultivars; UAE Khalas seed (Hilary); Tunisian Deglet Nour, Allig, Kentichi (Mrabet) | | | et al. (2020); Mrabet et al. (2020) |
| – Insoluble dietary fibre — 18 UAE cultivars; Tunisian Deglet Nour, Allig, Kentichi; Tunisian Deglet Nour fibre fractions (Elleuch) | 50.0 – 78.0 | 66.4 ± 6.1 | Habib and Ibrahim (2009); Mrabet et al. (2020); Elleuch et al. (2011) |
| – Soluble dietary fibre — 18 UAE cultivars; Tunisian Deglet Nour, Allig, Kentichi; Tunisian Deglet Nour fibre fractions | 2.5 – 8.0 | 5.0 ± 1.4 | Habib and Ibrahim (2009); Mrabet et al. (2020); Elleuch et al. (2011) |
| Ash — Deglet Nour and Allig; 14 Algerian cultivars; 18 UAE cultivars; four Indian cultivars Hillawi, Khadrawi, Shamran, Medjool | 1.0 – 2.0 | 1.4 ± 0.2 | Besbes et al. (2004); Alhaj et al. (2010); Habib and Ibrahim (2009); Singh and Singh (2012) |
| Energy (kcal/100 g) — 18 UAE cultivars; 14 Algerian cultivars; review (Alkhoori) | 380 – 460 | 425 ± 22 | Habib and Ibrahim (2009); Alhaj et al. (2010); Alkhoori et al. (2022) |

The unusually high dietary fibre content of date seeds is a consequence of their endosperm structure, in which most carbohydrate is stored as cell-wall mannans, galactomannans and cellulose rather than as free sugars or starch (Ishrud et al., 2001; Mrabet et al., 2020; Elleuch et al., 2011). Insoluble fibre dominates at 60–78 %, while soluble fibre — much of it constituted by water-extractable galactomannans — accounts for 3–8 %. This composition has direct consequences for the technological functionality of date seed flour, which exhibits high water-holding capacity (3–6 g water per g flour), substantial oil-absorption capacity (1.5–3 g oil per g) and pronounced swelling properties, all of which favour incorporation into baked goods and dairy products as a bulking and texturising agent (Mrabet et al., 2020; Platat et al., 2015; Benchikh & Louaileche, 2014). It also underpins the prebiotic and metabolic effects discussed in Section 5.6.

### 3.2. Mineral and vitamin content

Date palm seeds contain a relatively modest but well-diversified mineral fraction, with potassium, magnesium, calcium and phosphorus as the dominant macroelements and iron, zinc, copper, manganese and selenium as trace elements (Habib & Ibrahim, 2009; Alhaj et al., 2010; Singh & Singh, 2012; Hamad et al., 2015). Potassium consistently emerges as the most abundant mineral, with values commonly reported between 200 and 700 mg/100 g dry weight, followed by magnesium (50–110 mg/100 g), calcium (20–70 mg/100 g) and phosphorus (50–110 mg/100 g).

Iron is particularly notable on a 100 g basis (3–14 mg/100 g), making date seed flour a useful contributor to dietary iron intake when incorporated into staple foods (Habib & Ibrahim, 2009; Singh & Singh, 2012). Zinc, copper, manganese and selenium are present at lower but biologically meaningful concentrations and contribute, together with several phenolic constituents, to the antioxidant capacity of seed extracts (Alkhoori et al., 2022; Alu'datt et al., 2025).

The vitamin profile of date seeds has been less systematically studied than that of the flesh. Nevertheless, the available data indicate appreciable levels of fat-soluble vitamins, particularly vitamin E (tocopherols and tocotrienols), discussed in detail in Section 4.3 because of its joint nutritional and pharmacological relevance, together with smaller amounts of provitamin A (β-carotene and related carotenoids) and traces of B-group vitamins inherited from the embryonic tissue (Boudries et al., 2007; Kamal-Eldin & George, 2020; Muñoz-Tebar et al., 2023). The carotenoid fraction is more abundant in the flesh than in the seed but has been characterised in Algerian cultivars including Ghars (Boudries et al., 2007). Among lipophilic vitamins, α-tocopherol predominates in seed oils and reaches values of 200–450 mg/kg in some Algerian cultivars (Amir Hamzah et al., 2022).

Comparative work on Algerian and other North African seeds (Boudries et al., 2007; Boukouada & Yousfi, 2009; Nouri et al., 2015; Amir Hamzah et al., 2022) confirms that the mineral and lipophilic-vitamin patterns are conserved across the Algerian cultivar mosaic, with quantitative variation that is more strongly linked to soil mineralisation, irrigation water composition and ripening stage than to genotype *per se*. From a nutritional standpoint, the implication is straightforward: date seed flour or seed oil can be expected to contribute meaningfully to potassium, magnesium and α-tocopherol intake when incorporated into food matrices, while their iron content represents a useful complement in diets where animal-source iron is limited (Platat et al., 2015; Muñoz-Tebar et al., 2023).

**Table 5.** Mineral and vitamin content of date palm seeds (per 100 g dry weight unless otherwise stated).

| Element / Vitamin and Cultivar(s) studied | Range | References |
|---|---|---|
| Potassium (mg) — 18 UAE cultivars; 14 Algerian cultivars; four Indian cultivars Hillawi, Khadrawi, Shamran, Medjool; Saudi cultivars (Hamad, metabolomic study of multiple cv.) | 200 – 700 | Habib and Ibrahim (2009); Alhaj et al. (2010); Singh and Singh (2012); Hamad et al. (2015) |
| Magnesium (mg) — 18 UAE cultivars; 14 Algerian cultivars; four Indian cultivars (Hillawi, Khadrawi, Shamran, Medjool) | 50 – 110 | Habib and Ibrahim (2009); Alhaj et al. (2010); Singh and Singh (2012) |

| | | |
|---|---|---|
| Calcium (mg) — 18 UAE cultivars; 14 Algerian cultivars; four Indian cultivars | 20 – 70 | Habib and Ibrahim (2009); Alhaj et al. (2010); Singh and Singh (2012) |
| Phosphorus (mg) — 18 UAE cultivars; 14 Algerian cultivars | 50 – 110 | Habib and Ibrahim (2009); Alhaj et al. (2010) |
| Sodium (mg) — 18 UAE cultivars; four Indian cultivars | 5 – 35 | Habib and Ibrahim (2009); Singh and Singh (2012) |
| Iron (mg) — 18 UAE cultivars; four Indian cultivars | 3 – 14 | Habib and Ibrahim (2009); Singh and Singh (2012) |
| Zinc (mg) — 18 UAE cultivars; 14 Algerian cultivars | 0.4 – 1.2 | Habib and Ibrahim (2009); Alhaj et al. (2010) |
| Copper (mg) — 14 Algerian cultivars; four Indian cultivars (Hillawi, Khadrawi, Shamran, Medjool) | 0.2 – 0.8 | Alhaj et al. (2010); Singh and Singh (2012) |
| Manganese (mg) — 18 UAE cultivars; 14 Algerian cultivars | 0.1 – 1.0 | Habib and Ibrahim (2009); Alhaj et al. (2010) |
| Selenium (µg) — 14 Algerian cultivars; review of multiple cultivars (Alkhoori) | 1 – 6 | Alhaj et al. (2010); Alkhoori et al. (2022) |
| α-Tocopherol (mg/kg oil) — Algerian Ghars and Tafezouine seed oils; review including UAE Khalas (Kamal-Eldin & George); *Phoenix canariensis* seed oil from Saudi Arabia (Nehdi) | 200 – 450 | Amir Hamzah et al. (2022); Kamal-Eldin and George (2020); Nehdi et al. (2010) |
| Total tocopherols (mg/kg oil) — Algerian Ghars and Tafezouine; review chapter on date fruit chemistry | 250 – 600 | Amir Hamzah et al. (2022); Kamal-Eldin and George (2020) |
| β-Carotene (µg/100 g, seeds) — Algerian Deglet-Nour, Hamraya, Tantebouchte (Boudries); review of by-product valorization | trace – 50 | Boudries et al. (2007); Muñoz-Tebar et al. (2023) |
| B-group vitamins (thiamine, riboflavin, niacin) — review of multiple cultivars (Al-Shahib & Marshall); review (Alkhoori) | trace amounts | Al-Shahib and Marshall (2003); Alkhoori et al. (2022) |

### 3.3. Amino acid and fatty acid profiles

The protein fraction of date palm seeds, although quantitatively modest, is nutritionally well-balanced. Comprehensive amino-acid analyses by Alhaj et al. (2010) and Singh and Singh (2012), corroborated by Hamad et al. (2015) on Saudi cultivars, demonstrate that all essential amino acids are present in nutritionally relevant amounts. Glutamic acid and aspartic acid are the most abundant non-essential amino acids, each accounting for 9–14 % of total amino-acid nitrogen, while leucine, valine, phenylalanine, lysine and arginine dominate the essential and conditionally essential pool. Lysine — typically limiting in cereal-based diets — reaches 280–400 mg/100 g of seed dry weight, supporting the use of date seed flour as a complement to wheat or millet (Alhaj et al., 2010; Singh & Singh, 2012). Methionine and tryptophan are present at lower but detectable concentrations, and their values place date seeds within nutritional ranges typical of palmaceous endosperm tissues.

From a functional standpoint, the amino-acid profile contributes to the technological behaviour of date seed flour in dough systems, where free amino acids and short peptides influence Maillard browning, aroma generation and antioxidant activity during baking (Platat et al., 2015).

**Table 6.** Major fatty acids of date seed (*Phoenix dactylifera* L.) oil (% of total fatty acids).

| Fatty acid / Cultivar(s) studied | Symbol | Range (% of total FA) | Type | References |
|---|---|---|---|---|
| Caprylic acid — Tunisian Deglet Nour and Allig; *Phoenix canariensis* seed oil (Saudi Arabia); review of lipid fraction | C8:0 | 0.1 – 1.5 | SFA | Besbes et al. (2004); Nehdi et al. (2010); Zaaboul and Liu (2022) |
| Capric acid — Tunisian Deglet Nour and Allig; *Phoenix canariensis* seed oil | C10:0 | 0.2 – 1.8 | SFA | Besbes et al. (2004); Nehdi et al. (2010) |
| Lauric acid — Tunisian Deglet Nour and Allig; Algerian Ghars, Degla Beïda, Tafezouine; Algerian Ghars and Tafezouine seed oils; review | C12:0 | 12.0 – 23.0 | SFA, medium-chain | Besbes et al. (2004); Boukouada and Yousfi (2009); Nouri et al. (2015); Amir Hamzah et al. (2022); Zaaboul and Liu (2022) |
| Myristic acid — Tunisian Deglet Nour and Allig; Algerian Ghars and Degla Beïda; Algerian Ghars and Tafezouine; review | C14:0 | 8.0 – 12.0 | SFA, medium-chain | Besbes et al. (2004); Nouri et al. (2015); Amir Hamzah et al. (2022); Zaaboul and Liu (2022) |
| Palmitic acid — Tunisian Deglet Nour and Allig; Algerian Ghars, Degla Beïda, Tafezouine; Algerian Ghars (Oued Righ); Algerian Ghars seed oil | C16:0 | 8.0 – 13.0 | SFA | Besbes et al. (2004); Boukouada and Yousfi (2009); Boudries et al. (2012); Amir Hamzah et al. (2022) |
| Stearic acid — Tunisian Deglet Nour and Allig; Algerian Ghars and Degla Beïda; Algerian Ghars seed oil | C18:0 | 2.5 – 5.5 | SFA | Besbes et al. (2004); Nouri et al. (2015); Amir Hamzah et al. (2022) |
| Oleic acid — Tunisian Deglet Nour and Allig; Algerian Ghars, Degla Beïda, Tafezouine; Algerian cultivars Oued Righ; Algerian Ghars seed oil; Algerian seed pollens and seeds (Bentrad); review | C18:1 ω-9 | 35.0 – 55.0 | MUFA | Besbes et al. (2004); Boukouada and Yousfi (2009); Boudries et al. (2012); Nouri et al. (2015); Amir Hamzah et al. (2022); Bentrad et al. (2017); Zaaboul and Liu (2022) |

| | | | | |
|---|---|---|---|---|
| Linoleic acid — Tunisian Deglet Nour and Allig; Algerian Ghars and Degla Beïda; Algerian Ghars; review | C18:2 ω-6 | 7.0 – 14.0 | PUFA, essential | Besbes et al. (2004); Nouri et al. (2015); Amir Hamzah et al. (2022); Zaaboul and Liu (2022) |
| Linolenic acid — Tunisian Deglet Nour and Allig; Algerian Ghars and Degla Beïda; Algerian Ghars | C18:3 ω-3 | 0.2 – 1.0 | PUFA, essential | Besbes et al. (2004); Nouri et al. (2015); Amir Hamzah et al. (2022) |
| Total saturated (∑ SFA) — Tunisian Deglet Nour and Allig; Algerian Ghars, Degla Beïda, Tafezouine; Algerian Ghars seed oil | — | 35 – 50 | — | Besbes et al. (2004); Boukouada and Yousfi (2009); Amir Hamzah et al. (2022) |
| Total mono-unsaturated (∑ MUFA) — Tunisian Deglet Nour and Allig; Algerian Ghars and Degla Beïda; Algerian Ghars | — | 35 – 55 | — | Besbes et al. (2004); Nouri et al. (2015); Amir Hamzah et al. (2022) |
| Total poly-unsaturated (∑ PUFA) — Tunisian Deglet Nour and Allig; Algerian Ghars; review | — | 8 – 15 | — | Besbes et al. (2004); Amir Hamzah et al. (2022); Zaaboul and Liu (2022) |

SFA, saturated fatty acid; MUFA, mono-unsaturated fatty acid; PUFA, poly-unsaturated fatty acid. Algerian cultivars from Boudries et al. (2012) refer to seeds collected in the Oued Righ region.

The fatty-acid profile summarised in Table 6 is the single most diagnostic feature of date seed oil. Two acids dominate: oleic acid (C18:1 ω-9), a mono-unsaturated fatty acid that accounts for 35–55 % of total fatty acids; and lauric acid (C12:0), a medium-chain saturated fatty acid that contributes 12–23 % (Besbes et al., 2004; Boudries et al., 2012; Amir Hamzah et al., 2022; Zaaboul & Liu, 2022). Myristic (C14:0, 8–12 %), palmitic (C16:0, 8–13 %), linoleic (C18:2 ω-6, 7–14 %) and stearic (C18:0, 2.5–5.5 %) acids constitute the secondary fraction. The combination of a substantial medium-chain saturated component (lauric and myristic) with a clear oleic-acid majority is unusual: it places date seed oil in a category intermediate between coconut/palm-kernel oils (dominated by lauric acid) and olive oil (dominated by oleic acid), which is potentially attractive both for nutritional and for industrial purposes (Ghnimi et al., 2017; Zaaboul & Liu, 2022). Algerian cultivars, in particular Ghars, Tafezouine and Degla Beïda studied by Boukouada and Yousfi (2009), Nouri et al. (2015), Boudries et al. (2012) and Amir Hamzah et al. (2022), conform to this pattern, with Ghars consistently in the upper part of the oleic-acid distribution.

