Vegetation History and Archaeobotany
https://doi.org/10.1007/s00334-024-01013-8

REVIEW

Agrobiodiversity and crop diffusion in Morocco from Antiquity to the early Modern period (8th century BCE–17th century CE): an archaeobotanical review

Jérôme Ros[1] · Fatima-Ezzahra Badri[1,2] · Ruth Pelling[3]

Received: 22 February 2024 / Accepted: 31 July 2024
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Abstract
Over the past millennia, Morocco has undergone a great number of socio-economic changes, its lands having been dominated or occupied in turn or at the same time by Berber, Phoenician, Punic, Mauri, Roman, Arab and Portuguese populations. As elsewhere in the Mediterranean, these socio-economic dynamics have been accompanied by agricultural changes of varying degrees, contributing to the introduction and spread of new plants and practices. From a chronologically and geographically unbalanced corpus of 13 archaeological sites, this paper proposes a general overview of the identified taxa, in order to set out our current knowledge of Moroccan agricultural productions from Antiquity to the early Modern period. A total of 47 cultivated/gathered species are attested by seeds and/or fruits, divided into 8 cereals, 7 pulses, 9 vegetables and condiments, 20 fruit trees, 3 oilseed and textile plants and 1 possibly cultivated grass plant. Greater taxonomic diversity is recorded during the medieval period, which is the most extensively researched. To complete this work, an overview of emerging approaches aimed at better characterizing diversity and agricultural practices (manuring, irrigation) is also proposed.

Keywords Carpology · Summary · Late Iron Age · Antiquity · Middle Ages

Introduction

Over the past millennia, Morocco has undergone a great number of socio-economic changes, its lands having been dominated or occupied in turn or at the same time by Berber, Phoenician, Punic, Mauri[1], Roman, Arab and Portuguese populations. As elsewhere in the Mediterranean, these socio-economic dynamics have been accompanied by agricultural and culinary changes of varying degrees, contributing to the introduction and spread of new plants and practices. In Morocco, ancient and medieval agriculture is usually considered from two positions: textual and, more recently, archaeobotanical, rarely conducted jointly due to the high degree of specialization required by each (e.g. Fariat 2023; Vanz et al. 2024).

The first approach is based on Arabic texts of diverse nature and origin, among which agronomic and geographic treatises dominate (e.g. Al-Idrîsî 1866; Al-Bakrî 1911; Ibn Hawqal 1938). These texts have provided – and continue to provide – valuable information not only in the field of Arabic philology, in terms of the agricultural terms used, but also in that of agronomic traditions and affiliations, of plants and their cultivation methods, with ramifications in the medical, pharmaceutical and culinary fields. But these sources, although rich and varied, are not available for all periods or in a uniform way across the country, and are biased towards the interest of the particular author, underlining the importance of complementary approaches. Recently,

[1] Ancient Mauretania was a kingdom in northwest Africa, encompassing regions of modern-day Morocco and Algeria, named after the Mauri (Moors), a Berber tribe.

Communicated by D. Fuks.

✉ Jérôme Ros
jerome.ros@umontpellier.fr

[1] ISEM, Univ Montpellier, CNRS, IRD, Montpellier, France

[2] INSAP, Rabat, Morocco / ISEM, Univ Montpellier, CNRS, IRD, Montpellier, France

[3] Historic England, Fort Cumberland, Portsmouth, Hampshire, UK

Published online: 13 September 2024

in the Western Mediterranean, more holistic approaches to understanding the developments of Islamic agriculture have included linguistic approaches (Blench 2021), as well as archaeological field work, multi-proxy sampling and dating techniques (e.g. Kirchner et al. 2023) providing new perspectives and chronological nuance.

At more local levels, the archaeobotanical details can be linked to local fluctuating socio-economic and climatic conditions, as well as the broader influences of the ruling caliphates and technological advances. For this reason, patterns in the crop repertoire are not necessarily global but can be linked to local customs and environmental conditions. Unfortunately, archaeobotanical research on the Mediterranean Islamic world is uneven. In some parts of North Africa, political instability has limited excavation and archaeobotanical studies in recent years, such as in Libya and Algeria, and we are reliant on old data. Elsewhere in the Western Mediterranean, the renewed interest in medieval archaeology and revisiting of the Islamic Green Revolution model (Watson 1983) has prompted sampling for archaeobotanical remains as well as other environmental proxies, at sites in Tunisia (e.g. van Zeist et al. 2001), Portugal and Spain (e.g. Peña-Chocarro et al. 2019; Ros et al. 2019), Italy (Fiorentino et al. 2024), as well as Morocco (e.g. Ruas 2018). In Morocco, for a long time, archaeobotanical studies of historical contexts were carried out on an ad hoc basis, depending on the sensitivity of the archaeological teams to bioarchaeological and palaeoenvironmental issues and methods. In the 1970s and 80s, a few archaeological missions initiated archaeobotanical research on medieval contexts, leading to some pioneer publications (Pollock 1986), although several studies remained unpublished and difficult to access (e.g. at Sijilmasa, Mahoney unpubl. reports 1994, 1995, 1996). The years since 2000 have seen a new development of this type of analysis, thanks in particular to large operations carried out on certain emblematic sites of ancient and medieval Morocco, such as Lixus and Volubilis (Grau Almero et al. 2001, 2010; Fuller 2002, 2004; Pérez Jordà 2005; Fuller and Stevens 2009; Fuller and Pelling 2018). Since the 2010s, new sites have been or still are the subject of large-scale archaeobotanical research (carpology, anthracology), the palaeoenvironmental component forming a significant part of the approach. In the absence of Moroccan archaeobotanists, it is especially through Moroccan-French, Moroccan-Spanish, Moroccan-British and Moroccan-Italian collaborations that this research was developed. We will mention, for example, the large-scale excavations carried out at Îgîlîz (Ruas et al. 2011, 2016a; Ros et al. 2021a), at Thamusida (Allevato et al. 2013, 2017), at Rirha (Ruas et al. 2016b; Carrato et al. 2020), at Aghmat (Ros et al. 2021b, 2024) and new work emerging from the Middle Draa Project in the Wadi Draa (Mattingly et al. 2017; Fenwick et al. 2022).

The collaborations established over the last decade and important institutional support (e.g. INSAP, MNHN, CNRS, MAE, Casa de Velázquez) have allowed the creation of research programs entirely dedicated to the study of ancient and/or medieval Moroccan agriculture and palaeoenvironments. For example, the HARGANA project (Histoire et Archéologie des Ressources biologiques et stratégie de Gestion vivrière de l'Arganeraie médiévale en montagne Anti-atlasique (Maroc), led by J.-P. van Staëvel and M.-P. Ruas) was an interdisciplinary project that aimed to study the domestic and wild plant and animal resources of a population of the medieval (Almohad) Anti-Atlas, at Îgîlîz, and the methods of management and use of their territory through *Argania spinosa* (argan tree), an endemic species. Among these institutional supports, we must make special mention of the Casa de Velázquez and of the École des Hautes Études Hispaniques et Ibériques (EHEHI), which, in addition to providing institutional and financial support for several archaeological programs on medieval Morocco, were also the first institutions to finance a postdoctoral position for JR entirely dedicated to the archaeobotany of medieval Morocco and co-funding the first workshop dedicated to the archaeobotany of medieval Iberian Peninsula (International Workshop "Archaeobotanical research on medieval agriculture in the Iberian Peninsula" (2018), organized by L. Peña-Chocarro and JR). Today, several archaeobotanical studies follow their course while new ones are initiated (Ros and Badri 2020; Fenwick et al. 2022). However, in view of the scarcity of studies, priority is now given to training and dissemination of the results obtained to date. The current projects are therefore aimed at raising the awareness of new generations of Moroccan archaeologists to the themes and methods of bioarchaeology, thanks in particular to the investment of specialists in the field and in academic institutions. It should also be noted that, since 2023, the National Institute of Archaeological Sciences and Heritage (INSAP) of Rabat funded the first doctoral research dedicated to the study of Moroccan medieval agriculture, based on the study of archaeobotanical samples (F-E Badri: Agriculture and exploited forest landscapes in the medieval Haouz: an interdisciplinary approach in Aghmat, led by JR, ISEM; A. Ettahiri, INSAP and A. Fili, Univ. Chouaïb Doukkali).

