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The Economic and Agricultural Significance of Phoenix dactylifera: Challenges and Opportunities for Sustainable Development in Morocco's Date Palm Sector

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ABSTRACT

The present study discusses the date palm (Phoenix dactylifera) in Morocco concerning its economic and agricultural importance, genetic diversity, and ecological adaptability; its importance within the economies of oases is underlined. The paper focuses on the eighteen main varieties, which highlight that the date palm economic sector in Morocco has a high risk because of various causes, such as water shortage, climate change, and market fragmentation. Through morphological, cultural, and economic analyses, the major growth constraints affecting the sector were identified. It further assesses the effectiveness of government initiatives to enhance productivity and sustainability. It reveals that improved water management, market access, and varietal recognition will raise the status of Morocco in the date global market. The paper concludes with strategic recommendations on how to balance traditional agriculture with modernization to make it sustainable in the long term.

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1- Introduction

The date palm, scientifically referred to as Phoenix dactylifera, is a plant species important for both ecological and economic reasons. It plays an integral role in arid and semi-arid agricultural ecosystems across North Africa up into the Middle East. This perennial fruit tree is renowned for its hardiness toward harsh climate conditions, its socioeconomic importance, and its ability to produce dates a staple food in many cultures. Of all its species, only Phoenix dactylifera is cultivated for its fruit and has played a very important role in maintaining a population in situ to maintain agriculture.
The date palm is the central plant in the oasis system of agriculture in Morocco, but particularly in the region of Drâa-Tafilalet. Though traditionally famous for date-palm cultivation, several challenges confront this sector, including climate change, water shortage, and competition from imported varieties at relatively cheap prices. Such are to be identified and overcome in order to improve productivity, quality, and enhance economic value for the different varieties of Moroccan palm dates. The main goals of the investigation will be:

- The morphological and genetic variabilities of Phoenix dactylifera cultivars within Morocco will be assessed for adaptability to different environmental conditions.
- The economic contribution of date palm cultivation in Morocco will be analyzed based on the local economy, especially in the oasis zones.
- The critical challenges concerning climate constraints, water management issues, and market competition will be highlighted for the Moroccan date palm sector, with strategies to address them being suggested.

Assess the contribution of modern agricultural practices and government initiatives to the improvement in yield and quality characteristics in date palm production in Morocco.
It intends to present an overview of the date palm sector in Morocco regarding its sustainable development at both the local and international market levels, coupled with the identification of opportunities to improve the socio-economic impact of date palm farming.
Through this comprehensive study, we aim to provide insight into the sustainable development of the Moroccan date palm sector and give practical recommendations on how to optimize its contribution to the agricultural economy.

2-METHODOLOGY

The methodology applied is focusing on both primary and secondary data. The sources include peer-reviewed journal articles, research handbooks, conference proceedings, and reports from international organizations such as the FAO. Additionally, government reports and strategic documents on agricultural development in Morocco form a crucial part of the resource base. The references span a wide range of years, with many recent studies published between 2020 and 2024, offering updated insights into modern agricultural practices and challenges. Older foundational research from the 1990s and early 2000s is also incorporated, especially in sections focusing on the botanical and morphological aspects of the date palm.
The review covers a diverse array of topics. These include agronomy, where various cultivation techniques, soil and water management strategies, and varietal

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differences are discussed. In the botanical section, the morphology, genetic diversity, and taxonomy of Phoenix species are explored in depth. The methodologies used to study the classification of the date palm varieties in Morocco focused on key physical characteristics, such as fruit size, color, and consistency. Fruit size refers to the dimensions of the dates, with larger fruits typically being more desirable in both local and international markets. Color is another important feature, as it affects consumer perception of quality, ranging from light to dark brown. Consistency, which refers to the texture of the fruit (soft, semi-soft, or dry), is a critical factor in determining marketability and consumer preference. These traits were assessed through morphological measurements and visual inspection, techniques that are commonly used in studies of plant.

The study also integrates both ecological and cultural analyses to understand the traditional farming practices and the cultural significance of date palm cultivation in Morocco. It examines key practices, such as irrigation methods, soil management techniques, and harvesting practices, and their contributions to the overall sustainability and productivity of date palm farming, particularly in Morocco's arid regions. The cultural analysis focused on understanding traditional farming practices, including irrigation methods, soil management, and harvesting techniques. This analysis, using both qualitative and quantitative data from agricultural organizations, identified constraints such as inefficient water management and the need for modernization of farming practices to ensure sustainability and improve productivity in arid regions.

In the economic analysis, the study utilized production costs, market prices, and yield data provided from international and national statistics to a broader context of the economic landscape to evaluate the economic challenges facing the date palm sector. Market surveys, interviews with farmers, and government reports helped identify constraints like high production costs, limited market access, and competition from imported dates. The study also assessed government policies aimed at improving irrigation techniques, climate adaptation, and market access, offering insights into how these policies could address the economic constraints and improve sustainability.

Together, these analyses offer a comprehensive understanding of the challenges and opportunities facing the Moroccan date palm sector, and how cultural practices can be adapted to enhance its productivity and sustainability in the face of changing environmental conditions.

I. Global Phoeniciculture

I.1. Phoenix

The etymology of the word "phoenix" is as rich and fascinating as the myths and stories surrounding it. In Greek mythology, the Phoenix is a legendary bird that is cyclically regenerated or reborn. Associated with the sun, the nomenclature (Phoenix) also reflects the close cultural and commercial ties between the Greeks and the Phoenicians, skilled navigators and traders of antiquity. It’s also the name given by the Greeks to the palm fronds.

The diversity within the Phoenix genus includes several species, each with its ecological, morphological, and usage peculiarities. Based on the researches some type of Phoenix are more studies and recognized by investigators than others such as Dactylifera, Reclinata, Sylvestris and Canariensis [1]. For the others it could be related to the availability of direct scientific recourse databases or specific botanical works such as those by Barreveld in 1993. The differences between some of the species mentioned are based on the information

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available up to the last point of knowledge in April 2023

Phoenix canariensis (Canary Island Date Palm): Native to the Canary Islands, this species is widely used for ornamental purposes due to its majestic appearance.

Phoenix reclinata (Senegal Date Palm): Characterized by an often leaning and sometimes branched trunk. It is native to Africa and appreciated for its aesthetic appeal in landscaping.

Phoenix sylvestris (Indian Date Palm): This species is exploited for the sweet sap it produces, which can be turned into sugar or fermented to produce alcohol.

Phoenix roebelenii (Pygmy Date Palm): This is a small species often used as an indoor plant or in landscaping for small gardens.

Phoenix dactylifera (Date Palm): Cultivated for its fruits, dates.