The pharmacological consequences of this lipid composition are several. Oleic acid is a recognised cardio-metabolic protective fatty acid, contributing to favourable LDL/HDL profiles and to the modulation of membrane fluidity, while medium-chain saturated fatty acids such as lauric acid have been linked to direct antimicrobial activity through membrane perturbation in pathogenic bacteria, fungi and enveloped viruses (Bentrad et al., 2017; Alkhoori et al., 2022). The natural co-occurrence of oleic and lauric acids in date seed oil has been highlighted by several authors as a possible explanation for both its hypolipidaemic effects and its broad-spectrum *in vitro* antimicrobial activity (Bentrad et al., 2017; Bouhlali, Ramchoun, et al., 2016; Aoudeh et al., 2023).

**Table 7.** Major amino acids of date palm (*Phoenix dactylifera* L.) seeds (mg/100 g dry weight),

| Amino acid / Cultivar(s) studied | Concentration range (mg/100 g DW) | Note | References |
|---|---|---|---|
| L-Glutamic acid — 14 Algerian seed cultivars; four Indian cultivars Hillawi, Khadrawi, Shamran, Medjool; Saudi cultivars (multiple, metabolomic study) | 700 – 1,100 | Most abundant; flavour-active | Alhaj et al. (2010); Singh and Singh (2012); Hamad et al. (2015) |
| L-Aspartic acid — 14 Algerian seed cultivars; four Indian cultivars | 500 – 850 | Major non-essential | Alhaj et al. (2010); Singh and Singh (2012) |
| L-Arginine — 14 Algerian seed cultivars; four Indian cultivars | 400 – 700 | Conditionally essential; nitric oxide precursor | Alhaj et al. (2010); Singh and Singh (2012) |
| L-Leucine — 14 Algerian seed cultivars; four Indian cultivars; Saudi cultivars (Hamad) | 400 – 600 | Essential; branched-chain | Alhaj et al. (2010); Singh and Singh (2012); Hamad et al. (2015) |
| L-Lysine — 14 Algerian seed cultivars; four Indian cultivars | 280 – 400 | Essential; limiting in cereals | Alhaj et al. (2010); Singh and Singh (2012) |
| L-Valine — 14 Algerian seed cultivars; four Indian cultivars | 320 – 460 | Essential; branched-chain | Alhaj et al. (2010); Singh and Singh (2012) |
| L-Phenylalanine — 14 Algerian seed cultivars; four Indian cultivars | 250 – 380 | Essential | Alhaj et al. (2010); Singh and Singh (2012) |
| L-Isoleucine — 14 Algerian seed cultivars; four Indian cultivars | 220 – 340 | Essential; branched-chain | Alhaj et al. (2010); Singh and Singh (2012) |
| L-Threonine — 14 Algerian seed cultivars; four Indian cultivars | 200 – 320 | Essential | Alhaj et al. (2010); Singh and Singh (2012) |
| L-Histidine — 14 Algerian seed cultivars; four Indian cultivars | 130 – 220 | Essential in infants | Alhaj et al. (2010); Singh and Singh (2012) |

| | | | |
|---|---|---|---|
| L-Methionine — 14 Algerian seed cultivars; four Indian cultivars | 90 – 180 | Sulphur-containing essential | Alhaj et al. (2010); Singh and Singh (2012) |
| L-Tryptophan — 14 Algerian seed cultivars; Saudi cultivars (Hamad) | 50 – 120 | Essential; serotonin precursor | Alhaj et al. (2010); Hamad et al. (2015) |
| L-Proline — 14 Algerian seed cultivars; four Indian cultivars | 250 – 450 | Osmoprotectant; abundant in xerophytic seeds | Alhaj et al. (2010); Singh and Singh (2012) |
| Glycine, alanine, serine — 14 Algerian seed cultivars; four Indian cultivars | 200 – 500 (each) | Non-essential | Alhaj et al. (2010); Singh and Singh (2012) |

### 3.4. Polysaccharides, fibre fractions and structural carbohydrates

The carbohydrate fraction of date palm seeds is overwhelmingly composed of structural cell-wall polysaccharides rather than soluble sugars. Soluble mono- and disaccharides are scarce in fully matured seeds (typically < 3 % of dry weight) and are dominated by glucose, fructose and small amounts of sucrose, in clear contrast with the flesh, which is highly sugar-rich (Hilary et al., 2020; Alkhoori et al., 2022). The bulk of seed dry mass is therefore polysaccharidic and comprises four principal fractions: (1) galactomannans, (2) heteroxylans and other hemicelluloses, (3) cellulose, and (4) pectin and pectin-like polymers (Ishrud et al., 2001; Elleuch et al., 2011; Mrabet et al., 2020; Subhash et al., 2024). Lignin, in the strict chemical sense, is present in modest amounts but contributes to the mechanical hardness of the endocarp.

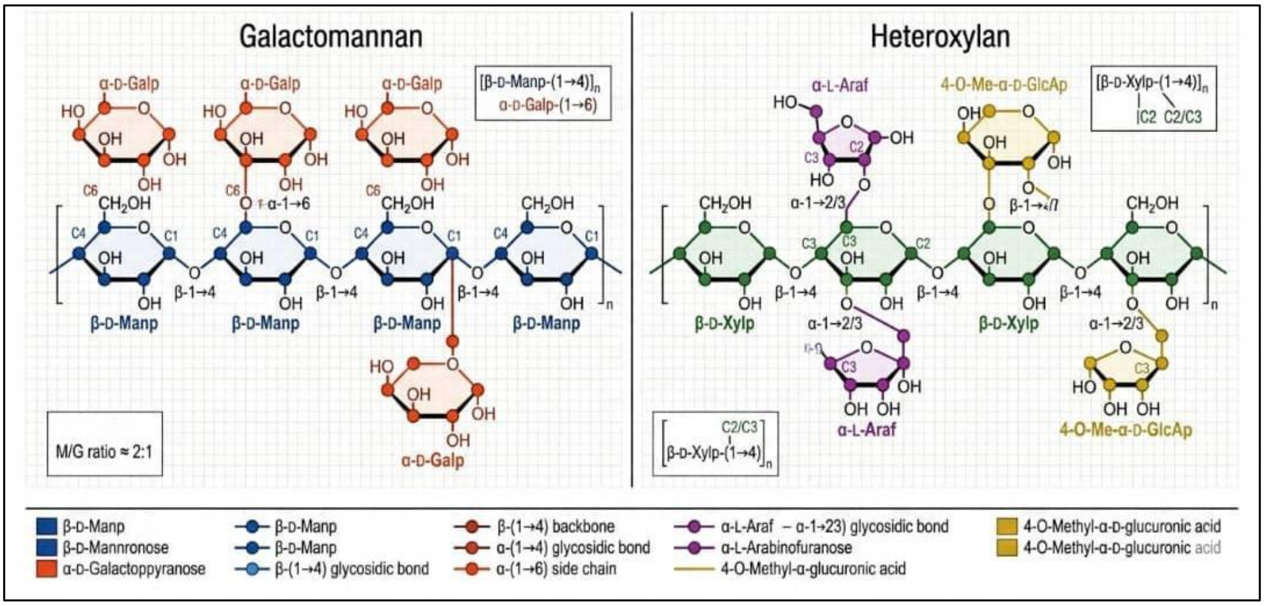


**Figure 6.** Schematic molecular structures of the two principal polysaccharides of date palm (*Phoenix dactylifera* L.) seeds. Top: water-soluble galactomannan, characterised by a (1→4)-β-D-

mannopyranosyl backbone with α-D-galactopyranosyl side chains attached at the C-6 position (mannose : galactose ≈ 5 : 1). Bottom: heteroxylan (arabinoxylan-type hemicellulose), characterised by a (1→4)-β-D-xylopyranosyl backbone with α-L-arabinofuranosyl side substitutions and minor 4-*O*-methyl-glucuronic acid units. After Ishrud et al. (2001); Elleuch et al. (2011); Subhash et al. (2024).

The galactomannan fraction has been the most studied of the seed polysaccharides since the seminal structural work of Ishrud et al. (2001), who demonstrated by chemical methylation, periodate oxidation, NMR spectroscopy and lectin binding that the water-soluble polysaccharide of date seeds consists of a linear (1→4)-β-D-mannopyranosyl backbone bearing α-D-galactopyranosyl substituents at C-6 with a mannose-to-galactose ratio of approximately 5:1. This structure is similar in topology to the galactomannans of guar and locust bean and confers comparable rheological behaviour, including high solution viscosity at low polymer concentration and pronounced synergistic gelling with κ-carrageenan and xanthan (Mrabet et al., 2020; Elleuch et al., 2011). More recent work by Subhash et al. (2024) using microwave-assisted deep-eutectic-solvent extraction characterised the major non-cellulosic seed polysaccharide as a complex heteropolysaccharide of weight-average molecular mass 246.5 kDa containing galacturonic acid, glucose, mannose, fructose and galactose, indicating that part of the soluble fibre fraction also displays pectic features.

Heteroxylans constitute a second major hemicellulose family. They consist of a (1→4)-β-D-xylan backbone with arabinofuranose, glucuronic acid (and its 4-*O*-methyl ether) and acetyl substitutions, with substitution pattern and degree dependent on tissue and ripening stage (Elleuch et al., 2011; Mrabet et al., 2020). Cellulose is the primary insoluble fibre, organised in microfibrillar bundles within the endospermic and endocarp cell walls, where it provides the mechanical rigidity that is responsible for the well-known hardness of the date stone. Pectins are minor but present, predominantly as homogalacturonans and rhamnogalacturonan I, and their proportion increases slightly in unripe seeds.

The functional properties of these polysaccharides — water-holding capacity, oil-absorption capacity, swelling, viscosity, prebiotic fermentability, glucose-and lipid-binding effects in the gastrointestinal lumen — collectively underpin much of the metabolic activity of date seed extracts. Mrabet et al. (2020) reported that defatted date seed dietary fibre exhibits water-holding capacity of approximately 5 g/g, oil-absorption capacity of 2.5 g/g, swelling power of 6 mL/g, and substantial faecal-fermentation potential generating short-chain fatty acids on contact with human colonic microbiota. These properties translate, in human and animal studies, into improved bowel transit, reduced postprandial glycaemia, modulated lipid absorption and prebiotic effects on

*Bifidobacterium* and *Lactobacillus* populations (Eid et al., 2015; Platat et al., 2019; Subhash et al., 2024). They also explain, in mechanistic terms, the technological behaviour of date seed flour in functional bakery formulations described by Platat et al. (2015) and Benchikh and Louaileche (2014).

## 4. Phytochemical Profile of Date Palm Seeds

### 4.1. Overview of the major phytochemical classes

Beyond their nutritional macromolecules, date palm seeds harbour a chemically diverse repertoire of specialised metabolites that confer their pharmacological reputation. The seed is, in fact, considerably richer in phenolics and lipophilic bioactives than the flesh, a pattern observed in essentially every comparative study (Al-Farsi & Lee, 2008a; Vayalil, 2012; Hilary et al., 2020). Five major chemical families dominate the seed metabolome: (i) polyphenols, including phenolic acids, flavonoids, condensed tannins (proanthocyanidins) and minor stilbenes; (ii) lipophilic bioactives, comprising tocopherols and tocotrienols, phytosterols (notably β-sitosterol), carotenoids and minor unsaponifiable components; (iii) galactomannan- and pectin-type polysaccharides (already discussed in Section 3.4); (iv) free and protein-bound amino acids of nutritional and metabolic relevance; and (v) minor constituents including sterols, oxylipins and trace alkaloids (Alkhoori et al., 2022; Alu'datt et al., 2025; Kamal-Eldin & George, 2020). Table 8 provides a synoptic view of these classes.

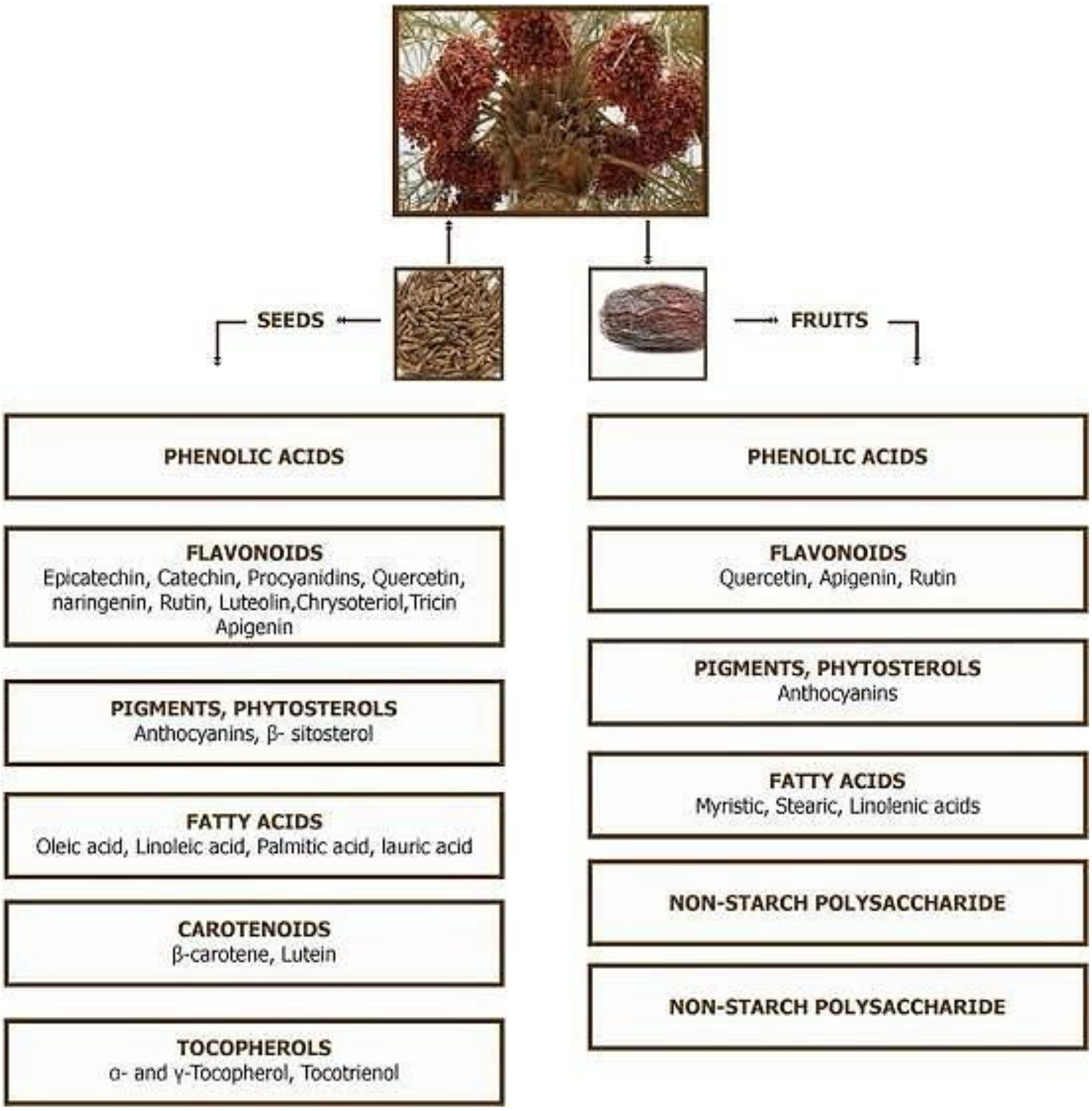


**Figure 7.** Major phytochemical classes identified in date palm (*Phoenix dactylifera* L.) seeds and their representative compounds. The diagram organises the seed metabolome around five families: (1) polyphenols — phenolic acids (gallic, *p*-coumaric, ferulic, caffeic, syringic, vanillic), flavonoids (catechin, epicatechin, rutin, quercetin, luteolin, apigenin) and condensed tannins (procyanidin B-type dimers and trimers); (2) lipophilic bioactives — tocopherols (α-, γ-), phytosterols (β-sitosterol, campesterol, stigmasterol), carotenoids (lutein, β-carotene); (3) structural and soluble polysaccharides (galactomannan, heteroxylan, cellulose, pectin); (4) amino acids; (5) minor constituents (oxylipins, sterol esters). Compiled from Habib et al. (2014); Hilary et al. (2019, 2020); Alkhoori et al. (2022); Alu'datt et al. (2025).

