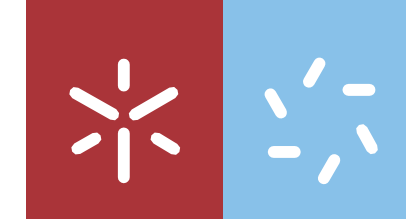




Luana de Albuquerque Mello Dias

Diseases and pests that affect date palm
culture and biocontrol methods



University of Minho
Science School



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**Diseases and pests that affect date palm culture
and biocontrol methods**

Master thesis

Master in environmental sciences and technologies –
Environmental Monitoring and Remediation

This work was realized under supervision of

Doctor Maria Teresa Correia Guedes Lino Neto

October 2023

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Acknowledgements

Gostaria de agradecer à minha orientadora, Professora Teresa Lino Neto, não somente por aceitar trabalhar mesmo que à distância, mas por todo incentivo, apoio e esforço dispensado para que pudéssemos concluir este projeto. Agradeço pela fé em mim depositada, pela paciência e gentileza ao me orientar e por todo conhecimento que compartilhou comigo.

Agradeço à minha família, em especial minha mãe, Christianne Dias, e minha prima Caroline Dias, pelo amor, apoio e encorajamento durante esse processo. Por terem torcido por mim e não terem me deixado desistir.

Também agradeço aos meus amigos, Amanda Sotero, Ana Luiza Oliveira, Ananda Santiago, Bruna Paiva, Felipe Sciammarella, Isadora da Costa, Isis Rollim, Lorryne Duarte, Mayara Louzada e a todos aqueles que seguraram a minha mão, mesmo que virtualmente, pelo apoio incondicional nessa aventura além-mar.

Por fim, agradeço às minhas primeiras orientadoras, Cláudia Barbieri e Vânia Esteves, sem as quais minha jornada acadêmica jamais teria acontecido.

Statement of integrity

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

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Diseases and pests that affect date palm culture and biocontrol methods

Resumo

A tamareira (*Phoenix dactylifera* L.) apresenta elevada importância social e económica para os países do Norte da África. As tâmaras têm uma relevância cultural e religiosa significativa, sendo cruciais para a subsistência das populações locais na região. Além disso, a economia da maioria dos países do Norte-Africanos depende fortemente da produção de tâmaras. No entanto, esta espécie tem sido severamente afetada por muitas doenças e pragas ao longo dos anos, traduzindo-se em enormes danos ao nível da produção e qualidade dos frutos. As maiores ameaças à cultura das tamareiras são o fungo *Fusarium oxysporum* (agente causador da *bayoud*), o oomicete *Phytophthora palmivora* (agente causador da *bélâat*) e o ácaro da tamareira *Oligonychus afrasiaticus*. A maior parte dos métodos tradicionais de controlo destes patógenos e pragas são preventivos, principalmente focados na gestão das culturas. No entanto, no caso de surtos em larga-escala, como epidemias, esses métodos revelam-se ineficientes. A utilização de métodos de biocontrolo pode ser uma alternativa bastante promissora, mas ainda são requeridos estudos adicionais para garantir a sua eficiência em locais específicos. Ao adotar estas alternativas mais sustentáveis, o rico património cultural rica associado com a tamareira é preservado, permitindo uma maior prosperidade económica da região.

Palavras-chave: *Phoenix dactylifera*, ameaças à cultura, doenças, pragas, agentes de biocontrolo

Diseases and pests that affect date palm culture and biocontrol methods

Abstract

Date palm (*Phoenix dactylifera* L.) holds a great social and economic significance for the countries of North Africa. Dates have a significant cultural and religious importance, while also serving as a vital source of income for local populations in the region. The economy of countries in North Africa heavily relies on the production of dates. However, this plant species has been severely affected by many diseases and pests over the years, bringing great damage to production levels and fruit quality. The major threats to date palm cultures are *Fusarium oxysporum* (the causal agent of *bayoud*), *Phytophthora palmivora* (the causal agent of *bayoud*) and *Oligonychus afrasiaticus* (the date palm spider mite). Traditional methods for controlling these pathogens and pests are mostly on the prevention side, focused more on crop management. However, in the case of larger-scale outbreaks, such as epidemics, these approaches have proven to be inefficient. As an alternative, the use of biocontrol methods is promising but needs to be further studied to guarantee their efficiency in specific local conditions. By embracing sustainable approaches, the rich cultural heritage associated with date palm is preserved and the economic prosperity of the region is enhanced.

Keywords: *Phoenix dactylifera*, cultivation threats, diseases, pests, biocontrol agents

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Chapter 1: A date palm overview

Date palm (*Phoenix dactylifera* L.) is a plant species whose origin is still hard to be traced. Currently, this plant species is mainly spread across North Africa, where it holds high economic importance due to the date fruit.

The date palm (*Phoenix dactylifera* L.) belongs to the diverse *Arecaceae* family (Table 1.1), which includes around 200 genera and 1500 species (Dowson, 1982; FAO, 2022). Besides *P. dactylifera*, the *Phoenix* genus comprises 11 other species: *P. acaulis* Roxb., *P. atlantica* A. Chev., *P. canariensis* Chabeaud., *P. farinifera* Roxb., *P. hanceana* Naudin, *P. humilis* Royle., *P. paludosa* Roxb., *P. reclinata* Jacq., *P. robelinic* O'Brein., *P. rupicola* T. Anders, and *P. sylvestris* Roxb (Table 1.2). This genus can be found across the “Old World”, from the Canary Islands to Hong Kong, in tropical and subtropical Africa, the Arabian Peninsula, and the Indian subcontinent (FAO, 2022). All *Phoenix* species are well-used as ornamental species, with *P. canariensis* having the highest economic value for its ornamental landscaping purposes. Besides being an ornamental species, the sap from *P. sylvestris* is also a source of sugar in India (Jain *et al.*, 2018). In the *Phoenix* genus, six species are known for their edible fruits: *P. acaulis*, *P. atlantica*, *P. dactylifera*, *P. farinifera*, *P. humilis*, *P. reclinata* (FAO, 2022).

Table 1.1: Full taxonomic classification of the *Phoenix dactylifera* [FAO, 2022; Sistema APG IV, 2016].

Taxa	Designation
Kingdom	Plantae
Division	Tracheophyta
Class	Liliopsida
Order:	Arecales
Family:	Arecaceae
Sub-family:	Coryphoideae
Tribe:	Phoeniceae
Genus	<i>Phoenix</i>
Species	<i>Phoenix dactylifera</i>

Table 1.2: *Phoenix* genus species distribution [FAO, 2022].

Species	Common Name	Distribution
<i>Phoenix dactylifera</i> L.	Date Palm	Mediterranean countries, Africa, and part of Asia; the introduced in North America and Australia
<i>P. atlantica</i> A. Chev.		Occidental Africa and the Canary Islands
<i>P. canariensis</i> Chabeaud.	Canary Palm	Canary Islands and Cape Verde
<i>P. reclinata</i> Jacq.	Dwarf Palm	Tropical Africa (Senegal and Uganda) and Yemen (Asia)
<i>P. sylvestris</i> Roxb.	Wild Date Palm or Sugar Palm	India and Pakistan
<i>P. humilis</i> Royle.		India, Burma, and China
<i>P. hanceana</i> Naudin.		Meridional China and Thailand
<i>P. robelinic</i> O'Brein.		Sri Lanka, Toukin, Annam, Laos, and Thailand
<i>P. farinifera</i> Roxb.	Pigmy Palm	India, Ceylon and Annam
<i>P. rupicola</i> T. Anders.	Rocky Date Palm	India
<i>P. acaulis</i> Roxb.	Dwarf Palm	Bengaladesh and India
<i>P. paludosa</i> Roxb.	Hental or Juliana Palm	Bengaladesh, Tenasherim, Andaman, Nikobaren and Thailand

1.1 Morphological description of the date palm

The morphology of vegetative and reproductive organs of *Phoenix dactylifera* are well documented. Plants present a dominant apical growth, exhibiting the trunk with a constant diameter at plant maturity. Plants comprise a root system, a vegetative body including the trunk and leaves, and a reproductive system composed of inflorescences and flowers (male or female). All these characteristics can vary within the species depending on the cultivar, environmental conditions, and growing techniques (Sedra, 2003; FAO, 2022).

Root system

Date palms exhibit a dense fasciculate root system, composed of fibrous roots and aerenchymatous structures (pneumatodes) that display a role in root aeration. Roots are spread around the palm trunk (as far as 25 m from the palm trunk and deeper than 6 m) but are mainly distributed 2 m away from the palm trunk (Munier, 1973). In this system, most of the roots do not pass over 1.5 cm in diameter and

can grow above the ground up to 50 cm the height of the trunk (M. H. Sedra, 2003). The root system could be divided into four zones: (I) a respiratory zone, formed by primary and secondary roots, all presenting negative geotropism: (II) a nutritional zone, where the greatest concentration of primary and secondary roots are found that can also be found projecting laterally from the palm canopy; (III) an absorption zone, mostly composed of primary roots and disposed on a gradient of density from top to bottom; and (IV) the deepest zone, dependent on underground water, which is composed by both primary and secondary roots (Figure 1.1, according to Oihabi, 1991). In shallower depths, the distinction between zones III and IV is more challenging. Generally, in greater depths, roots present positive geotropism (Oihabi, 1991; FAO, 2022).