The varieties of the Phoenix genus hold significant value in their environments, and each is exploited and cultivated for various uses such as the horticultural industry, human and animal food (molasses, jam, coffee) [2]. Our study focuses particularly on those producing date fruits, being the only species of its kind cultivated for its fruits, underscoring their importance not only in terms of biological diversity but also for their substantial contribution to the agricultural economy. These varieties, through their ability to produce fruits sought for their nutritional qualities and their adaptability to arid climatic conditions, play a crucial role in sustaining local communities and perpetuating agricultural traditions in desert regions.

I.2. Phoenix dactylifera

Phoenix dactylifera is a dioecious fruit tree native to the warm and arid regions of the world. Its name is derived from two parts. The term "Phoenix" comes from the name given by the ancient Greeks to the date palm, which they associated with the Phoenicians, as explained in the first part, and "Dactylifera" comes from the Latin "dactylos," itself derived from the Greek "daktulos," meaning finger, in reference to the shape of the date (fruit) [3].

a. Botanical Origin (Taxonomy)

The taxonomy of Phoenix dactylifera has been extensively studied by researchers such as Munier (1973). The taxonomy of Phoenix dactylifera, has been a subject of extensive research over the decades. This species belongs to the Arecaceae family, which is characterized by monocotyledonous flowering plants. The classification of Phoenix dactylifera has evolved over time, reflecting advancements in botanical science and phylogenetic analysis. The traditional classification, as established by Linnaeus in 1734 and Munier in 1973, has undergone various revisions leading to the modern scientific taxonomy. The table 1 below showcasing the current classifications of the date palm.

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***Table 1: Classification Phoenix dactylifera* [4]**

Rank	Classification
Kingdom	Plantae
Phylum	Magnoliophyta
Class	Liliopsida
Subclass	Arecidae
Order	Arecales
Family	Arecaceae
Genus	Phoenix
Species	dactylifera

b. Morphological Characteristics

The morphological characteristics of Phoenix Dactylifera, represented in Figure 1, are traditionally studied to predict the uses of the different parts of the date palm on the one hand and more specifically to identify, classify, and evaluate genetic diversity based on morphological. Numerous studies have been conducted that utilize morphological characteristics for cultivar identification, genetic diversity through biochemical or other molecular markers [5].

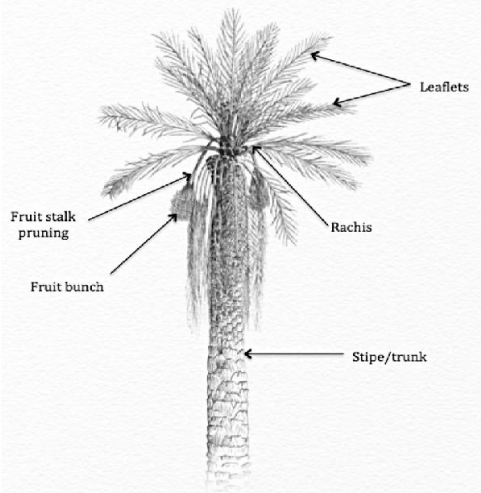

Figure 1: Phoenix dactylifera [6]

The tree can reach up to 30 meters in height, making it a remarkably large species among other Phoenixes. Illustration 1 contains the three essential different parts:

1. **Stipe (Trunk):** Generally straight. It can measure up to 75 cm in diameter at its base. It is marked by diamond-shaped or diamond patterns
2. that are the scars left by the bases of old leaves after they have fallen.
3. **Fruit bunch:** The fruit bunches are large and pendulous, consisting of numerous individual dates. Each bunch can contain hundreds of dates.
4. **Fruits (Dates):** Clustered in heavy bunches that hang under the fronds. Ripe takes a color ranging from golden yellow to dark brown depending on the variety. The fruits can measure from 4 to 8 cm long and contain a single large pit.
5. **Rachis:** The rachis is the central axis or stem from which the leaflets of a compound leaf extend. In the case of the date palm, it is the main support structure for the leaflets, providing both stability and the means for nutrient transport.
6. **Leaflets:** The leaves are large palms that can measure from 3 to 5 meters in length. These fronds are composed of many leaflets (small leaves) arranged pinnately (i.e., on each side of a central axis).

c. Culture and Cultivation

Palms are distinguished by their remarkable resilience and adaptability, allowing them to thrive in a variety of conditions, including those considered limiting. Nevertheless, certain specific climatic conditions optimally promote their growth and development. The cultural requirements of Phoenix dactylifera, as described below, include specific climatic,

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hydraulic, agrological, and nutritional factors that are essential to ensure ideal growth and high-quality date production.

Climatic factors: High temperature, almost total absence of rains, and a low hygrometric degree. Rain and cold during fertilization can cause problems, notably the death of organs. Favorable factors for the maturation of dates, prolonged summer heat, and relatively low humidity are crucial.

- High temperatures for flowering vary from 17°C to 22°C depending on the regions [7].
- Sum of temperatures from 5000°C to 6000°C from flowering to maturation for early and late varieties respectively [7].
- Great brightness is paramount for date production. In palm groves, it is observed that the best-lit trees are always the most laden with fruits [7].

Hydraulic factors: Abundant irrigation is crucial; irrigation water volumes vary depending on the regions and the nature of the soil and water used for irrigation (a preference for salinity) [8]. The water consumption of the palm tree varies according to the age of the tree.

- In Morocco, the irrigation dose per tree per month varies from 9 to 16 m^3 in the cold period and from 17 to 25 m^3 in the hot period.
- In Morocco, the submission irrigation is the most used method for palm [9], and groves is watered with waters having between 9 to 10 g/l of salt [10].

Agrological factors: The date palm grows well in various terrains but prefers neutral, deep, light, and normally moist soils. It can tolerate saline soils and supports clay soils if aerated.

- For normal growth, the soil must allow water penetration to a depth of 2 to 2.5 meters [7].

Nutritional factors: The palm has nutrient needs that vary with its age. After harvest, during the formation of fruit buds, during fertilization, and at the beginning of summer, nutrient inputs are necessary for its growth and fruit production. Amendments such as adding organic matter may be necessary to improve soil quality.

- Analyses of date palm leaves show high levels of dry matter, chlorides, and sulfur.

  A study suggests that, the concentration of most mineral elements was increased in date palm leaves as a response to the improvement of soil fertility [11].

d. History

The date palm (Phoenix dactylifera) is among the very first fruits to have been domesticated in the world; it is considered a traditional fruit of the Old World. Along with the olive (Olea europaea L.) in the Mediterranean basin, the common fig (Ficus carica L.), and the wine grape (Vitis vinifera L.) in the Near East [12]. A timeline illustrating the estimated periods of domestication of the date palm relative to other fruits estimates 6300–6800 BP (before the present) [13].

The dates of domestication indicate the estimated periods based on available archaeological and historical data. The beginning of the timeline starts around -9000 BCE, marking the domestication of the common fig and progresses to -6000 BCE where the Date Palm is noted.