**Table 8.** Major phytochemical classes of date palm seeds, representative compounds and indicative biological roles.

| Class | Representative compounds | Indicative biological role | References |
|---|---|---|---|
| Phenolic acids (hydroxybenzoic) | Gallic, *p*-hydroxybenzoic, syringic, vanillic, protocatechuic acids | Antioxidant, anti-inflammatory, antiglycation | Al-Farsi and Lee (2008b); Habib et al. (2014); Hilary et al. (2019, 2020); Bouhlali et al. (2017, 2020) |
| Phenolic acids (hydroxycinnamic) | *p*-Coumaric, ferulic, caffeic, sinapic, 5-*O*-caffeoylshikimic acids | Antioxidant, neuroprotective, hepatoprotective | Mansouri et al. (2005); Habib et al. (2014); Bouhlali et al. (2017, 2020); Benchikh, Louaileche, George, and Merlin (2011, 2014) |
| Flavan-3-ols and condensed tannins | (+)-Catechin, (–)-epicatechin, procyanidin B-type dimers and trimers | Antioxidant, antiglycation, antidiabetic, vascular | Habib et al. (2014); Hilary et al. (2019, 2020); Sirisena et al. (2015); Amir Hamzah et al. (2022) |
| Flavonols and flavones | Quercetin, rutin, kaempferol, luteolin, apigenin, isorhamnetin glycosides | Antioxidant, anti-inflammatory, anticancer | Bouhlali et al. (2017, 2020); Hilary et al. (2019); El-Far et al. (2019) |
| Tocopherols / tocotrienols | α-Tocopherol, γ-tocopherol, α-tocotrienol | Antioxidant (lipid-phase), neuroprotective | Amir Hamzah et al. (2022); Kamal-Eldin and George (2020); Nehdi et al. (2010) |
| Phytosterols | β-Sitosterol, campesterol, stigmasterol | Hypocholesterolaemic, anti-inflammatory | Nehdi et al. (2010); Kamal-Eldin and George (2020); Boudries et al. (2012); Alu'datt et al. (2025) |
| Carotenoids | Lutein, β-carotene, zeaxanthin | Antioxidant, provitamin A activity | Boudries et al. (2007); Muñoz-Tebar et al. (2023) |
| Polysaccharides | Galactomannan, heteroxylan, cellulose, pectin | Prebiotic, hypoglycaemic, hypolipidaemic | Ishrud et al. (2001); Elleuch et al. (2011); Mrabet et al. (2020); Subhash et al. (2024) |
| Free amino acids and minor alkaloids | Glutamic, aspartic, proline, arginine; trace alkaloids | Nutritional, antioxidant | Alhaj et al. (2010); Singh and Singh (2012); Alkhoori et al. (2022) |

### 4.2. Polyphenols: phenolic acids, flavonoids and tannins

Polyphenols constitute the most pharmacologically prominent fraction of the date seed metabolome. Their total concentration, expressed as gallic acid equivalents (GAE), spans an exceptionally wide range across the literature: representative figures include 30–90 mg GAE per gram of dry extract for routine methanolic extracts, but values as high as 271 mg GAE/g dry matter have been reported for the highest-performing varieties under optimised extraction conditions (Aoudeh et al., 2023; Hilary et al., 2020; Bouhlali et al., 2017; Alkhoori et al., 2022). On a whole-seed dry-weight basis, total phenolic content is typically reported between 1,000 and 5,000 mg GAE/100 g, with seeds containing 5–10 times more polyphenols than the corresponding flesh (Al-Farsi & Lee, 2008a; Vayalil, 2012). This variation reflects three layers of biological and methodological variability: cultivar genetics, ripening stage and growing environment, and extraction conditions (solvent polarity, temperature, ultrasonic or microwave assistance, deep-eutectic-solvent extraction) (Kchaou et al., 2013; Yaiche Achour et al., 2022; Djaoudene et al., 2021, 2022; Subhash et al., 2024). Algerian studies, in particular Benchikh, Louaileche, George, and Merlin (2011, 2014), Benmeddour et al. (2013), Boukouada and Yousfi (2009), Djaoudene et al. (2019, 2021, 2022) and Yaiche Achour et al. (2022), consistently place Algerian seeds in the higher part of the international phenolic distribution, with gallic acid prevailing in some cultivars and *p*-coumaric and ferulic acids dominating in others.

Phenolic acids are the most consistently reported individual compounds. HPLC-DAD and UPLC-MS analyses converge on a core profile of gallic, protocatechuic, *p*-hydroxybenzoic, vanillic, syringic, *p*-coumaric, ferulic, caffeic, sinapic and 5-*O*-caffeoylshikimic acids as the principal phenolic acids (Mansouri et al., 2005; Habib et al., 2014; Hilary et al., 2020; Bouhlali et al., 2017, 2020; Al-Farsi & Lee, 2008b). Within this set, *p*-coumaric, ferulic and gallic acids tend to dominate quantitatively. Mansouri et al. (2005), in their pioneering LC-DAD-MS work on Algerian dates from Ghardaïa, identified *p*-coumaric, ferulic and sinapic acids as principal hydroxycinnamates, together with 5-*O*-caffeoylshikimic acid as a characteristic *Phoenix* metabolite. Benchikh, Louaileche, George, and Merlin (2011, 2014) confirmed and extended this profile to the seeds of seven Algerian cultivars, and Yaiche Achour et al. (2022) showed that gallic acid is the dominant phenolic in seeds of selected Algerian cultivars at certain ripening stages. Kchaou, Abbès, Mansour, et al. (2016) reported *p*-coumaric acid as the dominant phenolic acid in second-grade Tunisian dates (1,998 µg/100 g), with associated antimicrobial and cytotoxic activities. From a mechanistic standpoint, hydroxybenzoic acids contribute primarily to direct radical-scavenging and metal-chelation activity, whereas hydroxycinnamic acids (caffeic, ferulic, *p*-coumaric) display additional anti-inflammatory effects through inhibition of cyclooxygenases and lipoxygenases, and have well-documented hepatoprotective and neuroprotective potential through Nrf2/Keap1 modulation (Bouhlali et al., 2020; Essa, Subash, Akbar, et al., 2015; Essa, Subash, Dhanalakshmi, et al., 2015; Hassan et al., 2024).

Flavonoids and condensed tannins constitute the other major polyphenol class of date seeds. Flavan-3-ols ((+)-catechin, (–)-epicatechin) and their condensation products (B-type proanthocyanidins from dimers up to high-molecular-weight polymers) consistently emerge as the dominant flavonoid family (Habib et al., 2014; Hilary et al., 2019, 2020; Sirisena et al., 2015; Amir Hamzah et al., 2022). Habib et al. (2014), using UPLC-DAD-ESI-MS, characterised B-type procyanidin dimers and trimers together with monomeric catechin and epicatechin in Emirati seeds; Hilary et al. (2019, 2020) extended this profile and demonstrated the predominance of procyanidins in the antiglycation activity of seed extracts. Amir Hamzah et al. (2022), in their detailed analysis of Algerian seed oils including Ghars, identified catechin (up to 22 mg/kg) and vanillin (up to 10 mg/kg) as major lipophilic phenolics, together with α-tocopherol. Other flavonoids reported in date seed extracts include rutin, quercetin and quercetin glycosides, kaempferol, luteolin, apigenin and isorhamnetin glycosides (Bouhlali et al., 2017, 2020; Hilary et al., 2019). Bouhlali et al. (2020) showed that rutin, quercetin, *p*-coumaric and caffeic acids were dominant in four Moroccan date seed varieties and correlated with significant *in vitro* anti-inflammatory activity through nitric oxide scavenging, membrane stabilisation and protein denaturation inhibition. Quercetin, in particular, is a well-studied anticancer flavonoid; its presence in date seeds has been linked to anti-proliferative activity in cancer cell lines and to documented chemopreventive mechanisms involving cell-cycle arrest, apoptosis induction, and modulation of NF-κB and PI3K/Akt signalling pathways (El-Far et al., 2019).

**Table 9.** Key phenolic acids and flavonoids identified in date palm seeds.

| **Compound / Cultivar(s) reporting source** | **Class** | **Indicative content (range)** | **Activity highlight** | **References** |
|---|---|---|---|---|
| Gallic acid — Algerian cultivars at varying ripening stages (Yaiche Achour); three Moroccan cultivars Bouskri, Aziza, Boufeggous (Bouhlali); Algerian cultivars by UAE-NADES extraction (Djaoudene) | Hydroxybenzoic acid | 50 – 1,500 mg/kg DW | Strong DPPH/ABTS scavenger; metal chelator | Yaiche Achour et al. (2022); Bouhlali et al. (2017); Djaoudene et al. (2022) |
| Protocatechuic acid — UAE Khalas seed (Habib; Hilary); Alzheimer mouse model (Essa) | Hydroxybenzoic acid | 10 – 400 mg/kg DW | Antioxidant, neuroprotective | Habib et al. (2014); Hilary et al. (2020); Essa, Subash, Akbar, et al. (2015) |
| *p*-Hydroxybenzoic acid — Omani Khalas, Khasab, Fardh (Al-Farsi & Lee, 2008b); UAE Khalas | Hydroxybenzoic acid | 20 – 300 mg/kg DW | Antioxidant, antimicrobial | Al-Farsi and Lee (2008b); Habib et al. (2014) |

| | | | | |
|---|---|---|---|---|
| Vanillic acid — seven Algerian cultivars (Benchikh); UAE Khalas | Hydroxybenzoic acid | 15 – 250 mg/kg DW | Antioxidant; precursor of vanillin | Benchikh, Louaileche, George, and Merlin (2011); Habib et al. (2014) |
| Syringic acid — UAE Khalas; three Moroccan cultivars Bouskri, Aziza, Boufeggous | Hydroxybenzoic acid | 10 – 200 mg/kg DW | Antioxidant, hepatoprotective | Habib et al. (2014); Bouhlali et al. (2017) |
| Caffeic acid — Algerian Ghardaïa cultivars (Mansouri); four Moroccan cultivars Bouskri, Aziza, Boufeggous, Najda (Bouhlali, 2020); Alzheimer mouse model | Hydroxycinnamic acid | 20 – 600 mg/kg DW | Antioxidant, anti-inflammatory, hepatoprotective | Mansouri et al. (2005); Bouhlali et al. (2020); Essa, Subash, Akbar, et al. (2015) |
| *p*-Coumaric acid — Algerian Ghardaïa cultivars; second-grade Tunisian cultivars Korkobbi, Eguioua (Kchaou); seven Algerian cultivars (Benchikh) | Hydroxycinnamic acid | 50 – 2,000 mg/kg DW | Antioxidant, antimicrobial | Mansouri et al. (2005); Kchaou, Abbès, Mansour, et al. (2016); Benchikh, Louaileche, George, and Merlin (2014) |
| Ferulic acid — Algerian Ghardaïa cultivars; four Moroccan cultivars (Bouhlali, 2020); Alzheimer mouse model | Hydroxycinnamic acid | 30 – 800 mg/kg DW | Antioxidant, neuroprotective | Mansouri et al. (2005); Bouhlali et al. (2020); Essa, Subash, Dhanalakshmi, et al. (2015) |
| Sinapic acid — Algerian Ghardaïa cultivars; UAE Khalas | Hydroxycinnamic acid | 5 – 150 mg/kg DW | Antioxidant | Mansouri et al. (2005); Habib et al. (2014) |
| 5-*O*-Caffeoylshikimic acid — Algerian Ghardaïa cultivars; UAE Khalas | Hydroxycinnamic conjugate | 50 – 800 mg/kg DW | Antioxidant; *Phoenix*-characteristic | Mansouri et al. (2005); Habib et al. (2014); Hilary et al. (2020) |
| (+)-Catechin — UAE Khalas (Habib; Hilary); Algerian Ghars and Tafezouine seed oils | Flavan-3-ol | 30 – 1,500 mg/kg DW | Antioxidant, antiglycation | Habib et al. (2014); Hilary et al. (2019, 2020); Amir Hamzah et al. (2022) |
| (–)-Epicatechin — UAE Khalas | Flavan-3-ol | 20 – 1,000 mg/kg DW | Antioxidant, vascular | Habib et al. (2014); Hilary et al. (2020) |
| Procyanidin B-type dimers/trimers — UAE Khalas; six international varieties | Condensed tannin | 100 – 4,000 | Antioxidant, antiglycation, antidiabetic | Habib et al. (2014); Hilary et al. (2019, |

| | | | | |
|---|---|---|---|---|
| (Sirisena: Khudari, Khalas, Hayyani, Sukkari, Lulu, Khirma) | | mg/kg DW | | 2020); Sirisena et al. (2015) |
| Rutin — three Moroccan cultivars Bouskri, Aziza, Boufeggous; four Moroccan cultivars (Bouhlali, 2020); UAE Khalas (Hilary) | Flavonol glycoside | 10 – 250 mg/kg DW | Antioxidant, anti-inflammatory, vascular | Bouhlali et al. (2017, 2020); Hilary et al. (2019) |
| Quercetin and glycosides — three and four Moroccan cultivars (Bouhlali); review on quercetin in tumours (El-Far) | Flavonol | 5 – 200 mg/kg DW | Antioxidant, anticancer, anti-inflammatory | Bouhlali et al. (2017, 2020); El-Far et al. (2019) |
| Luteolin / apigenin — UAE Khalas (Hilary); four Moroccan cultivars (Bouhlali) | Flavone | 2 – 80 mg/kg DW | Antioxidant, anti-inflammatory | Hilary et al. (2019); Bouhlali et al. (2020) |
| Isorhamnetin hexoside — UAE Khalas | Flavonol glycoside | 5 – 100 mg/kg DW | Antioxidant | Hilary et al. (2020); Habib et al. (2014) |

TPC, total phenolic content; DPPH, 2,2-diphenyl-1-picrylhydrazyl; ABTS, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); BSA-MGO, bovine serum albumin–methylglyoxal; AGE, advanced glycation end-product.