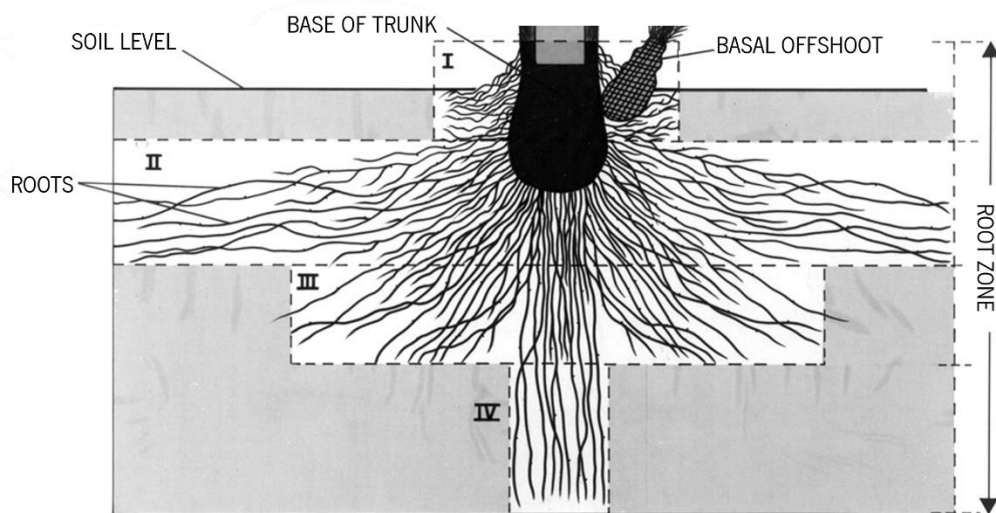


Figure 1.1: Root system of *P. dactylifera*, where the different root zones are highlighted: (I) respiratory zone, (II) nutritional zone, (III) absorption zone, and (IV) deepest zone [FAO, 2022].

Date palm trunk

Date palm trunk, also called stem or stipe, is cylindrical and even all throughout its length. At maturity (*i.e.*, once the canopy finishes being developed), the trunk does not increase further in girth and does not give rise to ramifications (Figure 1.2a). As a monocotyledon, date palm does not exhibit a vascular cambium and trunk is made of fibrous vascular bundles that are cemented together. The outer part of the trunk is lignified with “scars” from where leaves have fallen. Under specific circumstances (dichotomy, disease attack, axillary bud development, or polyembryony), the trunk can present branching that will not affect the date fruit production (Zaid 1987). However, trunks do not have true branches, presenting instead buds that can be pushed to the axis and form suckers or offshoots (Figure 1.2). If left alone these

offshoots can grow, not quite reaching the size of the parent tree, but developing stems (Mason, 1915; Barrow, 1998). When cut off in the early stages and planted alone, offshoots can grow much like the parent individual, being a form of propagation (Mason, 1915).

Date palm leaves

The leaves sprout from the trunk in an alternate way, with the bases overlapping. They are arranged in spirals either to the left or to the right. This makes the tree very geometrical in appearance (Mason, 1915; FAO, 2022). The leaf morphology, particularly in terms of size, exhibits variation and is influenced by environmental factors. The petiole, located in the lower portion of the leaf, is slightly triangular in section, presenting two lateral angles and one dorsal. The leaf base connecting to the trunk is broad and thins out towards the end of the blade (Figure 1.2b). The blade makes part of the leaf from the start of the leaflet-like spines (near the petiole) to the leaf tip (Mason, 1915), which might have one leaflet or two forming a V (FAO, 2022).

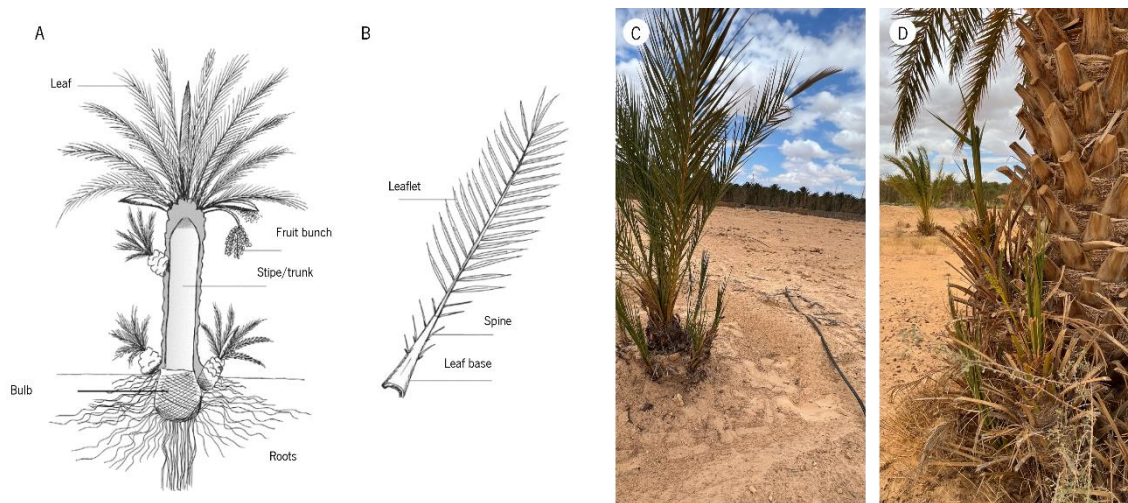


Figure 1.2: Date palm overall representation (A) and detailed leaf morphology (B). In (A), the root and trunk offshoots are represented, which are pictured in (C) and (D), respectively. [A and B, FAO, 2022; C and D, Teresa Lino Neto].

Date palm flowers

As a dioecious plant, date palm presents pistillate and staminate flowers on separate palms. The flowers are gathered in clusters in a type of inflorescence called spadix, which contains a central stem (rachis) and several strands (usually 50-150, Figure 1.3). In the early stages, the spadix is covered by a leaf-like tissue forming the spathe. At pollination, a longitudinal tear happens, and the spathe opens making the

inflorescence available. Male flowers are sweet-scented and have six stamens surrounded

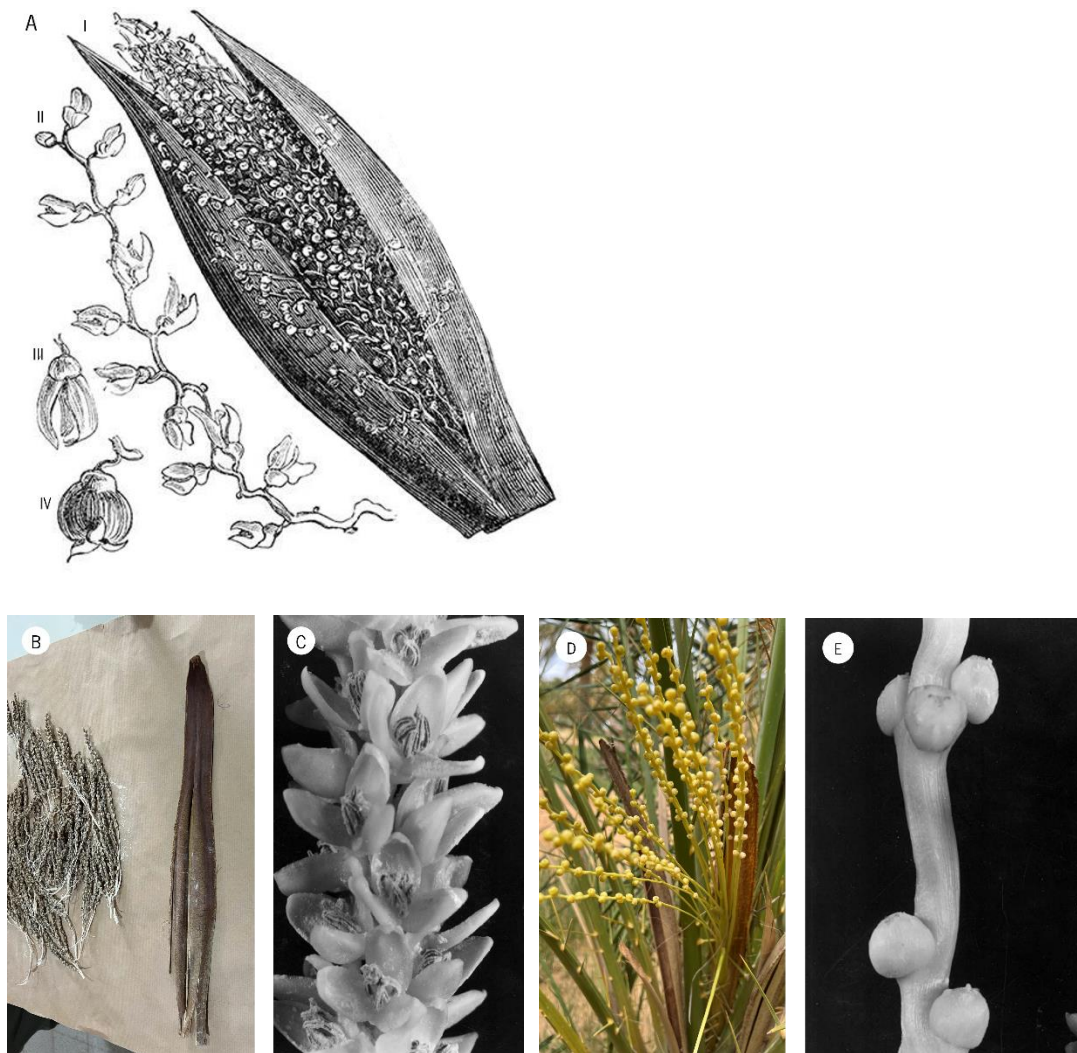


Figure 1.3: Inflorescences and flower morphology of date palm. In (A), the progression of female flower development leading to the production of dates is illustrated. Initially, the female spathe contains the female inflorescence (I), comprising several strands of female flowers (II). Many flowers remain unpollinated (III), but others initiate the process of fruit formation (IV). Male and female flowers are further pictured, including (B) male flowers and detached spathe, (C) male flowers under Scanning Electron Microscope (SEM), (D) female flowers emerging from their spathe, and (E) female flowers in SEM. [A, Troussset, 1885; B and D, Teresa Lino Neto, C and E, USDA archival photograph].