In recent years, the first syntheses of data have made it possible to address the ancient and medieval history of certain plant categories in the Western Maghreb, for example fruit and vegetables (Ruas 2018) or cereals (Ruas 2020), based on the presence/absence of the cultivated taxa and on their ubiquity. This new review complements the existing ones, first by adding three new archaeological sites, among which two are located in the south of the country, responding

to a major shortfall in terms of spatial distribution of data, and secondly by bringing together, for the first time, all the available quantified data from across the country. We aim: (1) to present a critical assessment of the archaeobotanical data available, (2) to explore the general characteristics of medieval agriculture in Morocco, its legacies and novelties, and (3) to outline the current research on past varietal diversification and agricultural techniques.

Materials and methods

For northern Morocco, the available archaeobotanical data is concentrated in the northwest of the country (Gharb plain, Jbala mountains) and concerns the sites of Asilah, Qsar es-Seghir, Nakur, Badis, Thamusida, Lixus, al-Basra, Volubilis and Rirha (Table 1; Fig. 1). For the south, data are from Sijilmasa in the oasis region of Tafilalt, the jbel of Îgîlîz in the Anti Atlas, Aghmat in the Ourika valley (south of Marrakech) and from the Coude du Draa in the Wadi Draa region (Table 1; Fig. 1). This corpus covers a chronological range including the Roman (1st–4th century (c.)), Medieval (8th–15th c.) and Modern (16th–17th c.) periods, with reference to the Late Iron Age, Phoenician, Punic and Mauri data when available.

Each of these sites offers a variable window of information depending on the duration of occupation, the contexts and the preserved vegetal deposits. The cities of al-Basra, Sijilmasa, Qsar es-Seghir, Aghmat and the rural fortress of Îgîlîz are settlements from the Islamic period. The excavated sectors of Thamusida correspond to the Roman military and civil quarters. Lixus, a city founded by Punic settlers in the 8th c. BCE, and Rirha, whose first settlements date from the Mauri period (5th–4th centuries BCE), became important cities in the Roman period, whose ruins were reinvested by settlements from the Islamic period. For Volubilis, the available archaeobotanical data derives only from the Islamic levels, with recent excavations adding data for the earliest Islamic occupation of the site[2]. The contexts in which the plant remains have been preserved mostly correspond to levels of domestic or agricultural dumps, emptying of combustion structures (domestic and artisanal ovens, domestic fireplaces), habitation floors, contents of disused containers or silos reused as dumps, or even storage spaces, sometimes destroyed by fire (Table 1).

The comparison between the different sites suffers from several biases inherent to unequal status (urban, rural, commercial, religious), strong geographical disparity (north, south, coast, plain, mountain), variable corpus of samples (diversity of sampled contexts, quantity of studied samples, original volume of sampled sediment), and, finally, to the study protocol that was applied (proper sieving and extracting method, quantification of the remains). For this reason, it is important to keep in mind that the comparison we propose is preliminary.

To decide which species to include in our list of cultivated or exploited/consumed taxa, we based our choice on several criteria: type and abundance of remains of said taxon in the samples, frequency of appearance identified by archaeobotanists (e.g. Ruas 2018), contexts of discovery (domestic hearth, latrines), mention of consumption/cultivation of the taxa in textual and/or ethnographic sources.

Results

From an unbalanced corpus of 13 sites or study areas for the whole country, it seems premature to attempt a statistical treatment of the data. We therefore propose a general overview of the identified cultivated/gathered taxa, in order to present an updated account of our knowledge on agricultural production. The total number of selected plants, attested by seeds or fruits, includes 47 species that were cultivated/gathered (ESM). They are divided into 8 cereals, 7 pulses, 9 vegetables and condiments, 20 fruit trees, 3 oilseed and textile plants and 1 possibly cultivated grass (Table 2; Fig. 2).

Cereals and possibly cultivated grass

In the different sites of the corpus, *Hordeum vulgare* (hulled barley) and *Triticum aestivum/durum* (naked wheat) seem to constitute the staple cereal productions. Of the identified barleys, it would appear that both types (two-row, poly-row) are farmed, although it is not clear whether one type is more prevalent than the other within each site and positive separation of the two types is often not possible. Barley grain appears to be slightly more common than naked wheat at some, but not all sites, especially in southern Moroccan sites.

The presence of sufficiently well-preserved rachis demonstrates the presence of both hexaploid (*aestivum*) and tetraploid (*durum*) types, as early as the Early Neolithic in the case of *T. durum* (Morales et al. 2013), although durum wheat was long considered to be a novelty linked to the Muslim expansion in the Western Mediterranean (Watson 1983). Unlike *T. dicoccum* (emmer), which is regularly documented in Morocco during previous phases (Punic, Mauri, Roman), *T. monococcum* (einkorn) disappears from

[2] Moroccan-British interdisciplinary cooperation (since 2018) "Medieval Volubilis Archaeological Project" (funding: ERC grant EVERYDAYISLAM (Grant no: 949367), Barakat Trust, Gerald Averay Wainwright Fund for Near Eastern Archaeology), directed by C. Fenwick and E. Fentress (UCL, London) and H Limane (INSAP, Rabat).

Table 1 List of the Moroccan archaeological sites that have been subject of carpological studies

Site/location	Chronology	Period	Status	Type of contexts	No. of contexts	References
Al Basra/ Al Basra	9th–12th c. CE	Islamic–Medieval	Provincial capital city	Potter's kilns, dumps, housing floors	35	Pollock 1986; Mahoney 2004; Pelling 2007
Aghmat/ Ghmat	10th–15th c. CE	Islamic–Medieval	Ephemeral capital, city, village	Hearths, charcoal/ash levels, traffic levels, dumps, garden soil	22	Ros et al. 2021b, 2024
	16th–19th c. CE	Islamic–Modern	Village	Hearths, charcoal/ash levels, traffic levels, dumps	8	
Asilah/ Asilah	5th–3rd c. BCE	Mauri	Rural	Housing floors	1	Ros and Badri 2020
	11th–13th c. CE	Islamic–Medieval	Rural	Housing floors	5	
Badîs/ Bades	9th–15th c. CE	Islamic–Medieval	Port city	Concentration of ashes in an inhabited space	1	Pollock 1986
Coude du Draa/ Wadi Draa	5th–8th c. CE	Late Iron Age	Fortified hilltop site, trans-Saharan network	Occupation layers	11	Fenwick et al. 2022
	8th–13th c. CE	Islamic–Medieval	Fortified oasis, trans-Saharan network	Mudbrick fortified buildings, qasr	18	
	15th–18th c. CE	Late Medieval/ Early Modern	Rural, trans-Saharan network	Buildings, Mosque	5	
Îgîlîz/ Tughmart	10th–15th c. CE	Islamic–Medieval	Rural fortress	Habitats, fireplaces, ovens, latrines, garbage dumps	210	Ruas et al. 2011, 2016a
Lixus/ Larache	8th–4th c. BCE	Phoenician	Foundation of the first city	Large landfill and landfill levels	28	Pérez Jordà 2005; Grau Almero et al. 2001, 2010
	5th–2nd BCE	Punic			10	
	2nd–1st c. BCE	Punic–Mauri	Renovated city, sanctuary	Pits, fire levels, waste	42	
	1st–2nd c. CE	Roman	City, *Colonia*, temple	Dwellings with storage space and activity waste	12	
	5th–6th c. CE	Late Roman	Reoccupation of a city	Landfills, domestic garbage	7	
	8th–14th c. CE	Islamic–Medieval			4	
Nakûr/ Nakûr	9th–11th c. CE	Islamic–Medieval	Dynastic capital of the kingdom of Nakkûr, pole for trans-Saharan trade	Pit filling	1	Pollock 1986
Qsar es-seghir/ Fahs-Anjrar	12th–15th c.	Islamic–Medieval and Portuguese	Port city, commercial center, fortress	Oven, manures	3	Pollock 1986
Rirha/ Sidi Slimane	5th–2nd c. BCE	Mauri	Agglomeration of habitats	Soil, domestic and agricultural waste, households	10	Ruas et al. 2016b; Carrato et al. 2020
	1st c. BCE/1st c. CE	Late Mauri	Agglomeration of habitats	Soil, domestic and agricultural waste, households	35	
	1st–5th c. CE	Roman	Urban city	Burned levels of *domus*, presses, basin	29	
	9th–14th c. CE	Islamic–Medieval	Occasional re-occupation of a city	Dumps, domestic and artisanal ovens/kilns	28	
Sijilmasa/ Rissani	7th–12th c. CE	Islamic–Medieval	Trans-Saharan urban commercial city	Habitat floors, ovens, dumps	52	Mahoney unpublished
Thamusida/ Rabat	end of the 1st c. BCE/4th c. CE	Roman	Military quarter	Streets, dumps, bread oven, military barracks	10	Allevato et al. 2013, 2017
Volubilis/ Moulay Idriss Zerhoun	8th–11th c. CE	Islamic–Medieval	City	Storage and activities areas	Two sectors	Fuller 2002, 2004; Fuller and Pelling 2018

