BIODIVERSITY OF DATE PALM

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Contents

Summary

The date palm (*Phoenix dactylifera*) is the dominant component upon which the sustainable biophysical and socio-economic structures of the oasis ecosystem are based; a fruit tree with unique nutritional, biochemical and biophysical characteristics, a rich source of aesthetic and cultural values, and a genetic resource. The date palm is the only indigenous wild desert plant definitely domesticated in its native harsh environment. Along with the camel (*Camelus dromedarius*), the date palm was responsible for

opening the vast desert territories for human activity and the development of oasis agro-ecosystems. The oasis represents the climax of rigorous management of scarce water and land resources in alliance with the date palm. *Phoenix dactylifera* is composed of genetically discrete clones representing thousands of cultivars without the benefits of a dynamic mutation-recombination system. It is closely related to a variable aggregate of wild and feral palms distributed over a desert belt across the Middle East and North Africa. Genetic diversity and genetic structure of the gene pool complex of date palm have been shaped and greatly altered by natural and human selection, clonal propagation, and spatio-temporal exchange and movement of germplasm. Traditional oases continue to play a vital role in the maintenance and enrichment of date palm genetic resources and their genetic diversity through multiple processes and dynamic conservation practices. However, a better understanding of the intra-specific genetic variation of date palm and its distribution in oasis agro-ecosystems is essential for the conservation and sustainable use of its biodiversity. If properly designed and implemented, strategies for conservation and sustainable use of date palm biodiversity will minimize anthropogenic disturbance, interference and impact, optimize ecosystem functions, and result in integrated protection of environmental resources of fragile oasis agro-ecosystems. Sustainability and provision of multiple services of these ecosystems depend largely on a highly diverse genetic base of date palms. In-depth assessment of the genetic vulnerability of date palm to climate change, desertification and salinity stress requires knowledge of the extent and distribution of its genetic diversity, both of which depend on the species evolution and unique breeding system, past genetic bottlenecks, and ecological, geographical and anthropogenic factors.

1. Introduction

Biodiversity of date palm refers to variation within the species, while genetic diversity represents the heritable variation that can be found within and between oases, populations, and cultivars of the date palm throughout its distributional range. The pool of genetic variation is the basis for selection as well as for the date palm improvement as a functional genetic resource within the oasis agro-ecosystem. Therefore, conservation of genetic diversity is essential for present and future functioning of the oasis agro-ecosystems and for the survival of human communities therein. Recently, there has been increasing awareness of, and interest in, the need to adopt a holistic view of dynamic conservation and sustainable utilization of date palm within its natural habitat, the oasis. Spatiotemporal dynamics in genetic diversity is generally recognized in the date palm; however, the extent and distribution of which depend on a number of interacting factors including the tree's evolution and breeding system, ecological and geographical factors, past bottlenecks, and anthropogenic factors.

A thorough understanding of date palm genetic diversity and how it is structured in different oases, populations and cultivars is essential for its dynamic conservation and sustainable use. It will help farmers, scientists and policymakers determine what to conserve as well as where to conserve, and will improve our understanding of the taxonomy, origin and evolution of this unique fruit tree. Additionally, this knowledge is essential for germplasm collecting and use of the cultivated species and its wild relatives. The vast array of adaptive genetic variation available in date palm, which is generally quantitative and responsive to habitat differences, often reacts to biotic, abiotic and anthropogenic factors. Genetic diversity studies on date palm have clearly demonstrated that there is a clear association between population characteristics and the environments (i.e., oases) in which they grow; whereas, ecological factors largely determine the extent and distribution of genetic diversity in its wild relatives. However, plasticity has apparently been sufficient to allow genetically similar date palm cultivars to grow and produce in widely differing oasis environments. Ecotypic differentiation in date palm affects many plant traits such as the relative rates of development in this slow-growing tree, resistances to biotic and abiotic stresses, edaphic responses and response to soil fertility, and adaptation to different management practices (e.g., cultivation, irrigation and harvesting methods) as well as differences in fruit quality.