by three petals and three sepals (Figure 1.3). The female flowers do have rudimentary stamens and three carpels pressed together (with a superior ovary). Their petals and sepals are fused, only separating at the

very top. Only one ovule per flower is fertilized, but the respective carpels of the two aborted ovules persist as brown spots in the extremities of the date fruit.

Dates and seeds

Dates display a great diversity, depending on the cultivar, environment and cultural practices (which includes different fertilization, pollination or thinning techniques). In general, dates have a six-month period of development (Figure 1.4), but this period can vary depending on factors such as climate, date palm variety, and cultivation practices. Pollination typically occurs within a day or two after flowering. The fertilized flower begins to develop into a small, green, and firm fruit known as the *Kimri* stage. The fruit begins to elongate and to change color, turning from green to a yellow or red hue, depending on the variety. The fruit reaches the *Khalal* stage when it is fully colored, sweet, and its flesh is soft. At this stage they are considered ripe and suitable for consumption. However, the fruit continues to ripen and increase in size, while their texture becomes even softer and juicier. The most highly prized dates are those that are in the *Rutab* stage, where they are very soft, moist, and have a caramel-like consistency. If the dates are left to mature further on the palm, they enter the *Tamar* stage. At this point, the fruit loses moisture, becomes drier, and the sugars concentrate. These dried dates are suitable for long-term

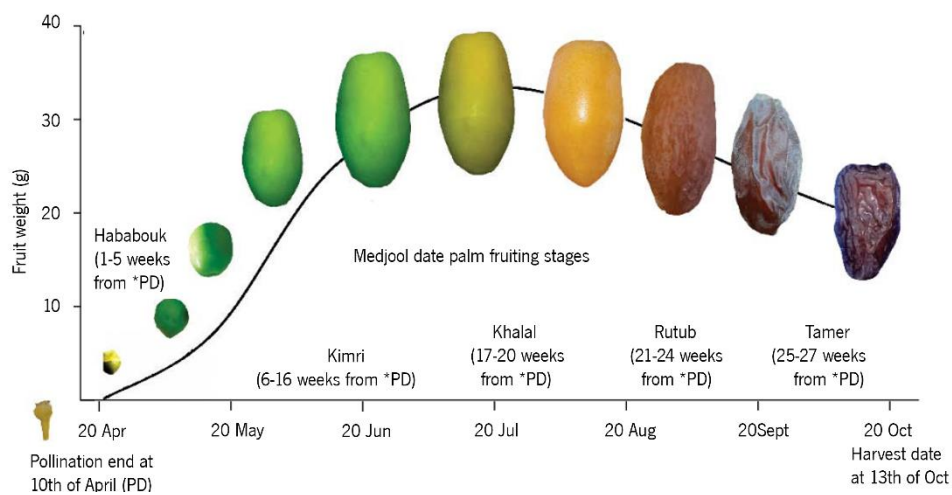


Figure 1.4: Different development stages of the date fruit and the period they occur after pollination [Al-hajjaj & Ayad, 2018].

storage and have a longer shelf life. At maturity, dates can be described as a single, oblong, one-seeded fruit (drupe), containing a fleshy pericarp and a membranous endocarp (Figure 1.5) (Yahia & Kader, 2011; Lobo *et al.*, 2013).

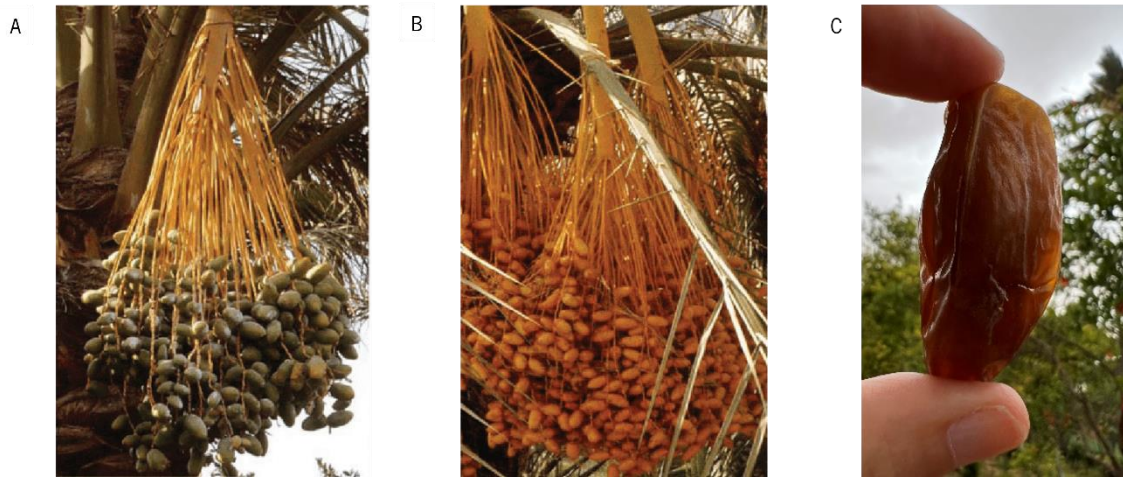


Figure 1.5: Inflorescence of date fruits during development, namely during the *Kimri* (A) and *Khalal* (B) date stages. A detached date at *Rutub* stage is also pictured (C). [A and B, Lobo *et al.*, 2013; C, Teresa Lino Neto]

1.2. Origin and world distribution of the date palm

The origin of date palm is quite difficult to trace back. However, the date palm and dates use are documented and can be traced as far back as 4,000 B. C. (FAO e Dowson 1982). With a range of occurrences that spans from Morocco to India, this species had (and still have) enormous economic, symbolic and social importance (Barrow, 1998; Al-Khayri *et al.*, 2021). Date fruits, besides being the major perennial fruit crop in hot and arid regions of Afro-Eurasia, also served as a staple of subsistence farming and a source of economic prosperity dating back to the earliest civilizations of West Asia (Fuller & Stevens, 2019; Gros-Balthazard & Flowers, 2021). The early cultivation of date palm has given rise to two primary gene pools: the eastern and western gene pools. The eastern was originated in the south of Mesopotamia (during the 5th millenium BC) and makes up for 70% of chloroplast DNA diversity in Algeria, whilst the western was originated in the Egypt (in the 4th century BC) and makes up for 89% to 58% of chloroplast diversity in Tunisia and Morocco (Moussouni *et al.*, 2017). Although the exact origin is still uncertain, recent phylogenetic studies also provided insights that suggest the origin of the domesticated species to be in West-Asia. Later, the date palm cultivation expanded throughout North Africa, during the roman period (Gros-Balthazard & Flowers, 2021). Combined genomics and archaeometry suggested that the residual populations of what could be the wild progenitor of date palms still persist today in the Arabian

Peninsula (Gros-Balthazard *et al.*, 2017). For the diversification of the crop, introgressive hybridizations might have played a major role (Flowers *et al.*, 2019).

Nowadays, the distribution of date palms is so extensive and globally widespread that FAO recognizes the importance of categorizing their occurrence to paint a broader picture. The organization proposes to look at three important factors: latitude, altitude and overall number of date palm trees. The latitude parameters establish limits of occurrence based on climate, define geographically where the presence of date palm will be most successful in producing fruits. The altitude parameters, on the other hand, will define the success of crops based on the correlation between water availability and temperature. The quantity of date palms in the world enhances the overall perspective.

Origin and culture of date palm in Tunisia

First introduced in Tunisia by the Phoenicians, before the Roman occupation, the development of date palm cultivation only occurred after the settlement of Arabs in southern Tunisia, specifically in the region of Jerid (Hodgson, 1932). The cultivation of this crop then gained an important role in establishing oases and caravan trade routes. These oases became more organized and, in the 13th century, gained a water sharing system from the sources of Tozeur. The next century brought a demographic explosion driven by the increase of agricultural area, which in turn attracted pilgrims and travelers passing through the area. This movement in the region facilitated the introduction of date palm seedlings from the East. However, the most cultivated and consumed date palm cultivar from Tunisia – *Deglet Noor* - was only introduced four centuries ago from Oued Souf, western Algeria (Ho, 1969); Kearney 1906; Hamza *et al.*, 2015). This was followed by a challenging period with high taxes and external attacks, which ultimately led to the destruction of the oases. With the decline of the caravan trade in the 19th century, the oases plantations gradually disappeared (Rouissi 1969). During the 20th century, indigenous people and nomads founded new oases, which combined with the role played by the French protectorate, contributed to the creation of settlements around water sources (Figure 1.6).