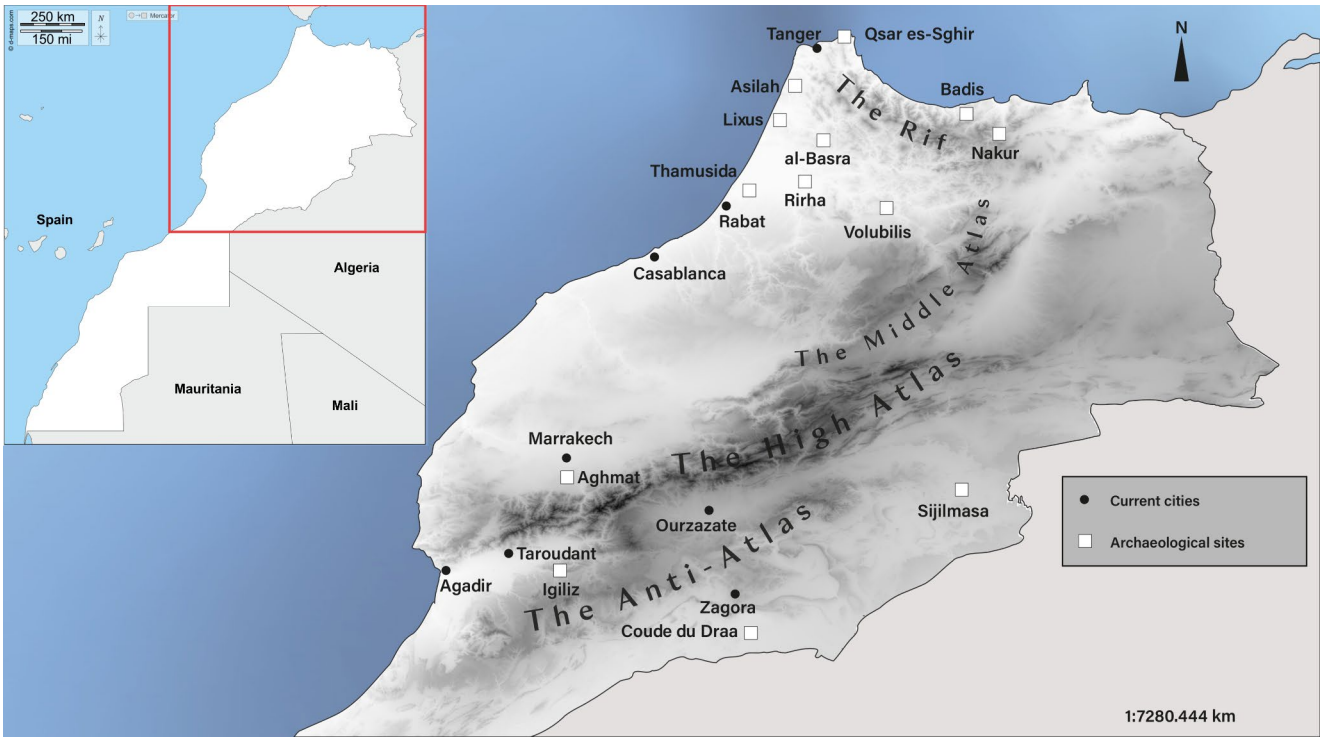

Fig. 1 Map of Morocco showing the sites that have been the subject of a carpological study

the archaeological record after the Neolithic period, and reappears during the Middle Ages in northern Morocco (Al Basra, Lixur and Volubilis).

The Panicoideae subfamily is represented in Morocco by three species: *Panicum miliaceum* (broomcorn millet), *Setaria italica* (foxtail millet), and *Sorghum bicolor* (sorghum). *Panicum miliaceum* is attested from the Punic/Mauri phases onwards, but is generally discreet in the samples. During the medieval period, it is only recorded in the north (Rirha; Al Basra), but appears in the late medieval–modern samples of Aghmat. *Setaria italica* only appears in the Punic/Mauri contexts of Lixus and has not been recorded in Roman or medieval samples so far. Finally, *S. bicolor* is only recorded in one archaeological site so far, in the medieval rural fortress of Îgîlîz in the Anti-Atlas. In some contexts of this settlement, *S. bicolor* seems to be, with hulled barley, a staple crop, being more frequent and abundant than naked wheat. *Avena* sp. (oat) is present in several medieval sites, but its status (cultivated, wild) has not been established so far. The cereals tend to be best represented by grain, chaff finds being very rare across the sites with a few exceptions (threshing residues, in situ stock feeding, e.g. at Aghmat, Îgîlîz, Volubilis). Finally, *Phalaris canariensis* (canary grass), found on a number of medieval sites in northern Morocco, sometimes in large numbers (at Volubilis), should also be considered as a potential crop plant. During the 20th c., this "small cereal" was mainly grown with durum wheat as a fodder crop, in the Rharb zone and in the sub-littoral areas of Casablanca, Mazagan and Safi (Perrin de Brichambaut 1952).

Pulses

Summarized data show that before the Roman period, five pulses were exploited: *Pisum sativum*, *Lathyrus cicera/sativus* (peas), *Vicia faba* var. *minor* (faba bean), *V. sativa* (vetch) and *Lens culinaris* (lentil). It appears that *Pisum*, more frequent in Phoenician contexts (e.g. at Lixus), seems to have been replaced over time by *V. faba*, finds of which increase from the 5th–4th centuries BCE onwards (Ruas 2018). This preeminence is also confirmed during the Islamic period, both in the north and in the south. *Lens* is the second most common medieval pulse crop after *V. faba* in the northern sites, becoming more common than *Pisum*. Other pulses (*V. sativa*, *V. ervilia*) occur sporadically, in Punic-Mauri and Roman contexts, then in medieval deposits, but without ever reaching high quantities or frequencies. A new legume also appears, *V. faba* var. *equina* or var. *major*, a large-seeded bean, in the medieval context of Rirha, although it is unclear if it was imported and just consumed, imported then locally grown (introduction) or a local development of a new variety (Ruas 2018). The absence of *Cicer arietinum* (chickpea) is surprising, the cooked or roasted seeds being as likely to be preserved in archaeological deposits as peas or beans. The distribution of carpological finds of the species seems

Table 2 Presence/absence of the main cultivated/used plant taxa in Morocco between the 8th c. BCE and the 17th c. CE

	Phoenician 8th–4th c. BCE	Punic–Mauri 5th c. BCE–1st c. CE	Roman 1st–5th c. CE	Islamic–Medieval 7th–14th c. CE	Islamic–Modern 15th–19th c. CE
Cereals					
Triticum aestivum/durum	●	●	●	●	●
Hordeum vulgare	●	●	●	●	●
Panicum miliaceum		●	●	●	●
Triticum dicoccum		●	●	●	
Setaria italica		●			
Triticum monococcum				●	
Sorghum bicolor				●	
Pulses					
Vicia faba var. *minor*	●	●	●	●	
Lathyrus cicera/sativus	●	●	●	●	
Lens culinaris	●	●	●	●	
Pisum sativum	●	●	●	●	
Vicia sativa		●	●	●	
Vicia ervilia			●		
Vicia faba var. *equina/major*				●	
Vegetables/condiments					
Beta vulgaris		●	●	●	●
Amaranthus sp.		●	●	●	
Coriandrum sativum		●	●	●	
Brassica/Sinapis		●	●	●	
Sinapis alba		●		●	
Portulaca oleracea			●	●	
Lagenaria siceraria				●	
Capparis spinosa				●	
Vitex agnus-castus				●	
Apium graveolens					●
Fruits					
Ficus carica	●	●	●	●	●
Olea europaea	●	●	●	●	
Punica granatum	●	●		●	
Vitis vinifera		●	●	●	●
Pinus pinea	●			●	
Ceratonia siliqua		●		●	
Prunus domestica			●		
Prunus dulcis			●	●	
Prunus persica			●	●	
Phoenix dactylifera				●	●
Rubus fruticosus				●	
Ziziphus jujuba				●	
Argania spinosa				●	
Juglans regia				●	
Wild fruits					
Pistacia lentiscus	●				
Ziziphus lotus			●	●	
Chamaerops humilis			●	●	
Crataegus monogyna			●		
Quercus sp.					
Oilseed and textile plants					
Linum usitatissimum		●		●	●
Cannabis sativa				●	
Gossypium sp.				●	
Carthamus sp.				●	
Possible cultivated grass					
Phalaris canariensis				●	