Local date palm cultivars with outstanding adaptation to climatic, edaphic, and management factors, are the products of centuries of interaction between farmers, the genetic and breeding systems of the date palm, and the environment. The breeding system of date palm as well as several ecological pressures affect the distribution of intra-population variability and determine the genetic composition of cultivars within oases. In addition, selection for ecological adaptation may have resulted in the accumulation of differences in originally identical clones grown in oases with different environmental and management factors. The breeding system of date palm profoundly affected allele distribution; whereas, the mating system, floral morphology and mode of reproduction all impacted the extent and distribution of genetic diversity. Wild palm species often have breeding systems different from those of the domesticated species, and therefore raise different problems with respect to their biodiversity, collecting, maintenance and regeneration in field gene_banks or horticultural gardens. Partitioning of genetic diversity within and between oases, populations, and date palm cultivars is an important factor to be considered in biodiversity studies and genetic resources conservation efforts of date palm. The data on the extent, structure and distribution of date palm genetic diversity is necessary in managing both *in situ* and *ex situ* conserved genetic resources. So far, deliberate *in situ* conservation of cultivated date palm and its wild relatives have been rather limited.

2. The Eco-geographical and Societal Settings

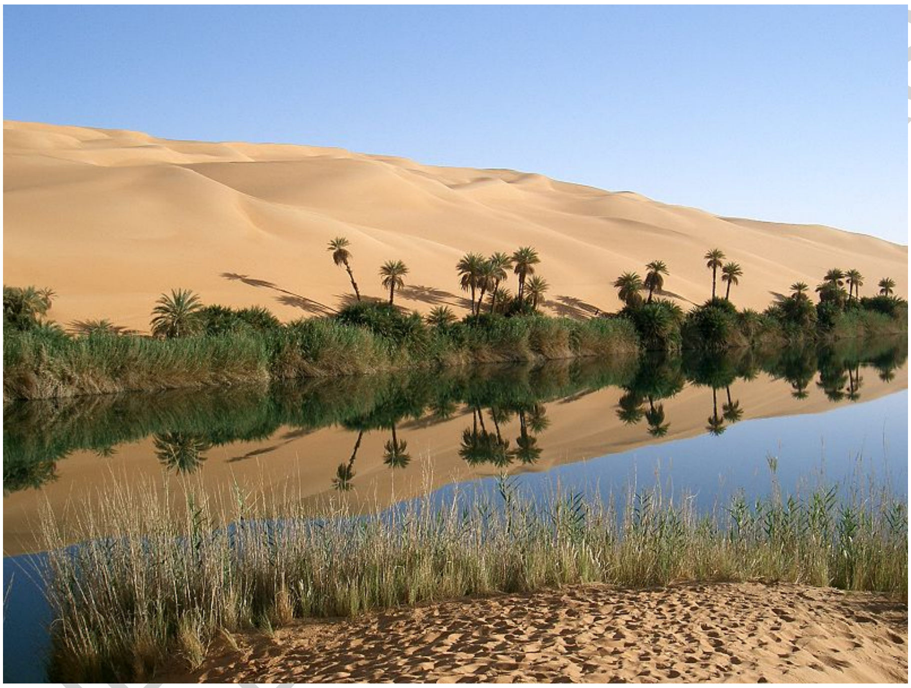
The earliest records of date palm cultivation date from about 7,000 years ago in Eridu in southern Mesopotamia; however, cultivation probably began thousands of years earlier. Date palm culture spread from its centre of origin to the wider centre of diversity, encompassing Arabia Deserta, Arabia Felix, the Fertile Crescent, and North Africa. Especially with the rise of Islam, its cultivation increased in importance; it spread to Spain, and from there was carried to the New World. Historically, date palm trees have been integral component of farming systems in oases throughout arid and semi-arid parts of the Middle East and North Africa (MENA). More recently, date palm trees are being produced equally well in small orchards or in large-scale commercial plantations. Currently, date palm cultivation is centered in a rainless belt of the deserts south of the Mediterranean Sea and in the southern fringes of the Middle East, from south Iran in the east to the Atlantic coast of North Africa in the west. The date palm is adapted to areas with long, hot summers with little rain and low humidity, but with abundant underground water. These conditions are mainly found in oases and river valleys in the arid sub-tropical deserts of the MENA countries. Date palm flourishes where other fruit production would be marginal at best. Several factors, including its resilience, requirement for limited inputs, long-term productivity, and multi-purpose attributes, all contributed to the special affection for, and the habitat created by the tree.