Available documents and archaeological (date seeds) sites (caves) show that the cultivation of the date palm is confirmed from the 5th millennium BP [14-15].

The cultivation and geographical origin of the date palm are uncertain and debated. It seems that it was born in Mesopotamia [16], a historical region of the Middle East located between the Tigris and Euphrates. It corresponds for the most part to present-day Iraq and Syria, represented in Figure 2.

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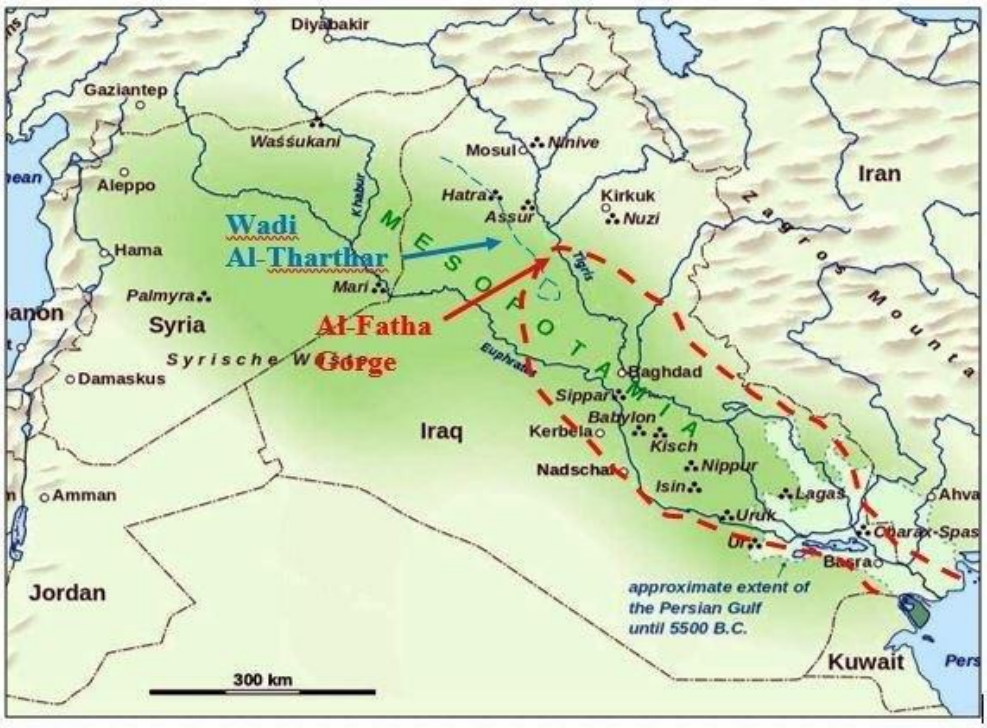

Figure 2: Mesopotamia Zone [17]

The Date Palm has been spread and implanted in the world where the conditions were favorable, and as a result, date palm has wielded a major influence in shaping of the culture and heritage in many countries such as Egypt [18]. The closest expansion theory is that of Munier in 1973, who described the dispersion of the date palm along two major historical routes, the first route from Mesopotamia southward to the Arabian Peninsula and eastward to undivided India, and the second route begins in Egypt (itself the site of an independent domestication of the date palm) across North Africa to Morocco [12].

e. Geographical Distribution

The date palm (Phoenix dactylifera), although specifically associated with arid and semi-arid zones, has been widely distributed in the world from its region of origin thanks to exchanges. Ranging from South-West Asia and North Africa countries [19]. It has spread to regions including Southern Europe, the American continents and Australia [20].

In the North Africa region, dates were first introduced to Spain during the Moorish invasion. The Spaniards later transported date seeds to the Americas, initially to Peru and then to Mexico, which accounts for the presence of date palms in those regions. While historically, transporting young shoots over long distances has been effective, modern plantations of date palms are now being established or developed using carefully selected varieties in several countries. These nations include the United Arab Emirates, Oman, Kuwait, the United States, Mexico, India, Israel, Jordan, Namibia, Australia, and various countries in the Sahelian region of Africa.

f. Global Production and Cultivation

The date palm is extensively cultivated around the world, with the majority of production coming from Asia, particularly the Middle East, which accounts for 56.31% of the global production. Africa, specifically North Africa, contributes to 42.72% of the world's date production [21].

Data on the annual production of the main date-producing countries have been collected from member countries of the United Nations

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Food and Agriculture Organization [22] and are mentioned in Table 2.

Table 2: Major date-producing countries in 2021 and 2022 **[22]**

Zone	Value (tons) 2021	Value (tons) 2022
Egypt	1713610	1733432.48
Saudi Arabia	1565830	1610731.00
Algeria	1188803	1247403.75
Islamic Republic of Iran	1168066.45	1030459.72
Pakistan	838251	732935.96
Iraq	750225	715293.32
Sudan	460090.68	442667.08
United Arab Emirates	382988.27	397328.94
Oman	374200	376980.00
Tunisia	345000	369000.00
Libya	180823.28	187870.08
Mainland China	161929.72	161120.80
Morocco	150301.00	137393.77

The majority of the main date producers saw an increase in their production between 2021 and 2022, which can be attributed to improvements in agricultural techniques, favorable climatic conditions, or government efforts to support date production. However, some countries, such as Iran, Pakistan, and Morocco, have experienced a decrease in production. These declines may be due to various factors, including unfavorable weather conditions.

II. Phoenicicultural in Morocco

II.1. Sector in a few figures

a. Area

In the past few years, Morocco has seen significant developments in date palm cultivation. As of 2020, the country has been implementing strategic plans to enhance agricultural productivity, including the cultivation of date palms. Recent data indicate that Morocco has approximately 4.250.200 productive date palms spread across several regions [23]. These efforts are part of broader initiatives to modernize agriculture and enhance the economic impact of key crops such as dates, which are considered a strategic product of Moroccan oases [24].

Phoenicicultural cultivation in Morocco was carried out on a staff of 59.000 hectares according to the Minister of Agriculture and Maritime Fishing [25]. And another source estimates the area of 50.000 ha for a total staff of nearly 5 million feet, which represents 48% of the global phoenicicultural heritage in 2019 [26]. And whose dominant region is that of Drâa-Tafilalet represented in Figure 3, which contains more than 70% of the national global staff of this production and a geographical distribution of 77% according to Minister of Agriculture [25].