After Tunisia independence, the government encouraged the cultivation of *Deglet Noor* cultivar for the purpose of exportation. This economic progress made the authorities invest in new modern oases in the late 1980s, addressing critical water resource challenges. This strategic initiative increased the production of dates in Tunisia, turning the nation into one of the most important date producers (Hamza *et al.*, 2015). In the last decades, date palm cultivation gained importance as an income source for farmers, encouraging the creation of new plantings. In addition, the introduction of intercropping with other agricultural species well-adapted to Tunisian oases has enhanced their profitability. This success

was so much pronounced that agricultural cooperatives have been established since 2011, mounting programs of oasis development (Hamza *et al.*, 2015).

Unfortunately, the expansion of date palm culture did not solely occur under the government oversight. Illicit date groves were created, involving unauthorized well-drilling and the monoculture of *Deglet Noor* date palms. Indeed, these plantations constitute nearly half of all date groves in the Nefzaoua region, turning the water availability into an issue. In addition to these challenges, diseases also threaten production. For example, even though the *bayoud* disease might not be present in Tunisia, its prevalence in neighboring countries and the high sensitivity of *Deglet Noor* to this pathogen pose a great threat to the existing date palm cultures (Hamza *et al.*, 2015).



Figure 1.6: Date palm oases distribution in Tunisia. 1 - Nefzaoua, 2 - Jerid, 3 - Chebika and Tamerza, 4- Gafsa, 5 - Gabès, 6 - Tataouine, 7 - Jerba, and 8 - Kerkena [Hamza *et al.*, 2015].

The production of date fruits takes place within oases, which can be either traditional or modern and industrialized (Figure 1.7). The modernization was needed to reduce water stress, since the restoration of traditional oases happened with surrounding scattered water sources back in the 20th century. The irrigation method in traditional Tunisian oases is typically based on the flood technique, leading to the waste of a great volume of water to evaporation. To address this issue, modern oases determine the precise water requirement for achieving the desired dates yield. Regrettably, this innovation is not financially accessible to all farmers, primarily due to the lack of government aid. The fertilization in Tunisian oases relies on mineral fertilizers (Hodgson, 1932; Hamza *et al.*, 2015).



Figure 1.7: Aerial view of a modern dates production oasis in Jemna. [Google Earth, 2023].

Origin and culture of date palm in Algeria

The cultivation of date palm in Algeria could have ancient origins. Indeed, a historical connection between Algerian date palms and those from the eastern regions, potentially including Mesopotamia, seems to be possible. Indeed, a significant portion (70%) of the chloroplast DNA diversity in Algerian date palms comes from the eastern gene pool (Moussouni *et al.*, 2017). For centuries, the water management of date palm oases relied on stream water, ground water and other sources, which were channeled through a system of underground conduits called *foggaras*. The French colonization of Algeria, initiated in the early 19th century, not only increased the number of date palms, but also improved the cultivation techniques. In addition, the well-prized *Deglet Noor* cultivar was introduced, which became the most desired dessert and exportation fruit, while establishing other cultures nearby. Currently, the date palm genetic diversity is evident through the existence of three types of dates: wet (*Hanyany* variety), semi-wet (*Deglet Noor* and *Medjool* varieties) and dry (*Ameri*, *Halawi*, *Khadrawy*, *Thoory*, and *Zahidi* varieties) (Bouguedoura *et al.*, 2015; Sarraf *et al.*, 2021).

In the early 20th century, the date palm cultivation in Algeria was mainly a subsistence crop and played a fundamental role in the local economy. After the Algerian independence (1962) came a period of rural exodus, leading to the loss of knowledge around cultivating dates. The farmers also switch their preference to other more profitable crops, mainly cereals and vegetables. Consequently, the country experienced the decline in date palm plantations and the neglect of *foggaras*. However, by the end of the 20th century, a revival of date palm plantations occurred, due to the establishment of new Saharan agriculture areas (Bouguedoura *et al.*, 2015). The current extension of cultivation areas goes from the Moroccan border in the west to the east Tunisian-Libyan border (Figure 1.8). Geographically, date palm

cultivation spans from the southern Saharan Atlas Mountains to Djanet (Bouguedoura *et al.*, 2015; Moussouni *et al.*, 2017).

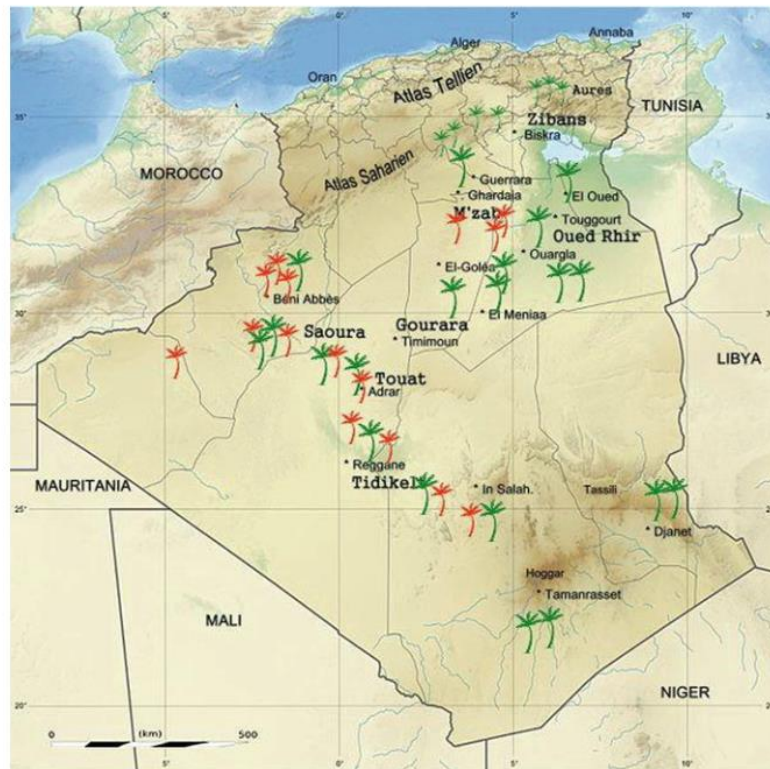


Figure 1.8: Oases distribution in Algeria; in red are the areas affected by *bayoud* disease, in green areas not infested (Bouguedoura *et al.*, 2015)

All these regions have a hot and dry climate, and the cultivation of date palms happens in oases, which are areas artificially established in arid regions where water resources are available. Typically, a structure called *ksar* is built and date palms are planted surrounding it. This method of production is very complex and relies on a fragile balance, even though it is indispensable. Date palms provide protection to adjacent cultures from intense sunlight exposure, limit the sand damage within the oases, and play an important role in conserving local animal species of these regions (Bouguedoura, 2010). In addition to their environmental significance, date palms play an important role for the population inhabiting these areas. Not only dates are nutritious fruits for consumption, but their production also serves as the primary source of income for more than 100.000 families in southern Algeria (Bouguedoura, 2010). Besides traditional oases, Algeria also features modern oases that share common features and objectives with those found in Tunisia, given their similar geographical and environmental challenges. The Algerian oases traditionally utilize organic fertilizers and employ methods such as wells and pendulum water lifts for

irrigation. Tillage, which is the drilling of the soil to open canals, however, is not a common practice anymore, drainage, currently, is done by opening ditches. It's a technique that presents quite a lot of disadvantages, like soil salinization, but it is still common practice (Bouguedoura *et al.*, 2015; Larbi, 2019).

1.3. The socio-economic relevance of date palm production

Date palm cultivation has a great social-economic importance to the people and farmers of Saharan regions. Historically, dates have been mentioned in the religious discourse as the “fruit of most people”, due to their high nutritional value. Indeed, dates are a rich source of both macro- and micro-nutrients and exhibit many antioxidant properties (Hussain *et al.*, 2020; Sarraf *et al.*, 2021; Shaghaghian *et al.*, 2014). As a result, dates are incorporated into the diet of numerous populations. Moreover, date production provides a means of subsistence for local communities in arid and semi-arid desert areas. From an environmental perspective, date palm cultivation in oases, especially when combined with the planting of other species, has demonstrated a positive impact on these regions. Date palms avoid excessive sunlight exposure, sand damage and protection of animal life (Bouguedoura *et al.*, 2015; Larbi, 2019).

Presently, date palm production holds immense significance for Saharan countries. Globally, the production of date palms has experienced an exponential growth since the 1990s. From 1990 until 2018, the recorded global date production reached 3.43 million tons (Figure 1.9, (Sarraf *et al.*, 2021; FAO, 2022). North Africa is the second most productive zone (38.4% of global production), surpassed in production only by Asia (61%). The American continent and Europe only have a residual production (0.5% and 0.2%, respectively) (Sarraf *et al.*, 2021; FAO, 2022). The most productive countries for the past two decades have been Egypt, Iran and Saudi Arabia (Figure 1.10). Algeria is included in the top 10 date producers, holding the 5th position in terms of production. Tunisia, despite having a noteworthy production, has been surpassed by other countries, probably due to the rising preference of other, more profitable crops.