Beyond their direct antioxidant capacity, the seed polyphenols engage a number of well-defined molecular targets relevant to chronic disease. Procyanidin-rich seed fractions inhibit advanced glycation end-product (AGE) formation in BSA–methylglyoxal models with potency comparable to aminoguanidine (Hilary et al., 2019); seed methanol extracts inhibit α-glucosidase and α-amylase with IC50 values in the µg/mL range (Mohammed et al., 2018; Subhash et al., 2024); ethanolic and aqueous extracts reduce nitric oxide release and pro-inflammatory cytokine expression in cellular and animal models (Bouhlali et al., 2020; Saryono et al., 2020); and polyphenol-rich preparations modulate hepatic and renal antioxidant defences in toxicant-challenged rodents (Mortazavi et al., 2014; Ahmed et al., 2021; Al-Saad et al., 2020). The mechanistic corpus thus connects, in a coherent way, the chemical signature of the seed with the broad spectrum of biological activities discussed in Section 5.

### 4.3. Lipophilic bioactives

In parallel with polyphenols, date palm seeds contain a chemically diverse suite of lipophilic bioactives that partition into the oil fraction during extraction and contribute substantially to the antioxidant and metabolic activities of the seed. Three families predominate: tocopherols and tocotrienols, phytosterols, and carotenoids, together with minor amounts of squalene and phytosterol esters (Kamal-Eldin & George, 2020; Nehdi et al., 2010; Boudries et al., 2007; Amir Hamzah et al., 2022; Muñoz-Tebar et al., 2023; Alu'datt et al., 2025). Their joint presence places date seed oil in the same compositional family as several premium edible oils and supports its valorisation as a functional lipid ingredient.

Tocopherols are the principal lipid-soluble antioxidants of the seed oil. α-Tocopherol predominates and reaches concentrations of 200–450 mg/kg of oil in some Algerian cultivars, with γ-tocopherol contributing a smaller but biologically significant fraction (Amir Hamzah et al., 2022; Kamal-Eldin & George, 2020). Tocotrienols are also detectable in trace to moderate amounts. Mechanistically, α-tocopherol acts as a chain-breaking antioxidant in the lipid bilayer, preventing peroxyl-radical propagation and lipid peroxidation; this protective function complements that of the polyphenols, which are predominantly active in the aqueous phase, yielding a tightly coupled "lipid–water" antioxidant system that explains the high oxidative stability of date seed oil during storage (Amir Hamzah et al., 2022).

Phytosterols are the second major lipophilic family. β-Sitosterol is the dominant sterol, accounting for 50–70 % of the total sterol fraction, followed by campesterol (10–20 %) and stigmasterol (5–15 %) (Nehdi et al., 2010; Kamal-Eldin & George, 2020; Boudries et al., 2012). Total phytosterol content of date seed oil typically ranges from 1.5 to 3.5 g/kg of oil, comparable to corn or rapeseed oil. The hypocholesterolaemic and anti-inflammatory roles of dietary phytosterols are well established and provide a plausible mechanistic basis for the lipid-lowering effects observed in animal studies of seed oil supplementation (Bouhlali, Ramchoun, et al., 2016; Hasan & Mohieldein, 2016; Alu'datt et al., 2025). Squalene, a minor unsaponifiable component, contributes additional oxidative stability and may possess intrinsic anti-inflammatory and chemopreventive effects.

Carotenoids are quantitatively minor in date seeds but qualitatively informative. Boudries et al. (2007), in a pioneering Algerian study, identified lutein, β-carotene and zeaxanthin as the principal carotenoids of *P. dactylifera* and quantified their decrease during fruit maturation, with values for seeds substantially below those of the flesh. Their presence contributes to the lipid-soluble antioxidant pool and, in the case of β-carotene, to provitamin A activity. Beyond the principal lipophilic bioactives, recent work has documented the presence of minor oxylipins, sphingolipids and phospholipids whose pharmacological relevance is still being explored (Alu'datt et al., 2025).

**Table 10.** Lipophilic bioactives of date palm (*Phoenix dactylifera* L.) seeds and seed oil.

| Compound class / Cultivar(s) studied | Examples | Indicative content | Activity | References |
|---|---|---|---|---|
| Tocopherols — Algerian Ghars and Tafezouine seed oils; review including UAE Khalas; *Phoenix canariensis* seed oil (Saudi Arabia) | α-Tocopherol, γ-tocopherol | 200 – 600 mg/kg oil (∑ tocopherols) | Lipid-phase antioxidant; neuroprotective | Amir Hamzah et al. (2022); Kamal-Eldin and George (2020); Nehdi et al. (2010) |
| Tocotrienols — review chapter on date fruit chemistry (multiple cv.); review of by-product valorization | α-Tocotrienol | trace – 60 mg/kg oil | Antioxidant; cardio- and neuroprotective | Kamal-Eldin and George (2020); Muñoz-Tebar et al. (2023) |
| Phytosterols — *Phoenix canariensis* seed oil (Saudi Arabia); Algerian cultivars Oued Righ (Boudries et al., 2012); review chapter; review (Alu'datt) | β-Sitosterol, campesterol, stigmasterol | 1,500 – 3,500 mg/kg oil | Hypocholesterolaemic; anti-inflammatory | Nehdi et al. (2010); Boudries et al. (2012); Kamal-Eldin and George (2020); Alu'datt et al. (2025) |
| Carotenoids — Algerian Deglet-Nour, Hamraya, Tantebouchte (Boudries, 2007); review | Lutein, β-carotene, zeaxanthin | trace – 50 µg/100 g seed | Antioxidant; provitamin A | Boudries et al. (2007); Muñoz-Tebar et al. (2023) |
| Squalene — review chapter on date fruit chemistry; review (Alu'datt) | Squalene | trace – 100 mg/kg oil | Antioxidant; chemopreventive | Kamal-Eldin and George (2020); Alu'datt et al. (2025) |
| Vanillin and lipophilic phenolics — Algerian Ghars seed oil | Vanillin, methylated phenolics | 5 – 30 mg/kg oil | Antioxidant; aromatic | Amir Hamzah et al. (2022) |

**Note:** Nehdi et al. (2010) studied seed oil of *Phoenix canariensis* (Canary Island date palm) cultivated in Saudi Arabia, a closely related species often cited in date-seed lipid studies.

### 4.4. Other bioactive constituents

Several less abundant but biologically informative metabolites complete the date seed phytochemical landscape. Vanillin, a methoxylated phenolic aldehyde with antioxidant and aromatic activity, has been quantified in Algerian seed oils at 5–20 mg/kg, where it contributes to characteristic organoleptic notes and antioxidant capacity (Amir Hamzah et al., 2022). Hydroxybenzaldehyde, syringaldehyde and other lignin-derived monomers appear in low concentration and are likely products of lignin breakdown in the heavily lignified endocarp. Trace alkaloids and sterol esters have been detected in untargeted metabolomic analyses (Hamad et al., 2015; Alu'datt et al., 2025). Sugars such as glucose and fructose are present in modest amounts in mature seeds but increase in immature ones, reflecting incomplete conversion of free sugars into structural polysaccharides during seed development (Hilary et al., 2020). Free amino acids, particularly proline (an osmoprotectant abundant in xerophytic seeds) and glutamic acid, have been documented (Alhaj et al., 2010; Singh & Singh, 2012; Hamad et al., 2015) and contribute to the fermentation behaviour of seed flour during baking (Platat et al., 2015).

Cumulatively, the metabolite landscape of date seeds combines hydrophilic polyphenols, lipid-phase antioxidants, structural and soluble polysaccharides, free amino acids and minor bioactives in a way that is characteristic of *Phoenix dactylifera* and partly distinct from other Arecaceae. This composition is the chemical foundation on which the biological activities reviewed in Section 5 rest.

## 5. Biological Activities of Date Palm Seed Extracts

The pharmacological literature on *Phoenix dactylifera* seeds has expanded considerably over the past two decades. Across hundreds of studies, the same major activities are repeatedly reported: antioxidant, anti-inflammatory, antidiabetic and antihyperglycaemic, antimicrobial in a therapeutic context, hepato- cardio- gastro- and renoprotective, neuroprotective, anticancer, hypolipidaemic, prebiotic and anti-obesity. The strength of the evidence varies considerably between activities. *In vitro* evidence is abundant for essentially all activities; *in vivo* evidence in rodent models is robust for hepatoprotection, antidiabetic and anti-inflammatory effects; clinical evidence in humans is still limited but growing, with controlled trials available for prebiotic and anti-inflammatory effects (Platat et al., 2019; Saryono et al., 2020). The following subsections critically review the available data, with attention to the type of evidence (in vitro / in vivo / clinical), the extracts and doses used, and the mechanistic links to the chemistry described in Section 4.

### 5.1. Antioxidant activity

Antioxidant activity is by far the most extensively documented biological activity of date seed extracts and is also the activity that is most directly traceable to a defined chemical composition. *In vitro* assays — DPPH, ABTS, FRAP, ORAC, β-carotene–linoleate bleaching — consistently show that hydro-alcoholic and aqueous date seed extracts exhibit dose-dependent radical-scavenging capacity that frequently exceeds, on a milligram-per-milligram basis, that of common dietary antioxidants such as ascorbate or BHT (Bouhlali et al., 2017; Aoudeh et al., 2023; Subhash et al., 2024; Alkhoori et al., 2022). Reported half-maximal inhibitory concentrations for DPPH range from a few micrograms per millilitre for the most polyphenol-rich Algerian and Emirati extracts to several tens of µg/mL for less concentrated preparations (Benchikh, Louaileche, George, & Merlin, 2014; Yaiche Achour et al., 2022). FRAP and total reducing capacity show parallel patterns, with strong correlations between assay outcomes and total phenolic content, total flavonoid content and procyanidin concentration (Benmeddour et al., 2013; Hilary et al., 2019; Djaoudene et al., 2019; Djaoudene et al., 2021).

The Algerian context provides several lines of comparative evidence. Boukouada and Yousfi (2009) reported significant antioxidant activity in seeds of three Algerian cultivars including Ghars, with strong DPPH scavenging correlated to total phenolics. Benchikh, Louaileche, George, and Merlin (2011, 2014) characterised the phenolic profile and antioxidant capacity of seven Algerian cultivars and demonstrated significant inter-cultivar variability, with seeds of soft cultivars including Ghars among the most active. Benmeddour et al. (2013) compared ten Algerian cultivars and provided the largest dataset to date for the country, again highlighting the variability and the strong genotype effect. Djaoudene, Benali, et al. (2019) reported high polyphenolic content and multifunctional bioactivities in seeds from eight cultivars of the M'zab oasis, and Djaoudene et al. (2022) demonstrated that ultrasound-assisted deep-eutectic-solvent extraction substantially improves both phenolic recovery and antioxidant capacity. Yaiche Achour et al. (2022) further showed that ripening stage exerts a strong effect on phenolic composition and antioxidant capacity, with gallic acid emerging as the dominant phenolic in seeds at certain stages. Most recently, Benali et al. (2025) reported strong DPPH and ABTS scavenging by Ghars seed ethanolic extract and demonstrated retention of antioxidant activity in a cosmetic cream formulation, reinforcing the practical relevance of these findings.

Mechanistically, the antioxidant activity of date seed extracts is multifactorial. Direct radical scavenging is dominated by the polyphenolic fraction, particularly catechin/epicatechin, procyanidins, gallic and *p*-coumaric acids (Habib et al., 2014; Hilary et al., 2019; Bouhlali et al., 2017). Lipid-phase antioxidant activity is contributed by α-tocopherol and minor lipophilic phenolics (Amir Hamzah et al., 2022). Cellular antioxidant effects, observed in hepatocyte, cardiomyocyte and neuronal models, involve activation of the Nrf2/Keap1 pathway, upregulation of catalase, superoxide dismutase (SOD), glutathione peroxidase (GPx) and glutathione-S-transferase (GST), and reduction of malondialdehyde (MDA) and protein carbonyls (Mortazavi et al., 2014; Al-Yahya et al., 2016; Al-Saad et al., 2020; Ahmed et al., 2021). This combination of direct and adaptive antioxidant effects explains why seed extracts perform well in *in vivo* models of oxidative stress, where the intracellular environment requires more than radical scavenging alone.

**Table 11.** Representative antioxidant activities reported for date palm seed extracts.

| Extract / Cultivar(s) studied | Assay | Activity | Reference |
|---|---|---|---|
| Methanol extract — three Moroccan cultivars Bouskri, Aziza, Boufeggous | DPPH, ABTS, FRAP | IC50 ≈ 5–20 µg/mL; high correlation with TPC | Bouhlali et al. (2017) |
| Aqueous extracts — six international cultivars: Khudari, Sakai, Safawi (Saudi Arabia), Majdool (Jordan), Zahdi (Iraq), Kabkab (Iran) | DPPH, ABTS | TPC 63.2–271.2 mg GAE/g DM; dose-dependent scavenging | Aoudeh et al. (2023) |
| Methanol extract — seven Algerian cultivars (Benchikh, including Ghars, Mech-Degla, Deglet Nour and others) | DPPH | Strong scavenging, cultivar-dependent | Benchikh, Louaileche, George, and Merlin (2014) |
| Methanol extract — ten Algerian cultivars (Benmeddour, Biskra region) | DPPH, ABTS | Inter-cultivar variability; significant TPC–activity correlation | Benmeddour et al. (2013) |
| UAE methanolic extract — Algerian cultivars (Yaiche Achour, including Deglet Nour and Degla Baïdha at three ripening stages) | DPPH, ABTS | Stage- and cultivar-dependent activity; gallic acid predominant | Yaiche Achour et al. (2022) |
| NADES + UAE extract — Algerian cultivars (Djaoudene, Ghardaïa) | DPPH, ABTS, FRAP | TPC up to 1,288.7 mg GAE/100 g; high antioxidant capacity | Djaoudene et al. (2022) |
| Microwave + DES seed polysaccharide — Khalas cultivar (UAE) | DPPH, ABTS, FRAP | Significant scavenging in addition to polyphenolic fraction | Subhash et al. (2024) |
| UAE seed extract (procyanidin-rich) — Khalas cultivar (UAE) | Antiglycation (BSA-MGO) | Significant inhibition of AGE formation | Hilary et al. (2019) |

| | | | |
|---|---|---|---|
| Algerian Ghars ethanol extract — Ghars cultivar | DPPH, ABTS | Strong scavenging; retained in cosmetic cream | Benali et al. (2025) |
| Saudi seed extract, *in vivo* — Saudi cultivars Ajwa and Sukkari | SOD, CAT, GSH | Restoration of antioxidant enzymes; lower MDA | Hasan and Mohieldein (2016) |

DPPH, 2,2-diphenyl-1-picrylhydrazyl; ABTS, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); FRAP, ferric reducing antioxidant power; TPC, total phenolic content; GAE, gallic acid equivalents; DM, dry matter; UAE, ultrasound-assisted extraction; NADES, natural deep eutectic solvent; DES, deep eutectic solvent; BSA-MGO, bovine serum albumin–methylglyoxal; AGE, advanced glycation end-product; SOD, superoxide dismutase; CAT, catalase; GSH, reduced glutathione; MDA, malondialdehyde; STZ, streptozotocin.