Fig. 2 Charred archaeobotanical remains: **a** *Hordeum vulgare* (Aghmat), **b** *Triticum aestivum/turgidum* (Aghmat), **c** *Punica granatum* (Aghmat), **d** *Phalaris canariensis* (Volubilis), **e** *Vitis vinifera* (Aghmat), **f** *Olea europaea* (Aghmat), **g** *Prunus domestica* (Aghmat), **h** *Phoenix dactylifera* (Coude du Draa). Photographed using a Leica MZ75 with Capture V2.3 and Keyence VHX7000 3-D digital microscope at 20–30x magnification; scale bars = 2 mm

eastern, since some remains are attested in the Islamic levels of Carthage (Tunisia) (van Zeist et al. 2001).

Vegetables and condiments/aromatics

The identification of vegetables and condiments/aromatics from archaeobotanical deposits is difficult due to preservation biases: seeds are often poorly preserved by charring and leafy or fleshy parts are unlikely to come into contact with fire. The presence in the corpus of contexts favouring preservation by mineral replacement (cesspits, middens) has increased the range of identified plant categories (van Staëvel et al. 2016). In the Punic/Mauri and Roman contexts, several taxa were identified, such as *Beta vulgaris* (chard), *Coriandrum sativum* (coriander), *Sinapis alba* (white mustard), *Portulaca oleracea* (purslane), *Daucus carota* (carrot) and *Brassica/Sinapis* (cabbage/mustard). Of these taxa, some (*Coriandrum*, *Sinapis*) have certainly been cultivated, while the status (cultivated, wild) of the others will need to be better clarified. All of them are also found in medieval contexts, with the addition of *Lagenaria siceraria* (gourd), *Capparis* cf. *spinosa* (caper), *Vitex agnus-castus* (monk's pepper), all found in the latrines of Îgîlîz. *Amaranthus* sp. (amaranth), *S. alba* and, to a lesser extent, *Brassica/Sinapis* and *Beta vulgaris* seeds form the most common vegetable/condiments/aromatics elements in the carpological assemblages of all periods. Seeds of other species appear at very low rates with fewer than ten remains (*Capparis*, *Portulaca*, *Vitex*). Several other cultivated fruiting and leafy vegetables are not recorded so far in the carpological spectra of Morocco e.g. cultivated *Cynara scolymus* (artichoke), *Cucumis sativus* (cucumber), *Spinacia oleracea* (spinach), *Solanum melongena* (eggplant) although they have been discovered in other parts of the Western Islamic (e.g. *S. melongena* in Islamic Sicily, Fiorentino et al. 2024) or Christian (e.g. *S. oleracea* in Christian France, Hallavant and Ruas 2014) world. Finally, seeds of *Apium graveolens* (celery) are recorded in late medieval–modern samples at Aghmat, but its status is still under debate.

Fruits

A great diversity of fruit species is recorded in the corpus. Among them, *Ficus carica* (fig), *Olea europaea* (olive), *Punica granatum* (pomegranate) and *Pinus pinea* (pine) are attested from the Phoenician period (8th–7th centuries BCE) onwards. During the Mauri and Roman periods, other cultivated fruits are added, such as *Vitis vinifera* (grapevine), *Ceratonia siliqua* (carob), *Prunus domestica* (plum), *P. dulcis* (almond) and *P. persica* (peach), as well as wild fruits such as those of the *Chamaerops humilis* (dwarf palm), the *Ziziphus lotus* (wild jujube) and *Crataegus monogyna* (hawthorn). The greatest samples of grapevine are encountered during Late Antiquity (3rd–4th centuries CE), with evidence of wine production at Rirha (Carrato et al. 2020) and during the Middle Ages at Aghmat (12th c.). *Phoenix dactylifera* (date), *Juglans regia* (walnut), *Z. jujuba* (cultivated jujube), *Argania spinosa*, *Rubus idaeus* (raspberry), *R. fruticosus* (blackberry) and possibly *Cucumis* cf. *melo* (melon) are only recorded in the Islamic period. Anthracology makes it possible to confirm the presence of certain taxa in the local landscape. In the south of the country, the discovery of *Olea*, *Ficus*, *Punica* and *Vitis* charcoal, for example, is known from the local landscape of Aghmat from as early as the 12th c., and their important role in domestic fuel (Ros et al. 2024). The same is true of Îgîlîz, where the anthracological study reveals the presence of *Ficus*, *Olea*, *Vitis* and *Phoenix* charcoal, confirming the existence of irrigated gardens in this semi-arid context during the 12th c. (Cartier 2021).

Oilseed, textile plants

A total of three taxa has been recorded for this category. The only one recorded before the medieval period is *Linum usitatissimum* (flax), attested in Punic/Mauri contexts. So far, the plant is absent in the Roman period of the north, but appears regularly in medieval contexts, both in the north (Rirha, Volubilis) and the south (Aghmat) of the country. Although it is most commonly found in seed form, it is also recorded in stem/fibre form at al-Basra and as capsule fragment at Rirha (Ruas et al. 2016b). According to al-Bakri, the city of al-Basra was nicknamed "Basrat al-Kattān", because flax (al-Kattān) was used by its first inhabitants in commercial transactions as a form of currency (Ettahiri and Meftah 2015). Other plants in this category are recorded from medieval times onwards, but never in large quantities: *Gossypium* sp. (cotton, Volubilis) and *Carthamus tinctorius/Carthamus* sp. (safflower, Volubilis, Îgîlîz).

Discussion

Because of the major imbalance that currently exists between data, both geographically and chronologically, the discussion will first focus on the characterization of the agricultural heritage detected and its evolution, and then on emerging approaches that aim to better characterize diversity and ancient practices.

Between heritage and novelties: "new" plants?

As demonstrated, the staple crops encountered in Morocco for the studied period are those common to the entire Roman and medieval Western Mediterranean (for ex. Ruas 2005; Peña-Chocarro et al. 2019; Ros et al. 2023), regardless of the location or status of the sites, particularly cereals (hulled barley, naked wheat), legumes (peas, fava beans, lentils), and some fruit trees (olive, fig, grapevine). In Morocco, these staple crops, as well as several consumed wild plants (wild *Vitis*, *Chamaerops*, wild *Olea*, and *Ziziphus*), have been present since the Neolithic period, or even earlier (e.g. Morales et al. 2013, 2016).

With regard to "secondary" cultivars, it is difficult to determine what is really new, whether or not driven by certain socio-economic dynamics, such as the Muslim expansion, and what is due to the random nature of the sampling. For example, is the medieval increase in vegetable and fruit diversity really a consequence of socio-economic changes, or simply caused by the greater number and diversity of contexts (latrines) studied for this period? In Morocco, some taxa that are considered "classic" in the Roman eastern Mediterranean only appear during the medieval period; this is the case, for example, of *T. monococcum* (although it was recorded in the Neolithic samples of KafTaht el Ghar, Ballouche and Marinval 2003), *Cucumis melo*, *Rubus fruticosus* or *Juglans regia*. Other species appear in the carpological spectrum during the medieval period, without it being possible to determine their status in terms of novelties. This is the case, for example, of *Argania spinosa* and *Sorghum bicolor*, identified only in the medieval contexts of Îgîlîz, in an area where no sites prior to the medieval period have been studied or even detected. On the other hand, some taxa considered from textual sources as emblematic of Muslim agriculture, appear in the samples from the Islamic period onwards. This is the case, for example, of *Phoenix dactylifera* (at Rirha, Aghmat, Îgîlîz, Sijilmassa, Coude de Draa) *Ziziphus jujube* tree, at Rirha, Îgîlîz), *Lagenaria siceraria* (at Îgîlîz), *Capparis spinosa* (at Îgîlîz), *Gossypium* sp. (at Volubilis) and *Carthamus tinctorius/Carthamus* sp. (at Volubilis, Îgîlîz). But the archaeobotanical evidence of some of these taxa, such as *Lagenaria* or *Capparis*, are always scarce, a product of taphonomy and preservation; *Lagenaria*, of African origin, was known to the Romans, (Janick et al. 2007), and occasional seeds were found in 1st–4th c. CE deposits at Jarma, the Garamantian capital of Fazzān, Libya (Pelling 2013), potentially the product of trans-Saharan trade. The history of *Gossypium* is better known, with large numbers of seeds and cotton processing artefacts known from Islamic Mali and Senegal (Chavane 1985; Fuller 2000; Murray 2005), from a trans-Saharan trading town of Tadmakka/Essouk, northern Mali (Nixon et al. 2011). Pre-Islamic finds of cotton seed and historical texts attest to its cultivation in Nubia (Yvanez and Wozniak 2019), Dakhla Oasis, Egypt (Bagnall 1997; Thanheiser 1999) and Fazzān, Libya (Pelling 2013) from at least the early centuries CE. The origin and pathway of introduction of the new legume *Vicia faba* var. *equina*/*major* found at Rirha also require research, since its presence is documented earlier in the Western Mediterranean, in Byzantine Sicily (Fiorentino et al. 2024).