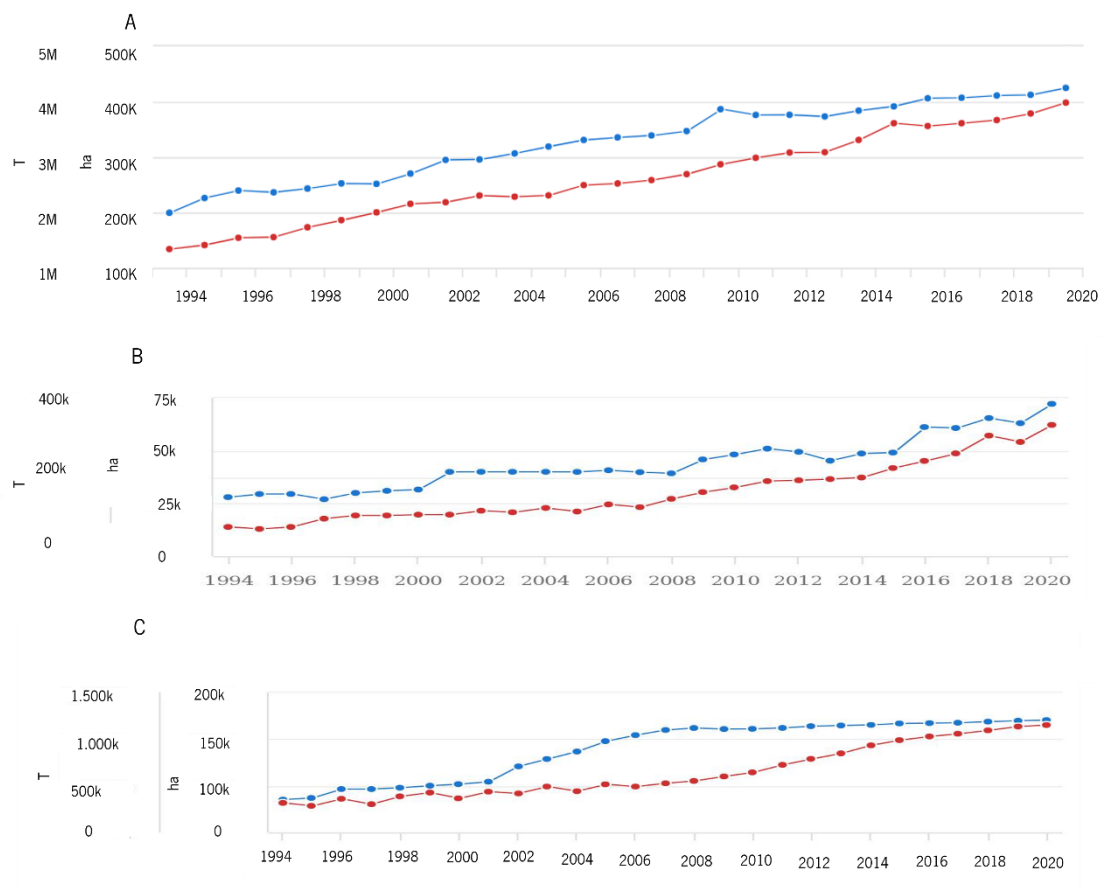


Figure 1.9: Date production (red line, production in tonnes, “T” axis) and harvested areas (blue line, area in hectares, “ha” axis) in North Africa (A), Tunisia (B) and Algeria (C) between 1990 and 2020 [FAOSTAT, 2023].

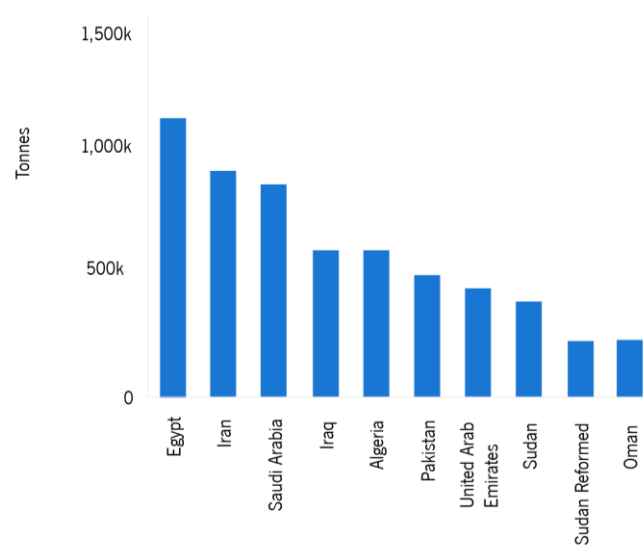


Figure 1.10: Date production (in tonnes) by the top 10 producing countries, between 1994 and 2020 [FAOSTAT, 2022].

The production of dates in the North of Africa has been increasing in the last decades (Figure 1.10). Both Tunisia and Algeria accompanied this significant growth in yield between the years of 1994 and 2020. Tunisia has shown a consistent increase of 44,437 ha in the harvested areas and a 258,000-ton increase in date production. During the same period, Algeria experienced an overall increase for the harvested area of 85,270 ha and 834,725.3 tons of produced dates. In this country, the main increase in harvested areas occurred during the decade of 2000. From 2001 to 2007, the harvested area increased nearly 50 %, from 100 ha to 160 ha, exhibiting a more modest growth in the following years. The expansion of the producing area resulted in a consistent increase of date production following 2007.

Overall, the majority of date fruit production happens in Arab-Muslim countries (Table 1.3), which are also the ones with the bigger production growth in the past decades (Sedra, 2003. FAOSTAT, 2022).

Chapter 2: Biotic interactions that restrict date palm production

The Saharan region, where the oases are concentrated has been facing environmental problems, such as desertification, dune encroachment, salinization of soil, and water limitation (Hamza *et al.*, 2015). All these factors are reducing the number of palms and their yield. Also, the aging of palms and the degeneration caused by diseases are known to bring changes in fruit quality as well as yield, leading many farmers to change their focus away from date palms and focusing on other, more profitable, crops. Indeed, date palm diseases and pests are currently two of the most worrying issues concerning date culture, both affecting the quantity and quality of date fruit production (Table 2.1) (Bouguedoura *et al.*, 2015; Hamza *et al.*, 2015).

Table 2.1 – Most frequent diseases and pests of date palms: common names, effects and distribution

Agent	Disease	Pest	Common name	Effects	Other affected countries in North Africa
Fungus					
<i>Fusarium oxysporum</i> fsp <i>albedinis</i>	X		Bayoud disease	Genetic erosion, fatal to date palms	Libya and Mauritania
Oomycete					
<i>Phytophthora palmivora</i>	X		Bélâat	Necrotic lesions, foliage blights, and the death of the shoot	Morocco, Algeria, Egypt and Tunisia
Insect					
<i>Rynchophorus ferrugineus</i> Olivier		X	Red palm weevil	Dryness and wilt, holes in the trunk leaking brown liquid	All countries
<i>Paysandisia archon</i>		X		Petiole or rachis perforation	All countries
<i>Asterolecanium phoenicis</i>		X		Yellowing of the affected areas	All countries
Bacteria					
<i>Erwinia chrysanthemi</i>	X		Sudden decline	Sudden death	All countries
Unknown					
unknown	X		Brittle Leaf Disease	Leaf dryness, structural alterations	Algeria, Tunisia

While some diseases affect the entire plant and could be fatal, others affect either the production or the quality of dates. In Algeria, the major concerns are diseases, such as the *bayoud* disease, caused by the fungus *Fusarium oxysporum* (Bouguedoura *et al.*, 2015). In Tunisia, mainly in the southern region, one of the major concerns is related with insect attacks – that is not to say that diseases do not occur (Hamza *et al.*, 2015). Besides being dangerous by nature, pest attacks also leave the plants vulnerable to diseases caused by pathogens. The fragile balance needed for the existence of oases is not always maintained. Farmers are usually occupied with other farming activities and might encounter challenges in attending the demands of date palm culture (Bouguedoura *et al.*, 2015).

2.1. Date palm diseases

2.1.1. *Bayoud* disease

Bayoud disease (also known as Fusarium wilt) is one of the most common date palm diseases in Algeria and Morocco (Figure 2.1). The name of this disease comes from the Arabic word “*abiadh*”, which means white, in reference to the whitening of leaves that is one of the *bayoud* disease symptoms (Figure 2.2) (Benzohra *et al.*, 2015). *Bayoud*, as commonly known, is a disease caused by the fungus *Fusarium oxysporum* fsp *albedinis* (Foa) Malençon Snyd and Hans (Malençon 1934). Firstly reported in Morocco in 1870, *bayoud* is fatal to date palms and has been recognized as responsible for the death of more than 3 and 10 million palm trees in Algeria and Morocco, respectively (Bouhlali *et al.*, 2020). The widespread of *bayoud* in Algeria and Morocco has wiped out a great variety of cultivars, putting both genetic diversity and the farmer’s income at risk (Jaiti *et al.*, 2007; Sedra, 2012; Bouhlali *et al.*, 2020). So far, there are no occurrences reported in Tunisia, but this disease still represents a risk due to the shared border with Algeria. For this reason, Tunisia has taken prophylactic measures by preventing the entry of contaminated material (offshoots, tree fragments, manure, infested soil, etc.) into their non-infected areas (El Modafar, 2010; Toma *et al.*, 1982).