Date palm cultivars throughout the oases of MENA derive their importance from their local adaptation to climatic, edaphic and socioeconomic conditions and due to the quality of their fruit. In addition to its local and regional commercial value, the date palm plays an important role in the diet and social life of communities across the oases of MENA. The date palm had great spiritual and cultural significance and achieved its greatest esteem in Middle Eastern cultures. It was depicted on ancient Assyrian and Babylonian tablets, including the famous Code of Hammurabi, which contained laws regulating date culture and sale. There are many references to the date palm in pre-Islamic chronicles, but it became more prominent ever since. The tree and the fruit have been revered because of the numerous horticultural, nutritional, medicinal, economic, architectural, environmental characteristics, and uses. The columnar architecture in the Mediterranean region, for example, is thought to have been inspired by the use of date palms as building material.

The precise number of date palm cultivars throughout the world is unknown since ecotypes exhibit homogenous traits and differ mainly by the fruit characteristics. However, of the estimated ~120 million date palms in the world, over two-thirds are in MENA countries, and approximately 800 different kinds of dates are available in these countries; these account for 60% of the world’s production. The development of date palm culture usually is limited by water availability. Nevertheless, date palms are being grown in traditional oases or modern-day plantations in many countries around the world, including Iraq, Kuwait, Bahrain, Saudi Arabia, United Arab Emirates, Oman, Yemen, Jordan, Syria, Israel, Palestine, Egypt, Libya, Tunisia, Algeria, Morocco, Mauretania, Senegal, Sudan, Somalia, Spain, Canary Islands, USA, Australia and New Caledonia. However, south of the great Sahara Desert of North Africa, increasing rainfall imposed a barrier to any extension of date palm culture which has been limited to small plantings along the northern edge of the equatorial rain belt from Senegal and the Upper Niger to Sudan (Darfur and the Blue Nile provinces). Until very recently, there was no record of date palms in Africa south of the equator; however, new plantations have been initiated in the Namibian Desert. In addition, recent plantations have been initiated in Southern Australia; whereas, earlier attempts to introduce date palm into the desert valleys of Central Asia failed due to low temperatures.