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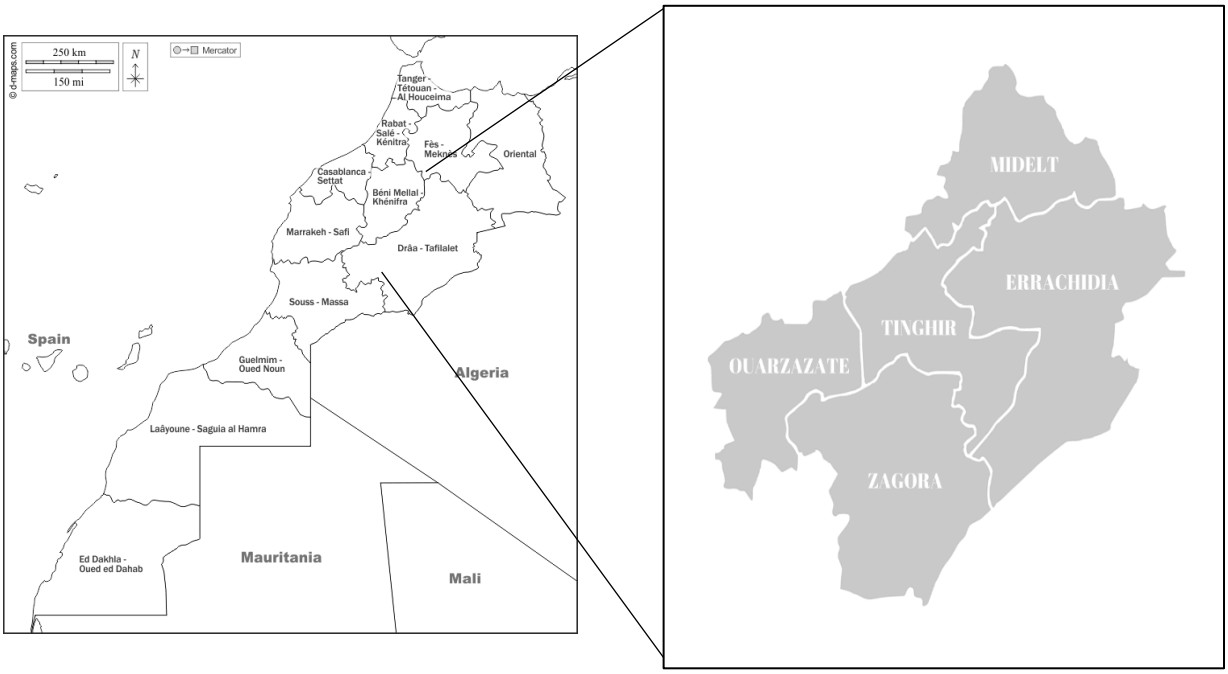

Figure 3: Drâa- Tafilalet Region [27]

The Draa Tafilalet region in southeastern Morocco spans an area of 88.836 km², representing 12.5% of the national territory and accounting for 46% of the country's oasis zones. This region experiences an arid, sub-desert climate with average annual temperature of 20°C [28]. These climatic conditions pose challenges makes it suitable of date cultivation.

b. Production

Date production in Morocco is part of the country's fruit crops, representing an essential pillar of the Saharan agricultural economy [29]. Production in Morocco records an annual average exceeding 112.000 tonnes [30]. The Ministry of Agriculture, Maritime Fishing, Rural Development, and Waters and Forests estimated a forecast production of 115.000 tonnes for the 2023-2024 agricultural campaign. Morocco was ranked the 12th largest date producer with a record of 143.000 tonnes for the 2019-2020 campaign [31]. Currently, according to FAO data, it occupies 13th place globally with a record of 137.393 tonnes in 2022.

c. Import

Morocco produces dates; however, it imports other varieties to meet its national demand. Dates are among the twelve agricultural products that the country imports the most. Table 3 presents the volumes imported for these twelve products during the year 2022 [32].

Table 3: Agricultural commodities most imported by Morocco in 2022 **[32]**

Product	Value	Unit
Wheat	6007646.51	tons
Corn	2097014.89	tons
Raw beet or cane sugar (centrifuged only)	1559937.79	tons
Barley	817291.02	tons
Soybean meal	583802	tons
Soybean oil	524604.56	tons

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Sunflower meal	258554	tons
Draffs and brewery or distillery wastes	246125	tons
Wheat bran	225069.35	tons
Beet pulp	200128	tons
Feed plant products n.a.c.	124882	tons
Dates	109092.15	tons

Morocco, despite notable domestic production, positions itself as a major importer of dates according to FAO data, represented in Table 4, due to several socio-economic and agricultural factors that increase its dependence on imports to meet domestic demand. Morocco, which was considered as a major exporter of date palm products, has become an importer

Table 4: Major date-importing countries in 2022 **[33]**

Zone	Value	Unit
India	439477.21	tons
United Arab Emirates	155774.66	tons
Niger	114479.15	tons
Morocco	109092.15	tons

d. The Socio-Economic Role of Date Palm Cultivation in Morocco

The date production and cultivation chain serve as a key economic driver in the southern oasis regions of Morocco. The date palm sector has significant socio-economic importance, deeply intertwined with the cultural and economic fabric of the desert, it represents a sign of presence and endurance in the heart of the vast desert expanses, especially in places like Tafilalet and Drâa-Tafilalet. For many rural families, it's more than just a crop it’s a vital source of income, jobs and social connection in areas where opportunities can be scarce due to harsh environmental conditions. In fact, date palm farming can represent 20–60% of annual agricultural income [24-34]. For local households and the sector helps create over 3 million workdays each year [35], spanning from planting and harvesting to processing and selling dates. Overall, it supports the livelihoods of nearly one million people in these fragile ecosystems [36]. Beyond its economic contributions, it plays a pivotal role in maintaining traditional knowledge and reinforcing cultural identity, especially through practices such as palm weaving, cooperative farming, and local festivals. Dates, a staple consumed during Ramadan, aligning with the religious and significance [37]. The date palm sector is also highlighted through key events such as the Erfoud Date Festival, which has evolved from a local gathering into a prominent trade event, now attracts both national and international participants. Held annually in the third week of October, it combines commercial exhibitions with cultural performances, underscoring the sector’s broader socio-cultural impact, Organized by the Ministry of Agriculture, Maritime Fisheries, Rural Development, Water and Forests, and the Association of the International Date Exhibition in Morocco (ASIDMA). The exhibition showcased the sector's growth and global relevance, with approximately 230 exhibitors and over 90,000 visitors in attendance [38].

e. Date Market in Morocco

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Despite the high quality of Moroccan dates, the sector faces significant challenges in competing in international markets, where consistency and quality are crucial for gaining consumer trust. A key barrier is the reliance on multiple intermediaries in the distribution chain, with 53% of dates being sold to collectors, which reduces profitability for producers [39]. Additionally, the seasonal demand for dates, largely driven by religious and festive events, creates market instability, leaving producers with unsold stock during off-peak periods despite large production volumes. High transportation costs, stemming from the geographical dispersion of farms, further limit market access and increase costs. The limited recognition of labelling Protected Geographical Indications (PGI) among consumers [40], combined with growing competition from cheaper imported dates, exacerbates these challenges and restricts the socio-economic potential of this crucial agricultural sector. At the heart of these issues is the fragmented structure of date production, dominated by small-scale producers, which hampers the sector's ability to scale effectively and develop efficiently. This fragmentation, coupled with the lack of standardized techniques (quality) and inadequate marketing efforts, prevents the sector from reaching its full potential on both domestic and international markets.