Of all the "new" crop species, the date palm is perhaps the most enigmatic. Despite the presence of cultivated *Ph. dactylifera* in Fazzān, southern Libya, since at least the 1st millennium BCE (Kaczmarek et al. 2024) and Egypt since at least the 2nd millennium BCE (Tengberg and Newton 2016), the introduction and cultivation of the species in Morocco is as yet unclear. The oldest archaeobotanical remains date from the medieval period, but, in the area where it could have been cultivated, no site prior to the 10th c. CE has been sampled systematically until recently. While its consumption is documented in medieval northern Morocco, in the south, where medieval textual sources mention the existence of large palm groves (e.g. Aghmat), archaeobotanical remains are very rare, limited to a few charred seeds, except at Sijilmassa where they have been found in slightly larger numbers in the 7th–12th c. CE deposits. At Îgîliz, the taxon is also present in the charcoal samples, but never by more than a few fragments. If this species is really as widespread as the texts suggest, how can we explain its rarity in archaeobotanical assemblages? Recent field survey and excavation in the Coude du Draa as part of the Middle Draa Project is sampling both Iron Age (pre-8th c. CE) and medieval sites including extensive irrigated field systems dating from the 8th c. onwards, the first project to target this significant transitional period in the region (Mattingly 2017; Fenwick et al. 2022). Carpological evidence for dates has so far only been found from the 10th–13th c. contexts and later. However, preservation bias may account for the absence of the stones: very few date stones were preserved by charring, while in the late and post-medieval deposits, the desiccated outer testa of the stones survived in much larger quantities, the seed having degraded. Date stones do not therefore appear to have been routinely used as a fuel source (in contrast, for example, to the Libyan oases where burnt date stones are present in abundance from the 1st millennium BCE (Pelling 2013), and they are less likely to become mineralized than smaller fruit seeds, while conditions are not sufficiently dry for desiccation. The absence of date in southern Morocco prior to the 10th c., may therefore be the result of preservation. Intriguingly, preliminary examination of silica phytoliths from the Coude du Draa by Sigrid Osborne (Bournemouth University) has identified likely palm (SPHEROID ECHINATE-types) in a possible Iron

Age silo as well as the medieval deposits (radiocarbon dates for the feature are awaited), although further morphometric analysis will be necessary to distinguish the phytoliths of *Ph. dactylifera* from *Chamaerops humilis*, a native palm (García-Granero et al. 2020). Further sampling for carpological and charcoal remains as well as phytoliths from sites prior to the 10th c. is therefore a priority for understanding the evolution of the extensive medieval palmeries as well as the processing, storage and trade of the fruits.

Emerging approaches to document medieval agricultural production and practices

In our attempt to produce a comprehensive review of current understanding of agricultural production and practices in ancient and medieval Morocco, we consider as essential the inclusion of emerging studies currently underway.

Documenting varietal diversification of several emblematic Mediterranean productions

According to various researches based on medieval textual sources (Watson 1983; rééd. 2008; Aubaile-Sallenave 1984; Lagardère 1997; Decker 2009; Albertini 2013), the Muslim area in the Western Mediterranean would have experienced an enrichment of its agricultural diversity, particularly of fruits, through the application of three processes: (1) the introduction and acclimatization of "new" plants[3], thanks to the development of irrigated agriculture (e.g. *Citrus* spp., *Pistacia vera*, *Prunus armeniaca*), which has also benefited other already well-established species such as the olive tree, (2) the improvement or creation of new varieties from indigenous plants, notably through grafting or transplanting (e.g. *Prunus avium/cerasus*, *P. dulcis*, *Pyrus communis*), and (3) the introduction of new varieties created in the East (e.g. *Prunus persica*, *Punica granatum*). To characterize fruit diversity and varietal diversification, classical biometrics and geometric morphometrics approaches are developed, conducted on the carpological remains of several sites. This type of approach has been successfully used in the Mediterranean, on archaeological remains of *Vitis vinifera* (pips), *Olea europaea* (pits), *Prunus avium* and *P. cerasus* (pits), *Phoenix dactylifera* (seeds), and, more recently, *Hordeum vulgare* (caryopsis), enabling a finer characterization of the processes of varietal diversification and cultivation of these species (Terral et al. 2004, 2010, 2012; Burger et al. 2011; Ros et al. 2014; Mureddu et al. 2022; Jeanty 2023; Coradeschi et al. 2023; Tsirtsi et al. 2024). The first studies carried out on different sites of the Moroccan corpus are encouraging, with large batches of grapevine pips and olive pits having been discovered at Rirha, Aghmat and Sijilmassa, covering a chronology that spans the 3rd to the 17th c. CE. These remains, already photographed, are currently undergoing geometric morphometrics analysis, led by J.-F. Terral (Univ. of Montpellier, UMR5554) and L. Bouby (CNRS, UMR55554). These data will be the very first archaeological data on the medieval varieties of grapevine and olives exploited in Morocco (Ater et al. 2016). This approach is all the more interesting, since, for example, Arab geoponica do not pay particular attention to the olive varieties grown in the Western Mediterranean (Albertini 2013, p 173).

Documenting ancient agro-horticultural practices

In the Muslim West (al-Andalus, Maghreb al-Aqsa), our knowledge of medieval land management was for a long time essentially based on textual sources and also, especially where irrigation is concerned, on archaeology (tools, creation of agricultural terraces, irrigation channels and wells) (e.g. Cressier 2006). To avoid soil depletion due to the cultivation of water- and nutrient-demanding species, and to improve production, medieval Muslim agronomists recommended, for example, extensive soil preparation, the use of green manure, animal manure, and irrigation (Albertini 2013). The use of artificial grasslands was also recommended for feeding livestock. Although these practical recommendations are known, their local application in the different areas studied by archaeology, which sometimes escape the textual sources, remain difficult to clarify by material sources. Besides classical carpological studies (taxonomic diversity, types of remains, weed ecology), two cutting-edge methods are currently developed on some Moroccan sites, shedding light on certain precise aspects of medieval agricultural practices.

The first one, quantitative eco-anatomy, involves the measurement of the vascular elements of the wood and their variations, the anatomy of the wood being influenced by virtually every event that takes place during the growth and development of the tree (age, soil conditions, altitude, exposure, cultural practices, silvicultural treatments, pathogens and pollutants). Quantitative eco-anatomy thus makes it possible to reveal the conditions in which the ancient trees grew, and thus to highlight certain agricultural practices. In Morocco, this approach was pioneered on *Argania spinosa* (Ros et al. 2021a), as part of the HARGANA project. The emergence of the argan tree as an agricultural, pastoral, cultural, economic and ecological keystone species in Southern Morocco is considered to be linked to the settlement

[3] The knowledge and methods of consumption/exploitation of a plant vary over time and space, depending on various socio-cultural factors (status of consumers, dietary patterns), economic factors (value of the plant, trade flows) and demographic factors (population movements). The status of "new" plant should thus be considered with caution, as it may be rediscovered and perceived as new at the time it is reintroduced into the food circuit at a given time (Ruas 1992).

of agropastoral communities that favoured its expansion. Nevertheless, the use and exploitation of argan trees is documented by few medieval written sources, and by archaeobotanical studies from a single location, Îgîlîz (Toughmart, Morocco). A quantitative eco-anatomical approach aiming to understand variations of wood characters involved in sap conduction and reserve storage, was developed from modern samples collected in the area of Îgîlîz and from archaeological samples. Results show that diameter of branches and environmental factors (especially irrigation and manure) are the major parameters explaining plasticity of wood anatomical characters. It would also seem that *A. spinosa* trees exploited in the medieval period have benefited from the input of irrigation and manure, their anatomical signature being very similar to that of modern cultivated argan trees. This approach will soon be carried out on charcoal of olive wood found at Rirha and Aghmat. In these sites, olive has played a central economic role since during the Roman and medieval periods, especially for fruit consumption, oil production oil and as fuel. The eco-anatomical study of different batches of charcoal fragments will allow new understanding of the evolution of cultivation practices (irrigation?) of this central species.