3. The Oasis Agro-ecosystem

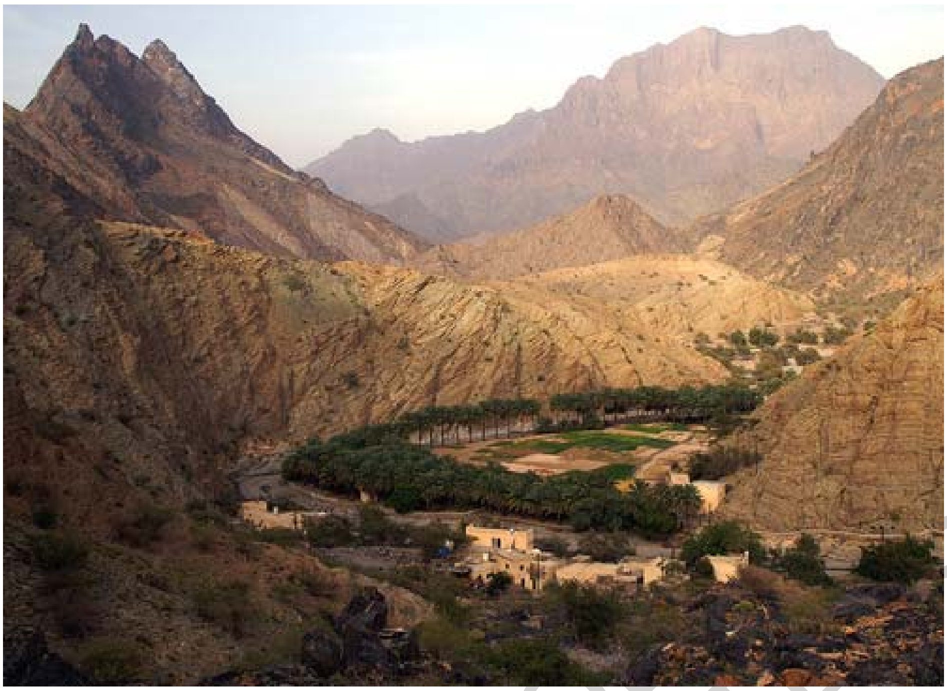
“Oasis” is a Greek word for watered green fertile land in the desert where the “oasis effect” is manifested as cooling caused by vegetation. Under the harsh desert environment, especially in MENA, farmers use their adaptive ingenuity which was accumulated over millennia to create sustainable palm-based agricultural systems. These systems are usually managed through local resource management institutions that enable farmers to make judicious decisions for sustainable resource use and to maintain stable and productive oasis agro-ecosystems. The oasis agro-ecosystem was patiently developed and evolved over millennia into a very complex ecological, social, and economic infrastructure. It is the final optimization of the interaction between cultural references, engineering constraints, economic limitations, and climatic diversity of an environment equally hostile to human, animal and plant life. Most of the unique oasis agro-ecosystems are found in MENA countries; although these oases cover a relatively small land area of about 1 million ha, however, they support the livelihood of about 10 million inhabitants, where the most important crop is date palm. Some of the notable oases in MENA are Al-Qatif and Al Ahsa in Saudi Arabia; Al Ain, UAE; Buraimi, Maghta, and Bahla in Oman; Bahraiya, Farafra, and Siwa in Egypt; Ghadames and Kufra in Libya; Ouargla, Taut, and Timimoun in Algeria; Tozeur and Tamerza in Tunisia; and Tafilalt and Ourzazat in Morocco (Figure. 1). The importance of cultivars in each oasis is related to the climatic conditions, the number of trees for each cultivar and the quality of the fruit.



(A)