Several measures can be taken to improve market access, including the creation of cooperatives to consolidate production and increase bargaining power. Additionally, establishing structured marketing channels and distribution networks can bridge the gap between producers and consumers [41]. This includes, training, extension, promotion, transportation [42], using digital innovations typically take the form of smartphone applications (apps), mobile aggregators, online platforms and services, social media, and chat as well where farmers, traders and exporters can collaborate [43], leading to more efficient market access and better price realization. The reluctance of producers to adopt technological innovations and the reliance on traditional agricultural practices hinder productivity and quality improvements [44]. Branding and geographical labeling would also add value by appealing to the growing consumer interest in food origins. These interventions could address the challenges posed by market fragmentation and seasonal demand fluctuations, contributing to more stable and sustainable market dynamics for Moroccan dates.

f. Competitiveness of Morocco's Date Palm Sector

The competitiveness of Morocco's date palm sector plays a crucial role in the country's agricultural economy. Despite the high quality of Moroccan dates, the sector faces numerous challenges that hinder its ability to compete effectively in international markets. Tunisian dates, which dominate the middle to high end market in Morocco, are insufficient to meet this demand [45]. Tunisia has successfully addressed these challenges by implementing cooperative farming models that have improved productivity and market access. Moreover, the success of the Deglet Nour variety, marketed as a Protected Geographical Indication (PGI) [46], has allowed Tunisia to build a strong brand identity, increasing the value of its exports. Morocco could benefit from adopting similar strategies, promoting cooperative farming and branding initiatives, which would enhance the competitiveness of Moroccan dates both nationally and internationally. Algeria, another key player in the date industry, also markets its Deglet Nour variety under PGI, which has preserved traditional farming methods and strengthened Algeria's global presence [47]. However, despite its strong production capacity, Algeria faces challenges in fully capitalizing on its date

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production potential, particularly in expanding exports [48]. Morocco could learn from Algeria's export strategies and leverage its rich cultural heritage to attract more international attention and investment. Furthermore, Egypt has made significant strides by investing in post-harvest technologies such as cold storage and advanced packaging, which have extended the shelf life of dates, improved product quality, and enabled Egypt to meet international standards [49], [50]. By investing in similar modern post-harvest technologies and providing training programs for local producers, Morocco could greatly enhance the quality of its dates, improving their competitiveness in the global market.

g. Growth Constraints Impacting Date Palm Cultivation in Morocco

Date palm cultivation in Morocco faces several significant growth constraints that impact both productivity and sustainability. One of the primary challenges is climate change, water scarcity, inefficient irrigation systems, Soil degradation etc…. Climate change plays a central role. Studies utilizing predictive models, such as CLIMEX, have projected that regions currently suitable for date palm cultivation may become less favorable under future climate scenarios. For instance, research indicates that many areas in North Africa, including Morocco, could experience a reduction in climatic suitability for date palms by 2100 due to increased cold and dry stresses [51]. Over the past three decades, Morocco has experienced increased frequency and intensity of droughts, changes in rainfall distribution, and rising temperatures**)**. The projections that indicate that average annual rainfall in Morocco will decrease by 6% by 2015, 13% by 2045, and 19% by 2075, worsening water scarcity issues [52].

Reduced rainfall is expected to exacerbate existing water management challenges in Morocco, where water scarcity and inefficient irrigation systems already pose significant threats to agricultural sustainability. Among the most affected is the traditional khettara irrigation system, which historically channeled water from underground aquifers to oasis fields. This system is now facing serious deterioration due to aging infrastructure and declining water flow, making sustainable water management vital for the continued resilience of date palm cultivation in Morocco's arid and semi-arid zones. However, the deterioration has led to challenges in water management, directly impacting date palm productivity. As a result, inefficient irrigation practices and inconsistent water supply have led to increased soil salinization and degradation, primarily caused by overuse and poor soil management practices such as extensive exploitation of date palm groves, driven by increasing human and livestock populations, has led to reduced soil fertility and compromised tree health, resulting in diminished productivity [53]. In Morocco's oases, soils are typically sandy with high pH levels and poor water and nutrient retention. Together, these growth constraints climate change, water scarcity, and soil degradation directly affect the productivity and sustainability of date palm cultivation in Morocco. Addressing these issues requires innovative solutions, including modern irrigation techniques, sustainable soil management practices, and climate change adaptation strategies to ensure the long-term viability of the sector.

h. Integrative Approaches to Sustainable and Productivity Oasis Agriculture in Morocco

To overcome the growing constraints affecting date palm cultivation in Morocco's

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oases, sustainable solutions must bridge traditional practices with modern innovations. Rather than replacing ancestral methods, strategies focus on revitalizing systems like the khettara ancient underground canals through community-based rehabilitation efforts supported by public and non-governmental funding [54]. When combined with modern technologies such as solar-powered pumping, drip irrigation, and aquifer monitoring via remote sensing, these systems can significantly improve water use efficiency while preserving cultural heritage [55], [56]. Integrating these techniques into agricultural extension programs and promoting knowledge-sharing between older and younger farmers helps maintain productivity and safeguard traditional wisdom [57]. In parallel, soil fertility and resource efficiency are addressed through the application of organic fertilizers that enhance soil quality and support sustainable farming [58]. Converting date palm residues into biochar has also proven effective in improving soil structure and promoting plant growth, offering a sustainable solution aligned with circular agriculture principles [59]. Additionally, composting techniques using palm waste further increase organic matter in the soil, reinforcing long term productivity [60]. Traditional systems like the three-tiered cropping model, where date palms provide canopy cover for fruit trees and understory crops, help reduce soil evaporation, foster biodiversity, and optimize land use [61]. However, the erosion of such practices due to modernization and environmental stress has contributed to soil degradation, salinization, and yield decline, weakening both ecological balance and socio-economic resilience. In response, Morocco is advancing adaptive strategies, including the Adaptation to Climate Change in Oasis Zones (PACCZO) project, which combines indigenous practices with institutional support to promote sustainable agriculture. These efforts are reinforced by national policy frameworks like Génération Green 2020–2030, emphasizing climate smart agriculture and resource sustainability [62]. In addition, innovative approaches such as fog and dew harvesting [63]. Together, these integrative solutions reflect a comprehensive strategy for enhancing the long-term sustainability and productivity of Morocco’s oasis agriculture.