The second method is based on the isotopic analysis of carpological remains, with the objective of highlighting practices related to manuring or irrigation of exploited soils, and the evolution of these practices over time. A CNRS-INEE PEPS project intitled "AGHMAT: AGrosystèmes Historiques du Maroc: Adaptations, Transformations – L'exemple de la région du Haouz" was initiated in 2020, aiming to highlight manuring and irrigation practices of certain species in the medieval site of Aghmat. A chemical approach (stable isotopes: Carbon, Nitrogen, Sulphur) was carried out on archaeological carpological remains (*Hordeum vulgare*, *Triticum aestivum/durum*, *Olea europaea*, *Vitis vinifera*), which allowed qualification of the cultivation conditions developed during the study period (12th–17th c. CE) (Ros et al. 2024). Within the framework of the national ANR project MICA (Modelling Interactions between Climate change and Agriculture in the ancient West, PI L. Bouby (ISEM), 2023–2027), the consolidation of the current isotopic reference system is in progress, and the archaeological dataset expanded by including archaeobotanical specimens from various Moroccan sites.

Conclusions

This initial summary has highlighted a great problem with the representativeness of the archaeobotanical data available in Morocco, which currently suffers from a major imbalance, particularly geographically, with a highly developed north, and a south that remains largely unexplored. Under the impetus of some researchers, certain periods, such as the Middle Ages, have been particularly well investigated, while other chronological phases, notably the Punic and Mauri periods, still require a major sampling effort. For future research, if we wish to better address the issue of species introduction, it will be important to study a greater number of sites, and to focus on two aspects: a better diversity of contexts, preferably urban, favouring a different type of conservation (latrines), and perhaps a more in-depth approach to particular agricultural systems that may have favoured the introduction/spread of certain plants of oriental or Near Eastern origin, such as oases. The recent excavation of new contexts at Sijilmassa, as well as sites in the Coude de Draa, will certainly allow for further research on this theme.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00334-024-01013-8.

Acknowledgements We would like to thank all our Moroccan colleagues, and especially the INSAP (Rabat), for their tireless work in the field over the last few decades, and for helping archaeobotany to become a discipline in its own right in Morocco. We would also like to thank M.-P. Ruas (UMR7209, AASPE) for having given a new impetus to archaeobotanical research in Morocco, through her involvement in the field and in the laboratory, and for having enabled the emergence of the first syntheses on agriculture in historic Morocco. This project received funding from the French "Agence Nationale de la Recherche" (ANR) (grant agreement No. ANR-23-CE27-0003) and AHRC Award AH/V011758/1 (part of the equipment).

References

Al-Bakrî (1911) Kitâb al-masâlik wa-'l-mamâlik, 2nd edn. Algiers

Al-Idrîsî (1866) Description de l'Afrique et de l'Espagne. Brill, Leiden

Albertini L (2013) Essor De l'agriculture en Al-Andalus (Ibérie arabe) X^e^–XIV^e^ siècle. Performances des agronomes arabo-andalous. L'Harmattan, Paris

Allevato E, Pecci A, Papi E, Di Pasquale G (2013) Evidence from charcoal analysis for the extensive exploitation of cork-oak (*Quercus suber*) forest in the Roman imperial period: the vicus of Thamusida (NW Morocco). In: Damblon F (ed) Proceedings of the Fourth International Meeting of Anthracology, Brussels, 8–13 September 2008, Royal Belgian Institute of Natural Sciences. BAR International Series 2486. Archaeopress, Oxford, pp 11–17

Allevato E, Buonincontri MP, Pecci A, D'Auria A, Papi E, Saracino A, Di Pasquale G (2017) Wood exploitation and food supply at the border of the Roman Empire: the case of the *vicus* of Thamusida – Sidi Ali Ben Ahmed (Morocco). Environ Archaeol 22:200–217. https://doi.org/10.1080/14614103.2015.1126685

Ater M, Essalouh L, Ilbert H, Moukhli A, Khadari B (eds) (2016) L'oléiculture Au Maroc De La préhistoire à nos jours: pratiques, diversité, adaptation, usages, commerce et politiques. Options Méditerranéennes: Série A: Séminaires Méditerranéens 118. CIHEAM, Montpellier

Aubaile-Sallenave F (1984) L'agriculture musulmane aux premiers temps de la conquête: apports et emprunts, à Propos De

Agriculture Innovation in the early islamic World De Andrew M. Watson. J Agric Tradit Bot Appl 31:245–256

Bagnall RS (1997) The Kellis Agricultural Account Book (P. Kell. IV Gr. 96). Dakhleh Oasis Project Monograph 7, Oxbow Monograph 92. Oxbow Books, Oxford

Ballouche A, Marinval P (2003) Données palynologiques et carpologiques sur la domestication des plantes et l'agriculture dans le Néolithique Ancien Du Maroc Septentrional (Site De Kaf Taht El-Ghar). Rev d'Archéométrie 27:49–54

Blench R (2021) Relating linguistic reconstructions of plant names in Berber to the archaeobotany of North Africa. J Archaeol Sci Rep 38:103009. https://doi.org/10.1016/j.jasrep.2021.103009

Burger P, Terral J-F, Ruas M-P, Ivorra S, Picq S (2011) Assessing past agrobiodiversity of *Prunus avium* L. (Rosaceae): a morphometric approach focussed on the stones from the archaeological site Hôtel-Dieu (16th century, tours, France). Veget Hist Archaeobot 20:447–458. https://doi.org/10.1007/s00334-011-0310-6

Carrato C, Ichkhakh A, Kbiri Alaoui M et al (2020) Recent Discovery of an urban winery in Rirha (Sidi Slimane, Morocco), 2nd–3rd Century CE. In: Brun J-P, Garnier N, Olcese G (eds) A. making wine in Western-Mediterranean/B. production and the Trade of Amphorae: some New Data from Italy, Panel 3.5. Archaeology and Economy in the Ancient World 9. Propylaeum, Heidelberg, pp 167–175

Cartier A (2021) Environnement végétal et exploitation du bois à Îgîlîz (Anti-Atlas, maroc) au Moyen Âge: étude anthracologique. Dissertation, University of Montpellier, Montpellier

Chavane BA (1985) Villages de L'ancien Tekrour. Karthala, Paris

Coradeschi G, Ucchesu M, Dias E et al (2023) A glimpse into the viticulture of roman Lusitania: morphometric analysis of charred grape pips from Torre dos Namorados, Portugal. Veget Hist Archaeobot 32:349–360. https://doi.org/10.1007/s00334-023-00912-6

Cressier P (2006) La maîtrise de l'eau en al-Andalus. Paysages, Pratiques et techniques. Collection De La Casa De Velázquez 93. Casa de Velázquez, Madrid

Decker M (2009) Plants and progress: rethinking the islamic Agricultural Revolution. J World Hist 20:187–206. http://www.jstor.org/stable/40542757

Ettahiri AS, Meftah N (2015) Quelques émissions monétaires de l'atelier d'al-Basra (Al-Maghrib al-'Aqsa). In: Sénac P, Gasc S (eds) Monnaies Du Haut Moyen Âge. Presses universitaires du Midi, Toulouse, pp 265–279. https://doi.org/10.4000/books.pumi.16885

Fariat R (2023) Consommer et produire la vigne au Maroc médiéval: croisement des données archéobotaniques et des sources textuelles. Dissertation, INSAP, Rabat, Morocco

Fenwick C, Sterry M, Mattingly DJ, Rayne L, Bokbot Y (2022) A medieval boom in the North-West Sahara: evolving Oasis landscapes in the Wadi Draa, Morocco (c.700–1500 AD). J Islam Archaeol 8(2021):139–165. https://doi.org/10.1558/jia.20440