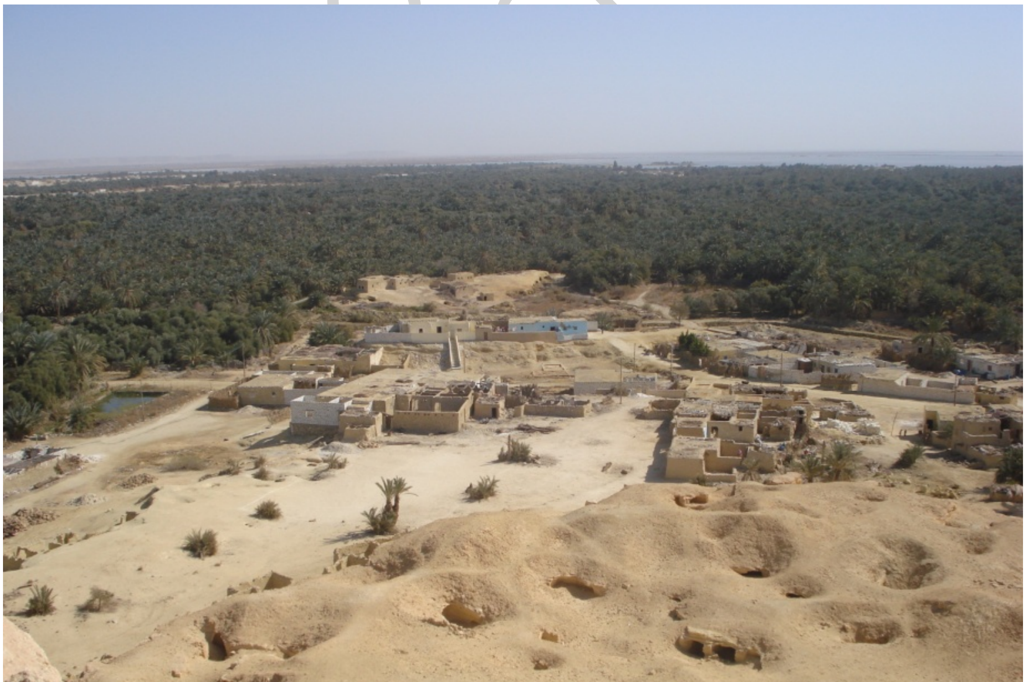
The oasis agro-ecosystem is a standard model for a spatially heterogeneous, three-story inter-cropping system of date palms, fruit trees and annual crops. The composition and configuration of the three-story system creates different profiles of horizontal wind speed, relative air temperature and relative air humidity. Date palms, fruit trees, and annual crops approximately intercept 20, 20 and 40% of daily net radiation, respectively. Highly adapted cultivars of date palm, fruit trees, and annual crops are managed through refined social practices and institutions.

The indigenous knowledge associated with this diversity and its management is crucial to ensure a sustainable life in the oases. Although agriculture in the oasis agro-ecosystem is mainly limited by the availability of suitable irrigation water, however, even with sufficient water, its use under the usually hot dry climate is often not sustainable, leading to soil salinization as a consequence of inappropriate irrigation and drainage techniques.



(B)

Figures 1(A&B). Examples of different oasis agro-ecosystems: (A) Um El-Ma'a, an oasis (or what is left of it) in the Sahara Desert, southern Libya, (B) Mountain oasis, Hajar mountains, Oman (Source: Google Earth).



(C)

(D)

Figures 1(C&D). Examples of different oasis agro-ecosystems: (C) Siwa, Egypt, and (D) Ourzazat, Morocco. (Source: Google Earth).

Oases in the major center of origin and diversity of date palm (i.e., lower Mesopotamia and eastern Arabia) typically cover thousands of hectares, contain a large number of date palm and other fruit trees, and are composed of a mixture of adapted cultivars. However, oases away from the center of origin are smaller in size, may cover a few hectares, and contain a few date palm cultivars. Historically, these oases have been developed by transport of seed and, occasionally, offshoots from existing oases. The mode of propagation impacted the level of diversity and varietal composition in the new oases. In the case of elite selections, propagation by transported offshoots resulted in dissemination of genetically identical or nearly-identical cultivars to various parts of a country or region. In the case of non-commercial or less desirable cultivars, seed dissemination resulted in the establishment of more localized and adaptive cultivars. Human selection of elite types traditionally was based on fruit characteristics and this would be the main selection pressure; however, some natural selection pressure in the new oases may have occurred due to resistance or susceptibility to biotic and abiotic stresses. Similarly, natural selection could have been applied on the non-elite cultivars that originated from seed.

The botanical composition and floristic inventory contained in even relatively small oases are rich and highly diverse. For example, 14-17 different date palm cultivars and a total of 107 different plant species have been recorded in three small oases in the northern mountains of Oman. In addition, the number of crops was very high in comparison with other small-scale cropping systems found under arid or semi-arid conditions. In this mountainous region, a completely different form of agriculture has persisted for millennia. Date palms and annual crops are cultivated in oases that are watered either by springs or by *aflaj*, tunnel systems dug into the ground or carved into the rock to tap underground aquifers. Both systems require the oases to be located at the foot of cliffs, below plateaus, which accumulate the scarce rainfall of a large area (i.e., water harvesting) and never developed a serious salinity problem.