### 5.2. Anti-inflammatory activity

Anti-inflammatory activity is the second most consistently reported pharmacological property of date palm seeds, supported by *in vitro* assays, animal models and a small number of clinical interventions. *In vitro*, methanolic and ethanolic seed extracts inhibit nitric oxide production in lipopolysaccharide-stimulated macrophages, stabilise erythrocyte membranes against hypotonic lysis and inhibit BSA denaturation, three classic surrogate markers of anti-inflammatory potential (Bouhlali et al., 2020; Benali et al., 2025; Alkhoori et al., 2022). Bouhlali et al. (2020) demonstrated, for four Moroccan date seed varieties, dose-dependent inhibition in all three assays correlated with rutin, quercetin, *p*-coumaric and caffeic acid content. Benali et al. (2025) reported strong anti-inflammatory activity for an ethanolic extract of Algerian Ghars seeds, retained when the extract was incorporated into a cosmetic cream, supporting topical applications.

In rodent models, date seed extracts reduce paw oedema in carrageenan- and formalin-induced acute inflammation models, lower pro-inflammatory cytokine expression in chronic models and modulate oxidative-inflammatory cross-talk in tissue-specific injuries (Al-Yahya et al., 2016; Al-Saad et al., 2020; Rahmani, Aly, et al., 2014; Alkhoori et al., 2022). Al-Yahya et al. (2016) showed that an Ajwa seed extract attenuated isoproterenol-induced cardiomyopathy in rats through downregulation of TNF-α, NF-κB, IL-6 and apoptotic markers, restoring cardiac architecture. Al-Saad et al. (2020) demonstrated that pre-treatment with date seed extract attenuated renal ischaemia-reperfusion injury through Nrf2 upregulation and reduction of TNF-α and caspase-3, explicitly linking anti-inflammatory and antioxidant pathways. The mechanistic picture that emerges from these studies positions seed polyphenols as inhibitors of NF-κB activation and modulators of cyclo- and lipoxygenase pathways (Alkhoori et al., 2022; Alu'datt et al., 2025).

Clinical evidence, although still limited, strengthens this picture. Saryono et al. (2020), in a quasi-experimental clinical study in middle-aged Indonesian women, reported that consumption of 2.5 g/day of steeped date seeds for 14 days significantly downregulated the expression of IL-1β, TGF-β, COX-1 and COX-2, providing direct biomolecular evidence of anti-inflammatory activity in humans. Although the study was open-label and without placebo, its findings are mechanistically congruent with the in vitro and animal data and motivate larger randomised controlled trials. Together, the available data support a robust, multi-target anti-inflammatory profile for date seed extracts, dominated by polyphenols and complemented by α-tocopherol and phytosterols.

### 5.3. Antidiabetic and antihyperglycaemic effects

The antidiabetic potential of date palm seeds has been investigated extensively because of the public-health weight of type 2 diabetes in date-consuming populations and because of the ethnopharmacological use of seed-based decoctions in traditional Maghrebi and Middle-Eastern medicine for diabetic complaints (Hammiche & Maiza, 2006; Beloued, 2009; Vayalil, 2012). The current evidence base is dominated by *in vitro* enzyme-inhibition data and *in vivo* studies in streptozotocin- or alloxan-induced diabetic rodents.

*In vitro*, methanolic, ethanolic and aqueous extracts of date seeds inhibit α-glucosidase and α-amylase, the two intestinal enzymes whose activity controls postprandial glucose absorption. Mohammed et al. (2018) reported dose-dependent inhibition of both enzymes by date seed extracts, with potencies in the µg/mL range comparable to the reference drug acarbose. Subhash et al. (2024) reported even more striking results for a microwave-DES-extracted seed polysaccharide fraction, with α-glucosidase inhibition of 79.6 % and α-amylase inhibition of 85.1 % at the tested concentrations, supporting the idea that the soluble polysaccharide fraction itself contributes to glycaemic control beyond the polyphenols. Djaoudene, Benali, et al. (2019) demonstrated that seed extracts from eight Algerian cultivars inhibit α-glucosidase, suggesting that the phenomenon is conserved across the Algerian cultivar mosaic.

Antiglycation activity provides a complementary mechanism. Hilary et al. (2019) showed that procyanidin-rich seed fractions significantly inhibit advanced glycation end-product (AGE) formation in BSA-methylglyoxal models, with potency comparable to aminoguanidine. Because chronic protein glycation is a major pathway of diabetic complications (retinopathy, nephropathy, vascular damage), antiglycation activity of seed polyphenols is likely to be of clinical importance independently of their effects on glycaemia *per se*. Combined α-glucosidase inhibition, antiglycation and direct antioxidant activity therefore provide a coherent multi-target rationale for the antidiabetic use of date seed preparations.

*In vivo* studies confirm and extend these findings. Hasan and Mohieldein (2016), in streptozotocin-induced diabetic rats, demonstrated that Saudi date seed extract significantly reduced fasting blood glucose, improved lipid profile (lower LDL, lower triglycerides, higher HDL) and enhanced antioxidant defences (SOD, CAT, GSH). The combination of antihyperglycaemic, hypolipidaemic and antioxidant effects in a single model resembles the multi-target action expected from polyphenol-rich extracts and is consistent with the clinical phenotype targeted by date-seed-based traditional remedies. Other rodent studies have similarly reported reductions in blood glucose, improved insulin sensitivity and partial restoration of pancreatic β-cell architecture (Alkhoori et al., 2022; Alu'datt et al., 2025).

**Table 12.** Antidiabetic studies on date palm seed extracts.

| Study type | Model | Main finding | Reference |
|---|---|---|---|
| *In vitro* — unspecified date palm seed cultivar | α-Glucosidase, α-amylase inhibition | Dose-dependent inhibition; activity correlated with phenolics | Mohammed et al. (2018) |
| In vitro — Khalas cultivar (UAE) | α-Glucosidase, α-amylase | 79.6 % and 85.1 % inhibition by seed polysaccharides | Subhash et al. (2024) |
| *In vitro* — Khalas cultivar (UAE) | BSA–methylglyoxal antiglycation | Significant inhibition of AGE formation by procyanidin-rich seed extract | Hilary et al. (2019) |
| *In vitro — eight* Algerian cultivars from M'zab/Ghardaïa (Ourous, Tazizaout, Tazarzeit, Tazoughart, Ouaouchet, Oukasaba, Delat, Tamezwertn'telet) | α-Glucosidase, AChE, lipase, tyrosinase | Multifunctional inhibition; eight Algerian cultivars (M'zab) | Djaoudene, Benali, et al. (2019) |
| *In vivo* — Saudi cultivars Ajwa and Sukkari | STZ-induced diabetic rats | Lower glucose; improved lipid profile; enhanced SOD, CAT, GSH | Hasan and Mohieldein (2016) |
| *In vivo* — Moroccan cultivars Jihel and Majhoul | High-fat diet + Triton-WR-1339 hyperlipidaemia | Reduced TC, TG, LDL-C; raised HDL-C; rutin/quercetin/coumaric/caffeic acid identified | Bouhlali, Ramchoun, et al. (2016) |
| Review (synthesis) — multiple cultivars | Multiple animal and in vitro models | Multi-target antidiabetic activity through enzyme inhibition, antioxidant defence and antiglycation | Alkhoori et al. (2022); Alu'datt et al. (2025) |

Abbreviations: AChE, acetylcholinesterase; AGE, advanced glycation end-product; BSA, bovine serum albumin; CAT, catalase; DES, deep eutectic solvent; DPPH, 2,2-diphenyl-1-picrylhydrazyl; GSH, reduced glutathione; HDL-C, high-density lipoprotein cholesterol; HFD, high-fat diet; LDL-C, low-density lipoprotein cholesterol; MDA, malondialdehyde; MGO, methylglyoxal; NADES, natural deep eutectic solvent; SOD, superoxide dismutase; STZ, streptozotocin; TC, total cholesterol; TG, triglycerides; TPC, total phenolic content; UAE, ultrasound-assisted extraction.

Clinical studies dedicated specifically to date seed antidiabetic effects are still scarce, and most data on diabetic outcomes in humans relate to whole-fruit consumption. This represents a significant gap in the literature and one of the directions for which Algerian Ghars seeds — abundant, well-tolerated, with consistent phenolic content — are well positioned.

### 5.4. Antimicrobial activity

The antimicrobial activity of date palm seed extracts is documented exclusively here in pharmaceutical and therapeutic terms — that is, in relation to human pathogens of clinical relevance and to the development of natural-product-based candidates for human therapy. *In vitro* evidence is consistent across studies: hydro-alcoholic, ethanolic and aqueous seed extracts inhibit the growth of Gram-positive and Gram-negative bacteria as well as yeasts of the genus *Candida* with minimum inhibitory concentrations (MICs) typically ranging from a few hundred µg/mL to a few mg/mL, depending on solvent, cultivar and pathogen (Bentrad et al., 2017; Al-Huqail et al., 2019; Aoudeh et al., 2023; Benali et al., 2025; Kchaou, Abbès, Mansour, et al., 2016). Among Gram-positive species, *Staphylococcus aureus* and *Bacillus subtilis* are most sensitive; among Gram-negative species, *Escherichia coli*, *Pseudomonas aeruginosa* and *Klebsiella pneumoniae* are commonly tested and consistently inhibited, although usually at higher concentrations than Gram-positives (Bentrad et al., 2017; Aoudeh et al., 2023). *Candida albicans* is sensitive to alcoholic extracts at clinically meaningful concentrations (Al-Huqail et al., 2019).

In the Algerian context, Bentrad et al. (2017) characterised the chemical composition and antimicrobial activity of date palm seed and pollen extracts from southern Algeria, identifying oleic acid (36.69 %) and lauric acid (20.49 %) as the dominant fatty acids and reporting strong inhibitory activity of organic seed extracts against bacterial and fungal pathogens of clinical relevance. The authors attributed activity to the synergistic action of medium-chain saturated fatty acids and polyphenolic constituents, consistent with the well-established membrane-perturbation mechanism of lauric acid and its monoglyceride monolaurin against Gram-positive and enveloped membranes. More recently, Benali et al. (2025) demonstrated that ethanolic extract of Algerian Ghars seeds produced inhibition zones up to 27 mm against *Bacillus subtilis*, *Staphylococcus aureus* and *Pseudomonas aeruginosa* in agar diffusion tests, with activity preserved when the extract was incorporated into a cosmetic cream — supporting the development of topical antimicrobial formulations based on Ghars seeds.

Outside Algeria, Al-Huqail et al. (2019) reported strong antibacterial and antifungal activity of *P. dactylifera* seed extracts against *E. coli*, *S. aureus* and *Candida* species *in vitro*, alongside antioxidant activity, framing seed extracts as candidates for pharmaceutical formulations. Kchaou, Abbès, Mansour, et al. (2016) reported antibacterial activity of *p*-coumaric-acid-rich Tunisian extracts against Gram-positive and Gram-negative bacteria, with the strongest activity against *E. coli*, alongside cytotoxic effects on HeLa cells. Aoudeh et al. (2023), in their comparative analysis of six date seed varieties, demonstrated that antibacterial activity was strongest against Gram-positive bacteria, and again correlated with phenolic content.

Mechanistically, the antimicrobial activity of date seed extracts is attributable to (1) polyphenols, particularly catechin/epicatechin, procyanidins, *p*-coumaric, gallic and caffeic acids, which interact with bacterial membranes and inhibit microbial enzymes (Bentrad et al., 2017; Aoudeh et al., 2023; Alkhoori et al., 2022); (2) medium-chain saturated fatty acids, particularly lauric acid and its monoglyceride, which disrupt the lipid bilayer of Gram-positive bacteria and enveloped pathogens (Bentrad et al., 2017); and (3) tannins, which bind microbial proteins and may inhibit virulence-associated enzymes. Subhash et al. (2024) further extended the antimicrobial spectrum of seed-derived molecules by showing that purified seed polysaccharide fractions display additional antibacterial activity. Taken together, the antimicrobial profile of date palm seeds is broad-spectrum, multi-mechanistic, and clinically relevant to topical and gastrointestinal infections, supporting their continued exploration as a source of candidate molecules for pharmaceutical development.

**Table 13.** Antimicrobial activities of date palm seed extracts (therapeutic context).

| Pathogen | Preparation | Activity | Reference |
|---|---|---|---|
| *Staphylococcus aureus* | Algerian Ghars ethanolic extract | Inhibition zone up to 27 mm | Benali et al. (2025) |
| *Bacillus subtilis* | Algerian Ghars ethanolic extract | Inhibition zone up to 27 mm; cream formulation active | Benali et al. (2025) |
| *Pseudomonas aeruginosa* | Algerian Ghars ethanolic extract | Significant inhibition zone | Benali et al. (2025) |
| *S. aureus*, *E. coli*, *Fusarium* | Algerian seed organic extracts | Strong antibacterial and antifungal activity; oleic + lauric acids identified as active | Bentrad et al. (2017) |

| | | | |
|---|---|---|---|
| *E. coli*, *S. aureus*, *Candida* spp. | Saudi seed extract | Antibacterial and antifungal activity *in vitro* | Al-Huqail et al. (2019) |
| Gram + and Gram – bacteria | Tunisian *p*-coumaric-rich extract | Strongest activity against *E. coli* | Kchaou, Abbès, Mansour, et al. (2016) |
| *S. aureus*, *L. monocytogenes*, *E. coli*, *S. enterica* | Aqueous extracts, six international cultivars | Activity strongest against Gram + bacteria; cultivar-dependent | Aoudeh et al. (2023) |
| Gram + and Gram – bacteria | Date seed polysaccharide (microwave-DES) | Antimicrobial effects of polysaccharide fraction | Subhash et al. (2024) |

Crucially, all of these data refer to the inhibition of human pathogens in pharmaceutical and therapeutic contexts: topical formulations (creams, ointments), gastrointestinal infections, oral health and adjunct therapy in nosocomial infections. They are not framed in terms of plant or crop protection, which is explicitly outside the scope of the present chapter. The therapeutic relevance of these findings is reinforced by the rising clinical importance of antibiotic resistance, which has prompted renewed interest in plant-derived antimicrobial leads with multi-target mechanisms unlikely to be circumvented by single-point bacterial mutations (Alkhoori et al., 2022; Alu'datt et al., 2025).