Fiorentino G, Grasso AM, Primavera M (2024) Introduction, spread and selective breeding of crops: new archaeobotanical data from southern Italy in the early Middle Ages. Veget Hist Archaeobot. https://doi.org/10.1007/s00334-024-00989-7

Fuller DQ (2000) The Botanical remains. In: Insoll T (ed) Urbanism, Archaeology and Trade. Further observations of the Gao Region (Mali). The 1996 Fieldseason results. BAR International Series, vol 829. Archaeo, Oxford, pp 28–35

Fuller D (2002) Environmental Archaeology at Volubilis 2002: archaeobotany, archaeozoology and phosphate analysis. In: Fentress E, Limane H, Palumbo G (eds) The UCL/INSAP Volubilis Project Excavation, Management and Conservation, April and October 2002. Excavation report, pp 9–11

Fuller D (2004) Archaeobotanical work, 2004. In: Fentress E, Limane H, Palumbo G (eds) Excavation and Conservation at Volubilis 2004, pp 8–9. https://sitedevolubilis.org/wp-content/uploads/2021/06/2004_Report.pdf

Fuller DQ, Pelling R (2018) Plant Economy: Archaeobotanical studies. In: Fentress E, Limane H (eds) Volubilis après Rome: Les fouilles UCL/INSAP, 2000–2005. Arts and Archaeology of the Islamic World. Brill, Leiden, pp 349–368

Fuller DQ, Stevens CJ (2009) Agriculture and the development of complex societies: an archaeobotanical agenda. In: Fairbairn A, Weiss E (eds) From Foragers to Farmers: Papers in honour of Gordon C. Hillman. Oxbow Books, Oxford, pp 37–57

García-Granero JJ, Skoula M, Sarpaki A, Cárdenas M, Madella M, Bogaard A (2020) A long-term assessment of the use of *Phoenix theophrasti* Greuter (Cretan date palm): the ethnobotany and archaeobotany of a neglected palm. J Ethnobiol 40:101–114

Grau Almero E, Pérez Jordà G, Iborra Eres MP, Rodrigo Garcia MJ, Rodriguez Santana CG, Carrasco Porras MS (2001) Gestión De recursos y economía. In: Aranegui Gascó C, Habibi M (eds) Lixus, colonia fenicia y ciudad púnico-mauritana. Anotaciones sobre su ocupación medieval. Saguntum Extra 4. Departament de Prehistòria i Arqueologia de la Facultat de Geografia i Història, Valencia, pp 191–230

Grau Almero E, Pérez Jordà G, Iborra Eres MP (2010) La gestión De Los recursos naturales. In: Aranegui C, Hassini H (eds) Lixus-3. Área suroeste del sector monumental [Cámaras Montalbán] 2005–2009. Saguntum Extra 8. Departament de Prehistòria i Arqueologia de la Facultat de Geografia i Història, Valencia, pp 61–68

Hallavant C, Ruas M-P (2014) The first archaeobotanical evidence of *Spinacia oleracea* L. (spinach) in late 12th–mid 13th century A.D. France. Veget Hist Archaeobot 23:153–165. https://doi.org/10.1007/s00334-013-0400-8

Ibn Hawqal (1938) Surat Al-Ard. Bibliotheca Geographorum Arabicorum, Leiden

Janick J, Paris HS, Parrish DC (2007) The cucurbits of Mediterranean Antiquity: identification of taxa from ancient images and descriptions. Ann Bot 100:1441–1457. https://doi.org/10.1093/aob/mcm242

Jeanty A (2023) L'orge dans les systèmes agraires du Nord-Ouest méditerranéen, du Néolithique au présent: évolution, diversité, pratiques et usages. Dissertation, University of Montpellier, Montpellier

Kaczmarek T, van der Veen M, Ivorra S, Mattingly D, Terral J-F, Gros-Balthazard M (2024) Origins and evolution of oasis agriculture in the Sahara: evidence from morphometric analyses of archaeological date palm seeds. Holocene 34:353–365. https://doi.org/10.1177/09596836231211879

Kirchner H, García-Contreras G, Fenwick C, Pluskowski A (2023) Re-thinking the 'Green Revolution' in the Mediterranean world. Antiquity 97(394):964–974. https://doi.org/10.15184/aqy.2023.91

Lagardère V (1997) Cépages, raisin et vin en al-andalus (X^{e}–XV^{e} siècles). Médiévales 33:81–90

Mahoney N (2004) Agriculture, industry, and the environment: archaeobotanical evidence from Al-Basra. In: Benco N L (ed.) Anatomy of a Medieval Islamic Town. Al-Basra, Morocco. Oxford

Mattingly DJ, Bokbot Y, Sterry M et al (2017) Long-term history in a Moroccan Oasis Zone: the Middle Draa Project 2015. J Afr Archaeol 15:141–172. https://doi.org/10.1163/21915784-12340009

Morales J, Pérez-Jordà G, Peña-Chocarro L, Zapata L, Ruíz Alonso M, López-Sáez JA, Linstädter J (2013) The origins of agriculture in North-West Africa: macro-botanical remains from Epipalaeolithic and Early Neolithic levels of Ifri Oudadane (Morocco). J Archaeol Sci 40:2:659–2669

Morales J, Pérez-Jordà G, Peña-Chocarro L, Bokbot Y, Vera JC, Martínez Sánchez RM, Linstädter J (2016) The introduction

of South-western Asian domesticated plants in North-Western Africa: an archaeobotanical contribution from Neolithic Morocco. Quat Int 412 Part B 96–109. https://doi.org/10.1016/j.quaint.2016.01.066

Mureddu M, Ucchesu M, Sarigu M, Del Vais C, Piras F, Sanna I, Bacchetta G (2022) Studies on archaeological olive fruitstones from the archaic and punic periods (7th–3rd century BC) of Sardinia, Italy. Veget Hist Archaeobot 31:511–524. https://doi.org/10.1007/s00334-022-00867-0

Murray SS (2005) The archaeobotanical research. In: Bedaux R, Polet J, Sanogo K, Schmidt A (eds) Recherches archéologiques à Dia dans Le Delta intérieur Du Niger (Mali): bilan des saisons de fouilles 1998–2003. Mededelingen van het Riksmuseum voor Volkenkunde Series, vol 33. CNWS, Leiden, pp 386–400

Nixon S, Murray MA, Fuller DQ (2011) Plant use at an early Islamic merchant town in the west African sahel: the archaeobotany of Essouk-Tadmakka (Mali). Veget Hist Archaeobot 20:223–239

Pelling R (2013) The Archaeobotanical Remains. In: Mattingly DJ (ed) The Archaeology of Fazzān, Vol 4: Survey and Excavations at Old Jarma (Ancient Garama) carried out by C. M. Daniels (1962–1969) and the Fazzān project (1997–2001). Society for Libyan Studies Monograph 9. Department of Antiquities, Tripoli, pp 473–494

Pelling R (2007) Agriculture and trade amongst the Garamantes and the Fezzanese: 3000 years of archaeobotanical data from the Sahara and its margins. Unpublished PhD thesis, Institute of Archaeology, University College London

Peña-Chocarro L, Pérez-Jordà G, Alonso N, Antolín F, Teira-Brión A, Pedro Tereso J, Montes Moya EM, López Reyes D (2019) Roman and medieval crops in the Iberian Peninsula: a first overview of seeds and fruits from archaeological sites. Quat Int 499 Part A 49–66. https://doi.org/10.1016/j.quaint.2017.09.037

Pérez Jordà G (2005) Estudio paleocarpológico. In: Aranegui Gascó C, Habibi M (eds) Lixus-2 Ladera sur. Excavaciones arqueológicas Marroco-españolas en la colonia fenicia. Campañas 2000–2003. Saguntum Extra 6. Departament de Prehistòria i Arqueologia de la Facultat de Geografia i Història, Valencia, pp 221–227

Perrin de Brichambaut G (1952) Note sur les Phalaris Nord-Africains et en particulier sur les Phalaris marocains. Revue internationale de botanique appliquée et d'agriculture tropicale, 32e année, Bulletin 353–354, Mars–avril 1952. 123–138. https://doi.org/10.3406/jatba.1952.6486

Pollock S (1986) Progress report on plant remains from Badis, Al-Basra and Qsar es-Seghir. Bull Archéol Maroc 15:355–360