F. oxysporum is a soilborne pathogen that becomes virulent when in contact with date palm roots (Figure 2.3). After penetrating the plant, this ascomycete infiltrates into the vascular system, reaching the leaves and causing their dryness and bleaching (Bouguedoura *et al.*, 2015). The pathogen keeps travelling upwards until reaching the terminal bud. After contaminating the bud, the plant dies within a few months. Internal symptoms comprise the browning of root and trunk, displaying attacked leaf vessels. However, *bayoud* symptoms are not always enough for a correct diagnosis as other diseases can present the same symptoms (Bouhlali *et al.*, 2020; Bouhssini & Faleiro, 2018).



Figure 2.1: *Bayoud* disease distribution in North Africa. Palm trees mark the places where the disease could be found. Tunisia so far has no documented occurrences. Adapted [Boulahouat *et al.*, 2022].

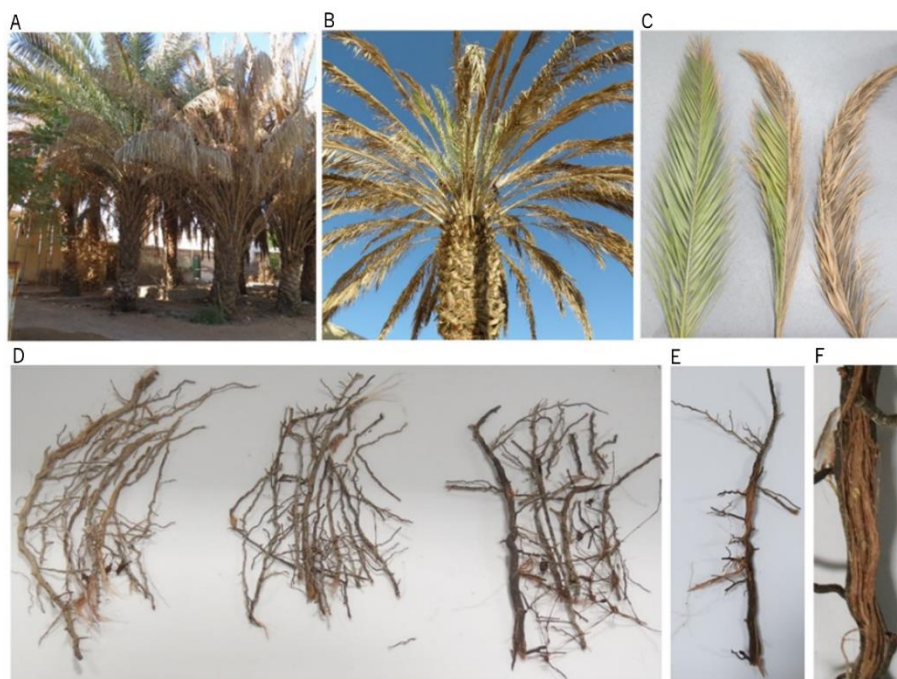


Figure 2.2: *Bayoud* disease external symptoms: A) group of palm trees with *bayoud* disease; B) single tree with *bayoud* symptoms in the leaves; C) progression of symptoms on a leaf; D) and E) progression of symptoms in the roots and; F) redness of vascular tissues. Adapted [Alwahshi *et al.*, 2019].

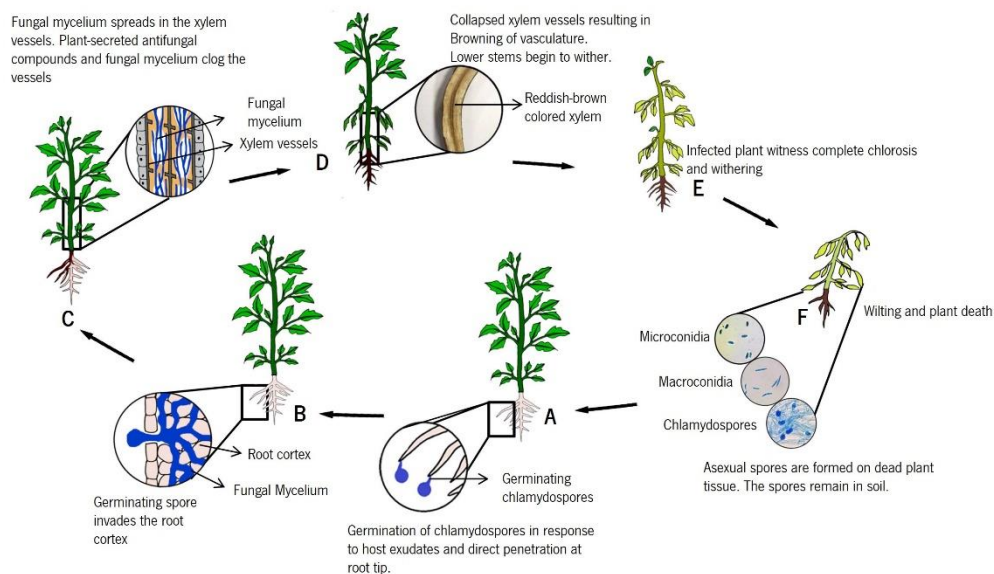


Figure 2.3: *F. oxysporum* life cycle: A) chlamydospore germination; B) spore invasion into the root cortex; C) mycelium spreading into xylem vessels; D) collapsed xylem vessels; E) chlorosis and withering of the plant host; F) plant death and formation of asexual spores in dead plant tissue. Adapted [Jangir *et al.*, 2021].

Control methods for bayoud disease

As *bayoud* disease is one of the most damaging vascular diseases of date palm, finding adequate ways of controlling the spread of its causal pathogen and treating *bayoud* symptoms is urgently required. So far, most treatments have shown themselves to be inefficient and difficult to apply. For example, the most effective way to prevent major losses has been the use of cultivars resistant to *F. oxysporum*. These cultivars gain their resistance from the activation of different defensive enzymes and compounds, such as the activation of peroxidases (Baaziz 1989), glucanases and chitinases (Amraoui, 1993), as well as by the accumulation of phenolics compounds, such as the hydroxycinnamic acid derivatives (Ziouti *et al.*, 1996, El Hadrami *et al.*, 1997). However, such resistant cultivars, apart from the *Nadja* cultivar, generally produce low-quality fruits. In contrast, cultivars such as the well-appreciated *Medjool* or the *Bouffegous* cultivars are very susceptible to the pathogen and need intense management to survive infection (Bouhlali *et al.*, 2020). Although replacing susceptible cultivars by the *Nadja* variety could reduce the susceptibility of date palm groves to disease, the total replacement of susceptible cultivars by this variety could create a reduction of date palm biodiversity. Another possibility for controlling *bayoud* disease relies on the use of bioactive secondary metabolites produced by other plant genera, such as *Acacia*, *Cupressus*, *Eucalyptus*, *Nerium*, and *Schinus*, all of which possess strong antifungal activities. For example, the

pruning waste of such plant species could be used as soil amendment in date plantations (Bouhlali *et al.*, 2020; Mezouari *et al.*, 2019).

Another way to induce date palm defense mechanisms against *F. oxysporum* (*Foa*) is the inoculation of seedlings with hypoaggressive *Foa* isolates, mainly combined with *Pseudomonas putida* (El Hassni *et al.*, 2004). There is also the possibility of inducing plant defenses by colonizing the roots with arbuscular mycorrhizal fungi. Mycorrhized plants accumulate hydroxycinnamic acid derivatives which play a crucial role in resistance to *Foa* (Dihazi *et al.*, 2012; El Hadrami *et al.*, 1997; El Hassni *et al.*, 2004; Jaiti *et al.*, 2007, 2009). Alternative methods for controlling *bayoud* disease could be the use of biocontrol agents against *F. oxysporum*. This strategy consists of the use of microorganisms (non-pathogenic bacteria or fungi) that would inhibit disease causal agents or enhance defense mechanisms. Biocontrol agents belonging to the *Trichoderma*, *Penicillium*, *Gliocladium*, *Sporidesmium*, *Burkholderia*, *Bacillus*, and *Serratia* are known to provide some level of protection against *Fusarium* pathogenic members (M'piga *et al.*, 1997; Larkin & Fravel, 1998; El Hassni *et al.*, 2007; Dihazi *et al.*, 2012). Bacteria, such as *Bacillus amyloliquefaciens* and *Burkholderia cepacia*, have been known for their antifungal activity in several plant-microbe interactions (Dihazi *et al.*, 2012; Boulahouat *et al.*, 2022). For example, such bacteria are candidates for repressing both *Fusarium oxysporum* and *P. palmivora* (Dihazi *et al.*, 2012). *B. cepacia* is also known to inhibit the spore germination of *Alternaria* fungi, which enables the suppression of this soilborne plant pathogen, thus preventing stem and leaf blight (Dihazi *et al.*, 2012). In addition, *B. amyloliquefaciens* has been found to be antagonistic to *Foa* in coconut, meaning that this bacterium also shows great potential for controlling *Foa* spread in date-palm populations (Jayasuja & Iyer, 2003).