### 5.5. Hepatoprotective, cardioprotective, gastroprotective and renoprotective effects

The cytoprotective activities of date palm seed extracts on the liver, heart, gastrointestinal tract and kidney form one of the most coherent and clinically relevant strands of the literature. They are largely supported by *in vivo* rodent models of chemical or ischaemic injury, with mechanistic readouts that consistently implicate antioxidant defence, anti-inflammatory signalling and modulation of apoptotic pathways. The activity profiles are therefore not generic protective effects but mechanistically rationalised responses traceable to seed polyphenols and lipophilic bioactives (Mortazavi et al., 2014; Al-Yahya et al., 2016; Al-Saad et al., 2020; Ahmed et al., 2021; Tang et al., 2013).

**Hepatoprotection.** Two complementary models of liver injury have been used to demonstrate the hepatoprotective potential of date seed extracts. Mortazavi et al. (2014) showed that aqueous-methanolic seed extract attenuated CCl4-induced hepatotoxicity in rats, normalising serum AST, ALT and ALP, reducing thiobarbituric-acid-reactive substances (TBARS) and oxidative DNA damage, and restoring SOD and GST activities. Ahmed et al. (2021) extended these findings to paracetamol-induced hepatotoxicity, a clinically relevant model of drug-induced liver injury, and reported that date seed extract was as effective as vitamin C in normalising serum hepatic enzymes, reducing oxidative stress markers and improving liver histology. The mechanistic basis of these effects has been linked to polyphenol-mediated radical scavenging, glutathione system restoration and downregulation of pro-inflammatory cytokines.

**Cardioprotection.** Al-Yahya et al. (2016) demonstrated that an ethanolic extract of Ajwa dates (containing a substantial seed-derived polyphenolic fraction) attenuated isoproterenol-induced cardiomyopathy in rats. The extract reduced markers of oxidative stress (MDA), restored reduced glutathione (GSH), downregulated pro-inflammatory mediators (TNF-α, NF-κB, IL-6) and decreased apoptosis (cleaved caspase-3, Bax/Bcl-2 ratio), with histological recovery of cardiac architecture. Although that study used whole-fruit extract, its mechanistic pattern is congruent with seed-extract data and reflects the joint activity of polyphenols, α-tocopherol and phytosterols (Alu'datt et al., 2025).

**Gastroprotection.** Date palm products are used in traditional medicine for dyspepsia, gastritis and constipation, and a series of pharmacological studies have begun to rationalise these uses. Tang et al. (2013), in a comprehensive review, summarise data on date-derived extracts demonstrating reduction of indomethacin- and ethanol-induced gastric mucosal lesions in rodents, with mechanisms involving prostaglandin-mediated mucosal protection, antioxidant activity and stimulation of mucin secretion. Date seed dietary fibre, by virtue of its high water-holding capacity and fermentability (Section 3.4), contributes to the regulation of bowel transit and to the protection of the colonic epithelium against genotoxic insult, as documented by Platat et al. (2019) in a randomised cross-over human intervention.

**Renoprotection.** Al-Saad et al. (2020) demonstrated that pre-treatment of rats with date palm fruit and seed extracts significantly improved kidney function and morphology in a renal ischaemia-reperfusion model. Mechanistic dissection identified Nrf2 upregulation, increased catalase activity, restoration of GSH and reduction of TNF-α and caspase-3 as principal mediators. These findings link renoprotection mechanistically to the antioxidant and anti-inflammatory activities of the seed and provide a coherent rationale for the traditional use of date-based preparations in renal complaints.

**Table 14.** Hepato-, cardio-, gastro- and renoprotective studies of date palm seed/seed-containing extracts.

| Toxicity / injury model — Cultivar(s) studied | Treatment | Outcome | Reference |
|---|---|---|---|
| $CCl_4$-induced hepatotoxicity (rats) — Iranian seed cultivar (unspecified in source) | Aqueous-methanolic seed extract | Normalised AST, ALT, ALP; reduced TBARS; restored SOD, GST | Mortazavi et al. (2014) |
| Paracetamol-induced hepatotoxicity (rats) — Saudi seed cultivar | Date seed extract vs. vitamin C | Comparable normalisation of hepatic enzymes and oxidative markers | Ahmed et al. (2021) |
| Isoproterenol-induced cardiomyopathy (rats) — Saudi cultivar Ajwa (whole-fruit extract) | Ajwa lyophilised extract (polyphenolic fraction) | Reduced MDA, TNF-α, NF-κB, caspase-3; restored cardiac histology | Al-Yahya et al. (2016) |
| Indomethacin / ethanol-induced gastric ulcer — review (multiple cultivars) | Date polyphenol-rich extract | Reduced lesion area; mucus restoration; antioxidant effects | Tang et al. (2013) |
| Constipation / colonic genotoxicity (humans) — UAE cultivar Khalas (date fruit and seed-derived fraction) | Date fibre + seed-derived fraction | Increased bowel movements; reduced stool ammonia; lower faecal-water genotoxicity | Platat et al. (2019) |
| Renal ischaemia-reperfusion (rats) — Iraqi date cultivars (Zahdi-type, regional source) | Date palm fruit + seed extracts | Nrf2 upregulation; CAT, GSH increase; TNF-α, caspase-3 reduction | Al-Saad et al. (2020) |
| *N*-nitroso-*N*-methylurea genotoxicity (mice) — Egyptian seed cultivar | Date seed pit extract | Reduced micronuclei and chromosomal aberrations; chemopreventive potential | Diab and Aboul-Ela (2012) |

AST, aspartate aminotransferase; ALT, alanine aminotransferase; ALP, alkaline phosphatase; TBARS, thiobarbituric-acid-reactive substances; SOD, superoxide dismutase; GST, glutathione-S-transferase; MDA, malondialdehyde; TNF-α, tumour necrosis factor alpha; NF-κB, nuclear factor kappa B; CAT, catalase; GSH, reduced glutathione; Nrf2, nuclear factor erythroid 2-related factor 2; NMU, *N*-nitroso-*N*-methylurea.

Across these protective activities, three mechanistic motifs recur: activation of the Nrf2/Keap1 pathway and the phase II antioxidant response; inhibition of NF-κB-driven inflammation; and modulation of mitochondrial apoptosis (cytochrome-*c* release, caspase-3 activation). All three are entry points actionable by dietary polyphenols (catechin, procyanidins, gallic acid, *p*-coumaric acid) and by lipophilic antioxidants (α-tocopherol, β-sitosterol) — the very compounds whose presence in date palm seeds is well documented (Section 4). The internal coherence between the biochemical composition of the seed and its cytoprotective activities is, in this respect, one of the more convincing aspects of the current literature.

### 5.6. Other relevant biological activities

Beyond the principal activities reviewed above, several additional pharmacological effects of date palm seed extracts have been reported and merit explicit treatment because of their direct relevance to chronic disease prevention and to the broader nutraceutical positioning of seed-derived ingredients.

**Neuroprotective activity.** A growing body of preclinical evidence supports the neuroprotective potential of *Phoenix dactylifera*, with mechanisms consistent with antioxidant, anti-inflammatory and cholinesterase-modulating actions. Essa, Subash, Akbar, et al. (2015) demonstrated that long-term dietary supplementation with dates (as part of a polyphenol-rich diet including pomegranate and figs) reduced neuroinflammation, decreased β-amyloid plaque burden and improved cognitive performance in a transgenic mouse model of Alzheimer's disease, with caffeic acid, ferulic acid and protocatechuic acid identified among the active constituents. Essa, Subash, Dhanalakshmi, et al. (2015) further reported that 2–4 % dietary date supplementation reduced memory deficits, anxiety behaviour and Aβ deposits in the same model at 18 months. Hassan et al. (2024), in a recent PRISMA systematic review of 17 selected studies, confirmed antioxidant-mediated neuroprotection by *P. dactylifera* polyphenols and emphasised the need for mechanistic clarification at the level of specific signalling pathways. Djaoudene, Benali, et al. (2019), in their study of Algerian seed extracts, reported acetylcholinesterase (AChE) inhibitory activity, providing a second mechanistic anchor relevant to Alzheimer's disease, since AChE inhibition is the principal therapeutic strategy for symptomatic relief in mild-to-moderate cognitive decline. Rahmani, Aly, et al. (2014) reviewed therapeutic effects of date fruits via modulation of cholinesterase activity, antioxidant and anti-inflammatory pathways, complementing the seed-specific data.

**Anticancer activity.** *In vitro* anticancer activity of date palm seed extracts has been reported across multiple cancer cell lines, including breast (MCF-7), cervical (HeLa) and colorectal (HCT-116) carcinomas, with growth inhibition mediated by induction of apoptosis, cell-cycle arrest, modulation of NF-κB and PI3K/Akt signalling, and direct genotoxicity-protective effects (Rahmani, Almatroodi, et al., 2014; Kchaou, Abbès, Mansour, et al., 2016; Aoudeh et al., 2023; El-Far et al., 2019). Diab and Aboul-Ela (2012) demonstrated *in vivo* antigenotoxic activity of date seed pit extract against N-nitroso-N-methylurea-induced DNA damage in mice, with reductions in micronuclei formation and chromosomal aberrations supporting chemopreventive potential. Eid et al. (2015) showed that date polyphenols, including those of seed origin, modulate gut microbial ecology and inhibit colon cancer cell proliferation, integrating prebiotic and anticancer mechanisms. Quercetin, identified as a constituent of date seeds (Bouhlali et al., 2017, 2020), is a particularly well-studied anticancer flavonoid whose mechanism of action — cell-cycle arrest, apoptosis induction, angiogenesis inhibition, modulation of PI3K/Akt and NF-κB — has been thoroughly reviewed by El-Far et al. (2019) and provides a plausible mechanistic anchor for the anti-proliferative effects of seed extracts.

**Hypolipidaemic activity.** Bouhlali, Ramchoun, et al. (2016) provided robust *in vivo* evidence that methanolic extract of Moroccan date seeds (200 mg/kg) significantly lowered total cholesterol, triglycerides and LDL-C and elevated HDL-C in Triton-WR-1339- and high-fat-diet-induced hyperlipidaemic rats, with rutin, quercetin, *p*-coumaric and caffeic acid identified as key compounds. Hasan and Mohieldein (2016), in STZ-diabetic rats, similarly demonstrated improvement in lipid profile alongside antidiabetic and antioxidant effects. The hypolipidaemic activity is mechanistically multi-pronged: phytosterols (β-sitosterol) inhibit intestinal cholesterol absorption; soluble polysaccharides bind bile acids and reduce enterohepatic recirculation; and polyphenols modulate hepatic lipid metabolism (Alu'datt et al., 2025; Tang et al., 2013).

**Prebiotic activity.** The role of date seed dietary fibre and polysaccharides as prebiotic substrates has been increasingly documented. Platat et al. (2019), in a randomised cross-over human intervention with 22 participants, reported that palm date consumption significantly increased bowel movements, reduced stool ammonia concentration and decreased genotoxicity in faecal water — three readouts that collectively support a prebiotic and chemopreventive effect on the colonic environment. Subhash et al. (2024) showed that microwave-extracted seed polysaccharides modulate gut microbiota composition with selective stimulation of beneficial taxa. Eid et al. (2015) demonstrated that date polyphenols modulate gut microbial ecology, bacterial metabolite production and colon cancer cell proliferation. Mrabet et al. (2020) and Elleuch et al.

(2011) detail the technological and prebiotic functionality of date seed fibres, supporting their incorporation into functional foods such as the date-seed-enriched pita bread documented by Platat et al. (2015) and the date-seed-enriched yoghurt by Benchikh and Louaileche (2014).

**Anti-obesity activity.** Although less extensively studied than the activities above, anti-obesity effects of date seed extracts are biologically plausible from the convergence of α-glucosidase inhibition, hypolipidaemic activity, prebiotic modulation and high satiogenic dietary fibre content. Djaoudene, Benali, et al. (2019) reported that Algerian seed extracts inhibit pancreatic lipase, an enzyme central to dietary fat digestion and a validated target for anti-obesity drug development (orlistat being the reference inhibitor). The combination of pancreatic lipase inhibition, α-glucosidase inhibition, satiogenic fibre and improvement of lipid profile thus supports the positioning of date seeds as a candidate anti-obesity functional ingredient (Bouhlali, Ramchoun, et al., 2016; Subhash et al., 2024; Alu'datt et al., 2025).

**Table 15.** Other biological activities of date palm seed extracts (neuroprotective, anticancer, prebiotic, anti-obesity).

| Activity / Cultivar(s) studied | Model | Finding | Reference |
|---|---|---|---|
| Neuroprotective — Omani date cultivars (mixed dietary source) and review | Transgenic Alzheimer mouse model (long-term) | Reduced neuroinflammation; decreased Aβ plaques; improved cognition | Essa, Subash, Akbar, et al. (2015); Essa, Subash, Dhanalakshmi, et al. (2015) |
| Neuroprotective — eight Algerian cultivars from M'zab/Ghardaïa (Ourous, Tazizaout, Tazarzeit, Tazoughart, Ouaouchet, Oukasaba, Delat, Tamezwertn'telet); review | AChE inhibition (*in vitro*), Algerian cultivars | Multifunctional inhibition relevant to symptomatic Alzheimer therapy | Djaoudene, Benali, et al. (2019); Hassan et al. (2024) |
| Anticancer — second-grade Tunisian cultivars Korkobbi and Eguioua | HeLa cells (*in vitro*) | Cytotoxicity correlated with phenolic content (*p*-coumaric acid) | Kchaou, Abbès, Mansour, et al. (2016) |
| Anticancer — review (multiple cultivars including Ajwa); six international cultivars (Aoudeh: Khudari, Sakai, Safawi, Majdool, | MCF-7, HCT-116, HeLa lines (review) | Growth inhibition; apoptosis induction; NF-κB modulation | Rahmani, Almatroodi, et al. (2014); Aoudeh et al. (2023); El-Far et al. (2019) |

| | | | |
|---|---|---|---|
| Zahdi, Kabkab); quercetin review | | | |
| Antigenotoxic / chemopreventive — Egyptian seed cultivar (unspecified) | NMU-induced DNA damage (mice) | Reduced micronuclei and chromosomal aberrations | Diab and Aboul-Ela (2012) |
| Hypolipidaemic — Moroccan cultivars Jihel and Majhoul | High-fat diet + Triton WR-1339 (rats) | Lower TC, TG, LDL-C; higher HDL-C | Bouhlali, Ramchoun, et al. (2016) |
| Prebiotic — UAE cultivar Khalas (palm-date intervention) | Randomised cross-over (humans, n = 22) | Increased bowel movements; lower stool ammonia; decreased faecal-water genotoxicity | Platat et al. (2019) |
| Prebiotic — UAE cultivar Khalas (Subhash, microwave-DES polysaccharide); review (Eid) | Microbiota modulation *in vitro* | Selective stimulation of *Bifidobacterium*, *Lactobacillus* | Subhash et al. (2024); Eid et al. (2015) |
| Anti-obesity — eight Algerian cultivars from M'zab/Ghardaïa | Pancreatic lipase inhibition (*in vitro*), Algerian cultivars | Inhibition of lipase activity comparable to reference inhibitors | Djaoudene, Benali, et al. (2019) |
| Functional food incorporation — UAE cultivar Khalas (Platat, pita bread); Algerian cultivar Mech-Degla (Benchikh & Louaileche, yoghurt) | Date-seed-enriched pita bread, yoghurt | Improved nutritional and antioxidant profile | Platat et al. (2015); Benchikh and Louaileche (2014) |

AChE, acetylcholinesterase; Aβ, β-amyloid; NMU, *N*-nitroso-*N*-methylurea; TC, total cholesterol; TG, triglycerides; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; DES, deep eutectic solvent.