II.2. Development of Morocco's Date Palm Sector

To address the challenges posed by climate change, socio-economic issues, and the need for sustainable development, the Ministry of Agriculture, Fisheries, Rural Development, Water and Forests has launched a series of ambitious projects under the “Green Generation 2020-2030” strategy. Several hydro-agricultural and groundwater mobilization projects were launched, particularly in the irrigated perimeters of the Drâa Tafilalet region, aimed at improving the resilience of oasis agriculture to climate change. One of the major goals is to plant 5 million date palms by 2030 [42], with initiatives supporting young agricultural entrepreneurs and promoting the emergence of a new generation of middle-class farmers, offering financial assistance, technical training, and subsidies for modern farming tools to help adopt more efficient agricultural practices. This section outlines the timeline of key events and flagship projects aimed at strengthening Morocco's date palm sector, highlighting both the challenges and opportunities for sustainable development in this critical industry.

The outcomes of these initiatives have been measured through various monitoring and evaluation systems. These systems track improvements in irrigation efficiency, the adoption of modern farming techniques, and market access. One key metric of success has been the improvement of water management, where irrigation systems have been

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upgraded, and water use has become more efficient, especially in water-scarce regions. For instance, hydro-agricultural projects have been implemented to optimize the use of groundwater in date-producing areas, reducing dependency on surface water and improving productivity. As a result, the government reports that yield improvements have been observed in areas where modern irrigation techniques have been applied [64]. Additionally, subsidies and technical training have contributed to a gradual increase in date palm productivity, particularly in regions with access to the plan's resources. However, despite these advances, challenges such as water scarcity, climate change, and market fragmentation still present significant barriers to fully achieving the plan's goals, particularly in remote, underdeveloped regions where date farming is highly dependent on traditional practices. The plan's outcomes show that while infrastructure improvements and productivity increases have been achieved, long-term sustainability still requires addressing these remaining challenges [65].

The study's findings suggest several crucial policy recommendations are necessary to overcome environmental constraints to ensure the long-term success of Morocco's date palm industry on both a local and international scale. At the local level, promoting water management through modern irrigation systems and rehabilitating traditional systems is vital. Nationally, investing in climate resilient date palm varieties, post-harvest technologies, and cooperative farming will help address the sector's challenges. At the international level, enhancing market access and branding Moroccan dates through geographical indications (PGI) could significantly improve global competitiveness.

II.3. Genetic Diversity of Date Palms in Morocco

The genetic diversity of Moroccan date palm varieties was analyzed using two complementary molecular markers, SSR (Simple Sequence Repeat) and DAMD (Differentiated Amplified Microsatellite Polymorphism). Both are well established tools in plant genetics and play a vital role in identifying traits like drought resistance, fruit quality, and productivity, all critical factors for selecting varieties suited to Morocco's challenging climate.

Previous studies, such as this one [66] have focused on microsatellite markers to assess genetic variation among Moroccan date palm cultivars. However, this study advances that work by combining SSR and DAMD markers to create more detailed genetic profiles. This dual marker approach offers deeper insights into the genetic relationships between varieties, helping to pinpoint those best adapted to environmental stresses. In addition, [67] highlights how genetic diversity directly influences adaptability to factors like drought, pests, and diseases. By leveraging this diversity, breeders and farmers can select date palm varieties that not only yield higher quality fruit but also perform better under arid and stressful conditions. This is particularly significant for Morocco's date palm industry, where maintaining sustainable and resilient production is essential for long-term economic stability. A rich genetic pool ensures that farmers have access to varieties capable of thriving despite climatic and ecological challenges.

II.4. Varieties

Morocco is renowned for its rich diversity of date palm varieties, each contributing significantly to the agricultural and economic importance of the sector. These varieties are well-regarded for their fruit quality, productivity, and drought resistance, making them suitable for cultivation across Morocco's diverse regions. The country's rich

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diversity of approximately 453 date palm varieties, including khalts (hybrids from natural sowing), which constitute about 55% of the total population [68]. Among the most prized varieties, Medjool stands out for its large size, soft texture, and sweet flavor, making it a top export product with significant international demand. Similarly, Boufeggous is highly appreciated for its unique flavor and excellent adaptability to arid conditions, adding great value to both local and international markets. Other varieties such as Aziza, Jihel, and Bouskri contribute notably to Morocco's date production, with Aziza and Jihel playing essential roles in local markets and traditional consumption, while Bouskri is valued for its sweetness and resilience. However, the extent to which these varieties are studied depends on their market potential and adaptability to the environment.

The Table 5 represents the 18 dominant date palm varieties [69], declared by the International Date Salon, including key characteristics such as consistency, color, and size, which directly influence the fruit quality. Consistency refers to the texture of the fruit whether it is soft, semi-dry, or dry impacting its appeal and consumer preference. Color is an important visual factor, with various shades of light brown or dark brown often being desirable depending on the variety. Size also plays a crucial role, as larger fruits are more highly valued, especially in international markets. In addition, Productivity is related to the yield produced by the tree, which is a vital aspect for farmers and commercial growers. Higher productivity translates to a greater number of dates per palm, making the variety more economically viable. The ability of date palms to adapt to environmental conditions, particularly drought resistance, also significantly contributes to their success and overall yield, especially in arid climates.

Table 5: Most dominant date varieties in Morocco

Image						
Name	**Medjool**	**Aguelid**	**Ahardan**	**Azigzao**	**Aziza**	**Boucerdoun**
Consistency	Semi-soft	Semi-soft	Semi-soft	Semi-dry	Semi-soft	Dry
Color	Dark brown	Light brown	Light brown	Light brown	Light brown	Light brown
Size	Large sized, tender, sweet flesh	Medium sized	Medium sized	Medium to large sized	Small to medium sized	Medium sized
Drought Resistance	Moderat, requires regular irrigation to maintain optimal production	High, well suited to dry environments	-	Well adapted to dry conditions, requiring less irrigation	Good, tolerates to dry conditions	High, tolerates dry conditions well
Productivity	High	Moderate	Low	Good	Moderate	Moderate

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Appreciation	Excellent high commercial value highly demanded on the international market	Relatively good valued in trade for its earliness	Medium trade for its earliness	Low appreciated locally	Appreciated in its cradle	Medium trade, less known
Image						
Name	**Bouijjou**	**Bouittob**	**Bourar**	**Boslikheene**	**Bouskri**	**Bouzeggar**
Consistency	Dry	Dry	Semi-dry	Semi-dry	Dry	Semi-soft
Color	Light brown	Light brown	Dark brown	Light brown	Dark brown	Black
Size	Medium to large sized	Small sized	Medium sized		Long sized	Small sized
Drought Resistance	Resilience to dry conditions	-	Resistance to dry conditions are limited	Highly resistant to drought, well-suited to arid conditions with minimal irrigation requirements	Moderate, benefits from adequate irrigation	-
Productivity	Moderate	Moderate	Moderate	Moderate	Good	
Appreciation	Medium rade	Medium highly appreciated in its cradle in Bani	Good highly appreciated in the Drâa Valley	Low but commercially appreciated in the Tafialet region	Medium highly appreciated for its sugar content and great ability to be preserved at the national level	Low appreciated in the Drâa Valley
Image						