2.1.2. *Bélâat* disease

Bélâat disease is a condition that affects date palms and is caused by the oomycete *Phytophthora palmivora* (Mont.) de Bary. The genus *Phytophthora* comprises 190 species and it is spread in different worldwide regions. In North Africa occurs in Algeria, Tunisia, and Morocco (Sedra, 2003; Bouhssini & Faleiro, 2018; Kasteel *et al.*, 2023); Regarding South America, *bélâat* disease has been reported in Colombia, Ecuador, and Brazil, affecting species other than date palm, such as cocoa and oil palm (Mohamed Azni *et al.*, 2019; Paterson, 2020; Misman *et al.*, 2022).

Phytophthora species are predominantly soilborne and cause necrotic lesions, foliage blights, and the shoot death. This genus is well-renowned for comprising the potato pathogen responsible for the Irish famine, *Phytophthora infestans* (Kasteel *et al.*, 2023). Like most oomycete plant pathogens, *Phytophthora* species infect their targets via zoospores, which are highly mobile agents capable of actively targeting

plant hosts. *Phytophthora* infection symptoms affect whole the plant from top to bottom. The first symptoms are manifested at the crown of the plant and progressively advance downward, causing the rotting the plant core (Fig 2.4). The first part of the plant to die is the frond and its death comes rather quickly after its whitening (Bouhssini & Faleiro, 2018; Kasteel *et al.*, 2023).

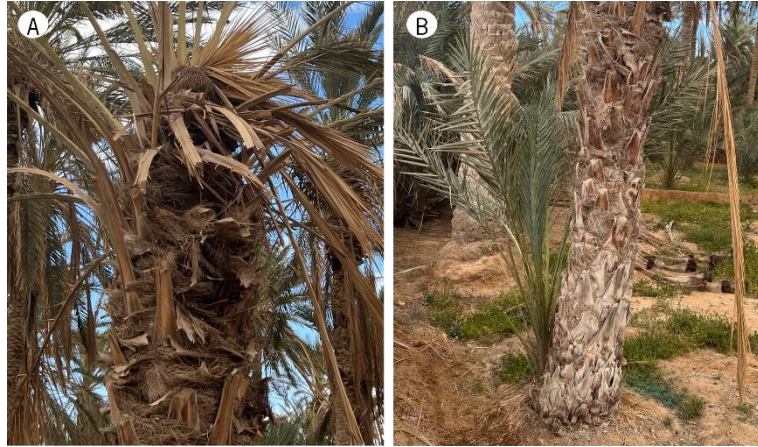


Figure 2.4: *B  l  at* disease symptoms: (A) infected cone shaped protrusion on the top of the plant; (B) infected lateral offshoot [(A) and (B), Teresa Lino Neto, 2023].

Phytophthora pathogens follow a hemibiotrophic strategy, where both living and necrotic tissues are used for the infection cycle of the pathogen. This strategy may contribute to its remarkable success. The *Phytophthora* life cycle also alternates between sexual and asexual reproduction (figure 2.5) respectively presenting dispersal spores (zoospores and sporangia) and resting spores (oospores and chlamydospores). While zoospores and sporangia guarantee the short-term survival of the pathogen when environmental conditions are favorable, the latter enable its long-term survival, preserving them in soil for long periods until suitable conditions are re-instated (Butubu, 2016; Misman *et al.*, 2022). The most favorable conditions include hot humid weather, which facilitates the flagellated zoospores to swim and infect the host. Some geographical areas can also contribute to date palm infection, as flat open lower areas, where water might accumulate, offer higher risks of infection (Misman *et al.*, 2022; Pscheidt & Ocamb, 2022). Due to its extremely adaptable nature, especially to temperature changes, the *b  l  at* disease has the potential to reach epidemic proportions. This is especially true in younger cultures where the plants might be incorrectly planted or the frequent flooding irrigation can create favorable conditions for its spread (Bouhssini & Faleiro, 2018; Wu *et al.*, 2020; Misman *et al.*, 2022).

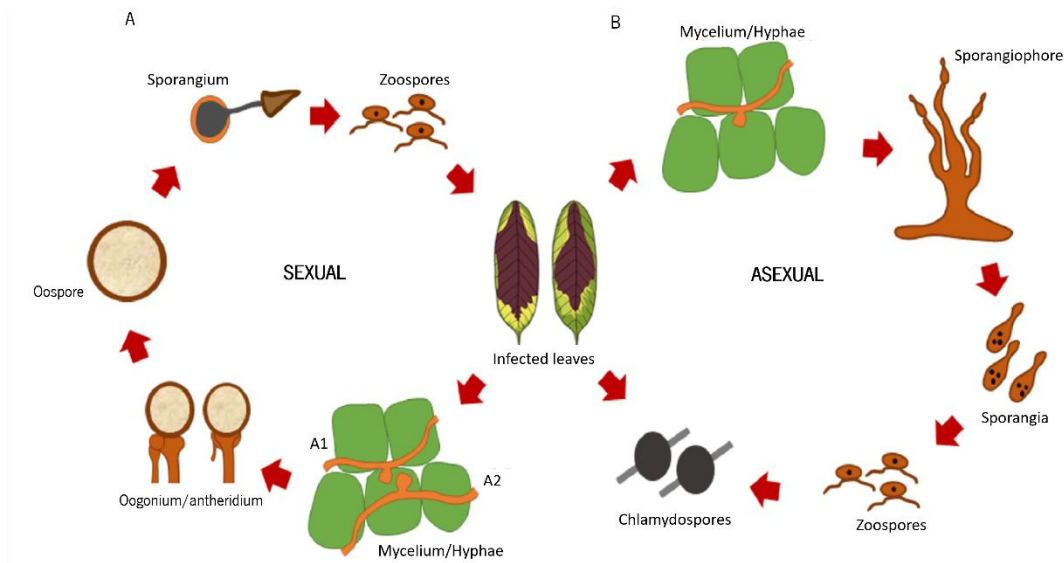


Figure 2.5: Detailed life cycle of *Phytophthora palmivora*, (A) details of the sexual phase, from infection to new zoospores; and (B) the asexual phase, from infection to chlamydospores. Adapted [Misman *et al*, 2022].

Control methods for b  l  at disease

Many of the control methods of *b  l  at* disease are typical of those used for most plant diseases caused by fungi or oomycetes. They are mostly centered around crop management practices, including irrigation, fertilization, or pruning (Bouhssini & Faleiro, 2018). Special attention is given to avoid gravity aided irrigation, which may cause water accumulation at the bottom of the plant and create favorable conditions for spores germination and infection. It is also advisable to avoid interconnecting containers between plants if an infection occurs. Farmers should also keep lateral buds under vigilance because they can serve as replacements for apical buds in case of infection. In addition to these proactive management practices, the use of fungicides is also common, both in preventative and curative instances (Bouhssini & Faleiro, 2018).

The causal agent of *b  l  at* disease (*Phytophthora palmivora*) alone is responsible for the infections of more than 200 crops globally, including cacao, durian, coconut, pineapple, rubber, papaya, and oil palm (Gunderson *et al.*, 1987; Oakeshott & Hall, 2013; Thines, 2014; Derevnina *et al.*, 2016; Delgadillo-Dur  n *et al.*, 2020). In these crops, the primary method of controlling this pathogen is the use of resistant plants. For example, in cacao (*Theobroma cacao* L.), where *P. palmivora* is responsible for black pod rot, stem canker, seedling blight, chupon wilt, and flower cushion infection (Hebbar, 2007; Vanegtern *et al.*, 2015; Misman *et al.*, 2022), the most effective approach to disease management has

been the establishment of *Phytophthora*-resistant individuals. Also, in oil palm crops (*Elaeis guineensis* Jacq.), the main control methods for *P. palmivora* disease involve the use of a *Phytophthora*-tolerant hybrid plant (*E. oleifera* x *E. guineensis*) (Sarria *et al.*, 2021). In addition, agronomic management practices have been also used in oil palm crops, as an early infection detection is combined with removal of affected tissue. Also vulnerable to *P. palmivora* infections are the rubber (*Hevea brasiliensis*) crops, which are also mainly controlled by the use of *Phytophthora*-resistant clones (Misman *et al.*, 2022). Such resistant plants have been reported to present a higher concentration of phenolic compounds, suggesting the production of lignin surrounding affected areas that promotes host resistance (Jayasuriya *et al.*, 2003; Misman *et al.*, 2022).

Besides the use of resistant individuals, alternative control and management practices could be based on the use of biocontrol agents, such as antagonistic species. Being a soilborne agent it is important to search for agents that do not negatively impact the biological functions of the soil and associated natural resources. *Trichoderma* genus seems to be a promising option due to its competitiveness for substrate and resources, as well as its resilience and long-lasting presence within the ecosystem. Indeed, different species of the *Trichoderma* genus have already been successfully used in the biocontrol of pathogens including some species of *Phytophthora* – other than *P. palmivora* (Ezziyyani *et al.*, 2007; Bae *et al.*, 2016; Sarria *et al.*, 2021).