## 6. Ethnopharmacological and Traditional Medicinal Uses of Date Palm Seeds

The pharmacological corpus reviewed in Section 5 cannot be fully understood without the ethnobotanical and ethnopharmacological tradition that has surrounded the date palm for millennia. Across the Saharo-Arabian belt, *Phoenix dactylifera* is described in classical medical texts and in living folk pharmacopoeias as a "complete" medicinal plant whose various organs — fruits, seeds, leaves, sap, pollen and even root portions — are used preventively or therapeutically for a remarkable diversity of indications (Hammiche & Maiza, 2006; Beloued, 2009; Miara et al., 2019; Vayalil, 2012). The seed in particular occupies an important place in this tradition: it is variously used as a roasted "date-seed coffee" tonic, as a powder added to milk or bread, as an aqueous decoction for diabetic and gastrointestinal complaints, as a paste applied topically for wounds and dermatoses, and as an ingredient in postpartum and reproductive remedies for both humans and livestock (Hammiche & Maiza, 2006; Ould El Hadj, Hadj-Mahammed, & Zabeirou, 2003; Miara et al., 2019; Beloued, 2009).

In central Saharan Algeria, Hammiche and Maiza (2006) documented the pharmacopoeia of nomadic populations of Tassili N'Ajjer and recorded the medicinal use of date palm products as part of a broader compendium of 80 wild and cultivated medicinal plants, with *Phoenix dactylifera* indicated for digestive complaints, fatigue and convalescence. In the Tuareg communities of Illizi (southeastern Algerian Sahara), Miara et al. (2019) documented 118 medicinal plant species, with date palm products specifically used for dietary therapy of diabetes, anaemia and gastrointestinal disorders, and as a supportive remedy in maternal and infant care. In the northeastern Sahara around Ouargla, Ould El Hadj, Hadj-Mahammed, and Zabeirou (2003) recorded the place of date palm in folk medicine as one of the few cultivated species systematically integrated into traditional therapeutic practice, used both as food and as medicine according to the holistic doctrine of *al-ghidha' wa al-dawa'* (food-as-medicine). In the broader Algerian pharmacopoeia, Beloued (2009) provides an authoritative compendium describing the traditional uses of *P. dactylifera* across multiple Algerian regions and indicating preparation methods including decoctions, infusions, pastes, fermented preparations and topical applications.

The traditional indications can be organised into a small number of recurring categories. Digestive uses dominate: powdered or roasted seeds are used as antidiarrhoeal and antidyspeptic remedies and as carminatives in case of postprandial discomfort. Metabolic uses are also prominent: aqueous and milk-based seed preparations are recommended for diabetes, fatigue and convalescence, and seed flour is added to bread or porridge as a tonic for chronically ill or undernourished patients. Hepatobiliary uses include the use of decoctions for jaundice, hepatic complaints and "liver heat", in line with the humoral logic of Maghrebi traditional medicine. Genitourinary uses are documented, particularly for postpartum recovery, lactation support and various forms of male sterility, with seeds combined with milk, honey and other galactogogues. Topical and dermatological uses include the application of seed paste and oil to wounds, eczema, hair loss and acne, exploiting both the antimicrobial and the anti-inflammatory activity of seed-derived constituents — uses that resonate strongly with the cosmetic-cream formulation developed by Benali et al. (2025) for Ghars seed extract.

The convergence between this traditional knowledge and the modern pharmacological evidence reviewed in Section 5 is striking. Antidiabetic and hypolipidaemic uses match the documented α-glucosidase inhibition, antiglycation, antioxidant and lipid-lowering effects of seed extracts (Hilary et al., 2019; Hasan & Mohieldein, 2016; Bouhlali, Ramchoun, et al., 2016; Mohammed et al., 2018; Subhash et al., 2024). Hepatoprotective traditional uses are corroborated by Mortazavi et al. (2014) and Ahmed et al. (2021). Gastrointestinal uses correspond to the prebiotic and gastroprotective activities documented by Platat et al. (2019), Tang et al. (2013), Mrabet et al. (2020), and Subhash et al. (2024). Topical uses are mechanistically supported by the antimicrobial and anti-inflammatory data of Bentrad et al. (2017), Al-Huqail et al. (2019) and Benali et al. (2025). Even the more diffuse traditional indication of "general tonic" maps onto the documented multi-target antioxidant, anti-inflammatory and cytoprotective profile of seed extracts (Vayalil, 2012; Alkhoori et al., 2022; Alu'datt et al., 2025; Rahmani, Aly, et al., 2014).

**Table 16.** Traditional uses of date palm seeds (*Phoenix dactylifera* L.) and corresponding modern validated activities.

| Traditional indication | Region(s) of documented use | Modern validated activity / mechanism | References |
|---|---|---|---|
| Diabetes and metabolic complaints | Algerian Sahara, Maghreb, Arabian Peninsula | α-Glucosidase / α-amylase inhibition; antiglycation; antioxidant; hypolipidaemic | Hammiche and Maiza (2006); Beloued (2009); Miara et al. (2019); Mohammed et al. (2018); Hilary et al. (2019); Hasan and Mohieldein (2016); Bouhlali, Ramchoun, et al. (2016); Subhash et al. (2024) |
| Digestive complaints, dyspepsia, antidiarrhoeal | Algerian Sahara, Sahel, Arabian Peninsula | Prebiotic effects; high-fibre/galactomannan content; antimicrobial activity | Hammiche and Maiza (2006); Beloued (2009); Miara et al. (2019); Platat et al. (2019); Mrabet et al. (2020); Subhash et al. (2024) |
| Hepatic and biliary complaints, jaundice | Algerian Sahara, Maghreb | Hepatoprotection vs. CCl4 and paracetamol; antioxidant defence | Beloued (2009); Mortazavi et al. (2014); Ahmed et al. (2021) |
| Renal complaints, urinary disorders | Maghreb, Arabian Peninsula | Renoprotection vs. ischaemia-reperfusion; Nrf2-mediated antioxidant defence | Beloued (2009); Al-Saad et al. (2020) |
| Cardiac fatigue and convalescence | Algerian Sahara, Maghreb | Cardioprotection vs. isoproterenol; anti-inflammatory and antioxidant | Beloued (2009); Al-Yahya et al. (2016); Rahmani, Aly, et al. (2014) |
| Postpartum recovery, lactation, fertility | Algerian Sahara, Saudi Arabia | Nutritional density; phytosterols; iron and B-vitamins | Hammiche and Maiza (2006); Beloued (2009); Vayalil (2012); Alu'datt et al. (2025) |
| Wounds, dermatoses, | Algerian Sahara, Maghreb | Topical antimicrobial; anti-inflammatory; antioxidant; cosmetic cream | Beloued (2009); Bentrad et al. (2017); Al-Huqail et al. (2019); Benali et al. (2025) |

| | | | |
|---|---|---|---|
| skin and scalp care | | | |
| General tonic, anti-fatigue, "blood-builder" | Algerian Sahara, Sahel, Maghreb | Antioxidant; anti-inflammatory; multi-mineral and amino-acid contribution | Hammiche and Maiza (2006); Beloued (2009); Vayalil (2012); Alkhoori et al. (2022); Alu'datt et al. (2025) |
| Memory and "mental fatigue" | Maghreb, Arabian Peninsula | Neuroprotection; AChE inhibition; reduction of Aβ in animal models | Beloued (2009); Essa, Subash, Akbar, et al. (2015); Essa, Subash, Dhanalakshmi, et al. (2015); Hassan et al. (2024); Djaoudene, Benali, et al. (2019) |
| Roasted "date-seed coffee" as caffeine-free tonic | Algerian Sahara, Arabian Peninsula | Antioxidant beverage; phenolic-rich infusion | Al-Shahib and Marshall (2003); Alkhoori et al. (2022); Beloued (2009) |

# CHAPTER II

## Materials and Methods

## 7. Materials and Methods

### 7.1. Plant Material Collection

Date palm seeds (*Phoenix dactylifera* L.) of the 'Ghars' cultivar, collected from fruits locally cultivated in the El Oued region (Douar El Ma, Taleb Larbi District, 33°22′20″ N, 7°41′10″ E; southeastern Algeria), were used as the plant material in this study. The seeds were manually separated from the fruit pulp, thoroughly cleaned to remove adhering residues and damaged material, and rinsed with distilled water to eliminate surface impurities. They were then spread in a thin layer and shade-dried at room temperature under a clean, breathable cover to protect them from dust, insects, and direct light while ensuring adequate air circulation. After complete drying, the seeds were stored in a tightly sealed glass container at room temperature, protected from moisture and light, until further use in the extraction procedures.

### 7.2. Preparation of the Extract and Fractionation of Plant Material

Date palm seeds (*Phoenix dactylifera* L.) of the 'Ghars' cultivar (200 g) were ground using an electric grinder to obtain a coarsely pulverized material (medium granulometry) suitable for solvent extraction. The resulting seed powder was macerated in 600 mL of a hydroalcoholic methanol/water solution (75:25, v/v) for 24 hours at room temperature with occasional stirring. This procedure was repeated three times, renewing the solvent every 24 hours, and the combined macerates were subsequently filtered. At a later stage, the hydroalcoholic filtrate was concentrated under reduced pressure using a rotary evaporator at 40 °C to obtain the crude dried extract.

### 7.3. Phytochemical Studies

#### 7.3.1. Determination of the Extraction Yield

The extraction yield of the hydromethanolic extract of *Phoenix dactylifera* L. seeds of the Ghars cultivar, cultivated in the El Oued region, was determined gravimetrically. Following the three successive 24-hour maceration cycles in methanol–water (75:25, v/v) described in Section 7.2, the combined filtrates were concentrated to dryness under reduced pressure using a rotary evaporator at 40 °C until a constant mass was attained. The resulting crude dried extract was carefully recovered into a pre-weighed glass container and weighed on an analytical balance. The initial mass of the shade-dried, ground seed material subjected to extraction was recorded prior to maceration on the same balance and served as the reference basis for the calculation.

The extraction yield was expressed as a percentage on a weight-by-weight basis (%, w/w), relative to the initial dry weight of the plant material, and was calculated according to the following equation:

$$\text{Extraction yield } (\%,\, w/w) = \frac{m_{\text{extract}}}{m_{\text{sample}}} \times 100 \text{ (Equation 01)}$$

where:

***m*_extract** is the mass of the crude dried hydromethanolic extract obtained after complete solvent removal under reduced pressure (g);

***m*_sample** is the initial mass of the shade-dried, ground *Phoenix dactylifera* L. seed powder (Ghars cultivar) subjected to maceration (g).

**7.3.2. Determination of Total Phenolics**

The total phenolic content of the hydromethanolic extract of Date palm seeds (*Phoenix dactylifera* L.) of the 'Ghars' cultivar was determined using the Folin–Ciocalteu colorimetric method as described by Li et al. (2007), with slight modifications. An aliquot of 0.2 mL of the appropriately diluted extract was mixed with 1.0 mL of Folin–Ciocalteu reagent (10%, v/v) and allowed to stand for 5 minutes at room temperature. Subsequently, 0.8 mL of a 7.5% (w/v) $Na_2CO_3$ solution was added, and the mixture was incubated in the dark at room temperature for 40 minutes. The absorbance was then measured at 765 nm against a reagent blank using a UV–Visible spectrophotometer.

Total phenolic content was quantified using a gallic acid calibration curve and expressed as micrograms of gallic acid equivalents per milligram of extract (µg GAE/mg extract), according to the linear regression equation $y = 0.006x + 0.0007$ ($R^2 = 0.99$).

**7.3.3. Determination of Total Flavonoid**

Total flavonoid content of the date palm seeds *(Phoenix dactylifera* L.*)* cv. 'Ghars' extract was determined according to the aluminum chloride colorimetric method described by Mbaebie et al. (2012), with slight modifications. Equal volumes of the appropriately diluted extract and aluminum chloride solution (0.2%, w/v in methanol or ethanol) were mixed thoroughly and allowed to incubate for 60 minutes at room temperature. After incubation, the absorbance of the reaction mixture was measured at 415 nm against a reagent blank using a UV–Visible spectrophotometer.

Total flavonoid content was calculated from a quercetin calibration curve and expressed as micrograms of quercetin equivalents per milligram of dry extract (µg QE/mg extract), according to the linear regression equation $y = 0.005x + 0.0402$ ($R^2 = 0.99$).

### 7.3.4. Determination of Tannins Content

Total condensed tannins were determined according to the vanillin–HCl method described by Kokoska et al. (2008) and Muthukrishnan et al. (2018), with slight modifications. In stoppered (coated) test tubes, 0.5 mL of the appropriately diluted extract was mixed with 1.5 mL of concentrated HCl and 3.0 mL of vanillin reagent (4%, w/v, prepared in methanol). The reaction mixtures were incubated at 20 °C for the specified reaction time, and the absorbance was then measured at 500 nm against a reagent blank using a UV–Visible spectrophotometer.

The total condensed tannin content was expressed as micrograms of catechin equivalents per milligram of dry extract (µg C/mg extract), based on the linear regression equation obtained from the catechin calibration curve $y = 0.0036x + 0.0249$ ($R^2 = 0.996$).