[DOI: 10.22034/FSCT.22.160.202]

Name	Otoukdim	Iklan	Racelahmer	Jihel	Boufeggous	Bousthammi
Consistency	Dry	Semi-soft	Dry	Semi-soft	Soft	Soft
Color	Light brown	Black	Light brown	Light brown	Dark brown	Black
Size	Small sized	Small sized	-	Medium sized	Medium to large sized	Small sized
Drought Resistance	-	-	-	Moderate, benefits from regular irrigation	High, well adapted to dry climates and requires less irrigation	Moderate , suggesting a degree of drought tolerance
Productivity	Moderate	High	Moderate	High	Good	High
Appreciation	Medium cultivated at a relatively medium altitude in the mountains	Low trade	Medium trade, less known	Low trade	Good trade	Low but appreciated for self-consumption excellent taste

Varieties that demonstrate a balance of excellent fruit quality and high productivity are more extensively studied and valued for both local consumption and export, such as Medjool and Boufeggous, have been extensively researched, particularly due to their large fruit sizes, high productivity, and strong market demand. These varieties are well-known for their exceptional commercial value, which drives significant research efforts focused on improving their productivity and drought resistance. Similarly, varieties like Aziza and Aguelid, appreciated for their early fruiting and adaptability to dry conditions, have also garnered attention in trade and research. The larger fruit sizes and the higher market demand for these varieties lead to more extensive studies aimed at enhancing their agricultural performance. On the other hand, varieties such as Ahardan, Bouittob, Bouzeggar, Otoukdim, Iklan, and Racelahmer, which are less commercially recognized or have lower trade value, receive considerably less research attention. These varieties typically feature smaller fruit sizes, lower productivity, and limited market appeal, making them less prioritized in breeding programs. Their relatively lower commercial demand and trade value result in less focus on improving their resilience and productivity. Ultimately, the level of study and recognition these varieties receive is directly linked to their potential for market success and their ability to thrive in arid climates, where adaptability is crucial for sustained agricultural production. That's why the choice of varieties, along with the investments play a significant role in shaping the economic success and agricultural efficiency of the date palm industry in Morocco that support long-term growth and profitability, ensuring a steady income for farmers in the country.

At the final stage of their maturation, dates undergo significant evaporation of their water content, resulting in an increased concentration of sugars. This transformation directly influences several essential attributes

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of the fruit. Indeed, at this critical stage, dates fully develop their distinctive taste profile as well as their characteristic color and texture. And on this basis, the classification of dates is done.

a. Classification

The analysis of the data in Table 5 reveals that the varieties of dates in Morocco are divided into four main categories according to their consistency: soft, semi-dry, dry, and semi-soft. These classifications rely on a specific indicator known as the quality or hardness index (r), calculated by dividing the total sugar content (in g total sugars /100 g dry matter) by the water content (in g of water/100 g dry matter) [70]. And whose value ranges from 15 to 63.

Internationally, three consistency categories have been established to classify dates: soft for an r index below 2, semi-soft for an r index between 2 and 35, and dry for an r index above 35 [71]. This same classification is adopted by The UNECE DDP-08 standard in 2010, which establishes detailed criteria for the marketing of dates, including quality requirements at the time of export after packaging and conditioning at the international level [72]. On a national level, the Ministry of Agriculture and Maritime Fishing of Morocco introduced in 2012 a standard called General Standards for the Marketing of Moroccan Dates (NGCDM). This standard incorporates the principles of the UNECE DDP-08 standard while integrating specificities related to local varieties. Figure 4 represents the distribution of consistency of the 18 Moroccan varieties (Table 5).

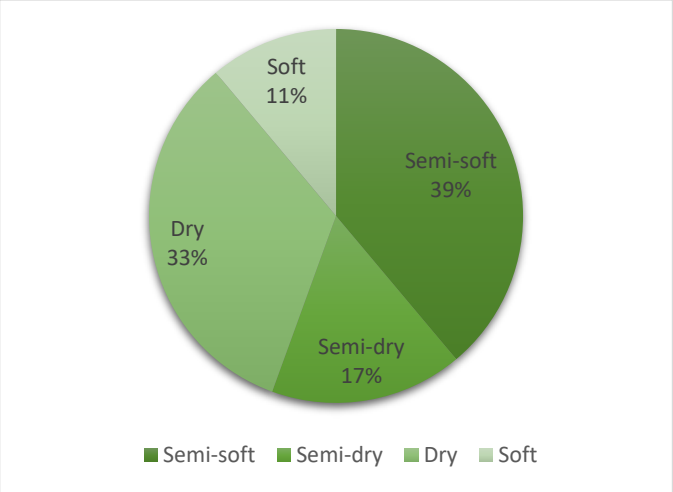

Figure 4: Approximate distribution of dominant date types by consistency in Morocco

Semi-soft dates represent the largest part of the diagram with 39%. This suggests that almost half of the varieties of dates available on the market have a texture neither too hard nor too soft. Dry dates follow with 33%, indicating that a third of the varieties are of firm consistency and contain less moisture. They may be ideal for long-term conservation. Semi-dry dates, which represent a non-standardized class like the others, account for 17%, showing that a notable portion of the production offers an intermediate texture. And finally, soft dates represent 11% of the total, indicating that this variety is the least common. Soft dates are often sought for their succulent texture and are generally consumed fresh. This distribution could reflect the climatic and cultivation conditions favoring the

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production of certain consistencies of dates more than others. The diversity of textures also shows a certain variety in the offering of dates, allowing to satisfy a range of tastes and technological uses. The color of dates can vary considerably, reflecting the diversity of cultivated varieties. When they reach maturity and are ready for harvest or consumption, dates can present a palette of colors ranging from light brown to dark brown and sometimes almost black.

Figure 5 allows a quick and easy visualization of the distribution of different color categories within the entire data set (Table 5). It is particularly useful for comparing proportions and for making quick deductions about the relative frequency of each category.