4. The Genus Phoenix

The genus *Phoenix* was considered as monotypic because different *Phoenix* species hybridize readily and produce fertile hybrids. Therefore, there have been disagreements between various taxonomic treatments and some confusion about species nomenclature and validity of their taxonomy. The taxonomy of the genus *Phoenix* has not been well established in the literature until relatively recently. Date palm (*Phoenix dactylifera* L.) is a long-lived dioecious monocotyledonous fruit tree plant (2*n*=36). It belongs to the Arecaceae (or Palmae) family. The genus *Phoenix* is the only member of the tribe *Phoeniceae*. Dioecy is a rare sexual system in flowering plants, with only 4-6% of all plant species being dioecious. The trunk in *Phoenix* spp. varies from a single to many trunks forming a clump. Trunks range in size tremendously; some species have rudimentary trunks, while trunks of other species reach more than 30 m in height. *Phoenix* spp. may be distinguished from other palms by a number of morphological features: the leaves have feathery surfaces; the basal leaflets are modified into spines; there is a terminal leaflet for each leaf; and there is a central fold or ridge on the leaflets which causes them to remain erect at all times. The inflorescences in the *Phoenix spp*. arise among the leaves; the small, pale yellowish flowers are borne singly; the sepals of each flower are fused into a cupule (cup-shaped structure), and there are three petals per flower. In this dioecious plant, male and female flowers are born on separate plants. Female flowers have three carpels, only one of which matures; whereas, male flowers usually have six stamens. The fruits of *Phoenix* spp. are drugs of variable sizes, depending on the species, and each fruit has a single grooved seed.

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Bibliography

Al-Ghamdi A.S. (2001). Date palm (*Phoenix dactylifera* L.) germplasm bank in King Faisal University, Saudi Arabia. Survival and adaptability of tissue cultured plantlets. *Acta Horticultura* 450, 241-244. [Information on composition of a local field gene bank and characteristics of palm trees derived from tissue culture].

Al-Ruqaishi I.A., Davey M., Alderson P. (2008). Genetic relationships and ecotype tracing in date palms (*Phoenix dactylifera* L.) in Oman, based on microsatellite markers. *Plant Genetic Resources: Characterization and Utilization* 6, 70-72. [Example of genetic diversity and relationships between date palm varieties in Oman].

Al-Yahyai R., Al-Khanjari S. (2008). Biodiversity of date palm in the Sultanate of Oman. *African Journal of Agricutural Research* 3, 389-395. [An example of a study on date palm biodiversity study in its centre of diversity].

Azeqour M., Amssa M., Baaziz M. (2002). Identification de la variabilité intraclonal des vitroplants de palmier dattier issus de culture in vitro par organogenèse: étude morphologique*.* *C.R. Biologies* 325, 947-956. [Examples of how to quantify and characteristics of variability caused by in vitro propagation of date palm].

Azeqour M., Majourhat K., Baaziz M. (2002). Morphological variations and isozyme polymorphism of date palm clones from in vitro culture acclimatized on soil in South Morocco. *Euphytica* 123, 57-66. [Description of how variable date palms produced through in vitro propagation acclimatized to edaphic conditions].

Benchelah A.-C., Maka M. (2008). Les dates: intérêt en nutrition. *Phytothérapie* 6, 117-121. [Information on the nutritional value of dates].

Bendiab K., Baaziz M., Majourhat K. (1998) Preliminary date palm cultivar composition of Moroccan palm groves as revealed by leaf isoenzyme phenotypes. *Biochem Syst Ecol* 26:71-82. [Example of genetic diversity of date palm based on isozyme polymorphism].