2.2. Date palm pests

Pests also represent a great concern in date production. They not only directly affect date populations, but they also create entry points for pathogens, facilitating the occurrence of epidemics (table 2.2) (Bouguedoura *et al.*, 2015; Hamza *et al.*, 2015). In southern Tunisia, for example, crops are especially vulnerable to insect attacks, increasing the concern for the potential emergence of diseases limited to neighboring regions, such as the case of *bayoud* disease (Hamza *et al.*, 2015).

Table 2.2: Most common pests in date palm and their effects

Scientific name	Common name	Effects
<i>Oligonychus afrasiaticus</i> McGr *	Boufaroua, Spider mite, Dust mite	Web-like covering of fruit, fruit scarring, damage to fruit quality
<i>Parlatoria blanchardii</i> Targ.	Djerb or Sem	Early leaves drop and yield reduction
<i>Myelois</i> sp.	Date Moth	
<i>Oryctes agamemnon</i> Burm		Weakening of respiratory roots
<i>Rhynchophorus ferrugineus</i> Oliv	Red palm weevil	Dryness and wilt, holes in the trunk leaking brown liquid
<i>Ommatissus binotatus</i> var. <i>lybicus</i> , De Berg		Damages to plant growth and fruit production
<i>Raoiella indica</i> Hirst	Red palm mite	Yellowing of the leaves

2.2.1. Boufaroua

Oligonychus afrasiaticus McGr (commonly known as *boufaroua*, spider mite or dust mite) was firstly identified as *Paratetranychus afrasiaticus* McGr in 1939. Currently, this pest is one of the greatest concerns in date culture, being easily widespread under hot and dry weather conditions that favor the pest growth, which is the case of North African countries including Algeria and Tunisia (Arbabi *et al.*, 2017; Hussain, 2021). The infestation starts in the early stages of the fruit development (Hussain *et al.*, 2020)(figure 1.4). The mite larvae produce a fine dust-retaining web that creates the perfect conditions for the development of adult mites. As this web collects the dust, the infected fruit branches gain a dusty appearance (Figure 2.6). The mite adults start feeding from the sap of date fruits in the *kimri* stage and the fruits will start presenting a green-ish hue and will increase in size, but reduce sugar content (figure 1.4) (Hussain, 2021; Latifian *et al.*, 2014)., egg laying will start in full potential and mite population will grow logarithmically. The dust-retaining web is maintained until the last fruit developmental stages, resulting in reduced fruit quality (Bouguedoura *et al.*, 2015; Chaaban *et al.*, 2012; Hussain, 2021; Sarraf *et al.*, 2021).

Traditionally, spider mite control is done by using broad-range acaricides. However, this approach has a negative environmental impact, as it is known for polluting the environment, having deleterious effects on other wildlife, and potential risks to human health and food safety. Presently, there is a growing demand for alternative methods, which may include more traditional methods, the transition from synthetic pesticides to plant-based solution or the use of biocontrol agents (Hussain, 2021; Hussain *et al.*, 2020; Hussain & AlJabr, 2020). Other traditional ways for mite controlling were found in crop organization and management of soil, water, crops and post-harvest management. Meaning that monocultures could be intercropped, soil would be treated with fertilizers, and crops would have specific plans and control of conditions to better avoid infestation (Latifian *et al.*, 2014).



Figure 2.6: Date fruit bunches covered by the white web of *Boufaroua* [Negm *et al.*, 2015].

Currently, the negative impacts of the indiscriminate use of acaricides has pushed for the development of more efficient, environmentally safe alternatives. So far, biocontrol methods are the most promising options, from which the use of entomopathogenic fungi, such as *Metarhizium robertsii* (formerly *Metarhizium anisopliae*) and *Beauveria bassiana*, have demonstrated significant efficacy, especially if the treatment is administered before flowering (Hussain, 2021; Hussain & AlJabr, 2020; Nawar *et al.*, 2020). These naturally occurring fungi are mostly from the Entomophthorales and Hypocreales orders. Such biocontrol method consists in the fungal invasion of the host, disrupting its defense mechanisms, with the effectiveness dependent on the virulence of the fungi (Hussain, 2021). This virulence may be assessed by the fungal activity of protease 1 and its hydrophobicity. The greater the values of these two parameters, the higher the virulence. In any case, it's important to note that this method presents a slow action, and over time, there is a decline in virulence which turns the

commercialization of such alternatives difficult (Hussain, 2021; Hussain *et al.*, 2020). One way of circumventing the hindrances associated with using entomopathogenic fungi involves their association with secondary metabolites to induce certain enzymatic actions. For example, *Beauveria bassiana*, when combined with (+)- α -pinene, induces plant antioxidant and defense-related enzymes, increasing the mortality rate of *O. afrasiaticus* (Hussain, 2021). Another example is the combination of *M. robertsii* with the secondary metabolite 1-chlorooctadecane, which also enhances the control efficacy against the second nymphal stages of the dust mite. Interestingly, using a higher quantity of the metabolite will reduce the concentration of the fungi in the solution and the time for achieving a higher mortality by altering their antioxidant mechanism (Hussain *et al.*, 2020).

Another biocontrol option is the releasing of predators of *boufaroua*, such as phytoseiid mites, namely *Neoseiulus californicus* McGregor (Negm *et al.*, 2012; Negm *et al.*, 2015). These mites have their ability to adapt to the climate conditions of Tunisia, making them a more suitable alternative compared to other introduced species. Additionally, there are the specialist predators for the dust mite, such as *Stethorus* spp. and *Parastethorus* spp. (Coccinellidae) (Biddinger *et al.*, 2009; McMurtry *et al.*, 1970; Negm *et al.*, 2015), as well as the naturally occurring predators *Stethorus gilvifrons* Mulsant occurring in Iran (Afshari *et al.*, 2007) or *S. punctillum* Weise in Algeria (Idder & Pintureau, 2008).

Chapter 3: Conclusions

Date palm is one of the oldest domesticated plant species and holds great economic and cultural significance for populations in Northern Africa. Date palm culture has seen fluctuations over the years in response to colonization, exodus, and environmental conditions. Currently, North Africa is the second region that produces dates, following closely behind Asia (Sarraf *et al.*, 2021; FAO, 2022). Date crops have been threatened by both diseases and pests, some of which turned into epidemics and severely impacted production and fruit quality (Bouguedoura *et al.*, 2015). Among these *bayoud* (caused by *Fusarium oxysporum*), *bélâat* (caused by *Phytophthora palmivora*), and *Oligonychus afrasiaticus* (a pest) have emerged as major concerns due to their rapid spread and history of evolving into epidemics. For these reasons, finding control methods for these challenges is of great importance.

Most of the traditional methods of control for date palm diseases and pests involve both preventative and curative methods. These methods include the physical segregation of already infected crops, the strategic cultivation placement, or the geographical positioning of the culture, the use of fungus-resistant clones, and the extensive use of chemical solutions through the application of pesticides, acaricides, fungicides, and other chemically oriented approaches (El Modafar, 2010; Bouguedoura *et al.*, 2015; Hussain, 2021). Unfortunately, some of these options are not as effective in the case of an epidemic, whilst others can have adverse effects on the environment and human health, compromising the quality of the fruit and the overall date production. As an alternative, the use of biocontrol agents is an important option, because they provide the possibility of diseases and pest management with minimal environmental and health risks (Hussain, 2021). For the major threats to date palms, *F. oxysporum* (*bayoud*), *P. palmivora* (*bélâat*) and *O. afrasiaticus* (date palm spider mite), some biocontrol agents were already reported. These agents have shown promising results, even though some were not studied in *P. dactylifera* itself, but in other *Arecaceae* (coconut, oil palm) (Sarria *et al.*, 2021) crops or even *Euphorbiaceae* (rubber) (Misman *et al.*, 2022) members. Still, the efficacy of biocontrol methods is dependent on more than just the specific species of the agent being used. Indeed, specific strains should be selected and adapted to the environmental conditions of the cultivation site, as is the case of a the phytoseiid mites, predatory species used to control *boufaroua* pest in Tunisia (Biddinger *et al.*, 2009). Furthermore, to enhance the biocontrol agent effectiveness, most agents are used in combination with secondary metabolites to increase their capabilities (Hussain, 2021).

Whether the threat is posed by a disease or a pest, the control method in use should be as sustainable as possible without losing efficacy. Which is the primary goal of the GreenPalm Project, where the present study is inserted, alongside enhancing the sustainability of date palm agrosystems. Within

the framework of this project, the rhizospheric and phyllospheric microbiota of different Tunisian date palm cultivars has been carried out using metabarcoding approaches. Knowing the main pathogens and agents that have been described to control them enables a more targeted screening on the presence/absence of specific genera and species. This will allow a better understanding about the spreading and prevalence of already-documented biocontrol agents on Tunisia. With this knowledge, innovative biocontrol strategies can be formulated, making use of microorganisms that are naturally adapted to the specific cultivation conditions in Tunisia. At the end, the strategies developed could be not only environmentally sustainable, but also economically feasible for managing crops, aiming to prevent infestations whenever possible or effectively control existing ones.

4. Bibliography

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