### 7.3.5. HPLC-PDA Analysis

The phenolic profile of the hydromethanolic extract of date palm seeds (*Phoenix dactylifera* L.) cv. 'Ghars' was determined by reversed-phase high-performance liquid chromatography coupled with photodiode-array detection (HPLC–PDA). The analyses were carried out on a Shimadzu HPLC system equipped with an LC-20ADXR binary low-pressure-gradient pump, a SIL-20ACXR autosampler, a CTO-20A column oven thermostated at 30 °C and a SPD-M20A photodiode-array detector. Chromatographic separation was achieved on a Restek Ultra C18 reversed-phase column (250 × 4.6 mm, 5 µm particle size). The mobile phase consisted of solvent B (acetonitrile) and solvent D (1% aqueous acetic acid, v/v) and was delivered at a constant flow rate of 1.0 mL/min using the following linear gradient program: 0.01 min, 10% B / 90% D; 0–55 min, linear increase to 100% B; 55–60 min, return to 10% B / 90% D; 60–70 min, 10% B / 90% D for column re-equilibration. The injection volume was 10 µL of the filtered hydromethanolic extract and the total run time was 70 min.

Photodiode-array detection was performed over the 190–800 nm wavelength range with a sampling frequency of 1.5625 Hz and a slit width of 1.2 nm; the quantification channel was set at 254 nm (bandwidth 4 nm, output range 1.0 AU/V). The flow-cell temperature was maintained at 30 °C. Individual phenolic compounds were identified by comparison of their retention times and UV–visible absorption spectra with those of authentic reference standards analysed under identical chromatographic conditions, and quantification was performed from the integrated peak areas obtained at 254 nm.

### 7.4. *In-Vitro* Antioxidant Activity

#### 7.4.1. DPPH Free Radical Scavenging Assay

The putative radical-scavenging activity of date palm seeds *(P. dactylifera* L.*)* cv. 'Ghars' extract was evaluated against $DPPH^{•}$ free radicals using the method described by (Jafri et al., 2017). Equal amounts of samples and 0.1mM of $DPPH^{•}$ solution were blended and placed in the dark for 30min at ambient temperature. The absorbance of the solutions was determined at a wavelength of 517 nm, Trolox and Ascorbic acid were used as standards in this assay, and the radical scavenging potential of $DPPH^{•}$ is determined as $IC_{50}$ values calculated according to the below equation:

$$\textit{Inhibition Percentage} = [1-(Abs/Abc)] \times 100 \quad \text{(Equation 02)}$$

$Ab_S$: absorbance of the sample or standard solution.

$Ab_C$: absorbance of control solution.

#### 7.4.2. ABTS Cation Radical Scavenging Assay

The test was conducted as described earlier (Re et al., 1999), 4 mL of ABTS (7mM) solution were mixed with 4 mL 2.45 mM $K_2S_2O_8$ solution and stored for 16 hours at room temperature. Prior to testing the ABTS solution was concentration with ethanol till the absorbance value at 734 nm came out to be 0.703 ± 0. 025. Volumes of 950 µL of $ABTS^{•+}$ solutions were mixed with 50µL different concentrations of date palm seeds *(P. dactylifera* L.*) cv.* 'Ghars' samples. Ethanol was used as negative control, while Trolox and Ascorbic acid were used as standard. The graph of the percentage scavenging effect with sample concentration was used to obtain the $IC_{50}$ values.

$$ABTS^{•+} \textit{ scavenging power (\%)} = [(Ab_0 - Ab_1)/Ab_0] \times 100 \quad \text{(Equation 03)}$$

$Ab_0$: absorbance of $ABTS^{•+}$ solution .

$Ab_1$: absorbance of $ABTS^{•+}$ standard or extract.

#### 7.4.3. Phenanthroline Antioxidant Assay

The antioxidant activity of the hydromethanolic extract of date palm seeds *(P. dactylifera* L.*)* cv. 'Ghars' was evaluated using the o-phenanthroline assay, following the iron(III)–phenanthroline total antioxidant capacity method described by Özyürek et al. (2007) and further discussed by Apak and co-workers, with slight modifications to adapt it to plant extracts. Briefly, an appropriate volume of the extract (or standard) was mixed in a test tube with phosphate buffer (0.1 M, pH 7.4), o-phenanthroline solution (5 mM), and ferrous sulfate solution (5 mM) to obtain a final reaction mixture volume of 3.0 mL. The mixture was incubated at 37 °C for 30 minutes, and the formation of the Fe(II)–o-phenanthroline complex was monitored by measuring the absorbance at 510 nm against a reagent blank using a UV–Visible spectrophotometer.

The assay was performed at different concentrations of the hydromethanolic extract of Ghars seeds to establish a concentration–response curve, while Trolox and Ascorbic acid were used as standard. Antioxidant activity was expressed as the percentage inhibition of the control reaction, calculated according to the following equation, commonly used in spectrophotometric antioxidant assays:

$$\text{Inhibition Percentage} = \left[1 - \left(\frac{\text{Abs}_S}{\text{Abs}_C}\right)\right] \times 100 \quad \text{(Equation 04)}$$

where $\text{Abs}_S$ is the absorbance of the reaction mixture containing the sample or standard solution and $\text{Abs}_C$ is the absorbance of the control reaction (without extract or standard). The $IC_{50}$ value (concentration providing 50% inhibition) can be determined from the plot of inhibition percentage versus sample concentration by linear regression.

### 7.5. Enzyme inhibitory activities

#### 7.5.1. Evaluation α-amylase inhibitory activity

α-amylase inhibitory activity was determined using the technique described by the Marmouzi study (Marmouzi et al., 2018).This involved incubating various concentrations of date palm seeds *(P. dactylifera* L.*)* cv. 'Ghars' extract (25 µL) with the α-amylase enzyme in a phosphate buffer (50 µL) and starch solution (50 µL) at 37°C. After 10 minutes, the reaction was stopped by adding 25 µL of 1 M hydrochloric acid and 100 µL of IPI (iodine-potassium iodide) solution. Following that, the absorbance was measured at 630 nm. As a positive control, acarbose was used. The inhibitory % activity was calculated in the following way (Equation 05):

$$\textit{Inhibition (\%)} = (1 - (\textit{Absorbance}_{sample}/\textit{Absorbance}_{control})) \times 100 \quad \text{(Equation 05)}$$

The results were represented as $IC_{50}$ values, which show the fraction concentration necessary to block 50% of enzyme activity.

#### 7.5.2. Evaluation of α-glucosidase inhibitory activity

To determine the inhibitory capacity of α-glucosidase using date palm seeds *(P. dactylifera* L.*)* cv. 'Ghars' extract as the test sample. Methodologies established by Marmouzi (Marmouzi et al., 2018) were utilised, with p-nitrophenyl-α-D-glucopyranoside as the substrate and a 96-well microplate format. A mixture of 50 µL of the extract, 50 µL of glutathione, and 50 µL of α-glucosidase solution in phosphate buffer (pH 6.8), and PNPG (50 µL) was prepared and incubated for 15 minutes. The process was then stopped by adding 50 µL of 0.2 M $Na_2CO_3$, and the absorbance at 400 nm was measured. Acarbose was employed as a positive control. The inhibitory percentage activity was estimated using the equation below (Equation 06):

$$Inhibition\ (\%) = (1 - (Absorbance_{sample}/Absorbance_{control})) \times 100$$ (Equation 06)

The results were subsequently expressed as $IC_{50}$ values.

### 7.5.3. Evaluation of acetylcholinesterase inhibition activity

The capacity of date palm seeds *(P. dactylifera* L.*)* cv. 'Ghars' to inhibit acetylcholinesterase was analysed through the method of Ellman et al (Ellman et al., 1961). The procedure involved mixing 300 µL of 50 mM Tris-HCl buffer (pH 8), 30 µL of AChE solutions, and 100 µL of the sample. Following a 15-minute incubation, 130 µL of acetylthiocholine iodide and 440 µL of DTNB (3 mM) were added to end the reaction, and the absorbance was determined at 412 nm. Galantamine was used as the standard, and $IC_{50}$ values were utilised to report the results. The inhibition potency was calculated using the equation below (Equation 07):

$$\%Inhibition = [(A-B)/A] \times 100$$ (Equation 07)

A is AChE capacity in the absence of an inhibitor, B is AChE capacity in the presence of an inhibitor.

### 7.6. Statistical Analysis

All experiments, including phytochemical quantification, *in vitro* antioxidant assays and enzyme inhibitory tests (α-amylase, α-glucosidase and acetylcholinesterase), were performed in triplicate (n = 3). Results are expressed as mean ± standard deviation (SD). $IC_{50}$ ($A_{0.5}$, where applicable) values were obtained by linear regression from concentration–response curves.

# GENERAL CONCLUSION AND RECOMMENDATIONS

## 10. General Conclusion and Recommendations

The present study was undertaken in order to characterize the phytochemical composition and to evaluate the in vitro biological activities of the hydromethanolic extract of date palm (Phoenix dactylifera L.) seeds of the 'Ghars' cultivar cultivated in the El Oued region (Douar El Ma, Taleb Larbi District, south-eastern Algeria), a locally emblematic Saharan cultivar whose seed fraction remains scientifically underexplored despite its recognized potential as a source of bioactive secondary metabolites. To meet these objectives, the seeds were manually separated from the fruit pulp, cleaned, shade-dried, ground to a medium granulometry, and submitted to hydromethanolic maceration using a methanol/water mixture (75:25, v/v) through three successive 24-hour cycles at room temperature, after which the combined macerates were filtered and concentrated under reduced pressure at 40 °C, yielding a crude dried extract of 24.61% (w/w) relative to the initial dry weight of seeds. The resulting extract was then subjected to colorimetric quantification of total phenolics (Folin–Ciocalteu), total flavonoids (aluminium chloride) and condensed tannins (vanillin–HCl), as well as to HPLC–PDA profiling of individual phenolic and related compounds, and to the in vitro evaluation of antioxidant activity through three complementary assays (DPPH, ABTS and o-phenanthroline), antidiabetic activity through α-amylase and α-glucosidase inhibition assays with acarbose as reference inhibitor, and anti-Alzheimer activity through the acetylcholinesterase inhibition assay (Ellman method) with galantamine as reference inhibitor.

The experimental results converged towards a coherent picture of a polyphenol-dense and biologically active matrix. The hydromethanolic extraction afforded a crude yield of 24.61% (w/w), and the colorimetric assays revealed a remarkably high total phenolic content of 284.19 ± 1.40 mg GAE/g of dry extract, accompanied by 94.33 ± 3.90 mg QE/g of total flavonoids and 68.62 ± 1.20 mg CE/g of condensed tannins, while HPLC–PDA fingerprinting targeted fifteen phenolic and related compounds, of which ten were detected and quantified, dominated by salicin (6949.30 µg/g extract), caffeic acid (431.74 µg/g extract) and esculin (207.34 µg/g extract). Functionally, the extract displayed considerable antioxidant activity, with $IC_{50}$ values of 8.300 ± 0.231 µg/mL (DPPH) and 3.984 ± 0.033 µg/mL (ABTS) and an $A_{0.5}$ of 5.474 ± 0.156 µg/mL in the *o*-phenanthroline assay, closely approaching the values recorded for Trolox and ascorbic acid. The extract also exhibited measurable anti-Alzheimer activity through acetylcholinesterase inhibition ($IC_{50}$ = 98.82 ± 5.25 µg/mL versus 28.00 ± 0.30 µg/mL for galantamine). Most notably, the antidiabetic activity was particularly remarkable: the extract inhibited α-amylase with an $IC_{50}$ of 50.03 ± 3.80 µg/mL — a value lower (i.e., more potent) than that obtained for the reference inhibitor acarbose (60.86 ± 1.58

μg/mL) — together with a complementary α-glucosidase inhibition ($IC_{50}$ = 120.00 ± 2.97 μg/mL versus 62.20 ± 1.38 μg/mL for acarbose).

Taken together, these findings indicate that the hydromethanolic extract of 'Ghars' date seeds could represent a valuable multi-target candidate for the development of natural products aimed at the management of oxidative stress, postprandial hyperglycaemia and cholinergic dysfunction.

Nevertheless, it must be explicitly emphasized that the present results were obtained exclusively under *in vitro* conditions and therefore require further validation through systematic *in vivo* pharmacological investigations, followed by appropriately designed clinical trials, in order to establish the effective dosages, the bioavailability and pharmacokinetic profile, the safety margins, the potential side effects, the contraindications, and the population subgroups — notably pregnant or lactating women, children, elderly patients and individuals under specific pharmacological treatments — for whom the consumption of date seed-based products derived from *Phoenix dactylifera* L. cv. 'Ghars' should be restricted or contraindicated. Subject to such validation, 'Ghars' date seeds constitute a rich reservoir of bioactive compounds that deserves to be exploited as a strategic natural resource, particularly for medical, pharmaceutical and, most especially, nutraceutical and dietary supplement applications.

On the strength of these scientific outcomes, a first recommendation is hereby formally addressed to the national scientific and economic communities, namely to renew and intensify their attention to local Algerian date palm cultivars, and in particular to the 'Ghars' cultivar of the El Oued region, given its historical, cultural, agricultural and scientific importance for the local population. It is increasingly observed in the region that many farmers tend to abandon, partially or totally, the traditional cultivation of the date palm in favour of more rapidly profitable seasonal crops such as potatoes and tomatoes, a concerning trend that may, in the medium term, threaten the genetic diversity of local cultivars, the integrity of the Saharan oasis ecosystem, and the ancestral know-how associated with palm cultivation transmitted across generations. The preservation of this biodiversity and of the associated traditional knowledge therefore appears as an urgent priority, in which scientific research can play a decisive role by demonstrating, as in the present work, the high added value of these local genetic resources.

A second recommendation is addressed to the scientific, industrial and economic sectors, regarding the integrated valorization of date palm by-products in general, and date seeds in particular. Date seeds represent one of the most abundant yet most underutilized residues of the date-processing industry, the majority of which are currently discarded as waste, while only a marginal fraction is redirected towards low-added-value uses such as animal feed. The establishment of an integrated, zero-waste production chain, in which every by-product of the date palm — seeds, fronds, fibres, spathes, pulp residues and lignocellulosic biomass — is systematically recovered, processed and channelled towards its most suitable pharmaceutical, nutraceutical, cosmetic, agricultural or bioenergetic application, would simultaneously generate scientific, economic and environmental benefits and contribute to the structuring of a genuinely circular Saharan bioeconomy.

In a forward-looking perspective, the present study illustrates how rigorous phytochemical and pharmacological research can articulate scientific knowledge with the imperatives of sustainable development, circular economy, local economic growth and the rational exploitation of natural plant resources. Complementary research efforts are therefore strongly encouraged, including in particular advanced metabolomic profiling by LC-MS/MS, the bioassay-guided isolation and structural elucidation of pure bioactive molecules, *in vivo* pharmacokinetic, pharmacodynamic and toxicological studies, and dedicated galenic and formulation work aimed at the development of standardized, safe and clinically validated nutraceutical and pharmaceutical products derived from *Phoenix dactylifera* L. cv. 'Ghars' seeds. Such an integrated research agenda may contribute, in the medium term, to transforming a long-neglected agro-industrial residue into a flagship resource of the Algerian Saharan biodiversity.

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