Bettencourt E., Hazekamp T., Perry M.C. (1992) Directory of Germplasm Collections. 6.1. Tropical and Subtropical Fruits and Tree Nuts. IBPGR, Rome. [Initial compilation of horticultural crops, including date palms, in the tropical and sub-tropical regions].

Chevalier A. (1952) Recherches sur les Phoenix Africains. *Rev Intl Bot Appl*, 32:205-236. [Extensive information on Palms of North Africa].

El-Assar A.M., Krueger R.R., Devanand P.S., Chao C.T. (2005) Genetic analysis of Egyptian date (*Phoenix dactylifera* L.) accessions using AFLP markers. *Genetic Resources and Crop Evolution* 52:601-607. [Description of genetic diversity of a number of representative date palm varieties from Egypt].

Elhoumaizi M.A., Saaidi M., Oihabi M., Cilas C. (2002). Phenotypic diversity of date-palm cultivars (*Phoenix dactylifera* L.) from Morocco. *Genetic Resources and Crop Evolution* 49, 483-490. [Description of genetic diversity of a number of representative date palm varieties from Morocco].

Elshibli S., Korpelainen H. (2008). Microsatellite markers reveal high genetic diversity in date palm (*Phoenix dactylifera* L.) germplasm from Sudan. *Genetica* 134, 251-260. [Description of genetic diversity of unique date palm populations from Sudan].

Elshibli S., Korpelainen H. (2008). Excess heterozygosity and scarce genetic differentiation in the population of *Phoenix dactylifera* L: human impact or ecological determinants. *Plant Genetic Resources: Characterization and Utilization* 7, 95-104. [An excellent example of how human and ecological factors impact genetic structure of date palm populations].

Francisco-Ortega J., Santos-Guerra A., Kim S-C., Crawford D. (2000). Plant genetic diversity in the Canary Islands: a conservation perspective. *American Journal of Botany* 87, 909-919. [A unique example of how the introduction of cultivated date palm can impact the genetic diversity of an endemic palm species, and implications for its conservation].

Friedman J., Barrett S.C.H. (2009). Wind of change: new insights on the ecology and evolution of pollination and mating in wind-pollinated plants. *Annals of Botany*. 103, 1515-1527. [Valuable information on the origin, dynamics and consequences of wind pollination in plants (applicable to date palm)].

Gebauer J., Luedeling E., Hammer K., Nagieb M., Buerkert A. (2007). Mountain oases in northern Oman: an environment for evolution and *in situ* conservation of plant genetic resources. *Genetic Resources and Crop Evolution* 54, 465-481. [Description of a unique situation where a mountain oasis can serve as an ideal location for the conservation of plant genetic resources].

González-Péerez M.A., Caujapé-Castells J., Sosat P.A. (2004). Molecular evidence of hybridization between the endemic *Phonex canariensis* and the widespread *P. dactylifera* with random amplified polymorphic DNA (RAPD) markers. *Plant Systematic and Evolution* 247, 165-175. [A unique example of the genetic interaction between two *Phoenix* species and what are the conservation and genetic diversity implications this interaction on the endemic species].

Hajjar R., Jarvis D.I., Gemmill-Herren B. (2008). The utility of crop genetic diversity in maintaining ecosystem services. *Agriculture Ecosystems & Environment* 123, 261-270. [A general example of how crop genetic diversity can be used to provide and maintain several eco-system services that can be applied to date palm and the oasis agro-ecosystem].

Hammadi H., Mokhtar R., Mokhtar E., Ali F. (2009). New approach for the morphological identification of date palm cultivars from Tunisia. *Pak. J. Bot*. 41, 2671-2681. [An example of how morphological descriptors can be used to identify and differentiate between date palm cultivars].

Jaradat A.A., Zaid A. (2004). Quality traits of date palm fruit in a centre of origin and centre of diversity. *Food, Agriculture & Environment* 2, 208-217. [Evaluation of fruit quality traits from representative date palm varieties in six Gulf countries and identification of hot-spots for specific fruit quality traits].