Ros J, Badri F-E (2020) Annexe 4: Ressources végétales exploitées: résultats de l'analyse archéobotanique. In: Akerraz A, Palumbo G (eds) Archéologie De La Péninsule Tingitane. Contribution à La Carte archéologique Du Maroc. Cartes Al Manzla, Melloussa, Asilah et Arba Ayacha, Villes Et sites Archéologiques Du Maroc Villes Et sites Archéologiques Du Maroc (VESAM) 8. INSAP, Rabat, pp 431–437

Ros J, Evin A, Bouby L, Ruas M-P (2014) Geometric morphometric analysis of grain shape and the identification of two-rowed barley (*Hordeum vulgare* subsp. *distichum* L.) in southern France. J Archaeol Sci 41:568–575. https://doi.org/10.1016/j.jas.2013.09.015

Ros J, Gilotte S, Sénac P, Gasc S, Rebull JG (2019) Alimentación vegetal y agricultura en Los márgenes de al-Andalus: nuevos datos arqueobotánicos. In: Delgado Pérez MM, Pérez-Aguilar L-G (eds) Economía Y Trabajo. Las Bases Materiales De La Vida en Al-Andalus. Ediciones Alfar, Sevilla, pp 43–80

Ros J, Terral J-F, Ruas M-P et al (2021a) Understanding anatomical plasticity of Argan wood features at local geographical scale in ecological and archaeobotanical perspectives. Sci Rep 11:10830. https://doi.org/10.1038/s41598-021-90286-4

Ros J, Badri F-E, Héritier-Salama V, Capel C, Fili A, Messier R (2021b) First archaeobotanical contribution to the history of food production and agriculture at Aghmat (Morocco) between the 11th and the 17th c. J Archaeol Sci Rep 38:102943. https://doi.org/10.1016/j.jasrep.2021.102943

Ros J, Jeanty A, Bouby L et al (2023) Agricultural dynamics in south-western mediterranean France from the end of the iron age to the early middle ages. Environ Archaeol. https://doi.org/10.1080/14614103.2023.2271257

Ros J, Badri F-E, Cartier A et al (2024) Forest and agricultural dynamics in the Haouz plain over the last millennium: archaeobotanical and isotopic research at Aghmat (Morocco). Hum Ecol 52:255–271. https://doi.org/10.1007/s10745-024-00507-3

Ruas M-P (1992) Les plantes exploitées en France Au Moyen Age d'après les semences archéologiques. In: Ruas M-P, Malpica Cuello A, Thoen E, Thirsk J, Perez García JM, Finzi R, Vandenbroeke C, Bolens L, Desplat C (eds) Plantes et cultures nouvelles en Europe occidentale Au Moyen Age Et à l'époque moderne. Actes des 12e Journées internationales d'Histoire de flaran, abbaye de flaran 11–13 Septembre 1990. Flaran 12. Presses universitaires du Midi. Comité départemental du tourisme du Gers, Toulouse, pp 9–35

Ruas M-P (2005) Aspects of early medieval farming from sites in Mediterranean France. Veget Hist Archaeobot 14:400–415. https://doi.org/10.1007/s00334-005-0069-8

Ruas M-P (2018) Fruits et légumes consommés au Maroc antique et médiéval: témoignages archéobotaniques. In: Oubalhi M (ed) Manger au Maghreb – Partie IV: Par les mots, les fruits et les légumes. Horizons Maghrébins-le droit la mémoire 34ème année-nº 79. Presses universitaires du Midi, Toulouse, pp 161–185

Ruas M-P (2020) Céréales et légumineuses de l'Antiquité en Afrique du Nord: une revue préliminaire des résultats archéobotaniques. In: Blandenet M, Bretin-Chabrol M (eds) La terre et le grain – Lectures interdisciplinaires de Columelle. De re rustica, 1 et II. Collection Études et Recherches sur l'Occident Romain 54. CEROR – Université Jean Moulin Lyon 3, Lyon, pp 125–148 (hal-03156585)

Ruas M-P, Tengberg M, Ettahiri AS, Fili A, van Staëvel J-P (2011) Archaeobotanical research at the medieval fortified site of Îgîlîz (Anti-Atlas, Morocco) with particular reference to the exploitation of the argan tree. Veget Hist Archaeobot 20:419–433. https://doi.org/10.1007/s00334-011-0306-2

Ruas M-P, Ros J, Terral J-F, Ivorra S, Andrianarinosy H, Ettahiri AS, Fili A, van Staëvel J-P (2016a) History and archaeology of the emblematic argan tree in the medieval Anti-atlas Mountains (Morocco). Quat Int 404 Part A 114–136. https://doi.org/10.1016/j.quaint.2015.09.030

Ruas M-P, Figueiral I, Heinz C, Ivorra S (2016b) Paléoenvironnement et paléoéconomie d'après l'anthracologie et la carpologie. In: Callegarin L, Kbiri Alaoui M, Ichkhakh A, Roux J-C (eds) Rirha: site antique et médiéval du Maroc, vol 1: cadre historique et géographique général. Collection De La Casa De Velázquez 150. Casa de Velázquez, Madrid, pp 42–109

Tengberg M, Newton C (2016) Origine et évolution de la phéniciculture Au Moyen-Orient et en egypte. In: Ruas MP, Bouby L, Durand A, Boissinot P, Mane P, Pradat B, Puig C, Terral JF (eds) Des fruits D'ici et d'ailleurs: regards sur l'histoire de quelques fruits consommés en Europe. Omnisciences, Paris, pp 83–105

Terral J-F, Alonso N, Buxo i Capdevila R et al (2004) Historical biogeography of olive domestication (*Olea europaea* L.) as revealed by geometrical morphometry applied to biological and archaeological material. J Biogeogr 31:63–77. https://doi.org/10.1046/j.0305-0270.2003.01019.x

Terral J-F, Tabard E, Bouby L et al (2010) Evolution and history of grapevine (*Vitis vinifera*) under domestication: new morphometric perspectives to understand seed domestication syndrome and

reveal origins of ancient European cultivars. Ann Bot 105:443–455. https://doi.org/10.1093/aob/mcp298

Terral J-F, Newton C, Ivorra S, Gros-Balthazard M, Tito de Morais C, Picq S, Tengberg M, Pintaud J-C (2012) Insights into the historical biogeography of the date palm (*Phoenix dactylifera* L.) using geometric morphometry of modern and ancient seeds. J Biogeogr 39:929–941. https://doi.org/10.1111/j.1365-2699.2011.02649.x

Thanheiser U (1999) Plant remains from Kellis: first results. In: Hope CA, Mills AJ (eds) Dakhleh Oasis Project: preliminary reports on the 1992–1993 and 1993–1994 field seasons. Dakhleh Oasis Project Monograph 8. Oxbow Books, Oxford, pp 89–103

Tsirtsi K, Pagnoux C, Bonhomme V, Ivorra S, Terral J-F, Margaritis E (2024) Development of olive cultivation at the site of Sikyon, Greece: evidence from the charred olive remains from the late Classical/early Hellenistic to the Roman period. Veget Hist Archaeobot 33:343–351. https://doi.org/10.1007/s00334-023-00943-z

Van Staëvel J-P, Ruas M-P, Ettahiri AS, Fili A (2016) Lieux D'aisances et de toilette en milieu rural dans le Maroc médiéval. L'exemple De Latrines Du site d'Îgîlîz et les déchets des plantes consommées. In: Cressier P, Gilotte S, Rousset M-O (eds) Lieux d'hygiène et lieux d'aisances en terre d'Islam (VIIe–XVe siècle). Médiévales 70. Presses Universitaires de Vincennes, pp 189–213

Van Zeist W, Bottema S, van der Veen M (2001) Diet and vegetation at ancient Carthage: the archaeobotanical evidence. Groningen Institute of Archaeology, Groningen

Vanz J, Cartier A, Ros J (2024) Le Maghreb, un espace déboisé durant le Moyen Âge? Approche croisée des sources textuelles et des données anthracologiques. Pallas 15/2024, Bois et architecture dans la Protohistoire et l'Antiquité (2):59–80

Watson AM (1983) rééd 2008) Agricultural Innovation in the Early Islamic World. The diffusion of crops and farming techniques, 700–1100. Cambridge Studies in Islamic Civilization. Cambridge University Press, Cambridge

Yvanez E, Wozniak MM (2019) Cotton in ancient Sudan and Nubia. Revue d'ethnoécologie 15:4429. https://doi.org/10.4000/ethnoecologie.4429

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