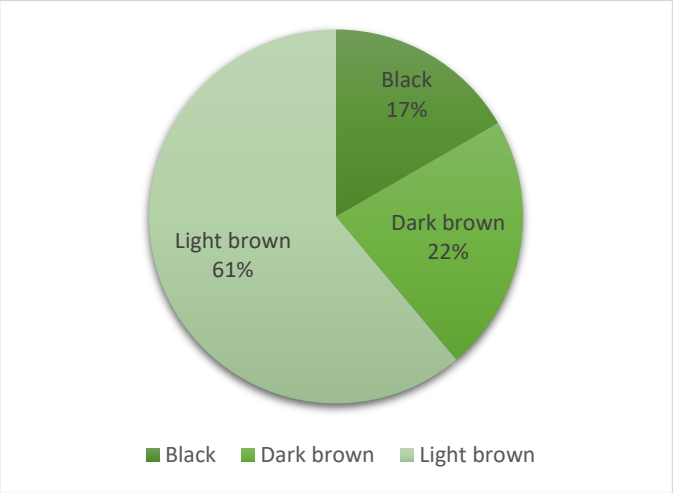

Figure 5: Approximate distribution of dominant date types by color in Morocco

Light brown represents the majority of the ensemble with 61% of the data classified in this category. This indicates that the light brown color is the most common or most prevalent in the observed group. The second most frequent color is dark brown, accounting for 22% of the data. This means that just over a fifth of the varieties exhibit a dark brown color. And finally, the black color represents 17% of the ensemble, making it the least widespread of the three categories present.

One can establish a relationship between consistency and color, as shown in Figure 6, which represents the distribution of colors according to consistency. Dry dates exhibit a bright color and a hard flesh while soft dates take on a dark black color and a soft flesh. Then the colors could be a matter of quality analysis where the colors represent grades or specific characteristics associated with the texture or consistency of the product. Black dates, potentially being softer or more mature, might have less of this component than light brown dates, which could be less mature or drier. These suggestions are hypothetical based on the distribution performed.

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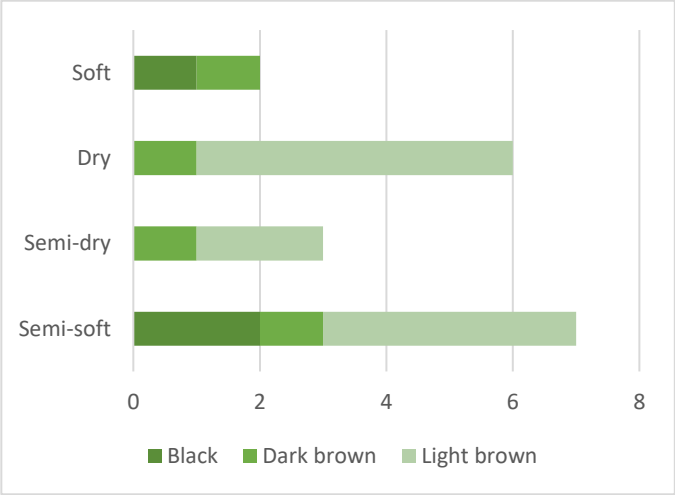

Figure 6: Approximate distribution of the distribution of dominant dates by consistency according to color in Morocco

Soft dates show a balanced distribution between the two colors (Black and Dark brown). This may indicate that soft dates tend to have a darker color in general, dry dates seem to be predominantly light brown with lesser amounts in dark brown, while the semi-dry category light brown dominates with lesser presences of dark brown. This may suggest that semi-dry dates retain a lighter hue similar to dried dates and the semi-soft dates show a more balanced distribution between the three colors compared to the others with a slight predominance of light brown followed closely by black and finally by dark brown. This trend could indicate that soft dates have a propensity to become darker in color and lighter for dried varieties. Here is a summarized representation of Table 6, which reviews the distribution of color and consistency across the dominant date varieties, with semi-dry and dry types showing a noticeable difference in the presence of lighter colors compared to softer varieties.

Table 6: Approximate review of the distribution of color and consistency of the dominant date varieties in Morocco

	Black	**Dark brown**	**Light brown**
Soft and Semi-soft	Presence	Moderate presence	Moderate presence
Semi-dry and Dry	Absence	Moderate presence	More present and perceptible

Color variations may be due to biological causes; each variety of date has its genetic characteristics that include consistency and color at maturity. The coloration of dates can be influenced by the ratio between sugar and water (r index) inside the fruit, especially during ripening, and with the loss of water, the sugars present in dates are concentrated, giving a sweet appearance for dried dates. The presence of a high-water rate can cause the Maillard reaction and oxidation, which can cause a darker coloration. Without chemical analyses and studies of the composition of dates, it is difficult to provide a definitive explanation of color variations in relation to consistency.

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To better understand the dispersion of the 453 date palm varieties, and not just the 18 studied, future research should actively involve stakeholders, particularly local farmers and cooperatives. Their engagement is crucial to ensure that the findings reflect the practical realities and challenges faced by producers. Farmers' feedback on agricultural practices, cooperatives' insights into market challenges, and policy input can help develop more targeted and actionable solutions. Incorporating local perspectives will be essential for designing sustainable policies and technological innovations that enhance productivity and improve market access for Moroccan date farmers. This inclusive approach will ensure that recommendations address the sector's needs effectively, supporting both local livelihoods and the broader economic growth of the date palm industry.

3-CONCLUSION

Date palm cultivation, especially in Morocco, stands for a kind of agricultural tradition. Among the main ones, some cultivars, which stand out due to quality, are Medjool, Boufgouss, and Jihel. In spite of this, it is nevertheless an economic sector plagued by persistent problems that cumulatively stymie it: climatic constraints, water scarcity, and market fragmentation-all deterrents to fully realizing the economic potential.

Varieties range from soft to semi-dry to dry dates, and diversity depends not only on adaptation to specific environmental conditions but also on different uses in local and international markets. In this respect, the future challenges for this sector will be higher competition from imported varieties and the need for foreign markets to realize the true quality of Moroccan dates.

Despite this leading position in global production, Morocco should focus on several key areas to improve productivity, sustainability, and market access. Firstly, optimizing water management systems through innovative technologies such as solar powered irrigation and rehabilitating traditional systems like khettara could enhance water use efficiency in Morocco's arid regions. Additionally, research on climate-resilient date palm varieties is essential to mitigate the impacts of climate change and ensure long-term production sustainability. Another important area for future research is improving post-harvest handling and storage technologies, including cold storage and modified atmosphere packaging, to reduce spoilage and extend shelf life, thereby increasing marketability. Finally, enhancing market access by establishing more efficient supply chains, promoting the formation of cooperatives, and exploring value-added products could provide greater economic opportunities for farmers and improve Morocco's competitiveness in the global market. These research directions will contribute to a more sustainable, resilient, and profitable date palm industry in Morocco. These priorities reflect the most pressing issues for improving the sustainability, productivity, and economic viability of the date palm sector in Morocco, aligning with global challenges such as climate change and the need for innovative agricultural practices. After all, the future of the Moroccan date palm sector rests in how it will be able to balance tradition with modernization so that its contribution, both economic and cultural, is assured to be perpetual while capitalizing on the wide variety of date palms that the country has.

[DOI: 10.22034/FSCT.22.160.202]

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