Kurup S.S., Hedar Y., Al Daheri M., et al. (2009). Morpho-physiological evaluation and RAPD marker-assisted characterization of date palm varieties for salinity tolerance. *Journal of Food, Agriculture & Environment* 7, 503-507. [Examples of molecular and phenotypic markers to identify salt-tolerant date palm varieties to help combat this growing problem in different oases].

Lightfoot D.R., Miller J.A. (1996). Sijilmassa: The rise and fall of a walled oasis in Medieval Morocco. *Annals of the Association of American Geographers* 86, 78-101. [Description of anthropogenic and environmental factors that led to the rise and fall of an oasis in Morocco].

Masmoudi-Allouche F., Châari-Rkhis A., Kriaâ W., Gargouri-Bouzid R., Jain S.M., Drira N. (2009). In vitro hermaphrodism induction in date palm female flower. *Plant Cell Rep* 28, 1-10. [Description of a valuable experimental procedure to induce the initiation of male and female flower parts in female date palm flowers].

Maunder M., Lyte B., Dransfield J., Baker W. (2001). The conservation value of botanic garden palm collections. *Biological Conservation* 98, 259-271. [Survey results of palms around the world and the status of date palm, in particular].

McKey D., Marianne E., Pujol B., Duputie A. (2009). The evolutionary ecology of clonally propagated domesticated plants. *New Phytologist* **186**, 318-332. [An in-depth description of how plant, similar to date palm, evolved in nature and the consequences of clonal propagation].

Nabhan G.P. (2007) Agrobiodiversity change in a Saharan Desert oasis, 1919-2005: Historic shifts in Tasiwit (Berber) and Bedouin crop inventories of Siwa, Egypt. *Economic Botany* 61, 31-43. [A botanical and historical treatment of a unique oasis in the western desert of Egypt and the biodiversity changes that took place during ~ 100 years].

Nixon R.W. (1951) The date palm: “Tree of life” in subtropical deserts. *Economic Botany* 5:274-301. [One of the most comprehensive treatments of date palm and its characteristics throughout its distributional range].

Sané D., Aberlence-Bertossi F., Gassama-Dia Y.K., Sanga M., Trouslot M.F., Duval Y., Borgel A. (2006). Histological analysis of callogenesis and somatic embryogenesis from cell suspensions of date palm (*Phoenix dactylifera* L.). *Annals of Botany* 98, 301-308. [Description of a novel procedure for date palm propagation].

Siljak-Yakovlev S., Benmalek S., Cerbah M., Coba de la Peňa T., Bounaga N., Brown S.C., Sarr S. (1996). Chromosomal sex determination and heterochromatin structure in date palm. *Sexual Plant Reproduction* 9, 127-132. [Describes the discovery of sex chromosome in date palm].

Weiblen G.D., Oyama R.K., Donoghue M.J. (2000). Phylogentic analysis of dioecy in monocotyledons. *The American Naturalist* 155, 46-58. [An in-depth analysis of the origin and implications of dioecy in monocotyledons, including the date palm].

Zehdi S., Trifi M., Billotte N., Marrakci M., Pintaud J.C. (2004). Genetic diversity of Tunisia date palm (*Phoenix dactylifera* L.) revealed by nuclear microsatellite polymorphism. *Hereditas* 141, 278-287. [Example of how genetic diversity of date palm is being quantified and what are the factors impacting its level and composition in a centre of diversity].

Zohary D. (2004). Unconscious selection and the evolution of domesticated plants. *Economic Botany* 58, 5-10. [Description of how early farmers were able to select and domesticate crop plants for food, feed, fibre, oil, etc., including date palm].

Zohary D, Hopf M (2000) Domestication of plants in the Old World. 3rd ed. Oxford University Press, Oxford (UK). [Extensive information on how plants, including date palm and other fruit trees, have been domesticated in the Old World].

Biographical Sketch

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